APPENDIX 1

LIST OF SUBMISSIONS

1	Mr Frank Kolver	QLD
2	Dr Mark Donohoe, Environmental & Nutritional Medicine	NSW
3	Dr Richard Teo	NSW
4	Mr Stephen Tyrell	ACT
5	Dr Jean Christophe Balouet,	FRANCE
5A	Dr Jean Christophe Balouet,	FRANCE
5B	Dr Jean Christophe Balouet,	FRANCE
6	Dr Chris Winder	NSW
7	Dr Judith Ford , *Genetic Consulting & Testing*	SA
8	Dr C Van Netten,	CANADA
9	Mr Andrew Thom & Mr Jonathon Burdon	VIC
10	Ms Deborah Carter	QLD
11	British Aerospace Australia Limited	NSW
11A	British Aerospace Australia Ltd	NSW
11B	British Aerospace Australia Ltd	NSW
11C	British Aerospace Australia Ltd	NSW
11D	British Aerospace Australia Ltd	NSW
11E	British Aerospace Australia Ltd	NSW
12	The National Industrial Chemicals Notification and Assessment Scheme	NSW
13	Mobil Oil Australia Ltd	VIC
13A	Mobil Oil Australia Ltd	VIC
14	Australian Federation of Air Pilots	VIC

14A	Australian Federation of Air Pilots	VIC
14B	Australian Federation of Air Pilots	VIC
15	Department of Public Health	WA
16	Ms Robin May	SA
16A	Ms Robin May	SA
17	Ms Judy Cullinane	WA
17A	Ms Judy Cullinane	WA
18	Ansett Pilots Association	VIC
19	Association of Flight Attendants	USA
20	Civil Aviation Safety Authority Australia	ACT
21	Qantas Airways Limited	NSW
21A	Qantas Airways	NSW
22	Ansett Australia	VIC
23	National Jet Systems Pty Ltd	SA
23A	National Jet Systems Pty Ltd	SA
24	Flight Attendants Association of Australia	QLD
24A	Flight Attendants Association of Australia	QLD
25	American Society of Heating Refridgerating & Air-conditioning Engineers (ASHRAE)	USA
26	Ms Susan Michaelis	NSW
27	Ms Lesley Williams	ACT
28	Captain Richard Buncher	NSW
29	Ms Belinda Hall	WA
30	Mr Richard Best	NSW
31	Ms Kerri Allison	NSW

SUBMISSION TO THE SENATE REFERENCES COMMITTEE
RURAL AND REGIONAL AFFAIRS AND TRANSPORT

ON THE INQUIRY INTO

AIR SAFETY – BAE 146
CABIN AIR QUALITY

SUBMISSION NUMBER 1

Captain Frank Kolver
PO Box 1463
CLEVELAND QLD 4163

Phone: 07 3821 4217
Fax: 07 3821 4217
Email: kolver@bit.net.au

FACISIMILE

TO: SENATOR WOODLEY
RURAL & REGIONAL AFFAIRS & TRANSPORT COMMITTEE
PARLIAMNET HOUSE
CANBERRA

FAX NO; 02 6277 5811

FROM: CAPTAIN FRANK KOLVER

PH/FAX 07 3821 4217

DATE: 30TH APRIL 1999

RE: Senate Inquiry into Air Safety with reference to air quality of Bae 146 Aircraft.

Senator Woodley;

The following page is a copy of my submission in regard to Bae 146 air quality. Please feel free to contact me should you require any further information.

Frank Kolver

Friday 30th April 1999
Brisbane. Qld. Aust.

EXAMINATION OF AIR SAFETY WITH REFERENCE TO AIR QUALITY OF BAE 146 AIRCRAFT.

Submission of Captain FRANK KOLVER

Contact Details;

P.O. Box 1463
Cleveland, Qld 4163 Phone/Fax 07 3821 4217 E-mail; kolver@bit.net.au

My name is Frank KOLVER and I am employed by National Jet Systems as captain on Bae 146 Aircraft based in Brisbane, Australia. The company operates Bae 146 aircraft under contract to various clients with the Brisbane base operation being mainly for Qantas Airlink and Australian Air express.

At 0030 hrs on the 10th July 1997 I was Captain of a Bae 146 aircraft registered VH-NJF which was on decent into Melbourne during a night freight flight from Sydney The crew consisted of myself, the First Officer and Senior Captain in the jump seat carrying out surveillance.

During the latter stage of the decent shortly after passing 10,000 feet I smelt strong oily odours and fumes in the cockpit. Some 3 to 4 minutes later after making a directional change of 25 degrees it was necessary to make another direction change in the opposite direction of about 10 degrees. I had great difficulty trying to do this because I felt it would roll the aircraft to an excessive angle towards becoming inverted. This was followed by considerable difficulty in flying the aircraft and concentrating on making the approach to land I became confused and was not quite sure what was going on at the time but realized I was having some sort of difficulty so I asked the first officer to take over flying the aircraft. He did so and continued to land safely.

For the next ten days or so I felt as if I was having a continuos hangover with a constant headache. This was accompanied with a feeling of strong pressure on the top of my head. At night if I got out of bed I had difficulty in standing upright. When I traveled in a motor vehicle the headache would get worse and after 20 minutes I would get nauseous and had to stop and get out.for some relief.

During this period I was on sick leave and for the next two months my health slowly improved to moderate continuos headaches and later mild headaches with a constant pain in the left or right temple area. Several medical examinations, blood tests and a CT scan gave no indication of any medical disorder or problem. At the time and prior to this incident I was medically and physically fit and had no sickness or virus of any kind.

Presently I am still operating BAE 146 aircraft and still often suffer from headaches and a pain in the temple area. This is often brought on and aggravated by exposure to bright light or any strong chemical odours such as cleaning agents, insecticides and fertilizers, oil, petrol or any fuel exhaust fumes and some strong chemically based perfumes.

I am 51 years of age and have over 15,000 hours flying experience. I have been flying Bae 146 aircraft since June 1990, and have acquired over 4500 hours on this aircraft.

(Frank KOLVER)

Friday 20th August 1999
Brisbane. QLD. Australia.

EXAMINATION OF AIR SAFETY WITH REFERENCE TO AIR QUALITY OF BAE 146 AIRCRAFT.

Submission of Captain Frank KOLVER updating original submission dated 30/4/99 with new information.

Due to oil fume related events, which occurred after my original submission of 30th April 1999, I herewith submit the following details;

On the 2nd of June 1999, while operating as Pilot in command of Bae 146 aircraft registration VH-NJD over four sectors between Brisbane, Canberra and Proserpine, oil fumes were experienced from the air-conditioning system. These occurred shortly after each take-off and also on the latter part of each decent below ten thousand feet. Attempts were made to select off individual engine air supplies but we were unable to notice a difference or verify a particular source.

At the end of the day's duty I had a slight headache and felt nauseous. Later that same evening I became quite ill with severe headache and vomiting. I then had to take sick leave for the following 26 days due to constant headaches particularly in the temple area. This was accompanied with a feeling of pressure in the head, and a constant feeling similar to a hangover after consuming large amounts of alcohol. I had not consumed any alcohol at all.

Medical examination by a Neuro-physician and blood test were unable to establish any other cause of the headaches. I returned to work on the 29th of June after being pronounced fit to fly by my Aviation medical practitioner.

Frank KOLVER
P.O. Box 1463. QLD 4163.
Phone 07 3821 4217

Email; frankk@primus.com.au

SUBMISSION TO THE SENATE REFERENCES COMMITTEE
RURAL AND REGIONAL AFFAIRS AND TRANSPORT

ON THE INQUIRY INTO

AIR SAFETY – BAE 146
CABIN AIR QUALITY

SUBMISSION NUMBER 2

Environmental & Nutritional Medicine

Dr Mark Donohoe MB BS
PO Box 328
MOSMAN NSW 2088

Phone: 02 9968 1087
Fax: 02 9968 4778/3378
Email:

DR MARK DONOHOE MB BS
[redacted]
Provider Number: 0376412J
PO Box 328
Mosman NSW 2088
Tel: 02 9968-1087
Fax: 02 9968-4778
Fax 2: 02 9968-3378
email. mark@geko com.au

30 June 1999

THE SENATE AIR SAFETY INQUIRY

Senator J Woodley
Australian Democrats
Transport Spokesperson
Parliament House
Canberra ACT
Fax: 02 6277-3725

Dear Sen. Woodley,

Submission regarding Safety of BAe-146

I am aware of the Senate's inclusion of safety of the BAe-146 jet in the terms of reference of this inquiry. I offer the following in my capacity as a medical practitioner who has been involved in the assessment and care of some of the staff of Ansett and National Jet airlines and some patients of mine who have been passengers on that particular type of aircraft.

1. PREAMBLE & INTRODUCTION

I have expertise and experience in the field of long term low level effects of chemicals on human health. I include my curriculum vitae with this report.

My interest arises because a number of employees of National Jet and Ansett have consulted me as a result of becoming unwell, and in some cases, too disabled to work, following work on the BAe-146 aircraft. Of course, I am unable to provide details which could possibly allow my patients to be identified, but I can confirm the close similarity of the health complaints of all five employees I have seen, including adverse neurological effects, alterations of immunology, and symptoms compatible with chronic fatigue syndrome. In one case, a pilot told me that he/she was sufficiently adversely affected that the safety of the aircraft was compromised.

I passed this information on to Mr Clive Phillips of the Bureau of Air Safety Investigations (BASI) in writing on May 5, 1998. To date, I have received no response to this concern regarding the safety of the aircraft due to crew impairment. My

understanding is that many incidents regarding aircraft safety on the BAe-146 have been reported, and that the issue is one of great importance for crew and passengers. I am at a loss to explain the non-response to my letter outlining my concerns.

Apart from the employees, two patients from my own medical practice have told me of similar illness and symptoms arising from travel on the BAe-146 aircraft. While both patients had previously been unwell (with different illnesses), the exacerbation of their underlying illness arose immediately following trips on BAe-146 aircraft, but not after travel on other aircraft. In both cases, the person was unaware of the type of aircraft they were on until after they became sick, and neither knew or suspected that there were fume or safety problems with these types of aircraft. Both people had remained unwell for over six months following a single flight. Both appear to have recovered slowly after, though neither regained the level of health they enjoyed prior to the aircraft exposure.

I am able to provide de-identified medical information on these cases as long as there is some guarantee of confidentiality and protection against negative employment outcomes, should any employer or third party seek to discipline, punish, intimidate or dismiss a person. who could possibly be identified.

More generally, I have a significant body of information on the problems with the BAe-146, amounting to some hundreds of pages which I have received from Ansett and many other sources. Should the Senator(s) which to view such documents (many of which are contained in patient medical records), I am happy to present these directly and de-identified, assuming the work required is adequately compensated.

II. OVERVIEW - MOBIL JET OIL II

It is my understanding that Mobile Jet Oil II is a synthetic phosphate-ester oil in which tricresyl phosphates are constituents. I do not know what the purpose of the tricresyl phosphates is, but one of the isomers, tri-ortho-cresyl phosphate (TOCP), is a highly neurotoxic contaminant found in the oil. It is one of a class of enzyme inhibiting chemicals known collectively as organophosphates (OP). I include references with this submission regarding acute and chronic neurobehavioural effects of OPs.

The oil also contains a broad range of other chemicals, including naphtalomines, many of which are also hazardous to human health. In addition, there may be other chemicals or mixtures apart from the Mobil Jet Oil II in the mist/vapour which is found in the cabins of the BAe-146, including thermal breakdown products of the Jet oil, and other organic pollutants from fuel combustion.

Mobile Jet Oil II is a synthetic oil rather than a mineral oil. As such, it is not appropriate to use the occupational exposure standard for mineral oil of 5 mg per cubic metre (5 mg/m3) which has been used as the mineral oil standard

The question arises, *"Is Mobil Jet Oil II a hazardous substance?"* From the warnings and details I have seen on the containers, it would appear that it is a hazardous substance,

although Mobil hold that it is not. This leads to a problem in that the manufacturer avoids the strict labelling requirements of hazardous substances.

I understand that the manufacturer has claimed that Mobil Jet Oil II has been tested on humans and has been shown to be safe. I have seen no such studies, and would be willing and interested to review any such studies held by the manufacturer. In the interim, I believe that it may be misleading to assert that such studies prove safety.

I have seen no information regarding the risks or safety of the commercial agent (Mobil Jet Oil II), and in particular I have seen no information on neurotoxicity, immunotoxicity, genotoxicity or reproductive toxicity. To the best of my knowledge, there are no reliable data to support the view that the chemicals to which the passengers and staff were exposed are safe. There is sufficient clinical data to suggest the opposite.

There are at least two issues which significantly alter assumptions used in toxicology in this case, and which would tend to increase the harm which the vapour mixture would cause to those in the cabin.

Firstly, cabin pressure is, I believe, set to the equivalent of an altitude of 2,500 metres (8,000 ft). Staff and passengers in the jet at cruising altitude are relatively hypoxic (short of oxygen), and the partial pressure of oxygen at this altitude is, as I understand it, below accepted occupational standards.

As well, the percentage of recirculation of cabin air is uncertain, but may be between 50% and 70%, further reducing the partial pressure of oxygen, and oxygen availability within the cabin.

The reason this is important is that oxygen is required both for protection of tissue (through the oxygen-dependent antioxidant systems) and for detoxification of hazardous chemicals such as organophosphates. Low oxygen availability diminishes tissue protection against harm caused by such chemicals, would tend to increase the half-life of circulating chemicals, increasing the risk of harm in an unpredictable fashion, varying greatly from person to person.

In summary, the circumstances in which exposure to the mist/vapour of the Mobile Jet Oil II occurs (ie in a pressurised cabin with low oxygen tension) increases the risk of harm from the chemicals in the mist in an unpredictable manner.

III. Issues Regarding the Toxicology and Expert Committee Findings

I have concerns regarding the constitution and findings of the so-called *"expert panel"* convened to assess the health risks associated with work on the BAe-146, and wish to make certain comments on matters which the committee failed to address in reaching their conclusions.

A. Selection of the "expert panel"

The panel chosen by Ansett or their advisors may have been *"expert"*, but can in no way be said to be either independent or neutral on the matter. There appears to have been a more than fortuitous gathering of *"experts"* whose views on the matter of adverse effects of chemicals on health were well known and well publicised. Dr Loblay and Dr Carrol, for example, have made strong prior statements in the media and in their medical reports on patients to the effect that they refused to believe that long term adverse effects of the type seen in BAe-146 staff could possibly occur. Dr Carrol, in particular, appears to have been the Queensland doctor nominated by Ansett as the doctor used by WorkCover to deny compensation for Queensland cabin staff (support document of conversation with Dr Dai Lewis, Ansett chief medical officer, is available if required by the Inquiry).

Findings of so-called *"expert committees"* or *"expert panels"* are meaningless and without value unless independence can be demonstrated. It is unclear from the documents I have seen what, if any, compensation, considerations, benefits, support, promises or payments were made by Ansett to members of this panel.

It is my view, based on the clinical presentations of BAe-146 cabin staff and two of my patients flying on this aircraft, that the findings of proven safety and low risk cannot be sustained by the available evidence. In fact, the contrary would appear to be true, namely that long term (and possibly permanent) symptoms and health problems remain well after the cessation of exposure, and cause a range of disabling chronic symptoms.

I would also note that there are at least two different issues with regards health and hazard in this matter, and that both must be assessed to gain a view on risks associated with the exposure.

Firstly health and safety risks are different issues. Safety hazard can occur without significant health hazard, and health hazards do not necessarily reduce safety.

By this, I mean that temporary neurotoxic effects or deficit may not be a health hazard for the sufferer, but may constitute a significant safety risk for others, such as passengers in a jet. The typical example would be alcohol use by pilots. Inebriation is arguably not a primary health risk for the pilot, but is a considerable safety risk if he or she pilots a jet while inebriated.

Conversely, increased cancer risk for pilots and cabin crew is a health risk for the individual, but does not reduce passenger safety.

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In my view, based on both clinical experience and a literature review, both types of risk exist in the case of the BAe-146 jet for cabin crew and passengers. The neurotoxic effects and neurobehavioural changes reduce the safety for all in the short term by prolonging reaction time and altering decision making capacity, as well as by inducing symptoms such as vertigo and balance changes. As well, the people I have reviewed have failed to recover from their induced neurological and other health problems even after leaving the workplace, and there is no good evidence that people so affected will recover in the future. The damage done to the health of staff and passengers by exposure would seem to be long term and possibly permanent.

Thus, risk is likely to be increased both in terms of health outcomes for cabin crew and passengers, and in terms of reduced neurological and functional capacity of those responsible for the safety of the aircraft. This may explain the reported incidents which would appear to have placed jets and occupants at risk in the past.

B. Chemical Mixtures

TOCP is by no means the only chemical toxin in the mist.vapour of Mobile Jet Oil II. The oil is a complex mixture of hazardous chemicals, many of which are toxic alone or in the commercial mixture. The other tricresyl phosphate isomers are organophosphates and are capable of inhibiting esterase function. Naphthalomines, for example, are present, and are important in terms of liver, brain and genetic function and damage/degeneration.

In general, exposure risk with such complex mixtures has been assessed as if each agent acted alone, without any attempt to allow for additive and synergistic effects. That has also occurred in this case, where no attempt has been made to model or describe the toxicity of the mixture of chemicals of the mist/vapour in the cabin.

Because of this, all *"expert"* views on the toxicity or hazard associates with the exposure to the chemicals is unhelpful and may be meaningless. In such circumstances, one must look to the clinical effects of exposure to define the toxic effects. In effect, the experiment to determine the toxicity is the exposure of humans to the chemicals in the cabin.

Given the number of cabin crew I have seen with similar symptoms, health problems and pathology, I believe there is sufficient evidence to implicate the exposure to cabin mist/vapour as a significant health hazard. The proportion of people so affected is very high, and considerably more than the prevalence of 0.1% to 1% reported in the population as a whole with similar symptoms and health problems.

IV. Summary & Conclusions

Based on the health complaints, symptoms and pathology of the BAe-146 cabin crew and pilots I have seen and examined, as well as the prolonged adverse health problems suffered by two patients in my practice after travel on the BAe-146 jets, I am of the strong opinion that travel in these jets constitutes a health risk for staff an occupants, and places the aircraft and occupants at increased risk of misadventure.

The similarity of the clinical complaints of the patients I have seen would suggest that common mechanisms of illness are at play in each case, and the jet exposure is implicated because it is the *only* common factor in the history of those reviewed.

In addition, there is insufficient independent information available from any source to come to conclusions about safety or toxic effects of the Mobil Jet Oil II mixture. The composition of the cabin fumes under operating conditions is unknown, while certain components of the mixture are known to be neurotoxic at low doses. The short term effects of exposure appears to cause inflammation of mucous membranes and altered neurological function. The long term effects are to date unstudied, and therefore are unknown. Information on the long term effects of organophosphorous compounds *is* becoming available in the medical literature, and the evidence is now strong that there are significant and persistent neurological and neuropsychological effects in those exposed.

In the absence of good evidence of long term safety, it is reasonable to turn to the available evidence, the documented histories and clinical assessment of doctors who have examined people complaining of long term health problems. There is a common and disturbing pattern of complaints and abnormalities of neurological and pathological testing. Such complaints and abnormalities are rare in the general population, and would be expected to be very rare in a group selected from a large group of applicants for this work, whose health and fitness is clearly greater than average for the population generally.

The complaints are also found in patients who had previously recovered from serious illness, and who relapsed within hours of travel on the BAe-146. In this case, one could argue that a previously sick person *may have developed* an increased susceptibility to the effects of chemical exposure, such as that found in the BAe-146. I believe that this is irrelevant, as those same people travelled in other aircraft without suffering health problems, and should reasonably have expected to be able to do the same in the BAe-146. If there were an increased susceptibility, it was not triggered in other similar situations, and none had anticipated problems caused by travelling in any aircraft.

Finally, the general shortcomings of toxicology, the science of poisons, are such that prediction of health problems in humans with recurrent or long term exposure to complex mixtures is inherently impossible at present. The discipline is currently attempting to address this shortcoming, and within the next decade, predictive tools and models may be available, but this is not the case at present.

In such circumstances, one must choose certain principles upon which to authorise or use such mixtures. While the precautionary principle is preferred (ie not authorising use until strong evidence of long term safety of the mixture in humans is available), it has been argued that his would lead to an unacceptable delay in the use of important new chemicals or mixtures, and would make innovation in the chemical industry uneconomic.

The economic principle, on the other hand, has become the dominant approach of recent decades, allowing for products to be developed and allowed relatively unrestricted use after basic testing of individual components for lethality and carcinogenicity in laboratory settings, using small and fast breeding mammals such as mice and rats. Testing for neurotoxicity and immunotoxicity is generally not performed, and all test results are extrapolated to humans in a way which fails to assess subtle, progressive loss of function and complex health complaints over time.

In either case, however, it is agreed that active and inclusive post-marketing surveillance of safety is vital to improve knowledge of safety and adverse effects. Clinical assessment of people with health complaints has become the foundation of such post-marketing surveillance, as there is no active pursuit on the part of manufacturers of early symptoms in users or those exposed.

Thus, to deny clinical presentations and health problems of those exposed on the basis of inadequate and flawed prior testing is illogical and dangerous, and tends to prolong the use of hazardous agents, unacceptably placing others at risk.

Causing health problems in some people exposed to chemicals or other hazards in certain environments is unavoidable, given the current use of the commercial principle in toxicology and business. The hallmark of a working post-marketing surveillance system is that such people with health problems are identified early, are quickly compensated for their suffering, and the circumstances of exposure and harm are identified, admitted, and changed to reduce such risk.

The denial of hazards, health complaints, and risks to others has become an endemic problem, placing tens of thousands of workers at risk in industry, and causing hundreds to thousands of deaths in Australia each year. It is a reaction almost universally adopted by industry, unfortunately, prior to ultimate admission of harm at a later date.

While such a reaction may be designed to minimise liability and maintain profitability of the industry, it is inexcusable that those who have suffered such injury also are forced to suffer ridicule, accusations of malingering or fraud, and personal investigations and attacks by employers, insurers and regulators. It is also inexcusable that others who have not been damaged are placed at risk, long after the hazard has been identified. This especially applies to children, pregnant women, the sick (or those previously sick, whose health is not robust), and the aged.

The health problems suffered by passengers and crew of the BAe-146 require our urgent attention and action to reduce hazard and risk for others, and to admit injury and compensate faultlessly those who have suffered in the name of the commercial principle. The denial of liability and risk places the health of all at risk, runs counter to the very principles of toxicology, and exacerbated the suffering and harm caused to those who have suffered in the name of commercial profitability.

In the case of the BAe-146, such denial increases the risks for passengers from misadventure as well. The environment of the cabin, and the exposure to hazardous agents which affect the nervous system, is unacceptable, and constitutes both a health hazard and an air safety hazard.

Signed

Dr Mark Donohoe MB BS

Documents referred to in this submission are available at the request of the Inquiry, except that patient records would need to be de-identified, and appropriate safeguards should be in place to protect patients who are employees of the airlines using BAe-146 aircraft.

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SUBMISSION TO THE SENATE REFERENCES COMMITTEE
RURAL AND REGIONAL AFFAIRS AND TRANSPORT

ON THE INQUIRY INTO

AIR SAFETY – BAE 146
CABIN AIR QUALITY

SUBMISSION NUMBER 3

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Senator Woodley
Australian Democrats Senator for Queensland
Parliament House
Canberra, ACT 2600
Australia

Re: Examination of air safety with particular reference to
air quality of the BAe 146 aircraft

Dear Senator Woodley,

I wish to inform you that I have seen five patients who were referred to me for assessment for brain function deficit as a consequence of their exposure to chemicals in the workplace as flight crews of the BAe 146 aircraft. They included two pilots and three flight attendants.

The results of the assessments indicated that in each case, there was a significant dysfunction in their ability to process information efficiently. This dysfunction has impacted on their ability, adversely affecting their performance on mental and psychomotor tasks. This could significantly increase the risk of air safety should they be performing tasks required of aircrews as part of their employment schedules. This risk could be exacerbated during the course of their duties as flight crews as a consequence of further exposure to the aircraft environment of the BAe 146 aircraft.

If I could be of assistance to your inquiry on air safety with regard to the air quality of the BAe 146 aircraft, please contact me at the above-mentioned address.

Please find enclosed my curriculum vitae, a list of my research publications and a list of recent conference presentations.

Yours sincerely,

Richard Teo
Psychologist
BA,MSc,PhD,MAPS,MESA

R C Teo

CURRICULUM VITAE

NAME: Richard Kong Choon Teo

ADDRESS: 4 Nixon Place, Bonnet Bay, NSW 2226

NATIONALITY: Australian

ACADEMIC QUALIFICATIONS:

Doctor of Philosophy 1987, University of Sydney

Master of Science (Psychopharmacology) 1979, University of Sydney

Master of Science Qualifying (Pharmacology) 1975, University of Sydney

Bachelor of Arts 1969, University of New South Wales
Major in: Psychology (social, clinical, industrial & abnormal) and Political Science.

POSITION HELD:

1996 to present
Consultant psychologist, private practice

Achievements:

Consultant to medical practitioners and other health professionals for psycho-neurological assessments of chemical exposure effects and stress management.

Consultants to legal practitioners: assessment of clients for compensation and rehabilitation cases.

Recognized researcher on chemical exposure effects on workers and the public at large at international level.

1991 to 1996

Senior Psychologist, WorkCover Authority of NSW.

Achievements:

WorkCover Authority's consultant psychologist for neurobehavioural testing, occupational stress monitoring and stress management.

WorkCover Authority Stress Project Committee member: Wrote a critique paper with regard to Sydney Transit Authority's stress programs for bus drivers in the Newcastle region. Wrote the stress prevention model and stress information paper for committee's draft paper for the Authority' Executive.
WorkCover Authority's Alcohol and Other Drugs Committee: Wrote a paper on the interactive effects of alcohol and other drugs on human performance.

Consultant psychologist in other areas including ergonomics, alcohol and other drug effects on human performance.

Medical/legal consultant on issues related to toxic effects on neurobehavioural functions.

1987 -1991

Psychologist, Division of Occupational Health, WorkCover Authority of NSW.

Achievements:

Development and management of the Division of Occupational Health Information and Research Services.

Development of a statistical system for the Division of Occupational Health Medical clinics.

Organisation and participation in research and management committees and working parties.

Research and consultant on occupational stress.

Research on the short and long term pesticide and solvent exposure effects.

Research and consultant on workers' chemical exposure risk in the workplace.

Preparation of papers and reports for publication at conferences and in scientific journals, and for executive management and policy implementation.

1980-1986

Psychologist, Division of Occupational Health, WorkCover Authority of NSW.

Achievements:

Research and development of the event-related potential technique for assessing human brain functions.

Research on the interaction of pesticide exposure and alcohol effects on workers.

Research on the effects of lead and mercury exposure effects on workers.

1972-1980

Research Psychologist, Department of Motor Transport of NSW (secondment to the University of Sydney, Department of Pharmacology).

Achievements:

Development of a battery of neurobehavioural tests for assessing human performance.

Research on the effects of alcohol and of drug-alcohol interaction effects on human perceptual, psychomotor and cognitive functions.

Establishment of the standard alcoholic drinks for New South Wales drivers for attaining blood alcohol level of 0.05%.

Survey conducted on drug usage of breathalysed drivers.

Lecture and supervision of senior students.

Develop a drink-driver traffic safety video for the promotion of safety campaign.

Organisation of seminars and conferences.

Presentation of research papers at seminars and conferences at national and international levels.

1969-1971

Research Psychologist, Department of Motor Transport of NSW.

Achievements:

Research on:

Breathalyser legislation in NSW
Driver licensing system
Driver behaviour
Seat-belt legislation in NSW

Membership of Professional Organisations

I am a member of:

The Psychologists Registration Board, NSW

The Australian Psychological Society

The Australian Society of Clinical and Experimental Pharmacologists

The Australian Psychophysiological Society

Ergonomic Society of Australia

PUBLICATIONS

1. Belgrave, B.E., Bird, K.D., Chesher, G.B., Jackson, D.M., Lubbe,K.E., Starmer, G.A., and Teo, R.K.C. (1979). The effect of (-) trans Δ^9 - tetrahydrocannabinol, alone and in combination with ethanol on human performance. *Psychopharmacology*, 62, 53-60.

2. Belgrave, B.E., Bird, K.D., Chesher, G.B., Jackson, D.M., Lubbe, K.E., Starmer, G.A., and Teo, R.K.C. (1979). The effect of cannabidiol alone and in combination with ethanol on human performance. *Psychopharmacology*, 64, 243-246.

3. Bird, K. D., Boleyn, T. Chesher,G.B., Jackson, D.M., Starmer, G.A., and Teo, R.K.C. (1980). Intercannabinoid and cannabinoid-ethanol interactions and their effects on human performance. *Psychopharmacology*, 71, 181-188.

4. Chesher, G.B., Franks, H.M., Hensley, V.R., Hensley, W.J., Jackson, D.M., Starmer, G.A., and Teo, R.K.C. (1976). The interaction of ethanol and Δ^9 - tetrahydrocannabinol in man. Effects of perceptual, cognitive and motor functions. *Medical J. Aust.*, 2, 159-163.

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R.K.C. Teo

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SUBMISSION TO THE SENATE REFERENCES COMMITTEE
RURAL AND REGIONAL AFFAIRS AND TRANSPORT

ON THE INQUIRY INTO

AIR SAFETY – BAE 146
CABIN AIR QUALITY

SUBMISSION NUMBER 4

Mr Stephen Tyrrell
Physicist
PO Box 393
DICKSON ACT 2602

Phone:
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. Box 393,
kson, A.C.T., 2602

re: Aircraft cabin air contamination

Senator John Woodley,
Parliament House,
Canberra, A.C.T. 2600
02 6277 5811 fax

Dear Senator Woodley,

I believe that the presence of ortho-cresol or a similar cresol in the turbofan engine lubricating oil of the BAe 146 aircraft is highly suspect as a cause or significant co-factor of the reported illness in exposed aircrew.
This phenolic coal tar distillate causes neurological disturbance and chronically, neural damage in exposed individuals.

I was surprised by the presence of this substance as revealed in the recent TV documentary on this allegedly cabin air induced illness. The documentary was screened by one of SBS-TV or ABC-TV perhaps 2 months ago. According to this documentary, Mobil Oil manufactured the lubricating oil for the jet engines.
It is this oil that escapes past the allegedly deficient oil seals into the compressor bleed air used to ventilate and pressurise the aircraft cabins.

Ortho-cresol 's toxicity is described under "Phenol" variously as "... even small amounts may cause nausea, vomiting ... paralysis, convulsions ... Chronic poisoning with renal and hepatic damage may occur from industrial contact." The Merck Index, 10th edn Merck & Co. 1983 7115. page 1043.

There will be a great deal of professional contention as to whether these phenolic compounds induce the reported ill health. I am a physicist and have been concerned with toxicology for 20 yrs past.

Other aircraft such as the McDonnell Douglas MD-80 nominated in this syndrome may or may not contaminate cabin air with jet engine lubricating oil.

The Avco Lycoming or Textron Lycoming ALF 502R-5 turbofans in the BAe 146 are used also in the Canadair CL-600 Challenger 14 seat business jet (2 x Avco Lycoming ALF 502L turbofans) and probably have exactly the same deficient seal design. Recent forms of the BAe-146 have been re-engined with new Textron Lycoming LF 507 turbofans which may not have the faulty gas/oil seals. Two of this latter type, the Avro 146 or Avro 146-RJ70 with Textron Lycoming LF 507 turbofans were on the national aircraft register in March 1998.
In March 1998 there were 29 BAe-146 type aircraft with ALF 502R engines and 2 BAe-146 types with ALF 507 engines on the CASA Australian Aircraft Register.

The causes of the syndrome may of course be multiple, there may be a number of conditions presently considered to be one syndrome and these may or may not be due to engine oil contamination.

I ask please that you investigate the toxicology of this specific substance and any role it may have in the aetiology of this syndrome.

Thankyou.

Yours faithfully,

Stephen Tyrrell
19th July 1999

RECEIVED 19 JUL 1999 Senate Rural and Regional Affairs and Transport Committee

Stephen Tyrrell

SUBMISSION TO THE SENATE REFERENCES COMMITTEE
RURAL AND REGIONAL AFFAIRS AND TRANSPORT

ON THE INQUIRY INTO

AIR SAFETY – BAE 146 CABIN AIR QUALITY

SUBMISSION NUMBER 5

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To Senator John WOODLEY,
Australian Democrat Senator for Queensland
Parliament House
Canberra ACT 2600
Australia

From Dr Jean Christophe BALOUET Université Paris 7-Denis Diderot UFR Environment

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Regarding : toxic smokes and fumes on the Bae 146.
Senate Rural and Regional Affairs and Transport Committee, note d)

Monsieur le Senateur WOODLEY,

As an international environment expert, collaborating with intergovernmental bodies (UNEP, WHO, ICAO) and international associations (chair of Occupational / Environmental Safety committee of the Aerospace Medical Association, chair of the Airborne Chemical Committee of the International Society of Automotive Engineers), I have been working on cabin air quality / toxicity issues in airplanes for over 4 years, including Bae-146, MD-80, B-737, B-777, A-300, A-320 ...

Statistically, Ansett/NJS and their BAe 146, Alaska Airlines and their MD80 and B737, Canadian/Air Canada with their A-300, Air BC (Bae-146) are responsible for 90% of the worldwide problems identified today, whereas they represent less than 3% of the commercial flights worldwide. Looking at its relative number of aircraft, Ansett/NJS, has the highest events/complaints ratio.

I attach a short submission for consideration by the Australian Senate Aviation Enquiry. This submission is summarized from extensive reports, information and data (from documentation 3 feet thick) and there is much more it could cover. Due to the importance of the related flight safety and crew/passenger health issues, I would prefer to give evidence as a witness, so that I could answer other questions that may be raised. I am aware of the submission by Assoc. Prof. Chris Winder.

Je me tiens à votre disposition et vous prie de recevoir, Monsieur le Sénateur, l'expression de ma consideration distinguée.

Dr Jean Christophe BALOUET

Submission to

Senate Rural and Regional Affairs and Transport References Committee Inquiry

Examination of air Safety, with particular reference to air quality in the cabins of BAE 146 aircraft

June 1999

By Dr Jean Christophe BALOUET, Dr 3°C, Sc
Université Paris 7-Denis Diderot UFR Environment
Environment International
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Dr Jean Christophe BALOUET is chair of the Occupational/Environmental Safety sub-Committee of the Aerospace Medical Association, chair of the Airborne Chemicals Committee of the International Society of Automotive Engineers, International Member of the Transportation Air Conditioning Technical Committee of ASHRAE. He worked as a post-doc scientist for the Smithsonian Insitution (Washington D.C.) and the Paris Museum of Natural History, then for five years as a collaborator of the United Nations Environment Programme, Industry and Environment Office.
He is *chargé de cours* in environment, La Sorbonne.

Submission by Dr Jean Christophe BALOUET

I Are aircraft engine and APU lubricating oils, hydraulic fluids toxic ?

Undoubtedly yes. These aircraft fluid are blends of chemicals. Amongst critically toxic chemical ingredients used in these aircraft fluids are organophosphates and Naphthalenamines. The toxicity of these chemicals is well known worldwide for over 20 years, including their use in aviation.

2 What is their toxicity ?

Organophosphates (OPs) have long be used as chemical weapons, neurotoxicants and pesticides. Acute exposure events as well chronic low dose exposures are known (over 30 years) as cause of critical neurotoxic effects, including Organophosphate Induced Delayed Neuropathy (OPIDN). This is ireversible damage to nerves in the nervous system. However, exposures that do not produce permanent neuropathy may still be neurotoxic.

Most worrisome symptoms for aviation safety include disorientation, impaired vision, memory, concentration, coordination, loss of balance, unconsciousness, respiratory failure... some of which can last for months or years . Other health effects include chronique fatigue, irritant effets, as direct exposure, observed on eyes, lungs, skin (usually short term), and other toxicity related symptoms such as vomiting, diarrhoea. Symptom severity usually depends on exposure levels, exposure duration and frequency, although potentiation factors such as previous incidental or chronic exposures, presence of other chemicals, altitude, individual variations can increase toxicity.

2-Naphthalenamine is a demonstrated human bladder carcinogen for which International Agency for Research on Cancer (IARC is a WHO body) does not allow any safe exposure.

3 What about aircraft leak events ?

It has long been acknowledged by the aviation industry that leaks do occur under incidental conditions, or « normal » operation on a chronic basis, and in cabin contamination occur through the bleed air. These are due to seal / aircraft parts design, age and wear, operating and maintenance conditions and documented by logs and maintenance « top-up » volumes. They can also be delineated by the examination of recirculation filters. Monitoring campaigns, would sampling and monitoring methods be appropriate, would be of major importance. However, the sampling and monitoring methods used on Bae-146 are selective, of very high blank values, and to date, the aerosolised fraction(mists/smoke/fumes) of aircraft fluids have been poorly and inadequately investigated.

4 : What about threshold limit values of the aircraft fluids and exposure toxicity:

Cabin air contains a blend of chemicals (over 400 different chemical species and isomers) such as irritants and chemicals toxic to the nervous system, or to liver, kidney, blood forming tissues and other organ systems. The neurotoxicity of cabin air is the sum of the effects of the neurotoxicants present. Over 100 neurotoxicants are listed as monitored / indentified and another 100 compounds are expected as part of compounds used or their thermal decomposition by-products.

The point is not to say that the concentration of an individual neurotoxic compound is below its individual Occupational Exposure Standard, when dozens of other neurotoxic compounds are present and at least additively contribute to exposure toxic effects.

One cannot dismiss the toxicity of a blend of contaminants without a systematic approach, using adequate sampling and monitoring methods, assessing symptoms where incidents occured, looking at thermal degradation by-products. Not being part of the aviation industry, I do not have access to all elements of the BAe 146 issue. Access to good monitoring data is essential in the Australian case, including monitoring by independent experts.

Modelisation methods based on documented flights, do show that standard and threshold limit values are exceeded in a number of existing flights, by orders of magnitude. For example, on one haze event, OP concentration in air (both aerosol and vapour phases) has been estimated at 800 mg/m3,–all crew were incapacitated, several passengers and crew incapacitation lasted for years or is still lasting-. Several complaint flights with neurotoxicity symptoms have an estimated OP concentration in the range of 3 mg/m3. The recommended value for TCP is 0.5 mg/m3

5 : What about correlating symptoms to exposures?

All cognizant authorities do work on symptoms, as this is the way, experimentally or in analyzing field events, to assess the toxicity. However, this can hardly be called preventive.

I have records of over 100 crew with long term incapacitation, following documented aviation leak/exposure events and have regular contacts, or have met with over 15 of them. They all share the cluster of symptoms described above. While cabin air contamination by aircraft fluids is now acknowledged by the aviation industry, it is surprising to see that only a few symptoms have been looked at in the Australian debate, agreeing on mild irritation but discarding the associated neurological impairment, when exposure to the same contaminants are known to cause both of them.

6 : How International and frequent is the problem ?

It is estimated that about 70 major smoke/haze events, no fire but cabin air contaminationby aircraft fluid leaks, occur worldwide annually (with 25 to 30 for the commercial aviation in the USA) and that the number of severe fume events is over 500 annually (40 000 passengers and crew). Alaska airline has filed over 1000 complaint flights in the past ten years. In Canada, over 600 complaint reports have been filed for the past 5 years. Over 30 legal cases are censused worldwide. Recently, under FBI investigations, maintenance records of one airline did demonstrate that the maintenance records were falsified.

Some aircraft types, especially BAe 146, MD 80, B 737, A 300, and a limited number of companies (ANSETT/NJS, Alaska Airlines, Air BC, Canadian operating these aircraft) have been cause of over 90 % of the worldwide problems identified today, whereas they represent less than 3% of world flights. The aviation understanding of these statistics is that some aircraft are more prone to leaks due to design, and that these leaks are considerably reduced with adapted maintenance and operations.

Anestt / NJS and Bae 146 are statistically the highest ranking for cabin air problems, before Alaska.

7 What kind of consequences could be expected ?

Flight safety is certainly a major concern. One cannot expect a pilot with disorientation, altered memory and concentration, blurred vision and blurred speech, loss of balance and coordination fly and land an aircraft safely. In-cabin contamination by aircraft fluids has been a suspected cause for several unexplained crashes. The Executive Director of Aerospace Medical Association, Dr Russ Rayman, investigating 89 USAF incidents, states that « *smoke fumes in the cockpit are not a rare event and is a clear threat to flying safety because of acute toxic effects. If smoke/fumes are detected, crewmembers should immediately follow established emergency procedures...* ».

Crew and passenger health is the other major concern. Short and long term incapacitation after documented exposure is a fact ; toxicity of aircraft fluid contaminants is known and in-cabin contamination/exposure events acknowledged.

Responsibilities and legal cases are most important as issue is further documented.

8 Can the problem be solved ?

Improved design and maintenance (including additional maintenance on ageing aircraft), procedures for grounding the aircraft when leaks or fumes are detected, top up needed, can drastically reduce the leak events and exposure levels, also increasing safety. Less toxic coumpounds ought to be developed while improved contaminant removal systems can be adopted. It is a poor practice to pretend that no procedures are required if a smoke/fumes event occurs. People should be informed and given advice on preservative procedures which reduce exposures. In the case of smoke/fume events, flight deck crew must use safety masks, the contaminating pack must be switched off, cabin crew and passengers must breath through blankets and emergency procedures applied. Leaks need to be repaired and air ducts cleaned (no pack burn out when people in aircraft) before further flight operation.

While the perspective is to have the very safest flying environment, all past technical and human aspects, engineering and health effects, should be compensated.

Dr Jean Christophe BALOUET JCBalouet@aol.com

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Responsibilities and legal cases are most important as issue is further documented.

8 Can the problem be solved ?

Improved design and maintenance (including additional maintenance on ageing aircraft), procedures for grounding the aircraft when leaks or fumes are detected, top up needed, can drastically reduce the leak events and exposure levels, also increasing safety. Less toxic coumpounds ought to be developed while improved contaminant removal systems can be adopted. It is a poor practice to pretend that no procedures are required if a smoke/fumes event occurs. People should be informed and given advice on preservative procedures which reduce exposures. In the case of smoke/fume events, flight deck crew must use safety masks, the contaminating pack must be switched off, cabin crew and passengers must breath through blankets and emergency procedures applied. Leaks need to be repaired and air ducts cleaned (no pack burn out when people in aircraft) before further flight operation.

While the perspective is to have the very safest flying environment, all past technical and human aspects, engineering and health effects, should be compensated.

Dr Jean Christophe BALOUET JCBalouet@aol.com

SUBMISSION TO THE SENATE REFERENCES COMMITTEE
RURAL AND REGIONAL AFFAIRS AND TRANSPORT

ON THE INQUIRY INTO

AIR SAFETY – BAe 146 CABIN AIR QUALITY

SUBMISSION NUMBER 5A
Date Received: 31 March 2000

Université Paris 7 - Denis Diderot UFR Environment

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From: JCBalouet@aol.com [SMTP:JCBalouet@aol.com]
Sent: Thursday, March 30, 2000 7:43 PM
To: Trish.Carling@aph.gov.au
Subject: BAe 146

Sénateurs,

I thank you for the honor of being invited to contribute to your committee on March 13.

In a complementary submission to you, and in accordance with proposed continued contact, I would like to add the following elements.

I would invite the committee to consult the US EPA Federal Register, Guidelines for neurotoxicity risk assessment [FRL-6011-3] RIN 2080-AA08, dated May 14, 1998 (Volume 63, number 93). I especially invite the committee to section 3: hazard characterization.

Also, I attach a Word file on aviation existing or draft requirements by FAA and JAA. This document is a working document at SAE AC/9 level, developed by aviation industry under the Airborne chemical committee which I chair. I know this represents significant additional reading, although sections dealing with our issues are selected to save you time. This may eventually demonstrate that cabin air contamination by airborne chemicals is not considered as normal at design, operation or requirement levels.

You might also be interested to get in contact with Professor Robert Haley. He is a professor of epidemiology at Southwestern Medical University, Dallas, Texas. He has been working for the US Center for Disease Control and has most solid expertise in the field of Gulf War Syndrome, which looks pretty close in symptoms to the aerotoxic syndrome while exposure events to organophosphated compounds are shared. His contacts are :
Professor Robert HALEY
rhaley@mednet.swmed.edu
Epidemiology Division, Dept of Internal Medicine
Southwestern Medical University Dallas Texas 75235-8874
Tel : 2146483075

You might be interested to add his paper to your references : Robert W. Haley, Scott Billecke, and Bert N. La Du : 1999 ; Association of low PON1 type Q (type A) arylesterase activity with neurologic symptoms complexes in Gulf war veterans. Toxicology and Applied Pharmacology, 187, pp 227-233.
This deals with possible genetic / enzymatic factors that could explain individual susceptibility factors.

Looking at leak rates, I think the point is not at comparing a leaking aircraft with another leaking aircraft (even if an A 340 transports more passengers than a Bae 146, has a higher airflow, or much longer range and rotation). The figure of 2 to 3 quarts per rotation on a Bae 146 is way too high compared to other aircraft. Also, an

average leak rate is meant to be exceeded in several circumstances. I feel that high and highest leak rate figures would help the Senate committee.

One might note that, in almost 10 years, only 12 reports have reached BASI on Bae 146 smoke, fire, fumes from any source (compared to higher numbers on other aircraft). This might indicate discrepancy in use of the reporting system within the required guidelines of the Aviation Regulations and the acceptance of this.

The issue of independent expertise is more than ever on. I will be available to the Senate Committee and Parties for such independent expertise, as discussed on March 13. Please feel free to contact me, or to let this offer known to Parties.

Please feel free to contact me for any questions,
Sincerely yours,
Dr Jean Christophe BALOUET

FAR's

FAR 23.831 Ventilation.

(a) Each passenger and crew compartment must be suitably ventilated. Carbon monoxide concentration may not exceed one part in 20,000 parts of air.
(b) For pressurized airplanes, the ventilating air in the flightcrew and passenger compartments must be free of harmful or hazardous concentrations of gases and vapors in normal operations and in the event of reasonably probable failures or malfunctioning of the ventilating, heating, pressurization, or other systems and equipment. If accumulation of hazardous quantities of smoke in the cockpit area is reasonably probable, smoke evacuation must be readily accomplished starting with full pressurization and without depressurizing beyond safe limits.

[Doc. No. 4080, 29 FR 17955, Dec. 18, 1964; 30 FR 258, Jan. 9, 1965, as amended by Amdt. 23-34, 52 FR 1831, Jan. 15, 1987; Amdt. 23-42, 56 FR 354, Jan. 3, 1991]

FAR 23.975 Fuel Tank Vents and Carburetor Vapor Vents.

(a) Each fuel tank must be vented from the top part of the expansion space. In addition-
  (1) Each vent outlet must be located and constructed in a manner that minimizes the possibility of its being obstructed by ice or other foreign matter;
  (2) Each vent must be constructed to prevent siphoning of fuel during normal operation;
  (3) The venting capacity must allow the rapid relief of excessive differences of pressure between the interior and exterior of the tank;
  (4) Airspaces of tanks with interconnected outlets must be interconnected;
  (5) There may be no point in any vent line where moisture can accumulate with the airplane in either the ground or level flight attitudes, unless drainage is provided. Any drain valve installed must be accessible for drainage;
  (6) No vent may terminate at a point where the discharge of fuel from the vent outlet will constitute a fire hazard or from which fumes may enter personnel compartments; and
  (7) Vents must be arranged to prevent the loss of fuel, except fuel discharged because of thermal expansion, when the airplane is parked in any direction on a ramp having a one-percent slope.
(b) Each carburetor with vapor elimination connections and each fuel injection engine employing vapor return provisions must have a separate vent line to lead vapors back to the top of one of the fuel tanks. If there is more than one tank and it is necessary to use these tanks in a definite sequence for any reason, the vapor vent line must lead back to the fuel tank to be used first, unless the relative capacities of the tanks are such that return to another tank is preferable.
(c) For acrobatic category airplanes, excessive loss of fuel during acrobatic maneuvers, including short periods of inverted flight, must be prevented. It must be impossible for fuel to siphon from the vent when normal flight has been resumed after any acrobatic maneuver for which certification is requested.

[Doc. No. 4080, 29 FR 17955, Dec. 18, 1964; 30 FR 258, Jan. 9, 1965, as amended by Amdt. 23-18, 42 FR 15041, Mar. 17, 1977; Amdt. 23-29, 49 FR 6847, Feb. 23, 1984; Amdt. 23-43, 58 FR 18973, Apr. 9, 1993; Amdt. 23-51, 61 FR 5136, Feb. 9, 1996]

FAR 23.1091 Air Induction System.

(a) The air induction system for each engine and auxiliary power unit and their accessories must supply the air required by that engine and auxiliary power unit and their accessories under the operating conditions for which certification is requested.
(b) Each reciprocating engine installation must have at least two separate air intake sources and must meet the following:
  (1) Primary air intakes may open within the cowling if that part of the cowling is isolated from the engine accessory section by a fire-resistant diaphragm or if there are means to prevent the emergence of backfire flames.
  (2) Each alternate air intake must be located in a sheltered position and may not open within the cowling if the emergence of backfire flames will result in a hazard.
  (3) The supplying of air to the engine through the alternate air intake system may not result in a loss of excessive power in addition to the power loss due to the rise in air temperature.
  (4) Each automatic alternate air door must have an override means accessible to the flight crew.
  (5) Each automatic alternate air door must have a means to indicate to the flight crew when it is not closed.
(c) For turbine engine powered airplanes-

(1) There must be means to prevent hazardous quantities of fuel leakage or overflow from drains, vents, or other components of flammable fluid systems from entering the engine intake system; and
(2) The airplane must be designed to prevent water or slush on the runway, taxiway, or other airport operating surfaces from being directed into the engine or auxiliary power unit air intake ducts in hazardous quantities The air intake ducts must be located or protected so as to minimize the hazard of ingestion of foreign matter during takeoff, landing, and taxiing.

[Doc. No. 4080, 29 FR 17955, Dec. 18, 1964, as amended by Amdt. 23-7, 34 FR 13095, Aug. 13, 1969; Amdt. 23-43, 58 FR 18973, Apr. 9, 1993; 58 FR 27060, May 6, 1993; Amdt. 23-51, 61 FR 5137, Feb. 9, 1996]

FAR 23.1109 Turbocharger Bleed Air System.

The following applies to turbocharged bleed air systems used for cabin pressurization:

(a) The cabin air system may not be subject to hazardous contamination following any probable failure of the turbocharger or its lubrication system.
(b) The turbocharger supply air must be taken from a source where it cannot be contaminated by harmful or hazardous gases or vapors following any probable failure or malfunction of the engine exhaust, hydraulic, fuel, or oil system.

[Amdt. 23-42, 56 FR 354, Jan. 3, 1991]

FAR 23.1111 Turbine engine bleed air system

For turbine engine bleed air systems, the following apply:

(a) No hazard may result if duct rupture or failure occurs anywhere between the engine port and the airplane unit served by the bleed air.
(b) The effect on airplane and engine performance of using maximum bleed air must be established.
(c) Hazardous contamination of cabin air systems may not result from failures of the engine lubricating system.

[Amdt. 23-7, 34 FR 13095, Aug. 13, 1969, as amended by Amdt. 23-17, 41 FR 55465, Dec. 20, 1976]

FAR 23.1121 General.

For powerplant and auxiliary power unit installations, the following apply-

(a) Each exhaust system must ensure safe disposal of exhaust gases without fire hazard or carbon monoxide contamination in any personnel compartment.
(b) Each exhaust system part with a surface hot enough to ignite flammable fluids or vapors must be located or shielded so that leakage from any system carrying flammable fluids or vapors will not result in a fire caused by impingement of the fluids or vapors on any part of the exhaust system including shields for the exhaust system.
(c) Each exhaust system must be separated by fireproof shields from adjacent flammable parts of the airplane that are outside of the engine and auxiliary power unit compartments.
(d) No exhaust gases may discharge dangerously near any fuel or oil system drain.
(e) No exhaust gases may be discharged where they will cause a glare seriously affecting pilot vision at night.
(f) Each exhaust system component must be ventilated to prevent points of excessively high temperature.
(g) If significant traps exist, each turbine engine and auxiliary power unit exhaust system must have drains discharging clear of the airplane, in any normal ground and flight attitude, to prevent fuel accumulation after the failure of an attempted engine or auxiliary power unit start.
(h) Each exhaust heat exchanger must incorporate means to prevent blockage of the exhaust port after any internal heat exchanger failure.
(i) For the purpose of compliance with §23.603, the failure of any part of the exhaust system will be considered to adversely affect safety.

[Doc. No. 4080, 29 FR 17955, Dec. 18, 1964, as amended by Amdt. 23-7, 34 FR 13095, Aug. 13, 1969; Amdt. 23-18, 42 FR 15042, Mar. 17, 1977; Amdt. 23-43, 58 FR 18974, Apr. 9, 1993; Amdt. 23-51, 61 FR 5137, Feb. 9, 1996]

FAR 23.1125 Exhaust Heat Exchangers.

For reciprocating engine powered airplanes the following apply:

(a) Each exhaust heat exchanger must be constructed and installed to withstand the vibration, inertia, and other loads that it may be subjected to in normal operation. In addition-
   (1) Each exchanger must be suitable for continued operation at high temperatures and resistant to corrosion from exhaust gases;
   (2) There must be means for inspection of critical parts of each exchanger; and
   (3) Each exchanger must have cooling provisions wherever it is subject to contact with exhaust gases.
(b) Each heat exchanger used for heating ventilating air must be constructed so that exhaust gases may not enter the ventilating air.

[Doc. No. 4080, 29 FR 17955, Dec. 18, 1964, as amended by Amdt. 23-17, 41 FR 55465, Dec. 20, 1976]

FAR 23.1197 Fire Extinguishing Agents.

For commuter category airplanes, the following applies:
(a) Fire extinguishing agents must-
   (1) Be capable of extinguishing flames emanating from any burning of fluids or other combustible materials in the area protected by the fire extinguishing system; and
   (2) Have thermal stability over the temperature range likely to be experienced in the compartment in which they are stored
(b) If any toxic extinguishing agent is used, provisions must be made to prevent harmful concentrations of fluid or fluid vapors (from leakage during normal operation of the airplane or as a result of discharging the fire extinguisher on the ground or in flight) from entering any personnel compartment, even though a defect may exist in the extinguishing system. This must be shown by test except for built-in carbon dioxide fuselage compartment fire extinguishing systems for which-
   (1) Five pounds or less of carbon dioxide will be discharged, under established fire control procedures, into any fuselage compartment; or
   (2) Protective breathing equipment is available for each flight crewmember on flight deck duty.

[Amdt. 23-34, 52 FR 1833, Jan. 15, 1987]

61 FR 63951 Allowable Carbon Dioxide Concentration in Transport Category Airplane Cabins; Final Rule

Date: December 2, 1996
Federal Register / Vol. 61, No. 232 / December 2, 1996 / Rules and Regulations
Part IV
Department of Transportation
14 CFR Part 25
[Docket No. 27704, Amdt. No. 25-89]
RIN 2120-AD47

AGENCY: Federal Aviation Administration (FAA), DOT.

ACTION: Final rule.

SUMMARY: This amendment revises the standards for maximum allowable carbon dioxide (CO2) concentration in occupied areas of transport category airplanes by reducing the maximum allowable concentration from 3 percent to 0.5 percent. This action is in response to a recommendation from the National Academy of Sciences to review the CO2 limit in airplane cabins, and provides a cabin CO2 concentration level representative of that recommended by some authorities for buildings.

EFFECTIVE DATE: January 2, 1997.

FOR FURTHER INFORMATION CONTACT: Kristin L. Larson, FAA, Flight Test and Systems Branch, ANM-111, Transport Airplane Directorate, Aircraft Certification Service, 1601 Lind Avenue SW., Renton, Washington 98055- 4056; telephone (206) 227-1760, facsimile (206) 227-1100.

SUPPLEMENTARY INFORMATION:

Background

This amendment is based on Notice of Proposed Rulemaking No. 94-14, published in the Federal Register on May 2, 1994 (59 FR 22718). As discussed in that notice, this action reduces the maximum allowable carbon dioxide concentration level from 3 percent to 0.5 percent.

In October 1984, the Department of Transportation was directed by Congress (Public Law 98-466) to commission the National Academy of Sciences (NAS) to conduct an independent study on the cabin air quality in transport category airplanes The NAS formed the Committee on Airliner Cabin Air Quality to study all safety aspects of airliner cabin air quality, and submitted its report, "The Airliner Cabin Environment--Air Quality And Safety," to the FAA on August 12, 1986. One of the recommendations in the report relates to the allowable carbon dioxide (CO2) concentration in the airplane cabin. This action is a result of that recommendation. For the purposes of this rule, the term "cabin" is meant to include the passenger cabin, the flight deck, lower lobe galleys, crew rest areas, and any other areas occupied by passengers or crew members in a transport category airplane

Discussion

Carbon dioxide is the product of normal human metabolism, which is the predominant source in airplane cabins The CO2 concentration in the cabin depends on the ventilation rate, the number of people present, and their individual rates of CO2 production, which varies with activity and (to a smaller degree) with diet and health. Carbon dioxide is also generated by sublimation of dry ice used to cool food in the galleys, and to preserve certain cargo carried in the cargo compartments. The carbon dioxide concentration level is frequently used as an indication of general air quality. At concentrations above a given level, complaints of poor air quality or "stuffiness" begin to appear.

The maximum CO2 limit of § 25.831(b)(2) of the Federal Aviation Regulations (FAR) is 3 percent by volume, sea level equivalent. This 3 percent limit was incorporated into § 4b.371 of the Civil Air Regulations (CAR) by Amendment 4b6 on March 5, 1952. This limit was carried over into 14 CFR part 25 when this part was codified in 1965. This high limit was established to allow for increases in the carbon dioxide levels in the crew compartment to ensure that, in airplanes with built-in carbon dioxide fire extinguishing systems, safe carbon dioxide concentration levels would not be exceeded in the occupied areas when combating fires in cargo compartments.

The American Conference of Governmental Industrial Hygienists (ACGIH) has adopted a short-term exposure limit (STEL) for CO2 of 30,000 parts per million (3 percent). The 3 percent limit specified in part 25 may therefore be satisfactory as a short-term limit, but is inappropriate for a steady-state condition. However, the NAS Committee notes in their report that this 3 percent limit is much higher than the limits adopted by the air conditioning industry for buildings and other types of interior environments, and recommends that the limit specified in part 25 be revised to more closely match the currently acceptable limits. The FAA concurs.

In contrast to the 3 percent limit specified in part 25, the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), in their Standard 62-1989, recommends an outside air ventilation rate of 15 cubic feet per minute for vehicles. Based on the ASHRAE calculations, this equates to a CO2 limit of 1,000 parts per million (PPM), or 0.1 percent, if the occupants have a low physical activity level. As most of the airplane occupants are passengers who are not active, this is a reasonable parallel. ASHRAE standards such as the 0.1 percent CO2 limit are frequently quoted in magazine and newspaper articles when reporting on airliner cabin air quality.

As CO2 concentration in the air increases, there is an increase in both the rate and the depth of breathing, reaching twice the normal rate at 3 percent concentration. At 3 percent concentration, there is some discomfort; at higher concentrations, headache, malaise, and, occasionally, fatigue occur, and the air is reported by those affected as being stale. People can function for long periods of time at levels of CO2 as high as 1 percent (as in nuclear submarines), but it is generally felt by ASHRAE that 0.1 percent is a better limit. This value, however, is based on the dissipation of smoke and odors and not on health considerations As noted above, according to ASHRAE Standard 62-1989, a steady-state CO2 concentration of 0.1 percent would require a fresh-air ventilation rate of 15 cubic feet per minute (cfm) per person. In the previous edition of the standard (62-1981), ASHRAE recommended a limit of 0.5 percent for office buildings and other occupied spaces, but suggested that 0.25 percent would provide an additional safety factor. The ASHRAE standard is intended to be used as a comfort standard rather than a health and safety standard. ASHRAE has recognized that the 0.1 percent CO2 concentration limit may not be appropriate for airliner cabins, and has formed an aviation subcommittee, the charter of which is to develop a transport airplane cabin air quality standard. While this subcommittee is not an FAA advisory committee, industry often uses ASHRAE standards in designing systems. The subcommittee will sponsor research studies to determine the quality of the ambient air and quantify the correlation between measurable contaminants and passenger perception of air quality. As noted above, ASHRAE standards were intended to be used for buildings rather than vehicles such as airplanes, and they consider it appropriate to establish a new standard for airplanes at this time.

The Occupational Safety and Health Administration (OSHA), in § 1910.1000 of part 1910 (CFR 29), sets an interim (transitional) limit for CO2 at 5,000 ppm or 0.5 percent, with a final rule limit of 10,000 ppm or 1 percent, effective December 31, 1993. The increase to 1 percent is apparently in deference to operators of commercial bakeries and breweries, both of which generate a significant amount of CO2 in their processes. The FAA does not believe it is appropriate to base the allowable CO2 concentration

in transport category airplanes on the needs of specific manufacturing processes. Other commercial enterprises have no difficulty in meeting the existing OSHA limit of 0.5 percent.

The American Conference of Governmental Industrial Hygienists, in its "Documentation of the Threshold Limit Values and Biological Exposure Indices—Sixth Edition," also recommends 0.5 percent as a limit, but ACGIH recommends this value as a time-weighted average limit for repeated daily exposure by workers. The FAA is adopting this value as a limit. A concentration limit of 0.5 percent is considered to be appropriate because there are no documented safety or health benefits associated with the establishment of a lower value.

Copies of the pertinent documents from ASHRAE, OSHA, and ACGIH have been placed in the public docket for this rulemaking.

Cabin ventilation provides air for dilution of airborne contaminants, and supplies oxygen for passengers and crew. Oxygen requirements for sedentary adults can be met with a fresh-air ventilation rate of only 0.24 cubic feet per minute (CFM) per person. Ventilation rates for current transport category airplanes vary from a low of approximately 7 cfm per person (with one or more air conditioning packs turned off for economy), to over 20 cfm per person (which includes up to 50 percent filtered, recirculated air). Thus, even at the lowest ventilation rates available on current airplanes, there is no significant reduction in the percentage of oxygen, or increase in the amount of water vapor in the cabin due to respiration. However, the design parameters for the ventilation systems are driven by operation on the ground during hot days. Contamination of air with CO2 varies inversely with the ventilation rate, because CO2 production by sedentary people is nearly constant.

In order to bring the maximum allowable carbon dioxide concentration into concert with accepted modern limits, this rule adopts a new maximum allowable carbon dioxide concentration of 0.5 percent. According to ASHRAE, for sedentary people this concentration can be maintained by a fresh air flow rate of 2.25 cfm per person, which is lower than that currently measured in transport category airplanes.

Section 25.831(b)(2) currently reads, "Carbon dioxide in excess of three percent . . . is considered hazardous in the case of crewmembers." The health and comfort considerations discussed earlier are equally valid for passengers. Therefore, the FAA has removed the reference to crewmembers. In addition, § 25.831(b)(2) also specifies that, "Higher concentrations of carbon dioxide may be allowed in crew compartments if appropriate protective breathing equipment is available." This sentence was incorporated when the 3 percent limit was established in CAR 4b.371 in 1952. As noted above, the origins of the 3 percent limit are unclear, but it is likely that the limit was set at this high level to account for the discharge of CO2 fire extinguishers in the flight deck, cabin, or cargo compartment. This thesis is supported by the mention of protective breathing in the existing rule. However, most CO2 extinguishers have been replaced by Halon or other types of fire extinguishers. Further, the rule is not intended to cover the short-duration rise in CO2 concentration that would accompany discharge of a fire extinguisher. Therefore, that sentence in § 25.831(b)(2) is removed because it is no longer considered necessary or appropriate.

Section 25.831(b)(1) specifies a limit for carbon monoxide (CO) concentration of 1 part in 20,000 parts air (0.005 percent). This limit is the same as currently recommended by ASHRAE and the Occupational Safety and Health Administration (OSHA), and therefore this action does not change this limit.

Discussion of Comments

Comments were received from foreign and domestic airplane manufacturers through their respective trade associations, foreign airworthiness authorities, trade organizations representing flight attendants and US and Canadian pilots, one US operator, an organization representing airline passengers, and several individuals.

Two commenters support the proposed change as it appears in the notice. Five commenters wrote to register dissatisfaction with the air quality on airplanes, mentioning both comfort for passengers and illnesses believed to be associated with inadequate fresh air flow. One commenter urges the FAA to "make the changes necessary so that we can fly in reasonable health." Another commenter is of the opinion that "very poor recirculation of air in planes is costing a lot of money in medical terms, not to mention suffering." Two commenters state that the FAA should perform tests on existing airplanes. The FAA infers from these comments that the commenters are in favor of revising the requirements to ensure acceptable air quality. Studies conducted by the FAA and others do not indicate that there is a health hazard associated with cabin air quality. As none of these commenters suggest specific changes to the proposal, there are no changes to the final rule in response to the comments.

One commenter misread the proposal as to the allowable concentration currently in the regulations and that proposed in the notice. This commenter states that the standards for cabin air quality should be better than the standard set for buildings, because the population density is higher in an airplane, and in an office building people may exit periodically. While the commenter made no specific recommendations, the FAA infers that the commenter advocates lower limits than proposed in the notice. The FAA does not concur that these factors justify a requirement for a lower carbon dioxide concentration. The existing standards are all based on a ventilation rate per occupant. To meet the same requirements with a higher population density, a greater volume of fresh air ventilation is required. It is not clear how this concern can be addressed by the airline industry or the FAA when the studies conducted indicate that the air quality in airplanes does not present a hazard to the health of the travelers.

Two commenters state that the proposed 0.5 percent carbon dioxide concentration limit is too high. One commenter suggests that the FAA "set a limit of 800 parts per million (ppm), the same level proposed by the Occupational Safety and Health Administration for indoor air quality," which is 0.08 percent. Another commenter recommends that the FAA adopt an airplane cabin carbon dioxide maximum concentration of 0.1 percent. Both commenters express concerns about the effect of higher carbon dioxide levels and increased recirculation on the spread of disease and on people with respiratory difficulties. One

commenter notes that concentrations above 0.1 percent may result in complications for persons with an existing respiratory difficulty, noting that 12.4 million Americans have asthma.

Another commenter states that flight attendants who are repeatedly exposed to carbon dioxide levels above 0.1 percent develop a tolerance, while passengers do not. Another commenter states that flight attendants are at a greater risk because of this same repeated exposure The FAA does not concur with these views. The documented studies contained in the docket for this rule indicate that the air quality currently present in the airliner cabins is comparable to that found in other indoor environments. The OSHA recommendation proposed in the Federal Register on April 5, 1994 (59 FR 16035), which has not been adopted at this time, addresses the carbon dioxide concentration as a comfort factor to be used in determining the need to verify proper operation of heating and ventilating equipment. Further, this proposal addresses non-industrial work environments and specifically excludes vehicles. A copy of the OSHA proposed amendment has been included in the docket for this rulemaking. There is no evidence that concentrations up to 0.5 percent present any health hazard in terms of general health or the spread of disease. In the economic evaluation conducted by the FAA, the higher costs associated with requiring a carbon dioxide concentration limit below 0.5 percent do not present a favorable cost/benefit ratio and cannot be justified. Further, there appears to be no specific concentration level, even at levels down to 0.1 percent, at which at least some passengers might not be affected. This rule, which will be contained in the airworthiness requirements of part 25, is intended to provide safe flight and landing for transport category airplanes. Because carbon dioxide in concentrations below 0.5 percent do not have adverse safety effects, the FAA has determined that a concentration limit of 0.5 percent provides a reasonable balance between cost and benefit, and provides a significant improvement over the existing allowable concentration.

Several commenters note that the OSHA and ACGIH standards are for an average concentration over a specific time period. ACGIH, for instance, recommends 5,000 ppm (0.5 percent) as a time-weighted average for a normal 8-hour workday or a 40-hour workweek. They note in their 1991 report that Australia, Germany, Sweden, and the United Kingdom all recommend a time-weighted value of 0.5 percent for carbon dioxide concentration. OSHA's limits also reflect the average airborne exposure in any 8-hour work shift of a 40-hour workweek. The FAA infers that the commenters advocate providing both a time weighted and a short term concentration limit. The FAA does not concur that the carbon dioxide level should be averaged over the entire flight for several reasons. Many flights exceed eight hours in duration, and the occupants are not able to leave the airplane as are workers in an office. Also, there are added stresses involved in being in an airplane cabin. The cabin pressure altitude is significantly above sea level, usually at 6,000 to 8,000 feet. The relative humidity is lower than is usually found in ground-based environments. There are unquantified stresses associated with being in a crowded airplane cabin. Many people experience anxiety from the mere fact that they are aloft. While most of these factors cannot be controlled, the FAA has determined that the present part 25 limit on carbon dioxide concentration does not reflect industry standards and should be reduced accordingly.

One commenter suggests that the average concentration should be limited to 0.5 percent, but "a limit of 3 percent by volume (sea level concentration) may be allowed for short term durations." The commenter points out that the 3 percent limit for short term durations corresponds to the short term exposure limit (STEL) adopted by the ACGIH, and having two limits should be similar to the two limits on cabin ozone concentration specified in § 25.832. Again, the FAA does not concur. The adverse health and safety effects of ozone are defined in available literature and § 25.832 of the FAR addresses that concern. There appears to be no reason to phrase the two requirements similarly.

The FAA has determined, however, that some short term excursions to values higher than 0.5 percent at some locations in the airplane may occur during normal, inflight operations when airplane pressurization and air conditioning systems are controlling the environment in the cabin. One commenter notes that the area in close proximity to the galley may experience higher carbon dioxide levels because meals are often cooled by dry ice, which releases gaseous carbon dioxide. Another commenter states that cabin air can be contaminated on the ground by exhaust ingestion or self ingestion during certain wind conditions. The FAA does not agree that this presents a problem. In one survey, conducted by the Harvard University School of Public Health, carbon dioxide levels were measured during boarding and deboarding operations. The typical levels reported were 2,000 to 2,550 ppm, or 0.2 to 0.25 percent, well below the 0.5 percent proposed by the FAA. However, the FAA does concur that it is not appropriate for the certification standards to apply to operations on the ground when the airplane systems are not operating (e.g., at the gate or during "push-back"). The final rule is changed to reflect this determination.

The same commenter expresses concern that the use of carbon dioxide hand-held fire extinguishers in the cabin could result in local concentrations exceeding 0.5 percent, noting that the present Halon extinguishers might be replaced by carbon dioxide devices now that production of Halon is banned, and suggests a higher short-term exposure limit. The FAA does not concur that this is a justification for a higher limit. The use of carbon dioxide fire extinguishers is not envisioned, although there are no prohibitions against their use in airplanes. When Halon is no longer available, the replacement extinguishers will be required to be safe in the concentrations predicted for use in occupied areas. Further, the use of fire extinguishers in the cabin is, by its nature, an emergency situation. This is not, in the context of the previous paragraph, normal in-flight operations. Therefore, there appears to be no need for the higher limit on carbon dioxide.

Two commenters state that the utilization of building criteria for establishing carbon dioxide concentration limits for airplane cabins is not appropriate. Both commenters add that the statement in the proposal that concentrations above 0.5 percent are hazardous is not justifiable. The FAA concurs with the general statement that carbon dioxide concentrations above 0.5 percent may not be hazardous for most people. Many standards in use today allow higher concentrations. As noted by one commenter, the World Health Organization considers 12,000 ppm (1.2 percent) to be a safe level. In any case, the final rule has been changed and no longer contains the word "hazardous." Both of these commenters note that the rule, as proposed, would limit carbon

dioxide concentrations in lower lobe galleys, accessible cargo compartments where animals are carried, cockpits, and other occupied areas. They express concern that local carbon dioxide concentrations in the galley areas where food is cooled with dry ice might exceed 0.5 percent. The FAA concurs in part with these comments. The ventilation requirements associated with this rule change are intended to address areas that are normally occupied. Cargo compartments accessible in flight, whether in all cargo or "combi" airplanes with main deck cargo compartments, are not "normally occupied." The final rule has been changed to reflect this determination.

One commenter disagrees with the statement in the preamble of the proposed rule that "This low ventilation rate is also sufficient to dissipate the water vapor * * *," noting that water buildup in insulation blankets is significant with present airplane fresh air inflow rates, especially in hot day ground conditions. The FAA concurs and the statement has been removed from the preamble. In stating this view, the commenter did not recommend any changes in the rule.

One commenter states that the term "sea level equivalent" should be clarified. The commenter suggests that the clarification include technical and/or medical rationale, including referenced sources, and provide an explanation of the methodology by which this value is to be calculated. If this rationale is not provided, the commenter states that the FAA should delete the phrase. The FAA does not concur that the term "sea level equivalent" is not defined, although the definition appears in reference to another gas. In FAA Advisory Circular 120-38, "Transport Category Airplanes Cabin Ozone Concentrations," sea level equivalent is defined as "* * * concentration in ppmv referenced to standard conditions of 25 ° C and 760 millimeters of mercury pressure." Based on this definition, and calculations provided in the AC, the maximum measured concentration, sea level equivalent, for a cabin altitude of 8,000 feet would be 0.5 percent multiplied by 0.74 (the ratio of air pressure at 8,000 feet to air pressure at sea level), or 0.37 percent. Values of this ratio for other cabin altitudes are provided in the AC. As the term sea level equivalent is defined, the rule is adopted as proposed.

The same commenter also notes that the statement in the preamble that control of carbon dioxide buildup due to respiration is the factor that dictates the design parameters for ventilation systems is incorrect. Operation on the ground during high ambient temperatures generally dictates the ventilation system design parameters. The FAA concurs and the preamble has been changed accordingly.

One commenter recommends that the new standards for carbon dioxide concentration not be applied to all-cargo airplanes. The commenter notes that measured carbon dioxide levels on the flight decks of these airplanes are well below both the current standard and that proposed in Notice 94-14. The commenter goes on to state that lowering the limit on carbon dioxide is a comfort issue, and would place a burden on the manufacturers of transport category airplanes that is not commensurate with any safety benefit that might result. The FAA does not concur. As noted elsewhere in this preamble, the FAA has determined that the existing concentration limit of 3 percent for carbon dioxide is not appropriate because many passengers and crewmembers are adversely affected at that level. The lower levels adopted by this amendment will provide a standard that, when met, will ensure that passengers and crewmembers, including those on all-cargo airplanes, will not be subjected to levels of carbon dioxide that would reduce their ability to perform their assigned duties. There are no costs associated with lowering the limit as proposed.

With the exception of the changes noted above, this final rule is adopted as proposed in Notice 94-14.

Regulatory Evaluation

Changes to Federal regulations must undergo several economic analyses. First, Executive Order 12866 directs Federal agencies to promulgate new regulations or modify existing regulations only if the potential benefits to society justify its costs. Second, the Regulatory Flexibility Act of 1980 requires agencies to analyze the economic impact of regulatory changes on small entities. Finally, the Office of Management and Budget directs agencies to assess the effects of regulatory changes on international trade. In conducting these assessments, the FAA has determined that this rule: (1) will generate benefits exceeding its costs and is not "significant" as defined in Executive Order 12866; (2) is not "significant" as defined in DOT's Policies and Procedures; (3) will not have a significant impact on a substantial number of small entities; and (4) will not constitute a barrier to international trade. These analyses, available in the docket, are summarized below, following FAA's disposition of comments on the economic aspects of the NPRM.

Response to Comments

One commenter calculates that it would cost about $0.076 per person per hour to provide 100 percent fresh air in the cabin of a typical 300-seat widebody airplane. The FAA disagrees with this commenter and estimates that the cost of 100 percent fresh air would be $0.095 per person per hour.

Another commenter states that the FAA did not account for the potential costs of applying the rule to all occupiable sections of the airplane because it evaluated only the passenger cabin area and ignored the flight deck and lower lobe galleys. The FAA concurs in part with this comment. The carbon dioxide concentration requirements are intended to apply to areas that are normally occupied. The final rule has been changed to reflect this intent. Thus, the commenter's statement does not alter the FAA's economic analysis.

Another commenter states that the FAA did not evaluate the possibility that ground-air contamination (ingestion of other airplanes' exhausts) may temporarily push the CO_2 level above the 0.5 percent limit. The FAA does not agree that this presents a problem. In one survey, conducted by the Harvard University School of Public Health, CO_2 levels were measured during boarding and deboarding operations. The typical levels reported were 0.2 percent to 0.25 percent, well below the 0.5 percent in this rule. However, the FAA does concur that it is not appropriate for the certification standards to apply to ground operations

when the airplane systems are not functioning. As a result, the final rule has been changed to reflect this determination Consequently, there is no economic impact as a result of this remote possibility.

Two commenters state that if live animal cargo areas are included under the definition of "inhabited" areas, there would be considerable potential costs. The FAA partly concurs with these comments in that cargo compartments accessible in flight, whether in all cargo or "combi" airplanes with main deck cargo compartments, are not normally occupied and the final rule has been changed to reflect this determination. As a result, there is no economic impact from excluding live animal cargo areas from this rule.

Costs

Airplane cabin CO2 levels can be reliably calculated from the number of passengers and the ventilation rate. In addition, engineering analyses have determined the amount of fuel used to provide a unit ventilation rate. These functional relationships allow the calculation of the costs to maintain a given cabin CO2 level. The FAA estimates that the 3 percent CO2 limit under the current rule costs about 0.27 cents per person per hour while the new 0.5 percent limit will cost about 1.7 cents per person per hour. Thus, the amended limit constitutes a 1.43 cent increase per person per hour, or about $4,475 per (newly certificated) airplane per year.

In point of fact, however, the ventilation rates in current transport category airplanes currently maintain cabin CO2 levels below 0.5 percent. As the FAA expects that the minimum ventilation rates of future aircraft designs will also maintain CO2 levels below 0.5 percent in order to control odors, temperature, water vapor, etc., no actual incremental costs or benefits will result from the rule change. However, codification of this limit will ensure that future designs maintain the 0.5 percent level.

Benefits

Although outdoor air contains CO2 at the 0.03 percent level, CO2 may produce respiratory center stimulation, mild narcotic effects, and asphyxiation under high levels and high exposure duration. At concentrations of 2 to 3 percent, CO2 can produce headaches, breathing difficulty, and increases in blood pressure and pulse. By comparison, no ill-effects have been observed at the 0.5 percent level.

Cost-Benefit Comparison

From a strict cost-benefit evaluation of the rule change itself, isolated from actual practice, the FAA concludes that it would cost about 1.43 cents per person per hour to increase the ventilation to reduce cabin CO2 levels from 3 percent to 0.5 percent. By comparison, this reduction eliminates the cabin CO2 levels known to produce headaches, breathing difficulty, and increases in blood pressure and pulse. While no precise economic value has been assigned to the benefit from avoiding these ill effects, the FAA has determined that they are worth more than 1.43 cents per person per hour.

Regulatory Flexibility Determination

The Regulatory Flexibility Act of 1980 (RFA) was enacted by Congress to ensure that small entities are not unnecessarily or disproportionately burdened by Government regulations. The RFA requires a Regulatory Flexibility Analysis if a proposed or final rule would have a significant economic impact, either detrimental or beneficial, on a substantial number of small entities. FAA Order 2100.14A, Regulatory Flexibility Criteria and Guidance, prescribes standards for complying with RFA review requirements in FAA rulemaking actions. The Order defines "small entities" in terms of size, "significant economic impact" in terms of annualized costs, and "substantial number" as eleven or more and which is more than one-third of the small entities subject to the proposed or final rule.

The final rule would affect manufacturers of transport category airplanes produced under future new airplane type certificates For manufacturers, Order 2100.14A defines a small entity as one with 75 or fewer employees. Since no part 25 airplane manufacturer has 75 or fewer employees, the rule would not have a significant economic impact on a substantial number of small entities.

International Trade Impact Assessment

As the certification rules apply to both foreign and domestic manufacturers that market airplanes in the United States, neither group will receive a competitive advantage. As no incremental compliance costs are expected, there will be no competitive trade disadvantage or advantage for U.S. manufacturers in foreign markets or for foreign manufacturers in the United States.

Federalism Implications

The regulations adopted herein will not have substantial direct effects on the States, on the relationship between the national government and the States, or on the distribution of power and responsibilities among the various levels of government. Therefore, in accordance with Executive Order 12612, it is determined that this final rule will not have sufficient federalism implications to warrant the preparation of a Federalism Assessment.

International Civil Aviation Organization (ICAO) and Joint Aviation Regulations

In keeping with U.S. obligations under the Convention on International Civil Aviation , it is FAA policy to comply with ICAO Standards and Recommended Practices to the maximum extent practicable. The FAA has determined that this rule does not conflict with any international agreement of the United States.

Paperwork Reduction Act

In accordance with the Paperwork Reduction Act of 1990 (44 U.S.C. 3501 et seq.), there are no reporting or recordkeeping requirements associated with this rule.

Conclusion

Because the revised standards for maximum allowable carbon dioxide concentration are not expected to result in a substantial economic cost or have a significant adverse effect on competition, the FAA has determined that this final rule is not significant under Executive Order 12866. In addition, the FAA has determined that this action is not significant as defined in Department of Transportation Regulatory Policies and Procedures (44 FR 11034, February 26, 1979). Since no actual incremental costs are expected to be incurred to comply with the requirements of this rule, the FAA certifies, under the criteria of the Regulatory Flexibility Act, that this regulation will not have a significant economic impact, positive or negative, on a substantial number of small entities. A copy of the regulatory evaluation prepared for this final rule has been placed in the public docket. A copy may be obtained from the person identified under the caption, FOR FURTHER INFORMATION CONTACT.

List of Subjects in 14 CFR Part 25

Aircraft, Aviation safety, Reporting and recordkeeping requirements.
Adoption of the Amendment
In consideration of the foregoing, the Federal Aviation Administration (FAA) amends 14 CFR part 25 of the Federal Aviation Regulations (FAR) as follows:

PART 25--AIRWORTHINESS STANDARDS: TRANSPORT CATEGORY AIRPLANES

1. The authority citation for part 25 continues to read as follows:
Authority: 49 U.S.C. 106(g), 40113, 44701-44702, 44704.
2. Section 25.831 is amended by revising paragraph (b)(2) to read as follows:

Ventilation

* * * * *

(b) * * *

(2) Carbon dioxide concentration during flight must be shown not to exceed 0.5 percent by volume (sea level equivalent) in compartments normally occupied by passengers or crewmembers.

* * * * *

Issued in Washington, D.C., on November 21, 1996.
Linda Hall Daschle,
Acting Administrator.

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BILLING CODE 4910-13-P

FAR 25.831 Ventilation.

(a) Under normal operating conditions and in the event of any probable failure conditions of any system which would adversely affect the ventilating air, the ventilation system must be designed to provide a sufficient amount of uncontaminated air to enable the crewmembers to perform their duties without undue discomfort or fatigue and to provide reasonable passenger comfort. For normal operating conditions, the ventilation system must be designed to provide each occupant with an airflow containing at least 0.55 pounds of fresh air per minute.

(b) Crew and passenger compartment air must be free from harmful or hazardous concentrations of gases or vapors. In meeting this requirement, the following apply:

(1) Carbon monoxide concentrations in excess of 1 part in 20,000 parts of air are considered hazardous. For test purposes, any acceptable carbon monoxide detection method may be used.

(2) Carbon dioxide concentration during flight must be shown not to exceed 0.5 percent by volume (sea level equivalent) in compartments normally occupied by passengers or crewmembers.

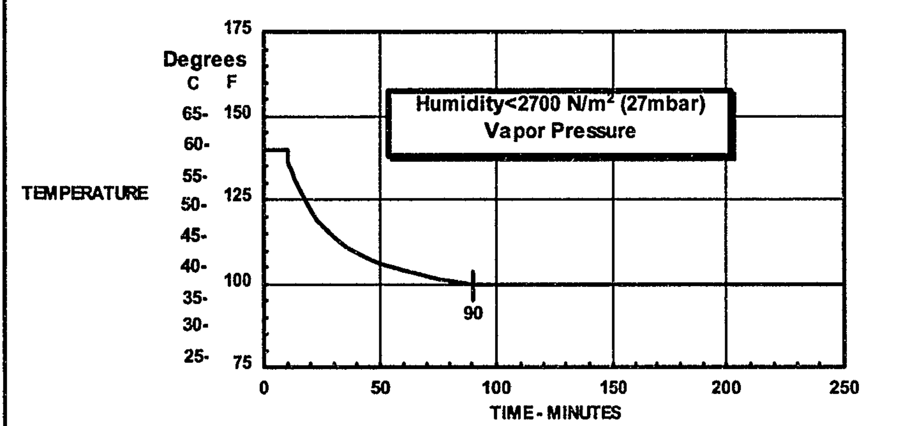
(c) There must be provisions made to ensure that the conditions prescribed in paragraph (b) of this section are met after reasonably probable failures or malfunctioning of the ventilating, heating, pressurization, or other systems and equipment.

(d) If accumulation of hazardous quantities of smoke in the cockpit area is reasonably probable, smoke evacuation must be readily accomplished, starting with full pressurization and without depressurizing beyond safe limits.

(e) Except as provided in paragraph (f) of this section, means must be provided to enable the occupants of the following compartments and areas to control the temperature and quantity of ventilating air supplied to their compartment or area independently of the temperature and quantity of air supplied to other compartments and areas:
  (1) The flight crew compartment.
  (2) Crewmember compartments and areas other than the flight crew compartment unless the crewmember compartment or area is ventilated by air interchange with other compartments or areas under all operating conditions.

(f) Means to enable the flight crew to control the temperature and quantity of ventilating air supplied to the flight crew compartment independently of the temperature and quantity of ventilating air supplied to other compartments are not required if all of the following conditions are met:
  (1) The total volume of the flight crew and passenger compartments is 800 cubic feet or less.
  (2) The air inlets and passages for air to flow between flight crew and passenger compartments are arranged to provide compartment temperatures within 5 degrees F. of each other and adequate ventilation to occupants in both compartments.
  (3) The temperature and ventilation controls are accessible to the flight crew.

(g) The exposure time at any given temperature must not exceed the values shown in the following graph after any improbable failure condition.



TIME - TEMPERATURE RELATIONSHIP

[Doc. No. 5066, 29 FR 18291, Dec. 24, 1964, as amended by Amdt. 25-41, 42 FR 36970, July 18, 1977; Amdt. 25-87, 61 FR 28695, June 5, 1996; Amdt. 25-89, 61 FR 63956, Dec. 2, 1996]

FAR 25.975 Fuel tank vents and carburetor vapor vents.

(a) *Fuel tank vents*. Each fuel tank must be vented from the top part of the expansion space so that venting is effective under any normal flight condition. In addition -
  (1) Each vent must be arranged to avoid stoppage by dirt or ice formation;
  (2) The vent arrangement must prevent siphoning of fuel during normal operation;
  (3) The venting capacity and vent pressure levels must maintain acceptable differences of pressure between the interior and exterior of the tank, during -
    (i) Normal flight operation;
    (ii) Maximum rate of ascent and descent; and
    (iii) Refueling and defueling (where applicable);
  (4) Airspaces of tanks with interconnected outlets must be interconnected;
  (5) There may be no point in any vent line where moisture can accumulate with the airplane in the ground attitude or the level flight attitude, unless drainage is provided; and
  (6) No vent or drainage provision may end at any point -
    (i) Where the discharge of fuel from the vent outlet would constitute a fire hazard; or
    (ii) From which fumes could enter personnel compartments.

(b) *Carburetor vapor vents*. Each carburetor with vapor elimination connections must have a vent line to lead vapors back to one of the fuel tanks. In addition -

(1) Each vent system must have means to avoid stoppage by ice; and
(2) If there is more than one fuel tank, and it is necessary to use the tanks in a definite sequence, each vapor vent return line must lead back to the fuel tank used for takeoff and landing.

FAR 25.1091 Air induction.

(a) The air induction system for each engine and auxiliary power unit must supply -
  (1) The air required by that engine and auxiliary power unit under each operating condition for which certification is requested; and
  (2) The air for proper fuel metering and mixture distribution with the induction system valves in any position.
(b) Each reciprocating engine must have an alternate air source that prevents the entry of rain, ice, or any other foreign matter.
(c) Air intakes may not open within the cowling, unless -
  (1) That part of the cowling is isolated from the engine accessory section by means of a fireproof diaphragm; or
  (2) For reciprocating engines, there are means to prevent the emergence of backfire flames.
(d) For turbine engine powered airplanes and airplanes incorporating auxiliary power units -
  (1) There must be means to prevent hazardous quantities of fuel leakage or overflow from drains, vents, or other components of flammable fluid systems from entering the engine or auxiliary power unit intake system; and
  (2) The airplane must be designed to prevent water or slush on the runway, taxiway, or other airport operating surfaces from being directed into the engine or auxiliary power unit air inlet ducts in hazardous quantities, and the air inlet ducts must be located or protected so as to minimize the ingestion of foreign matter during takeoff, landing, and taxiing.
(e) If the engine induction system contains parts or components that could be damaged by foreign objects entering the air inlet, it must be shown by tests or, if appropriate, by analysis that the induction system design can withstand the foreign object ingestion test conditions of § 33.77 of this chapter without failure of parts or components that could create a hazard.

[Doc. No. 5066, 29 FR 18291, Dec. 24, 1964, as amended by Amdt. 25-38, 41 FR 55467, Dec. 20, 1976; Amdt. 25-40, 42 FR 15043, Mar. 17, 1977; Amdt. 25-57, 49 FR 6849, Feb. 23, 1984]

FAR 25.1121 General.

For powerplant and auxiliary power unit installations the following apply:
(a) Each exhaust system must ensure safe disposal of exhaust gases without fire hazard or carbon monoxide contamination in any personnel compartment. For test purposes, any acceptable carbon monoxide detection method may be used to show the absence of carbon monoxide.
(b) Each exhaust system part with a surface hot enough to ignite flammable fluids or vapors must be located or shielded so that leakage from any system carrying flammable fluids or vapors will not result in a fire caused by impingement of the fluids or vapors on any part of the exhaust system including shields for the exhaust system.
(c) Each component that hot exhaust gases could strike, or that could be subjected to high temperatures from exhaust system parts, must be fireproof. All exhaust system components must be separated by fireproof shields from adjacent parts of the airplane that are outside the engine and auxiliary power unit compartments.
(d) No exhaust gases may discharge so as to cause a fire hazard with respect to any flammable fluid vent or drain.
(e) No exhaust gases may discharge where they will cause a glare seriously affecting pilot vision at night.
(f) Each exhaust system component must be ventilated to prevent points of excessively high temperature.
(g) Each exhaust shroud must be ventilated or insulated to avoid, during normal operation, a temperature high enough to ignite any flammable fluids or vapors external to the shroud.

[Doc. No. 5066, 29 FR 18291, Dec. 24, 1964, as amended by Amdt. 25-40, 42 FR 15043, Mar. 17, 1977]

FAR 25.1125 Exhaust heat exchangers.

For reciprocating engine powered airplanes, the following apply:
(a) Each exhaust heat exchanger must be constructed and installed to withstand each vibration, inertia, and other load to which it would be subjected in operation. In addition -
  (1) Each exchanger must be suitable for continued operation at high temperatures and resistant to corrosion from exhaust gases;
  (2) There must be means for the inspection of the critical parts of each exchanger;

(3) Each exchanger must have cooling provisions wherever it is subject to contact with exhaust gases; and
(4) No exhaust heat exchanger or muff may have any stagnant areas or liquid traps that would increase the probability of ignition of flammable fluids or vapors that might be present in case of the failure or malfunction of components carrying flammable fluids.

(b) If an exhaust heat exchanger is used for heating ventilating air -
(1) There must be a secondary heat exchanger between the primary exhaust gas heat exchanger and the ventilating air system; or
(2) Other means must be used to preclude the harmful contamination of the ventilating air.

[Doc. No. 5066, 29 FR 18291, Dec. 24, 1964, as amended by Amdt. 25-38, 41 FR 55467, Dec. 20, 1976]

FAR 25.1197 Fire extinguishing agents.

(a) Fire extinguishing agents must -
(1) Be capable of extinguishing flames emanating from any burning of fluids or other combustible materials in the area protected by the fire extinguishing system; and
(2) Have thermal stability over the temperature range likely to be experienced in the compartment in which they are stored.

(b) If any toxic extinguishing agent is used, provisions must be made to prevent harmful concentrations of fluid or fluid vapors (from leakage during normal operation of the airplane or as a result of discharging the fire extinguisher on the ground or in flight) from entering any personnel compartment, even though a defect may exist in the extinguishing system. This must be shown by test except for built-in carbon dioxide fuselage compartment fire extinguishing systems for which -
(1) Five pounds or less of carbon dioxide will be discharged, under established fire control procedures, into any fuselage compartment; or
(2) There is protective breathing equipment for each flight crewmember on flight deck duty.

[Doc. No. 5066, 29 FR 18291, Dec. 24, 1964, as amended by Amdt. 25-38, 41 FR 55467, Dec. 20, 1976; Amdt. 25-40, 42 FR 15044, Mar. 17, 1977]

FAR 135, Appendix A--Additional Airworthiness Standards for 10 or More Passenger Airplanes

49. *Turbine engine bleed air systems.* Turbine engine bleed air systems of turbopropeller powered airplanes must be investigated to determine-
(a) That no hazard to the airplane will result if a duct rupture occurs. This condition must consider that a failure of the duct can occur anywhere between the engine port and the airplane bleed service; and
(b) That, if the bleed air system is used for direct cabin pressurization, it is not possible for hazardous contamination of the cabin air system to occur in event of lubrication system failure.

JAR's

JAR 23.831 Ventilation.

(a) Each passenger and crew compartment must be suitably ventilated. Carbon monoxide concentration may not exceed one part in 20 000 parts of air.

(b) For pressurised aeroplanes, the ventilating air in the flight crew and passenger compartments must be free of harmful or hazardous concentrations of gases and vapours in normal operations and in the event of reasonably probable failures or malfunctioning of the ventilating, heating, pressurisation, or other systems and equipment. If accumulation of hazardous quantities of smoke in the cockpit area is reasonably probable, smoke evacuation must be readily accomplished starting with full pressurisation and without depressurising beyond safe limits.

JAR 23.975 Fuel Tank Vents and Carburetor Vapour Vents.

(a) Each fuel tank must be vented from the top part of the expansion space. In addition -
(1) Each vent outlet must be located and constructed in a manner that minimises the possibility of its being obstructed by ice or other foreign matter;
(2) Each vent must be constructed to prevent siphoning of fuel during normal operation;

(3) The venting capacity must allow the rapid relief of excessive differences of pressure between the interior and exterior of the tank;
(4) Airspaces of tanks with inter-connected outlets must be inter-connected;
(5) There may be no points in any vent line where moisture can accumulate with the aeroplane in either the ground or level flight attitudes unless drainage is provided.
(6) No vent may terminate at a point where the discharge of fuel from the vent outlet will constitute a fire hazard or from which fumes may enter personnel compartments; and
(7) Vents must be arranged to prevent the loss of fuel, except fuel discharged because of thermal expansion, when the aeroplane is parked in any direction on a ramp having a 1% slope.

(b) Each carburettor with vapour elimination connections and each fuel injection engine employing vapour return provisions must have a separate vent line to lead vapours back to the top of one of the fuel tanks. If there is more than one tank and it is necessary to use these tanks in a definite sequence for any reason, the vapour vent line must lead back to the fuel tank to be used first, unless the relative capacities of the tanks are such that return to another tank is preferable.

(c) For aerobatic category aeroplanes, excessive loss of fuel during aerobatic manoeuvres, including short periods of inverted flight, must be prevented. It must be impossible for fuel to siphon from the vent when normal flight has been resumed after any aerobatic manoeuvre for which certification is requested.

JAR 23.1091 Air Induction System.

(a) The air induction system for each engine and auxiliary power unit and their accessories must supply the air required by that engine and auxiliary power unit under the operating conditions for which certification is requested.

(b) Each reciprocating engine installation must have at least two separate air intake sources and must meet the following:
(1) Primary air intakes may open within the cowling if that part of the cowling is isolated from the engine accessory section by a fire-resistant diaphragm or if there are means to prevent the emergence of backfire flames.
(2) Each alternate air intake must be located in a sheltered position and may not open within the cowling if the emergence of backfire times will result in a hazard.
(3) The supplying of air to the engine through the alternate air intake system may not result in a loss of excessive power in addition to the power loss due to the rise in air temperature.
(4) Each automatic alternate air door must have an override means accessible to the flight crew.
(5) Each automatic alternate air door must have a means to indicate to the flight crew when it is not closed.

(c) For turbine engine-powered aeroplanes -
(1) There must be means to prevent hazardous quantities of fuel leakage or overflow from drains, vents or other components of flammable fluid systems from entering the engine or auxiliary power unit and their accessories intake system; and
(2) The aeroplane must be designed to prevent water or slush on the runway, taxi way, or other airport operating surfaces from being directed into the engine or auxiliary power unit air intake ducts in hazardous quantities, and the air intake ducts must be located or protected so as to minimise the ingestion of foreign matter during take-off, landing and taxying.

JAR 23.1109 Turbocharger Bleed Air System.

The following applies to turbocharged bleed air systems used for cabin pressurisation:

(a) The cabin air system may not be subject to hazardous contamination following any probable failure of the turbocharger or its lubrication system.

(b) The turbocharger supply air must be taken from a source where it cannot be contaminated by harmful or hazardous gases or vapours following any probable failure or malfunction of the engine exhaust, hydraulic, fuel, or oil system.

JAR 23.1111 Turbine engine bleed air system

For turbine engine bleed air systems, the following apply:

(a) No hazard may result if duct rupture or failure occurs anywhere between the engine port and the aeroplane unit served by the bleed air.

(b) The effect on aeroplane and engine performance of using maximum bleed air must be established.

(c) Hazardous contamination of cabin air systems may not result from failures of the engine lubricating system.

JAR 23.1121 General.

For powerplant and auxiliary power unit installations, the following apply:

(a) Each exhaust system must ensure safe disposal of exhaust gases without fire hazard or carbon monoxide contamination in any personnel compartment.
(b) Each exhaust system part with a surface hot enough to ignite flammable fluids or vapours must be located or shielded so that leakage from any system carrying flammable fluids or vapours will not result in a fire caused by impingement of the fluids or vapours on any part of the exhaust system including shields for the exhaust system.
(c) Each exhaust system must be separated by fireproof shields from adjacent flammable parts of the aeroplane that are outside of the engine and auxiliary power unit compartment.
(d) No exhaust gases may discharge dangerously near any fuel or oil system drain.
(e) No exhaust gases may be discharged where they will cause a glare seriously affecting pilot vision at night.
(f) Each exhaust system component must be ventilated to prevent points of excessively high temperature
(g) If significant traps exist, each turbine engine and auxiliary power unit exhaust system must have drains discharging clear of the aeroplane, in any normal ground and flight attitude, to prevent fuel accumulation after the failure of an attempted engine or auxiliary power unit start.
(h) Each exhaust heat exchanger must incorporate means to prevent blockage of the exhaust port after any internal heat exchanger failure.
(i) For the purposes of compliance with JAR 23.603 the failure of any part of the exhaust system will adversely affect safety.

JAR 23.1125 Exhaust Heat Exchangers.

For reciprocating engine-powered aeroplanes the following apply:
(a) Each exhaust heat exchanger must be constructed and installed to withstand the vibration, inertia and other loads that it may be subjected to in normal operation. In addition -
  (1) Each exchanger must be suitable for continued operation at high temperatures and resistant to corrosion from exhaust gases;
  (2) There must be means for inspection of critical parts of each exchanger; and
  (3) Each exchanger must have cooling provisions wherever it is subject to contact with exhaust gases.
(b) Each heat exchanger used for heating ventilating air must be constructed so that exhaust gases may not enter the ventilating air.

JAR 23.1197 Fire Extinguishing Agents.

For commuter category aeroplanes, the following apply:
(a) Fire extinguishing agents must -
  (1) Be capable of extinguishing flames emanating from any burning fluids or other combustible materials in the area protected by the fire extinguishing system; and
  (2) Have thermal stability over the temperature range likely to be experienced in the compartment in which they are stored.
(b) If any toxic extinguishing agent is used, provisions must be made to prevent harmful concentrations of fluid or fluid vapours (from leakage during normal operation of the aeroplane or as a result of discharging the fire extinguisher on the ground or in flight) from entering any personnel compartment even though a defect may exist in the extinguishing system. This must be shown by test except for built-in carbon dioxide fuselage compartment fire extinguishing systems for which -
  (1) Five pounds or less of carbon dioxide will be discharged, under established fire control procedures, into any fuselage compartment; or
  (2) Protective breathing equipment is available for each flight crew member on flight deck duty.

JAR 25.831 Ventilation

(a) Each passenger and crew compartment must be ventilated and each crew compartment must have enough fresh air (but not less than 10 cubic ft per minute per crew member) to enable crew members to perform their duties without undue discomfort or fatigue. (See ACJ 25.831 (a).)
(b) Crew and passenger compartment air must be free from harmful or hazardous concentrations of gases or vapours. In meeting this requirement, the following apply:
  (1) Carbon monoxide concentrations in excess of one part in 20 000 parts of air are considered hazardous. For test purposes, any acceptable carbon monoxide detection method may be used.

(2) Carbon dioxide in excess of 3% by volume (sea-level equivalent) is considered hazardous in the case of crew members. Higher concentrations of carbon dioxide may be allowed in crew compartments if appropriate protective breathing equipment is available.

(c) There must be provisions made to ensure that the conditions prescribed in sub-paragraph (b) of this paragraph are met after reasonably probable failures or malfunctioning of the ventilating, heating, pressurisation or other systems and equipment. (See ACJ 25.831 (c).)

(d) If accumulation of hazardous quantities of smoke in the cockpit area is reasonably probable, smoke evacuation must be readily accomplished, starting with full pressurisation and without depressurising beyond safe limits.

(e) Except as provided in sub-paragraph (f) of this paragraph, means must be provided to enable the occupants of the following compartments and areas to control the temperature and quantity of ventilating air supplied to their compartment or area independently of the temperature and quantity of air supplied to other compartments and areas:

(1) The flight-crew compartment.

(2) Crew-member compartments and areas other than the flight-crew compartment unless the crew-member compartment or area is ventilated by air interchange with other compartments or areas under all operating conditions.

(f) Means to enable the flight crew to control the temperature and quantity of ventilating air supplied to the flight-crew compartment independently of the temperature and quantity of ventilating air supplied to other compartments are not required if all of the following conditions are met:

(1) The total volume of the flight-crew and passenger compartments is 800 cubic ft or less.

(2) The air inlets and passages for air to flow between flight-crew and passenger compartments are arrange to provide compartment temperatures within 5°F of each other and adequate ventilation to occupants in both compartments.

(3) The temperature and ventilation controls are accessible to the flight crew.

ACJ 25.831(a) - Ventilation (Interpretative Material)

See JAR 25.831(a)

The supply of fresh air in the event of the loss of one source, should not be less than 0.4 lb/min per person for any period exceeding five minutes. However, reductions below this flow rate may be accepted provided that the compartment environment can be maintained at a level which is not hazardous to the occupant.

ACJ 25.831(c) - Ventilation (Interpretative Material)

See JAR 25.831(c)

1 To avoid contamination the fresh air supply should be suitably ducted where it passes through any compartment inaccessible in flight.

2 Where the air supply is supplemented by a recirculating system, it should be possible to stop the recirculating system and-

a. Still maintain the fresh air supply prescribed, and

b. Still achieve 1.

JAR 25.975 Fuel tank vents

(a) *Fuel tank vents*. Each fuel tank must be vented from the top part of the expansion space so that venting is effective under any normal flight condition. In addition --

(1) Each vent must be arranged to avoid stoppage by dirt or ice formation;

(2) The vent arrangement must prevent siphoning of fuel during normal operation;

(3) The venting capacity and vent pressure levels must maintain acceptable differences of pressure between the interior and exterior of the tank during--

(i) Normal flight operation;

(ii) Maximum rate of ascent and descent; and

(iii) Refuelling and defuelling (where applicable);

(4) Airspaces of tanks with interconnected outlets must be interconnected;

(5) There must be no point in any vent line where moisture can accumulate with the aeroplane in the ground attitude or the level flight attitude, unless drainage is provided; and

(6) No vent or drainage provision may end at any point --

(i) Where the discharge of fuel from the vent outlet would constitute a fire hazard; or

(ii) From which fumes could enter personnel compartments.

(b) Not required for JAR-25.

JAR 25.1091 Air Intake

(a) The air intake system for each engine must supply --
  (1) The air required by that engine under each operating condition for which certification is requested; and
  (2) The air for proper fuel metering and mixture distribution with the air intake system valves in any position

(b) Not required for JAR-25.

(c) Air intakes may not open within the cowling, unless that part of the cowling is isolated from the engine accessory section by means of a fireproof diaphragm.

(d) (1) There must be means to prevent hazardous quantities of fuel leakage or overflow from drains, vents, or other components of flammable fluid systems from entering the engine air intake system; and
  (2) *The aeroplane must be design to prevent water or slush on the runway, taxiway, or other airport operating surfaces* from being directed into the engine air intake ducts in hazardous quantities, and the air intake ducts must be located or protected so as to minimise the ingestion of foreign matter during take-off; landing and taxying. (See ACJ25.1091 (d)(2).)

(e) If the engine air intake system contains parts or components that could be damaged by foreign objects entering the air intake, it must be shown by tests or, if appropriate, by analysis that the air intake system design can withstand the foreign object ingestion test conditions of JAR-E 790 and JAR-E 800 without failure of parts or components that could create a hazard. (See ACJ25.1091(e).)

JAR 25.1121 General (Exhaust System)

For powerplant installations the following apply:

(a) Each exhaust system must ensure safe disposal of exhaust gases without fire hazard or carbon monoxide contamination in any personnel compartment. For test purposes, any acceptable carbon monoxide detection method may be used to show the absence of carbon monoxide. (See ACJ 25.1121(a).)

(b) Each exhaust system part with a surface hot enough to ignite flammable fluids or vapours must be located or shielded so that leakage from any system carrying flammable fluids or vapours will not result in a fire caused by impingement of the fluids or vapours on any part of the exhaust system including shields for the exhaust system. (See ACJ 25.1121(b).)

(c) Each component that hot exhaust gases could strike, or that could be subjected to high temperatures from exhaust system parts, must be fireproof. *All exhaust system components must be separated by fireproof shields from adjacent parts of* the aeroplane that are outside the engine compartment.

(d) No exhaust gases may discharge so as to cause a fire hazard with respect to any flammable fluid vent or drain.

(e) No exhaust gases may discharge where they will cause a glare seriously affecting pilot vision at night.

(f) Each exhaust system component must be ventilated to prevent points of excessively high temperature.

(g) Each exhaust shroud must be ventilated or insulated to avoid, during normal operation, a temperature high enough to ignite any flammable fluids or vapours external to the shroud.

JAR 25.1125 Exhaust heat exchangers

The following apply:

(a) Each exhaust heat exchanger must be constructed and installed to withstand each vibration, inertia, and other load to which it would be subjected in operation. In addition--
  (1) Each exchanger must be suitable for continued operation at high temperatures and resistant to corrosion from exhaust gases;
  (2) There must be means for the inspection of the critical parts of each exchanger;
  (3) *Each exchanger must have cooling provisions wherever it is subject to contact with exhaust gases (see ACJ 25.1125* (a)(3)); and
  (4) No exhaust heat exchanger or muff may have any stagnant areas or liquid traps that would increase the probability of ignition of flammable fluids or vapours that might be present in case of the failure or malfunction of components carrying flammable fluids.

(b) If an exhaust heat exchanger is used for heating ventilating air--
  (1) There must be a secondary heat exchanger between the primary exhaust gas heat exchanger and the ventilating air system; or
  (2) Other means must be used to preclude the harmful contamination of the ventilating air.

JAR 25.1197 Fire-extinguishing agents

(a) Fire-extinguishing agents must--
   (1) Be capable of extinguishing flames emanating from any burning of fluids or other combustible materials in the area protected by the fire extinguishing system; and
   (2) Have thermal stability over the temperature range likely to be experienced in the compartment in which they are stored.
(b) If any toxic extinguishing agent is used, provisions must be made to prevent harmful concentrations of fluid or fluid vapours (from leakage during normal operation of the aeroplane or as a result of discharging the fire extinguisher on the ground or in flight) from entering any personnel compartment, even though a defect may exist in the extinguishing system. This must be shown by test except for built-in carbon dioxide fuselage compartment fire extinguishing systems for which--
   (1) Five pounds or less of carbon dioxide will be discharged, under established fire control procedures, into any fuselage compartment; or
   (2) There is protective breathing equipment for each flight-crew member on flight deck duty.

JAR 25A1121 General (Exhaust System- APU)

(a) Each exhaust system must ensure safe disposal of exhaust gases without fire hazard or carbon monoxide contamination in any personnel compartment. For test purposes, any acceptable carbon monoxide detection method may be used to show the absence of carbon monoxide.
(b) Unless suitable precautions are taken, no exhaust system part may be dangerously close to parts of any system carrying flammable fluids or vapours, or under parts of such a system that may leak.
(c) Each component that hot exhaust gases could strike, or that could be subjected to high temperatures from exhaust system parts, must be fire-proof. All exhaust system components must be separated by fireproof shields from adjacent parts of the aeroplane that are outside the APU compartment.
(d) No exhaust gases may discharge so as to cause a fire hazard with respect to any flammable fluid vent or drain.
(e) No exhaust gases may discharge where they will cause a glare seriously affecting pilot vision at night.
(f) Each exhaust system component must be ventilated to prevent points of excessively high temperature.
(g) Each exhaust shroud must be ventilated or insulated to avoid, during normal operation, a temperature high enough to ignite any flammable fluids or vapours external to the shroud.

JAR 25A1197 Fire extinguishing agents (APU)

(a) Fire extinguishing agents must --
   (1) Be capable of extinguishing flames emanating from any burning of fluids or other combustible materials in the area protected by the fire extinguishing system; and
   (2) Have thermal stability over the temperature range likely to be experienced in the compartment in which they are stored.
(b) If any toxic extinguishing agent is used, provisions must be made to prevent harmful concentrations of fluid or fluid vapours (from leakage during normal operation of the aeroplane or as a result of discharging the fire extinguisher on the ground or in flight) from entering any personnel compartment, even though a defect may exist in the extinguishing system. This must be shown by test except for built-in carbon dioxide fuselage compartment fire extinguishing systems for which --
   (1) Five pounds or less of carbon dioxide will be discharged, under established fire control procedures, into any fuselage compartment; or
   (2) There is protective breathing equipment for each flight-crew member on flight deck duty.

JAR E690 Engine Bleed

(a) For an Engine having bleed(s) for aircraft and/or Engine uses, the standard Engine Endurance Test schedule shall be varied in accordance with this paragraph JAR-E 690(a) unless the use of the bleed(s) is substantiated by separate test and analysis acceptable to the Authority.
   (1) *General*
      (i) Exercise the bleed controls at the end of each stage of the Endurance Test.
      (ii) Complete any other tests which may be necessary to demonstrate the satisfactory functioning of the Engine and the bleeds.
      (iii) During the tests of (3) below the Engine rotational speed(s) may be reduced if necessary when the bleeds are in operation in order to avoid exceeding the maximum declared jet pipe temperatures. (See JAR-E 740(f)(2).)

(2) *Calibration Tests.* Include a calibration with each bleed in operation separately and one with all bleeds in operation (See JAR-E 730 and JAR-E 170.)
(3) *Endurance Test.* Run Stages 3, 7, 13, 17 and 23 with the bleed(s) in operation during all the conditions of running for which they are intended to be approved for use.

(b) *Contamination Tests of Bleed Air for Cabin Pressurisation or Ventilation.* The requirements of this paragraph (b) are applicable where it is desired to declare that compressor bleed air is suitable for direct use in an aircraft cabin pressurisation or ventilation system.
(1) Tests to determine the purity of the air supply shall be made.
(2) An analysis of defects which could affect the purity of the bleed air shall be prepared and where necessary the defects shall be simulated and tests, as agreed by the Authority, shall be made to establish the degree of contamination which is likely to occur. If the defect under consideration is such that the Engine would be shut down immediately, the tests required may be modified accordingly.

Advisory Circulars

AC23.909-1 Installation of Turbochargers in Small Airplanes with Reciprocating Engines

6.(a)(7) A turbocharger that pressurizes an airplane cabin should be investigated to substantiate that contamination of cabin air will not occur. Any contamination of cabin air from a failure of any component(s) of the turbocharger system should be avoided.

AC33-2B Aircraft Engine Type Certification Handbook

Section 33.5 Instruction manual for installing and operating the engine.

Each applicant must prepare and make available to the Administrator prior to the issuance of the type certificate, and to the owner at the time of delivery of the engine, approved instructions for installing and operating the engine. The instructions must include at least the following:

(a) Installation instructions.
(1) The location of engine mounting attachments, the method of attaching the engine to the aircraft, and the maximum allowable load for the mounting attachments and related structure.
(2) The location and description of engine connections to be attached to accessories, pipes, wires, cables, ducts, and cowling.
(3) An outline drawing of the engine including overall dimensions.

(b) Operation Instructions.
(1) The operating limitations established by the Administrator.
(2) The power or thrust ratings and procedures for correcting for nonstandard atmosphere.
(3) The recommended procedures, under normal and extreme ambient conditions for--
(i) Starting;
(ii) Operating on the ground; and
(iii) Operating during flight.

***

Guidance: The INTENT of this section is to assure that the engine installation and operating instructions are approved by the time the type certificate for the engine is issued.

Incorporations: None.

References: SAE Document ARP 1507, "Helicopter Engine/Airframe Interface Document and Checklist," issued September 1985. This reference offers further guidance on the types and formats of engine installations and operations information. Although this document is oriented to helicopter (turboshaft) engines, it may be useful as additional general guidance to authors of installation and operating instruction manuals.

a. The installation and operating instructions should incorporate all relevant and complete information on the characteristics, performance, and physical interfaces of the engine. A type certificated engine may include some external lines, equipment mountings, diaphragms, or firewalls which do not meet all certification requirements of some installations. Added line shrouding, relocation of fluid lines, or other changes constitute engine type design changes which may be required for the aircraft installation. Such FAA-approved changes are accomplished preferably by the engine type certificate holder, as approval based on engine compatibility and endurance qualification is usually necessary. However, upon achieving satisfactory coordination with the engine type certificate holder, accomplishment of such changes by the aircraft applicant is often acceptable as an alternative.

b. The engine type certificate holder or applicant may elect to incorporate items of equipment or accessories which are oftentimes handled as part of the aircraft installation responsibility. Examples of such items are engine mounted oiltanks, oil coolers, fuel heaters, generators, thrust reversers, inlet and exhaust nozzles, and various fluid pumps.
   (1) When the engine manufacturer elects to furnish such accessories, it is basically implied that he will substantiate them for engine compatibility, and be responsible for dealing with service difficulties.
   (2) If the engine type certificate holder elects to establish aircraft installation compliance, he should develop and provide the necessary installation data in accordance with applicable aircraft requirements.
   (3) If the engine type certification effort incorporates findings of compliance for aircraft installation items (i e , to FAR Part 23, 25, 27, or 29 requirements) then such should be identified on the engine TCDS.

c. The engine installation instructions should incorporate information on the means of limiting, and on the quality of engine compressor bleed air available for airframe use. Design bleed air quality, limit(s), and the means of limiting should be verified by the failure modes and effects analysis and by testing, as appropriate. An example of the need for such information is seen in the certification of FAR Part 23 turbine powered aircraft: Turbine engine bleed air systems of turbine powered airplanes must be investigated to determine that, if the bleed air system is used for direct cabin pressurization, it is not possible for hazardous contamination of the cabin air system to occur in the event of lubrication system failure;

d. The engine installation instructions should incorporate statements of instrumentation types, ranges, required precision, and accuracies for those engine parameters required for safe operation. These statements should be based upon the applicant-selected ratings for the specific engine design, as verified and substantiated throughout the type certification process, particularly the block tests.

AC23-XX-29 (Draft) Systems and Equipment Guide for Certification of Part 23 Airplanes

Section 23.831 Ventilation

Original Issue and Subsequent

The use of an alternate air supply, either automatic or manual, that picks up air from within the engine compartment is unacceptable for cabin ventilation because of possible contamination from fuel, oil or exhaust leaks.

Halon 1301 may be safely used in concentrations up to 10 percent in airplane cabins. Ventilation in airplane cabins is sufficient for the agent to disburse in less than 5 minutes, so the time limit need not be considered if the concentration is held below the 10 percent limit. Halon 1211, however, should not be used in airplane cabins.

Amendment 23-34 and Subsequent

If hazardous accumulations of smoke are found to be reasonably probable in the cockpit area, smoke evacuation to a non-hazardous level should be readily accomplished from full pressurization to minimum safe levels (per § 91.211). Smoke evacuation procedures should be included in the Airplane Flight Manual, Emergency Operations Section, or on approved placards.

AC25-XX (Draft) Transport Airplane Propulsion Engine and Auxiliary Power Unit Installation Certification Handbook

Section 25.1121 General.

a. Rule Text.

For powerplant and auxiliary power unit installations the following apply:

(a) Each exhaust system must ensure safe disposal of exhaust gases without fire hazard or carbon monoxide contamination in any personnel compartment. For test purposes, any acceptable carbon monoxide detection method may be used to show the absence of carbon monoxide.

(b) Each exhaust system part with a surface hot enough to ignite flammable fluids or vapors must be located or shielded so that leakage from any system carrying flammable fluids or vapors will not result in a fire caused by impingement of the fluids or vapors on any part of the exhaust system including shields for the exhaust system.

(c) Each component that hot exhaust gases could strike, or that could be subjected to high temperatures from exhaust system parts, must be fireproof. All exhaust system components must be separated by fireproof shields from adjacent parts of the airplane that are outside the engine and auxiliary power unit compartments.

(d) No exhaust gases may discharge so as to cause a fire hazard with respect to any flammable fluid vent or drain.

(e) No exhaust gases may discharge where they will cause a glare seriously affecting pilot vision at night.

(f) Each exhaust system component must be ventilated to prevent points of excessively high temperature.
(g) Each exhaust shroud must be ventilated or insulated to avoid, during normal operation, a temperature high enough to ignite any flammable fluids or vapors external to the shroud.

[Doc. No. 5066, 29 FR 18291, Dec. 24, 1964, as amended by Amdt. 25-40, 42 FR 15043, Mar. 17, 1977]

b. Intent of Rule.

The intent of this rule is to ensure adequate fire protection of the exhaust system as well as the adjacent areas of the airplane

c. Background.

(1) The regulatory history shows that the requirement originated from Section 467(a) of the Civil Air Regulations (CAR) 4b, December 31, 1953. Amendment 25-AD (29 FR 18289, December 24, 1964) added Part 25 [New] to the Federal Aviation Regulations and replaced Part 4b of the Civil Air Regulations. It was part of the Agency recodification program announced in Draft Release 61-25, published in the Federal Register on November 15, 1961 (26 FR 10698). Part 25 [New] was published as a notice of proposed rule making in the Federal Register on June 2, 1964 (29 FR 7169), and given further distribution as Notice No. 64-28. It was recodified from CAR 4b without any substantive changes.

(2) Amendment 25-40 (42 FR 15034, March 17, 1977) was based on two Notices of Proposed Rulemaking:
- Notice 75-10 (40 FR 10802, March 7, 1975) and
- Notice 75-19 (40 FR 21866, May 19, 1975).

Notice 75-19 proposed to revise both § 25.1121 and § 23.1121. The lead-in text to the provisions of § 25.1121 and § 25.1121(c) were revised to include reference to the Auxiliary Power Unit (APU), to make it clear that the subject requirements apply to APU exhaust systems as well as to engine exhaust systems. Likewise, § 25.1121(b) was revised to clarify that the shields used for shielding exhaust system parts are, indeed, considered part of the exhaust system.

d. Policy/Compliance Methods.

(1) The following excerpt from CAR 4b.467-1 provides guidance. The carbon monoxide detection policies, which have been applied to § 25.1121(a) and § 25.1125(b), are as follows:

(a) **Conditions for tests.** Any acceptable carbon monoxide detection method may be used in demonstrating compliance with the above sections. The tests should be conducted with the airplane's heater system in operation if there is any possibility of a system containing carbon monoxide. In aircraft employing thermal deicing, tests should be conducted with the system operating at full capacity.

(b) **Configuration.** Carbon monoxide tests should be conducted in the configurations that follow:

(1) Power-on level flight.
- Weight--optional
- C.G. position--optional
- Wing flaps—retracted
- Landing gear--retracted
- Engines--maximum continuous power
- Cowl flaps--appropriate for flight condition

(2) Power-off glide.
- Wing flaps--retracted
- Landing gear--retracted
- Engines--idling
- Cowl flaps--appropriate for flight condition

(3) Power approach:
- Wing flaps--approach position
- Landing gear--extended
- Engines--power for level flight
- Cowl flaps--appropriate for flight condition
- Airspeed--any speed from 1.4 to 1.6 V_{s1}

(c) **Test procedure and required data.** The air should be sampled with a carbon monoxide indicator in front of cabin heater opening(s) with heat on and at representative passenger and crew locations. If the airplane does not have pressurization equipment installed, the air should be sampled at the above locations with the windows closed and also partially opened. If the airplane is equipped for pressurization, carbon monoxide indications should be taken when the cabin is pressurized and also unpressurized.

(2) *Use of Shields.* Concerns with § 25.1121(b) have been raised concerning the location and shielding of exhaust system parts because of the lack of specifics on how to determine whether the location of a system carrying flammable fluid is acceptable. The rule specifically allows the use of exhaust system shielding as a method of avoiding impingement of

flammable fluids on a hot surface. It is not intended to state how an acceptable location would be determined since a number of acceptable methods might exist depending on the installation. Flammable fluid leak sources to be considered are those around fittings as well as those caused by rupture of a fluid carrying line, i.e., any leakage from a flammable fluid system including lines, fittings, and joints.

(3) *Windshield Glare.* The following guidance is from CAR 4b.467-2:
Determination of exhaust gas interference with visibility.
The effects of exhaust gas interference with visibility should be observed during tests to demonstrate other night flying requirements.

e. Refere nces:

(1) Civil Air Regulations (CAR) 4b, December 31, 1953.
(2) Amendment 25-AD (29 FR 18289, December 24, 1964).
(3) Amendment 25-40 (42 FR 15034, March 17, 1977).

Section 25.1125 Exhaust heat exchangers.

a. Rule Text:

For reciprocating engine powered airplanes, the following apply:

(a) Each exhaust heat exchanger must be constructed and installed to withstand each vibration, inertia, and other load to which it would be subjected in operation. In addition -
  (1) Each exchanger must be suitable for continued operation at high temperatures and resistant to corrosion from exhaust gases;
  (2) There must be means for the inspection of the critical parts of each exchanger;
  (3) Each exchanger must have cooling provisions wherever it is subject to contact with exhaust gases; and
  (4) No exhaust heat exchanger or muff may have any stagnant areas or liquid traps that would increase the probability of ignition of flammable fluids or vapors that might be present in case of the failure or malfunction of components carrying flammable fluids.

(b) If an exhaust heat exchanger is used for heating ventilating air -
  (1) There must be a secondary heat exchanger between the primary exhaust gas heat exchanger and the ventilating air system; or
  (2) Other means must be used to preclude the harmful contamination of the ventilating air.

[Doc. No. 5066, 29 FR 18291, Dec. 24, 1964, as amended by Amdt. 25-38, 41 FR 55467, Dec. 20, 1976]

b. Intent of Rule.

The intent of this rule is self-evident.

c. Background.

(1) The regulatory history shows that this requirement originated from section 4b.467(c) of the Civil Air Regulations (CAR) 4b, December 31, 1953. Amendment 25-AD was published in the Federal Register on December 24, 1964 (29 FR 18289), which added Part 25 [New] to the Federal Aviation Regulations and replaced Part 4b of the Civil Air Regulations. It was part of the Agency recodification program announced in Draft Release 61-25, published in the Federal Register on November 15, 1961 (26 FR 10698). Part 25 [New] was published as a notice of proposed rule making in the Federal Register on June 2, 1964 (29 FR 7169), and given further distribution as Notice No. 64-28. It was recodified from CAR 4b.467(c) without any substantive changes.

(2) Amendment 25-38 (41 FR 55454, December 20, 1976) revised the lead-in text to make it clear that this section applies only to reciprocating engine powered airplanes. While some early turbine-powered airplanes have had an ejector installation in the exhaust system to pull cooling air through the nacelle, this type of installation is not considered to be an exhaust heat exchanger and, therefore, turbine engine installations would not require compliance with this section based on the intent of the rule.

d. Policy/Compliance Methods.

The following is an excerpt from the guidance material contained in Advisory Circular (AC) 29-2B, "Certification of Transport Category Rotorcraft." (Although that AC provides guidance for transport rotorcraft, it may also provide insight into acceptable compliance methodology useful for other category aircraft.)

Exhaust Heat Exchangers:

Exhaust Heat Exchangers (EHE) and their installations are typically certified by analysis and installation tests conducted during the basic certification process, including flight tests or simulated flight tests, as follows:

(a) Because of their durability in the hot exhaust environment, EHE's are usually constructed from stainless steel or alloy steel of the appropriate structurally and thermally derived wall thickness. The EHE and its system should be designed to expand freely to minimize thermal expansion (thermal strain) induced loads on the EHE and its restraint system If thermal expansion-induced loads (in conjunction with deflection-induced loads and exhaust flow loads) are significant relative to the limit load of the EHE or its attachments, a fatigue check on critical design point(s) should be performed The fatigue check should establish a safe life or an approved limited life for the critical component(s) in the EHE system.

(b) EHE's should be properly supported so that the maximum loads anticipated in service are properly distributed and reacted and so that thermal-expansion-induced loading is minimized. Typically, the worst-case static design load conditions are either the emergency impact loads acting alone (reference § 29.561), or the critical combination of loads from thermal expansion, in-flight deflections and internal exhaust gas flow. Several combinations of these loads should be examined to determine the critical combination. The EHE should be supported and restrained so that critical frequencies are avoided and the induced vibration environment is minimized. Flight tests or bench tests, such as vibration surveys conducted during rotor system endurance testing, may be necessary in some cases, to properly define or validate the vibration environment and EHE's critical modes and their effect on EHE design. Operating modes such as ground idle, flight idle, 40 percent and 80 percent of maximum continuous power, maximum continuous power, OEI power settings, and other critical power settings should be investigated to determine their vibratory effect on the EHE system. The strength reduction of EHE materials at operating temperature and at critical temperatures should be properly considered in EHE design and structural substantiation (MIL-HDBK-5D contains material allowables versus temperature data for a wide variety of metallic engineering materials). The EHE and its restraint system should be designed to minimize loads induced by the relative motion (in-service deflections) of the components to which the EHE attaches. Isolation of significant deflection-induced loading (as required, based on analysis and strain surveys) by use of flexible joints, other equivalent flexible devices, or designs should be considered. Any such in-line device used to reduce deflection loading should meet applicable certification requirements and be leak-free.

(c) Expansion analysis and verification tests of the EHE should be conducted to ensure its thermal (and structural) integrity and to ensure that thermal expansion does not cause the EHE to contact (or come close to) ambient temperature aircraft materials, structure, or system components, and either create a fire hazard or an unintended reduction in strength. To ensure that expansion analyses and tests are properly conducted, the maximum in-service temperature excursion should be properly defined. The maximum temperature excursion should be based on the maximum temperatures of the EHE and exhaust gases, as affected by the insulatory characteristics of the EHE's enclosure, and as affected by a worst-case hot day. The worst-case temperature environment used for analysis can be verified by a temperature survey which, when run on cooler days, can be adjusted to the worst-case hot day environment using methods identical to those used for engine cooling tests (reference § 25.1043).

(d) Hot aircraft exhaust gases are very corrosive; thus, proper material selection and corrosion protection design should be performed and validated during certification. Advisory Circular (AC) 43-4, "Corrosion Control For Aircraft" contains a detailed discussion of exhaust gas corrosion problems. The in-service corrosive environment should be identified and characterized as thoroughly as possible by chemical analysis, tests and service experience. Once defined, appropriate design techniques and materials should be selected. Certification tests may be required to ensure proper substantiation. Phased inspections and inspectability should be considered.

(e) The EHE's design should be reviewed for inspectability to ensure that structural and thermal integrity is maintained over the intended life of the EHE. Also, if the design review is not conclusive relative to inspectability, a tear down inspection should be conducted.

(f) Each EHE design should be reviewed, analyzed, and tested to ensure that cooling provisions are adequate where EHE surfaces are subjected to hot exhaust gases. This is necessary to prevent hazardous hot spots or a burn through which may cause a fire and contaminate the occupied environment.

(g) Each EHE design should be reviewed, analyzed, and tested to ensure that stagnation areas and liquid traps do not exist. This can be a done using bench flow test. These stagnant areas and traps could become ignition sources if wetted with a leaking flammable fluid. A review of potential leaking flammable fluid hazards should be conducted and appropriate preventative measures such as drains and drip fences installed to ensure they are routed away from EHE's.

(h) **Each EHE design which will be used to heat ventilating air for occupants should be reviewed to ensure that the EHE is a double walled system, (i.e., it would require failure of two EHE surfaces to allow toxic exhaust gases to intermix with cabin ventilating air). Each EHE wall should be designed with equal thermal and structural resistance since a single undetected inner wall failure would subject the outer wall to the primary heat load. Also, inspectability provisions should be provided or means identified to ensure that inner wall failures can be detected in service. Any equivalent means, which is applied for, must clearly provide an equivalent level of safety to a double walled EHE.**

e. References:

(1) Civil Air Regulations (CAR) 4b, December 31, 1953.
(2) Amendment 25-AD (29 FR 18289, December 24, 1964).
(3) Amendment 25-38 (41 FR 55454, December 20, 1976).
(4) Advisory Circular 29-2B , "Certification of Transport Category Rotorcraft," July 30, 1997.

AC 20-32B Carbon Monoxide (CO) Contamination In Aircraft--Detection And Prevention

Date: November 24, 1972

Initiated by: FS-140

1. PURPOSE. This advisory circular provides information on the potential dangers of carbon monoxide contamination from faulty engine exhaust systems or cabin heaters of the exhaust gas heat exchanger type. It also discusses means of detection and procedures to follow when contamination is suspected.
2. CANCELLATION. Advisory Circular AC 20-32A, "Carbon Monoxide (CO) Contamination in Aircraft--Detection and Prevention," effective 9/13/68, is canceled.
3. REFERENCES.
   a. FAA Aircraft Development Service Technical Report No. ADS-80, "An Evaluation of Low Cost carbon Monoxide Indicators."
   b. FAA Aircraft Development Service Technical Report No. ADS-29, "Analysis of Engine Exhaust System Failures in General Aviation Aircraft."
4. GENERAL. Carbon monoxide is the product of incomplete combustion of carbonaceous material. It is found in varying amounts in the smoke and fumes from burning aircraft engine fuels and lubricants. The gas itself is colorless, odorless, and tasteless but is usually mixed with other gases and fumes which can be detected by sight or smell.
   When carbon monoxide is taken into the lungs, it combines with hemoglobin, the oxygen-carrying agent in blood. The affinity of the hemoglobin for CO is so much greater than for oxygen that oxygen starvation results. Oxygen starvation of the brain reduces a person's ability to reason and make decisions. Exposure to even very small amounts of CO over a period of several hours will reduce a pilot's ability to operate an airplane safely. Long exposure to low CO concentrations is as hazardous as short exposure to relatively high concentrations.
   Susceptibility to carbon monoxide poisoning increases with altitude. As altitude increases, air pressure decreases and the body has difficulty getting enough oxygen. Add carbon monoxide, which further deprive the body of oxygen, and the situation can become critical. Inhalation of tobacco smoke also introduces CO into the body in significant quantities.
   Many light aircraft cabins are warmed by air that has been circulated around the engine exhaust pipes. A defect in the exhaust pipes or cabin heating system may allow carbon monoxide to enter the cockpit or cabin. The danger is greatest during the winter months and any time the temperature is such that use of the cabin heating system becomes necessary and windows and vents are closed. But there is danger at other times, too, for carbon monoxide may enter the cabin through openings in the firewall and around fairings in the area of the exhaust system.
5. SYMPTOMS. Early symptoms of CO poisoning are feelings of sluggishness, being too warm, and tightness across the forehead. The early symptoms may be followed by more intense feelings such as headache, throbbing or pressure in the temples, and ringing in the ears. These in turn may be followed by severe headache, general weakness, dizziness, and gradual dimming of vision. Large accumulations of CO in the body result in loss of muscular power, vomiting, convulsions, and coma. Finally, there is a gradual weakening of the pulse, a slowing of the respiratory rate, and ... death.
6. WHAT TO DO ABOUT EXHAUST ODORS OR SYMPTOMS. If you smell exhaust odors or begin to feel any of the symptoms previously mentioned, you should immediately assume carbon monoxide is present and should take the following precautions:
   a. Immediately shut off the cabin air heater and close any other openings that might convey the engine compartment air to the cabin.
   b. Open a fresh air source immediately.
   c. Avoid smoking.
   d. Inhale 100 percent oxygen if available.
   e. If you are flying, land at the first opportunity and ensure that any effects from CO are gone before further flight.
   f. Determine that CO is not being allowed to enter the cabin because of a defective exhaust, unsealed opening between engine compartment and cabin, or any other factor.
7. IS YOUR AIRCRAFT A DEATHTRAP? Concentrations of CO exceeding one part in 20,000 parts of air (0.005 percent) are hazardous. To prevent an airplane from becoming a deathtrap, a thorough examination of the exhaust manifold and heater assembly should be conducted at regular intervals and whenever CO contamination of the cockpit or cabin is suspected because cracks and holes may occur in a relatively short time. Some aircraft manufacturers recommend that exhaust and heater systems be inspected as often as every 25 hours of flight time. Carbon monoxide in

the cabin or cockpit has been traced to worn or defective exhaust stack slip joints, exhaust system cracks or holes, openings in the engine firewall, "blowby" at the engine breather, defective gaskets in the exhaust manifold, defective mufflers, and inadequate sealing or fairing around strut fittings on the fuselage.

Other ways to experience CO contamination are to follow jet aircraft on takeoff, or to take a position downwind of a jet airplane that is "ground holding" prior to takeoff. If possible, aircraft should be positioned out of the exhaust area of preceding aircraft.

8 OPERATIONAL CHECKS. It is a good practice to supplement inspections of cabin heating and engine exhaust systems with operational CO detection tests. Carbon monoxide tests are reliable and may be accomplished without any disassembly operations. Tests should be conducted on the ground and in flight to determine the extent of CO contamination. These tests should be conducted with the cabin heat both "on" and "off."

9. CARBON MONOXIDE DETECTION EQUIPMENT. There are two types of indicators currently available that are practical for determining the concentration of CO in the air at any given time. One type is operated by drawing a sample of air into a transparent tube containing material which changes color according to the amount of CO present. An accurate measurement of the CO in the sample may be made by comparing the color in the tube to a color standard provided with the instrument.

Another type of CO indicator consists of a porous plastic disc about the size of a dime mounted in a solid plastic plate about two inches square and one tenth of an inch thick. The porous plastic contains a chemical that changes color upon contact with carbon monoxide. Measurement of the CO present is made by exposing the porous plastic disc to the atmosphere to be tested for a specific period of time, then comparing the disc color to a color standard on the "instruction card." A reading of "safe," "marginal," or "dangerous" is determined. Although not as accurate as the first type, its accuracy is adequate, and it has the advantage of being light in weight and low in cost. Only one model of plate type indicator has been tested by FAA. This is the model described in Paragraph 10d below.

10. USE OF CO DETECTION EQUIPMENT

a. Instructions for operating the sampling type indicator are furnished with each instrument. The actions listed in paragraph 6 of this advisory circular should be taken immediately if a CO concentration of more than 0.005 percent is indicated.

b. The plate type indicator should first of all be verified by the user as a type that functions properly. With a properly functioning detector and an appropriate color chart, the following technique has been found to be effective: Remove the transparent plastic cover from the plate thus exposing the disc to the atmosphere. After three minutes of timed exposure, compare the color of the disc with the color chart. If the exposure indicates a "dangerous" condition, the actions listed in paragraph 6 of this advisory, circular should be taken immediately. If there is any question about the degree of hazard present, the exposure may be continued for a timed total of 15 minutes as a verification of the 3-minute reading.

c. A plate, once exposed and found to have no appreciable disc discoloration may be left exposed in the cabin for up to 30 days. If, within that period, a distinct discoloration of the disc is noted, repeat the above procedure using a new unused plate. The sensitized spot will darken in the presence of humidity, CO, and other gases, but exposing the spot to direct sunlight and fresh air may restore it to its original color, indicating a serviceable condition. After 30 days' exposure, the plate is no longer serviceable.

d. The plate type indicator which the FAA tested and found satisfactory was a two-inch by two-inch square buff-colored plastic plate with a dime-size buff-colored sensitized spot (not an off-white plate with a brown-colored spot). It may or may not be labeled: DETECTOR CARBON MONOXIDE INDICATOR. The instruction card developed by FAA and labeled, INSTRUCTIONS FOR USE OF "DETECTOR" CARBON MONOXIDE INDICATOR, will be helpful to use with the indicator. This card has a color index with six gradations of color (not three) on the front side and TEST INSTRUCTIONS plus GENERAL REMARKS on the back. It is punched with five holes (not two).

11. REPORT AVAILABILITY. FAA Aircraft Development Service Technical Report No. ADS-80 titled "An Evaluation of Low Cost Carbon Monoxide Indicators" describes the tests conducted by FAA on the CO indicator. It also contains a reproduction of the color index. The report, which received wide distribution initially, is no longer available from FAA. It may be purchased for $6.00 per copy from:

National Technical Information Service
5285 Port Royal Road
Springfield Virginia 22151

Orders should include NTIF Accession No. AD 461670 together with the ADS report number and title.

JAMES F. RUDOLPH

Director, Flight Standards Service

AC 20-42C Hand Fire Extinguishers For Use In Aircraft

7. DISCUSSION.

e. Halon 1211 Extinguishers.

(4) If Halon 1211 extinguishers are installed in a nonventilated, passenger-occupied compartment, and the compartment cannot be vented, and the occupants cannot leave if the extinguishers are discharged, then the total Halon 1211 agent available from all the extinguishers should not be capable of producing a concentration greater than 2 percent by volume at 120°F (49°C) in the compartment. For compartments where egress is possible within one minute, the maximum design concentration can be 4 percent by volume. For ventilated compartments the guidelines in paragraph 8f(5) of this AC can be used.

f. Halon 1301 Extinguishers.

(2) If Halon 1301 extinguishers are installed in a nonventilated, passenger-occupied compartment, and the compartment cannot be vented, and the occupants cannot leave if the extinguishers are discharged, then the total Halon 1301 agent available from all the extinguishers should not be capable of producing a concentration greater than 5 percent by volume at 120°F (49°C) in the compartment. For compartments where egress is possible within one minute, the maximum design concentration can be 10 percent by volume. For ventilated compartments the guidelines in paragraph 8f(5) of this AC can be used.

(4) For occupied spaces on small aircraft where neat state (undecomposed) halon concentrations will be approaching allowable limits, Halon 1301 is the halogenated agent of choice for the following reasons:

(a) Both Halon 1211 and Halon 1301 decompose when exposed to flame producing toxic products of decomposition. Halon 1211 produces some decomposition products which are not produced by Halon 1301 and is, therefore, also considered more toxic in the decomposed state.

(b) Health and safety advantages associated with similar volume occupied spaces on larger aircraft (flight decks) do not usually exist for the smaller aircraft. These advantages are a forced ventilation system, availability of oxygen masks, and availability of a second individual capable of flying the aircraft.

8. GENERAL INFORMATION.

f. Precautions.

(2) Tests indicate that human exposure to high levels of Halon vapors may result in dizziness, impaired coordination, and reduced mental sharpness. Exposure to natural agents is generally of less concern than is exposure to the decomposition products. Exposure to undecomposed halogenated agents may produce varied central nervous system effects depending upon exposure concentration and time. Halogenated agents will also decompose into more toxic products when subjected to flame or hot surfaces at approximately 900°F (482°C). However, unnecessary exposure of personnel to either the natural agent or to the decomposition products should be avoided. The decomposition products of the Halon have a characteristic sharp, acrid odor, and an eye irritating effect, even in concentrations of only a few parts per million. Generally, decomposition products from the fire itself, especially carbon monoxide, smoke, heat, and oxygen depletion, create a greater hazard than the thermal decomposition products of Halon. See NFPA Standard 12A, Halon 1301 Fire Extinguishing Systems, and NFPA Standard 12B, Halon 1211 Fire Extinguishing Systems, for more detailed information.

(3) Under nonventilated conditions, Underwriters' Laboratories, Inc., recommends that the maximum concentration of Halon 1211 not exceed 2 percent in an enclosure, and the maximum concentration of Halon 1301 not exceed 5 percent. For sea-level altitude and a temperature of 120°F (48.9°C), the compartment volume in cubic feet that will result in these concentrations, for a given weight of agent, is found by multiplying the agent charge weight in pounds by 124.7 in the case of Halon 1211, and by 52.6 in the case of 1301.

(4) Carbon dioxide extinguishes fire by reducing the concentration of oxygen and/or the gaseous phase of the fuel in the air to the point where combustion stops. Carbon dioxide will not support life when used in sufficient concentration to extinguish a fire, and it should not be used in habitated, nonventilated aircraft compartments. Due to oxygen deficiency, prolonged occupancy can produce unconsciousness and death at higher concentrations. A concentration of 9 percent is about all most persons can withstand without losing consciousness within a few minutes. At concentrations above 9 percent, occupants would quickly lose consciousness. At concentrations of about 20 percent, death would follow in about 20-to-30 minutes, unless the victim was removed to a source of fresh air. (Ref. NFPA Standard 12, Appendix A). Carbon dioxide must be at a 34 percent concentration to effectively extinguish a gasoline fire.

(5) For ventilated compartments, the nomographs shown in Appendix 1, Figures 1, 2, and 3 of this AC can be used to find safe extinguisher sizes when compartment volume and ventilation rates are known. The nomographs are based on allowable doses of 4 percent minutes, 10 percent minutes, and 25 percent minutes for Halon 1211, Halon 1301, and CO2 respectively. Because of the effect of CO2 on human respiration rate, the allowable CO2 would have to be reduced by a factor of six from the amount allowed by the CO2 nomograph to reduce changes in human respiration rates. The Halon 1211 and 1301 homographs are entirely consistent with recognized standards. If extinguishers larger than those indicated by the selected nomographs are installed, use of protective breathing equipment should

be considered. These homographs are essentially for aircraft for which rates are controllable and known. To use a selected homograph, extend a straight line across the three vertical scales, crossing the air change and compartment volume scales at the figures appropriate for the aircraft, and crossing the agent scale at weight appropriate for that air change time and vole.

(6) Extinguishers containing a given weight of a mixture of Halon 1211 and 1301 should be treated as if the total agent weight were completely Halon 1211 in terms of quantitative guidelines cited in paragraphs 7e(4), 7e(5), 8f(3), and 8f(5) of this AC. For all aircraft applications in habitated compartments, Halon 1211, 1301, and mixtures of the two should be agents of choice as compared to CO2.

AC 25-7A Flight Test Guide for Certification of Transport Category Airplanes (Incorporates change 1 dated 6/3/99)

Chapter 4. Design and Construction

Section 8. Ventilation and Heating

84. Ventilation--§ 25.831.

a. *Explanation.*

(1) This requirement deals with minimum ventilation requirements for each occupant of the airplane, control of the ventilating air, accumulation and evacuation of smoke and harmful or hazardous concentrations of gases or vapors, and failure conditions of the ventilation system. Specific quantities of fresh air along with carbon monoxide and carbon dioxide concentration limits are specified in the rule. Reference should be made to the paragraphs in this AC dealing with Cargo and Baggage Compartments, § 25.855; Exhaust Systems, § 25.1121; and Fire Extinguishing Agents, § 25.1197. AC 25-20, "Pressurization, Ventilation, and Oxygen Systems Assessment for Subsonic Flight Including High Altitude Operations," also provides guidance for ventilation requirements.

(2) The objective of the inflight smoke evacuation test is to confirm that the flightcrew emergency procedures and the ventilation system are capable of handling heavy smoke, and to show that when using the emergency procedures, the smoke will dissipate at a reasonable rate. This is a quantitative and qualitative evaluation.

b. *Procedures.*

(1) Flight testing should be conducted to ensure the amount of ventilation air provided meets the requirements specified and the flightcrew is able to accomplish their duties without undue fatigue and discomfort. Ventilation system controls in the flight deck should be demonstrated to perform their intended function.

(2) The passenger and crew compartment should be monitored for the presence of carbon monoxide. Various flight and equipment configurations should be tested. A carbon monoxide test kit is normally used for this evaluation.

(3) Inflight smoke evacuation testing should be conducted in accordance with Advisory Circular 25-9A, "Smoke Detection, Penetration, and Evacuation Tests and Related Flight Manual Emergency Procedures," dated January 6, 1994.

Section 7. Exhaust System

137. General--§ 25.1121.

a. *Explanation.* Section 25.1121(a)--Carbon monoxide contamination. Carbon monoxide detection tests are conducted in accordance with this requirement to determine that the disposal of exhaust gases from each exhaust system does not cause carbon monoxide contamination of any personnel compartment.

b. *References.* Also see information related to the evacuation of other personnel compartment atmosphere contaminants contained in paragraphs 84 and 165 of this AC addressing the requirements of §§ 25.831 and 25.1197, respectively.

Section 9. Powerplant Fire Protection

165. Fire Extinguishing Agents--§ 25.1197.

a. *Explanation.* Carbon Dioxide in Flightcrew Compartments. Carbon dioxide has been found to adversely affect flightcrew personnel in the performance of their duties. Therefore, in airplanes equipped with built-in carbon dioxide fuselage compartment fire extinguisher systems, the carbon dioxide concentration occurring at the flightcrew stations as a result of discharging the fire extinguishers should be determined in accordance with the procedures of this section (also see paragraph 84 of this AC), except that such determination is not considered necessary if:

(1) Five pounds or less of carbon dioxide will be discharged into any one such fuselage compartment in accordance with established fire control procedures; or

(2) Protective breathing equipment is provided for each flight crewmember on flight deck duty.

b. *Procedures.* Flight Test Investigation.

(1) The carbon dioxide concentrations at breathing level at the flightcrew stations should be determined in flight tests during which fuselage compartment fire extinguishers are discharged in accordance with established fire control procedures. Since carbon dioxide is heavier than air, a nose-down attitude is likely to produce the critical concentrations in the crew compartment. Perform the tests described in paragraphs (2) and (3) below.

(2) A rapid descent at the "maximum operating limit speed" of the airplane with the flaps and landing gear up.

(3) A rapid descent with the flaps and landing gear down, at the maximum permissible speed for this configuration. If it appears that any other condition is likely to be critical on a particular airplane, it should also be investigated.

(4) In the flight tests specified above, it will be permissible to institute emergency ventilating procedures immediately prior to or following the discharge of carbon dioxide, provided such procedures can be accomplished easily and quickly by the flightcrew, and do not appreciably reduce the effectiveness of the fire protection system.

(5) If the measured carbon dioxide concentrations exceed three percent by volume (corrected to Sea Level, Standard Day conditions), protective breathing equipment should be provided for each flight crewmember on flight deck duty.

(6) Appropriate emergency operating procedures should be entered in the Airplane Flight Manual.

AC 25-20 Pressurization, Ventilation and Oxygen Systems Assessment for Subsonic Flight Including High Altitude Operation

4. PHYSIOLOGICAL LIMITING CRITERIA. The objective of the high altitude standards is to prevent exposing the airplane occupants to environmental conditions that would:
   a. Prevent the flightcrew from safely flying and safely landing the airplane, or
   b. Cause permanent physiological damage to the occupants.
5. VENTILATION.
   a. Section 25.831(a) specifies that the ventilation system must be designed to provide a minimum of 0.55 pounds of fresh air per minute per person (10 cubic feet per minute of air at 8,000 feet pressure altitude and at cabin temperature of 75°F.) for normal operations. If the airplane incorporates a recirculation system, the required fresh air may be mixed with filtered, recirculated air. A larger amount of fresh air may be required due to secondary considerations, such as equipment cooling, window or windshield defogging, control of smoke or toxic fumes, or smoke evacuation. Increased fresh air flow may also be needed in some instances to compensate for high ambient temperatures and humidity. The mass flow following probable failures is addressed in paragraph 5.e of this AC.
   b. Compliance with these requirements may be demonstrated by analysis, ground tests, and/or flight tests. Because it is not practicable to measure the air flow at each occupant's location, the fresh air supplied per minute per occupant may be determined by averaging the total cabin fresh air supply and cockpit fresh air supply for the number of occupants that each area can accommodate.
   c. The environmental systems should be investigated for the extremes of the airplane operating envelope. Tests (component, sub-system, airplane) and/or analysis should be used to establish the capabilities of the environmental systems at temperatures anticipated to be encountered in service. For informational purposes, guidelines for climatic extremes may be found in Reference 1, "Military Standard Climatic Extremes for Military Equipment," MIL-STD-210B.
   d. Takeoff with the air conditioning or bleed air system "off" may be an acceptable procedure provided the ventilation system continues to provide an acceptable environment in the passenger cabin and cockpit for the brief period when the ventilation system is not operating normally.
   e. For probable failure conditions, the ventilation system should be designed to provide enough fresh air to prevent the accumulation of odors and pollutants such as carbon dioxide. Under these conditions, the supply of fresh air should not be less than 0.4 pounds of fresh air per minute per occupant for any period exceeding five minutes. This value also appears in advisory material used by the Joint Aviation Authorities to establish a minimum flow rate following loss of one air source. Temporary reductions below this flow rate may be acceptable provided the compartment environment is maintained at a level which is not hazardous to occupants. This value is based on the minimum airflow for nonsmoking occupied spaces recommended in the ASHRAE 62-1981 standard (the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.). In addition, equipment cooling and ventilation for smoke evacuation should be provided following such failure conditions. The conditions to be considered should include failures of components such as fans, valves, and ducts, failures of a single air conditioning system or bleed air system, and failures of dual air conditioning systems or dual bleed air systems when the systems have common control systems, duct inlet systems, or distribution systems.

SAE

ARP 85 — **Air Conditioning Systems for Subsonic Airplanes**

Section 4.1- Ventilation
Focuses on control & dilution of cigarette smoke.
Section 5.1.5- Contamination
References AIR 1539. Specifies components should not add toxic or irritating materials to cabin air supply.
Section 5.2.1- Heat Exchangers
e) Liquid Cooled- design to minimize possibility of fuel or coolant leak into air.
Section 7.1- Minimizing Fresh Airflow
Techniques to minimize use of fresh air (maximize fuel economy) using recirculation, bleed flow scheduling, air treatment

ARP 731B (Draft) — **General Requirements for Application of Vapor Cycle Refrigeration Systems for Aircraft**

Section 3.4.1.1- Characteristics (Refrigerant Selection Considerations)
Discusses toxicity as one criteria for refrigerant selection.

ARP 986B — **Guide for Qualification Testing of Aircraft Air Valves**

Section 11.17- Contaminated Fluids
Requires injection of mixture of turbine oil, salt, water, dust & corrosion inhibiter.

AIR 1539 — **Environmental Control System Contamination**

Good discussion of types and sources of contamination. Focuses on effects on aircraft systems.

AIR 1796 — **Environmental Control System Contamination**

Section 4.11- Bleed Air Quality
Requires compliance with CFR Title 29, Part 1910, Section 1910.93 and AFOSH Standard 161-8.

AIR 4362 (Draft) — **NBC Protection Considerations for ECS Design**

Useful related information for detection of and protection from hazardous chemicals.

ARP 4418 — **Procedure for Sampling and Measurement of Engine Generated Contaminants In Bleed Air Supplies from Aircraft Engines Under Normal Operating Conditions**

Provides measurement procedures for eight (8) specific bleed air contaminants. Lists AIR 4766 (Draft) as the source of the limits for those contaminants, but also tabulates the limits.

AIR 4766 (Draft) — **Air Quality for Aircraft Cabins**

Don't have a copy.

Other

USAF AFOSH 48-8 — **Controlling Exposures to Hazardous Materials**

`http://afpubs.hq.af.mil/`
Replaces AFOSH Standard 161-8. Very extensive OSHA type monitoring and protection guide.

MIL-E-5007E — **Engines, Aircraft, Turbojet and Turbofan, General Specification for**

Attached.

"Airbus Cabin Air Quality- Only the Best", FAST Magazine

`http://www.airbus.com/customer_fast.html`
Inflight air quality measurement program on several Airbus airplanes.

Heating/Piping/AirConditioning Magazine

`http://www.hpac.com/`
Very useful source for air quality information. The November 1999 issue is devoted to proposed Addendum 62n to ASHRAE Standard 62-1989 for calculation of ventilation rates. It includes three pages of Internet links to IAQ organizations and web sites. It is also a free subscription.

SUBMISSION TO THE SENATE REFERENCES COMMITTEE
RURAL AND REGIONAL AFFAIRS AND TRANSPORT

ON THE INQUIRY INTO

AIR SAFETY – BAe 146 CABIN AIR QUALITY

SUBMISSION NUMBER 5B
Date Received: 12 April 2000

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[Federal Register: January 18, 2000 (Volume 65, Number 11)]

[Proposed Rules]

[Page 2555-2557]

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Proposed Rules

Federal Register

This section of the FEDERAL REGISTER contains notices to the public of the proposed issuance of rules and regulations. The purpose of these notices is to give interested persons an opportunity to participate in the rule making prior to the adoption of the final rules.

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[[Page 2555]]

DEPARTMENT OF TRANSPORTATION

Federal Aviation Administration

14 CFR Part 39

[Docket No. 99-NM-227-AD]

RIN 2120-AA64

Airworthiness Directives; McDonnell Douglas Model DC-9-81 (MD-81), DC-9-82 (MD-82), DC-9-83 (MD-83), and DC-9-87 (MD-87), Model MD-88 Airplanes, and Model MD-90-30 Series Airplanes

AGENCY: Federal Aviation Administration, DOT.

ACTION: Notice of proposed rulemaking (NPRM).

SUMMARY: This document proposes the adoption of a new airworthiness directive (AD) that is applicable to certain McDonnell Douglas Model DC-9-81 (MD-81), DC-9-82 (MD-82), DC-9-83 (MD-83), and DC-9-87 (MD-87) series airplanes, Model MD-88 airplanes, and Model MD-90-30 series airplanes. This proposal would require installation of a pipe support and clamps on the hydraulic lines in the aft fuselage; replacement of the hydraulic pipe assembly in the aft fuselage with a new pipe assembly; and installation of drain tube assemblies and diverter assemblies in the area of the auxiliary power unit (APU) inlet; as applicable. This proposal is prompted by reports of smoke and odor in the passenger cabin and cockpit due to hydraulic fluid leaking into the APU inlet, and subsequently, into the air conditioning system. The actions specified by the proposed AD are intended to prevent such hydraulic fluid leakage due to fatigue vibration and cracking in the flared radius of a hydraulic pipe in the aft fuselage, which could result in smoke and odors in the passenger cabin or cockpit.

DATES: Comments must be received by March 3, 2000.

ADDRESSES: Submit comments in triplicate to the Federal Aviation Administration (FAA), Transport Airplane Directorate, ANM-114, Attention: Rules Docket No. 99-NM-227-AD, 1601 Lind Avenue, SW., Renton, Washington 98055-4056. Comments may be inspected at this location between 9:00 a.m. and 3:00 p.m., Monday through Friday, except Federal holidays.

The service information referenced in the proposed rule may be obtained from Boeing Commercial Aircraft Group, Long Beach Division, 3855 Lakewood Boulevard, Long Beach, California 90846, Attention: Technical Publications Business Administration, Dept. C1-L51 (2-60).

This information may be examined at the FAA, Transport Airplane Directorate, 1601 Lind Avenue, SW., Renton, Washington; or at the FAA, Transport Airplane Directorate, Los Angeles Aircraft Certification Office, 3960 Paramount Boulevard, Lakewood, California.

FOR FURTHER INFORMATION CONTACT: Albert Lam, Aerospace Engineer, Systems and Equipment Branch, ANM-130L, FAA, Transport Airplane Directorate, Los Angeles Aircraft Certification Office, 3960 Paramount Boulevard, Lakewood, California 90712-4137; telephone (562) 627-5346; fax (562) 627-5210.

SUPPLEMENTARY INFORMATION:

Comments Invited

Interested persons are invited to participate in the making of the proposed rule by submitting such written data, views, or arguments as they may desire. Communications shall identify the Rules Docket number and be submitted in triplicate to the address specified above. All communications received on or before the closing date for comments, specified above, will be considered before taking action on the proposed rule. The proposals contained in this notice may be changed in light of the comments received.

Comments are specifically invited on the overall regulatory, economic, environmental, and energy aspects of the proposed rule. All comments submitted will be available, both before and after the closing date for comments, in the Rules Docket for examination by interested persons. A report summarizing each FAA-public contact concerned with the substance of this proposal will be filed in the Rules Docket.

Commenters wishing the FAA to acknowledge receipt of their comments submitted in response to this notice must submit a self-addressed, stamped postcard on which the following statement is made: "Comments to Docket Number 99-NM-227-AD." The postcard will be date stamped and returned to the commenter.

Availability of NPRMs

Any person may obtain a copy of this NPRM by submitting a request to the FAA, Transport Airplane Directorate, ANM-114, Attention: Rules Docket No. 99-NM-227-AD, 1601 Lind Avenue, SW., Renton, Washington 98055-4056.

Discussion

The FAA has received several reports of smoke and odor in the passenger cabin on McDonnell Douglas Model DC-9-82 (MD-82) series airplanes due to failure of a hydraulic pipe in the aft fuselage accessory compartment. Investigation revealed that hydraulic fluids leaked into the bilge area of the tailcone and out of the existing drains and were ingested into the air intake area of the auxiliary power unit (APU), and subsequently, into the air conditioning system. Further investigation revealed that the leaking fluid was due to fatigue vibration and cracking in the flared radius of a hydraulic pipe in the aft fuselage. This condition, if not corrected, could result in smoke and odors in the passenger cabin or cockpit.

The subject hydraulic pipe assembly on McDonnell Douglas Model DC-9-81 (MD-81), DC-9-83 (MD-83), and DC-9-87 (MD-87) series airplanes, Model MD-88 airplanes, and Model DC-90-30 series airplanes is similar to those on the affected Model DC-9-82 (MD-82) airplanes. Therefore, all of these airplanes may be subject to the same unsafe condition.

Explanation of Relevant Service Information

The FAA has reviewed and approved McDonnell Douglas Service Bulletin MD80-29-056, dated June 18, 1996 [for Model DC-9-81 (MD-81), DC-9-82 (MD-82), DC-9-83 (MD-83), and DC-9-87 (MD-87) series airplanes], which describes procedures for installation of a pipe support and clamps on the hydraulic lines in the aft fuselage.

The FAA also has reviewed and approved McDonnell Douglas Service

Bulletin MD80-29-062, Revision 01, dated August 3, 1999 [for Model DC-9-81 (MD-81), DC-9-82 (MD-82), DC-9-83 (MD-83), and DC9-87 (MD-87) series airplanes, and Model MD-88 airplanes], which describes procedures for replacement of the hydraulic pipe assembly in the aft fuselage with a new pipe assembly having a greater wall thickness.

In addition, the FAA has reviewed and approved McDonnell Douglas Service Bulletins MD80-53-286, dated September 3, 1999 [for Model DC-9-81 (MD-81), DC-9-82 (MD-82), DC-9-83 (MD-83), and DC-9-87 (MD-87) series airplanes, and Model MD-88 airplanes], and MD90-53-018, dated September 3, 1999 (for Model MD-90-30 series airplanes), which describe procedures for installation of drain tube assemblies and diverter assemblies in the area of the APU inlet.

Accomplishment of the actions specified in the service bulletins listed above is intended to adequately address the identified unsafe condition.

Explanation of Requirements of Proposed Rule

Since an unsafe condition has been identified that is likely to exist or develop on other products of this same type design, the proposed AD would require accomplishment of the actions specified in the service bulletins described previously.

Differences Between Proposed Rule and Service Bulletins

Operators should note that, although McDonnell Douglas Service Bulletins MD80-29-056, dated June 18, 1996; MD80-53-286, dated September 3, 1999; and MD90-53-018, dated September 3, 1999; recommend accomplishing the modifications at the earliest practical maintenance period (after the release of the service bulletin), the FAA has determined that such an interval would not address the identified unsafe condition in a timely manner. In developing an appropriate compliance time for this proposed AD, the FAA considered not only the manufacturer's recommendation, but the degree of urgency associated with addressing the subject unsafe condition, the average utilization of the affected fleet, and the time necessary to perform the modifications. In light of all of these factors, the FAA finds that an 18-month compliance time for initiating the proposed actions to be warranted, in that it represents an appropriate interval of time allowable for affected airplanes to continue to operate without compromising safety.

Cost Impact

There are approximately 1,126 airplanes of the affected design in the worldwide fleet. The FAA estimates that 634 airplanes of U.S. registry would be affected by this proposed AD.

It would take approximately 2 work hours per airplane [for 512 Model DC-9-81 (MD-81), DC-9-82 (MD-82), DC-9-83 (MD-83), and DC-9-87 (MD-87) series airplanes] to accomplish the proposed installation of the pipe support and clamps, at an average labor rate of $60 per work hour. Required parts would cost approximately $226 per airplane. Based on these figures, the cost impact of this installation proposed by AD on U.S. operators is estimated to be $177,152, or $346 per airplane.

It would take approximately 2 work hours per airplane [for 634 Model DC-9-81 (MD-81), DC-9-82 (MD-82), DC-9-83 (MD-83), and DC-9-87 (MD-87) series airplanes, and Model MD-88 airplanes] to accomplish the proposed replacement, at an average labor rate of $60 per work hour. Required parts would cost approximately $520 per airplane. Based on these figures, the cost impact of this replacement proposed by this AD on U.S. operators is estimated to be $405,760, or $640 per airplane.

It would take approximately 14 work hours per airplane (for 22 Model MD-90-30 series airplanes) to accomplish the proposed installation of drain tube assemblies and diverter assemblies, at an average labor rate of $60 per work hour. Required parts would cost approximately $4,503 per airplane. Based on these figures, the cost impact of the proposed AD on U.S. operators is estimated to be $117,546, or $5,343 per airplane.

The cost impact figures discussed above are based on assumptions that no operator has yet accomplished any of the proposed requirements of this AD action, and that no operator would accomplish those actions in the future if this AD were not adopted.

Regulatory Impact

The regulations proposed herein would not have substantial direct effects on the States, on the relationship between the national government and the States, or on the distribution of power and responsibilities among the various levels of government. Therefore, in accordance with Executive Order 12612, it is determined that this proposal would not have sufficient federalism implications to warrant the preparation of a Federalism Assessment.

For the reasons discussed above, I certify that this proposed regulation (1) is not a "significant regulatory action" under Executive Order 12866; (2) is not a ``significant rule" under the DOT Regulatory Policies and Procedures (44 FR 11034, February 26, 1979); and (3) if promulgated, will not have a significant economic impact, positive or negative, on a substantial number of small entities under the criteria of the Regulatory Flexibility Act. A copy of the draft regulatory evaluation prepared for this action is contained in the Rules Docket. A copy of it may be obtained by contacting the Rules Docket at the location provided under the caption ADDRESSES.

List of Subjects in 14 CFR Part 39

Air transportation, Aircraft, Aviation safety, Safety.

The Proposed Amendment

Accordingly, pursuant to the authority delegated to me by the Administrator, the Federal Aviation Administration proposes to amend part 39 of the Federal Aviation Regulations (14 CFR part 39) as follows:

PART 39--AIRWORTHINESS DIRECTIVES

1. The authority citation for part 39 continues to read as follows:

Authority: 49 U.S.C. 106(g), 40113, 44701.

Sec. 39.13 [Amended]

2. Section 39.13 is amended by adding the following new airworthiness directive:

McDonnell Douglas: Docket 99-NM-227-AD.

Applicability: Models and series of airplanes as listed in the applicable McDonnell Douglas service bulletin(s) specified in Table 1 of this AD, certificated in any category.

Table 1

Model of airplane	McDonnell Douglas service bulletin(s)
DC-9-81 (MD-81), DC-9-82 (MD-82), DC-9-83 (MD-83), and DC-9-87 (MD-87) series airplanes.	MD80-29-056, dated June 18, 1996; MD80-29-062, Revision 01, dated August 3, 1999; and MD80-53-286, dated September 3, 1999.
MD-88 airplanes	MD80-29-062, Revision 01, dated August 3, 1999 and MD80-53-286, dated September 3, 1999.
MD-90-30 series airplanes	MD90-53-018, dated September 3, 1999.

Note 1: This AD applies to each airplane identified in the preceding applicability provision, regardless of whether it has been modified, altered, or repaired in the area subject to the requirements of this AD. For airplanes that have been modified, altered, or repaired so that the performance of the requirements of this AD is affected, the owner/operator must request approval for an alternative method of compliance in accordance with paragraph (e) of this AD. The request should include an assessment of the effect of the modification, alteration, or repair on the unsafe condition addressed by this AD; and, if the unsafe condition has not been eliminated, the request should include specific proposed actions to address it.

Compliance: Required as indicated, unless accomplished previously.

To prevent hydraulic fluid leakage into the auxiliary power unit (APU) inlet due to fatigue vibration and cracking in the flared radius of a hydraulic pipe in the aft fuselage, which could result in smoke and odors in the passenger cabin or cockpit; accomplish the following:

Installation a Pipe Support and Clamps

(a) For Model DC-9-81 (MD-81), DC-9-82 (MD-82), DC-9-83 (MD-83), and DC-9-87 (MD-87) series airplanes, as listed in McDonnell Douglas Service Bulletin MD80-29-056, dated June 18, 1996: Within 18 months after the effective date of this AD, install a pipe support and clamps on the hydraulic lines in the aft fuselage in accordance with the service bulletin.

Replacement of the Hydraulic Pipe Assembly

(b) For Model DC-9-81 (MD-81), DC-9-82 (MD-82), DC-9-83 (MD-83), and DC-9-87 (MD-87) series airplanes, and Model MD-88 airplanes, as listed McDonnell Douglas Service Bulletin MD80-29-062,

Revision 01, dated August 3, 1999: Within 18 months after the effective date of this AD, replace the hydraulic pipe assembly in the aft fuselage with a new pipe assembly having a greater wall thickness, in accordance with the service bulletin. Except for Model MD-88 airplanes that have been modified in accordance with McDonnell Douglas MD-80 Service Bulletin 29-54, dated February 2, 1993, or Revision 2, dated December 17, 1993, the requirements of this paragraph must be accomplished concurrently with the requirements of paragraph (a) of this AD

Installation of Drain Tube Assemblies and Diverter Assemblies

(c) For Model DC-9-81 (MD-81), DC-9-82 (MD-82), DC-9-83 (MD-83), and DC-9-87 (MD-87) series airplanes, as listed in McDonnell Douglas Service Bulletin MD80-53-286, dated September 3, 1999; and Model MD-9-30 series airplanes, as listed in McDonnell Douglas Service Bulletin MD90-53-018, dated September 3, 1999: Within 18 months after the effective date of this AD, install drain tube assemblies and diverter assemblies in the area of the APU inlet, in accordance with the applicable service bulletin.

Spares

(d) As of the effective date of this AD, no person shall install a hydraulic pipe assembly, part number 7936907-603, on any airplane.

Alternative Methods of Compliance

(e) An alternative method of compliance or adjustment of the compliance time that provides an acceptable level of safety may be used if approved by the Manager, Los Angeles Aircraft Certification Office (ACO), FAA, Transport Airplane Directorate.

Operators shall submit their requests through an appropriate FAA Principal Maintenance Inspector, who may add comments and then send it to the Manager, Los Angeles ACO.

Note 2: Information concerning the existence of approved alternative methods of compliance with this AD, if any, may be obtained from the Los Angeles ACO.

Special Flight Permits

(f) Special flight permits may be issued in accordance with sections 21.197 and 21.199 of the Federal Aviation Regulations (14 CFR 21.197 and 21.199) to operate the airplane to a location where the requirements of this AD can be accomplished.

Issued in Renton, Washington, on January 11, 2000.

Donald L. Riggin,

Acting Manager, Transport Airplane Directorate, Aircraft Certification Service.

[FR Doc. 00-1118 Filed 1-14-00; 8:45 am]

BILLING CODE 4910-13-U

SUBMISSION TO THE SENATE REFERENCES COMMITTEE
RURAL AND REGIONAL AFFAIRS AND TRANSPORT

ON THE INQUIRY INTO

AIR SAFETY – BAE 146 CABIN AIR QUALITY

SUBMISSION NUMBER 6

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SCHOOL OF SAFETY SCIENCE

To: Senator John Woodley
Australian Democrat Senator for Queensland
Parliament House
Canberra ACT 2600
AUSTRALIA

From: Assoc Prof Chris Winder
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Regarding: Toxic fumes on the BAe 146

Dear Senator Woodley

You may recall I wrote to you earlier this year in March, outlining my concerns about the incidence of toxic fumes on the BAe 146. As you know, this is a British Aerospace jet being flown by various airlines around the world, on which smoke/mist/fume events are not uncommon. Symptoms of toxicity have been produced in some airline staff exposed to such fumes. However, the airlines do not seem to have been able to deal with this issue properly.

I am a toxicologist with a research interest into low level chemical exposures that produce toxicity. In 1997, I met and interviewed Ms Alycia Chew, a fight attendant with toxic symptoms from smoke/mist/fume exposures on the BAe 146, dating from 1992 (as you may know, Ms Chew's compensation case recently concluded in the NSW Workers Compensation Court). In my research activities, I am used to seeing a small number of individuals from various workplace sectors with symptoms of toxicity to exposures that do not affect their co-workers. However, what has concerned me in Ms Chew's case is an apparently significant number of similar cases in cabin crew and flight crew in Australia My concern quickly turned to alarm in 1998, when I became aware that this problem was not unique to Australia, when I learned of similar cases in Canada, the USA, the United Kingdom and France.

I have been discussing this issue with Dr Jean-Christophe Balouet, an environmental scientist in France, investigating similar cases worldwide. In our view, the symptoms reported in these cases are sufficiently consistent to indicate the development of a discrete occupational health condition, and we are using the term "aerotoxic syndrome" to describe it. Features of this syndrome are that it is associated with air crew exposure at altitude to atmospheric contaminants from engine oil or other aircraft fluids, temporally juxtaposed by the development of a consistent symptomology of irritancy, sensitivity, psychotoxicity and neurotoxicity. This syndrome may be reversible following brief exposures, but features are emerging of a chronic syndrome following further exposures.

In your reply of 7 April 1999 to my 10 March letter, you invited me to make a submission to the Senate Inquiry into Aviation. Please find attached my submission plus attachments, for the Inquiry's consideration.

Further, while I would be happy to give evidence to the Inquiry as a witness, please note that I am on sabbatical at the University of Surrey in the United Kingdom until mid-September 1999.

Yours sincerely

Chris Winder

ASSOC PROF CHRIS WINDER PhD
HEAD, SCHOOL OF SAFETY SCIENCE

12 June 1999

SCHOOL OF SAFETY SCIENCE
UNIVERSITY OF NEW SOUTH WALES

Submission to

Senate Rural and Regional Affairs and Transport References Committee Inquiry

Examination of air safety with particular reference to air quality in the cabins of BAe 146 aircraft

by

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Head, School of Safety Science
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June 1999

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EXECUTIVE SUMMARY

This submission has been prepared for the Australian Parliament Senate Rural and Regional Affairs and Transport Legislation Inquiry into Aviation. It addresses one of the terms of reference of this inquiry, that of "the examination of air safety with particular reference to air quality in the cabins of BAe 146 aircraft".

The personal details of the author of this report are outlined in Appendix 1.

The main points in this submission are:

1 Hazardous chemicals are used in aircraft, including the BAe 146.

2 Contamination of the cabin of aircraft is not unheard of. It is possible that chemicals may contaminate the passenger cabin of aircraft in flight as vapours, fumes, mists or smoke, either through normal operational activities or arising from abnormal conditions (henceforth called exposure events).

3 Engineering and maintenance staff handling such materials are providing with information, such as:
   - product labels and material safety data sheets (MSDS) from product suppliers, which contain advice on hazards and general information on control; and
   - engineering manuals from aircraft engine suppliers, which contain advice about minimising risks from toxic exposures in maintenance operations.

4 Hazard classifications, product labels and MSDS provided by product suppliers often minimise the hazards of the materials they relate to and suggest safety only "under normal conditions of use" using recommended preventive measures (see Appendix 2). No information is provided for unusual or abnormal conditions (such as those that may occur during an exposure event).

5 The "safe under normal conditions of use" statement has been uncritically extrapolated by airline operators to include exposures in all normal or abnormal conditions. This goes beyond exposure conditions the product manufacturer envisaged, and probably contravenes product liability.

6 The airlines in Australia have been aware of the issue of exposure events in the BAe 146 since at least 1992 (see Appendix 3). Airline flight and engineering documentation suggests that the numbers of exposure events on the BAe 146 are not insignificant.

7 No advice is provided to cabin crew (neither flight attendants nor flight crew) as to what actions to take in the event of exposure events.

8 Monitoring undertaken by various airlines to assess the extent of the problem has been inadequate. For example, no appropriately conducted monitoring has been conducted during an exposure event.

9 Symptoms of toxicity have been reported by flight attendants and pilots exposed during exposure events, including irritation, sensitisation, psychotoxicity and neurotoxicity.

10 Symptoms of toxicity may be exacerbated by the hypoxia of cabin pressure, other chemical exposures (such as carbon monoxide), temperature, humidity, workload or pre-existing health conditions.

11 While some of these symptoms are transient or reversible, others appear to more long lasting.

12 The presence of some of these symptoms (most notably neurotoxicity) in flight crew has serious implications for air safety.

13 The presence of these symptoms in airline personnel has significant implications for the health of staff and passengers.

14 The symptoms reported by airline staff in exposure events are sufficiently consistent to indicate the development of a discrete occupational health condition. The term "aerotoxic syndrome" is introduced to describe it. Features of this syndrome are that it is associated with air crew exposure at altitude to atmospheric contaminants from engine oil or other aircraft fluids, temporally juxtaposed by the development of a consistent symptomology of irritancy, sensitivity and neurotoxicity. This syndrome may be reversible following brief exposures, but features are emerging of a chronic syndrome following further exposures.

15 One airline (Ansett Australia) admits that exposure events occur, and that they may be associated with symptoms of toxicity (irritation).

16 Attempts to deal with the problem of exposure events remain reactive and piecemeal. Reasons for this include:

- minimal compliance with maintenance requirements (for example, no consideration is given to the maintenance requirements of ageing aircraft);
- attitudes which place pressure to fly aircraft over staff health;
- the unimportance that the airlines give to staff complaints about air quality.

Aerotoxic syndrome presents significant issues with regard to the health of pilots, cabin crew and passengers, but most notably with regard to air safety if pilots are incapacitated and cabin crew cannot supervise cabin evacuations during emergencies. Health effects include short term irritant, skin, gastro-intestinal, and respiratory and nervous system effects, and long term central nervous and immunological effects. Some of these effects are transient, others appear more permanent. The exacerbation of pre-existing health problems by toxic exposures is also highly probable.

This is a hidden issue. Staff of the airlines is worried about job security and what might happen to them if they complain about working conditions and makes their symptoms public. At present, with only a few cases proceeding in the courts, little compensation has been awarded to airline workers affected by toxic fumes. Therefore, staff is reluctant to come forward until their health in jeopardised sufficiently that they can no longer fly without compromising their health and safety.

INTRODUCTION

This submission has been prepared for the Australian Parliament Senate Rural and Regional Affairs and Transport Legislation Inquiry into Aviation It addresses one of the terms of reference of this inquiry, that of "the examination of air safety with particular reference to air quality in the cabins of BAe 146 aircraft".

Specifically, this submission concerns itself with the contamination of the cabin of the BAe 146 by toxic chemicals and the production of symptoms of toxicity in exposed airline personnel, both flight attendants and pilots

Personal details of the author of this report are attached at Appendix 1.

CHEMICAL EXPOSURES AT ALTITUDE

Chemical exposures in aircraft are not unheard of. Aircraft materials such as jet-fuel, de-icing fluids, engine oil, hydraulic fluids, and so on, contain a range of ingredients, some of which are toxic. For example, the aviation industry has used engine oil, hydraulic fluids and other materials that contain organophosphate compounds, including Tricresyl phosphates (TCP), Tributyl phosphates (TBP), Triphenyl phosphates (TPP) and their derivatives, from 3 to 25% in content. Some of these have been known to be toxic for many years.[1]

Although these chemicals are usually retained in the engines and equipment into which they have been added (such as auxiliary pack units or APUs), they can sometimes find their way into cabin air where crew and passengers are located, through incidents such as engine oil leaks, seal failures and fluid ingestion by APU/engines. Further, operational activities, such as APU "pack" burnouts or use of re-circulated air during take off and landing, can give rise to significant contamination.

In some cases, this contamination may be to the materials used in aircraft such as jet fuel or other materials in vapour, fume or mist forms.[2] However, effects are also possible from exposure to combustion or pyrolysis products such as smoke.

Dozens of in-cabin leak/smoke events are documented annually, often correlated to aircraft fluid leak events. Fume events are much more frequent, correlated to less important aircraft fluid leaks (in the order of hundreds a year).

For the purposes of discussion below, events leading to leak, smoke or fume incidents will be combined as "leak/smoke/fume events" or "exposure events". In total, aircraft fluid leak/fume/smoke events are estimated to impact over 300 flights per year worldwide, resulting in exposures to an estimated 40,000 or more crew and passengers.

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1 CARPENTER, H.M, JENDEN, D.J., SHULMAN, N.R. AND TUREMAN, J.R. Toxicology of a triaryl phosphate oil: I Experimental toxicology. *AMA Archives of Industrial Health* **20**: 234-252 1959

2 SMITH, L.B., BHATTACHARYA, LEMASTERS, G., SUCCOP, P., PUHULA, E., MEDVEDOVIC, M. AND JOYCE, J. Effect of chronic low level exposure to jet fuel on postural balance of US Air Force personnel. *Journal of Occupational and Environmental Medicine* **39**: 625-632, 1997.

The range of bleed air contaminants and their concentrations that may be found during in-cabin exposure events during flight can be extensive. Significant contaminants include: aldehydes; aromatic hydrocarbons; aliphatic hydrocarbons; chlorinated, fluorinated, methylated, phosphate, nitrogen compounds; esters; and oxides.

Engineering Considerations in the BAe 146

The BAe 146 was developed in 1973 and designed for short-range transport. It was first test flown in 1981, and was flying commercially by 1983 (Dan-Air was one of the first airlines using this plane). By the end of 1993, a total of 217 BAe 146 aircraft were in use worldwide, of which 193 were being operated by 59 different airlines.

The BAe 146 is known to have problems with cabin fumes and odours. The plane has four wing mounted Textron Lycoming turbojet engines (ALF 502R5) engines; these engines are only used on the BAe 146. Common to many jet engines, these comprise a high-pressure compressor, the burners/combustion chamber and the turbine section. The engine on the BAe 146 also has a high-pressure compressed air bleed from the engine section, which is used for pressurisation and air conditioning. This air bleed is ducted to the rear of the plane, where it is passed through to two air conditioning packs. The engines on the left wing of the BAe 146 service air conditioning pack 1 (provides air to the cockpit and passenger cabin) and the engines on the right wing service air conditioning pack 2 (provides air to the passenger cabin only).

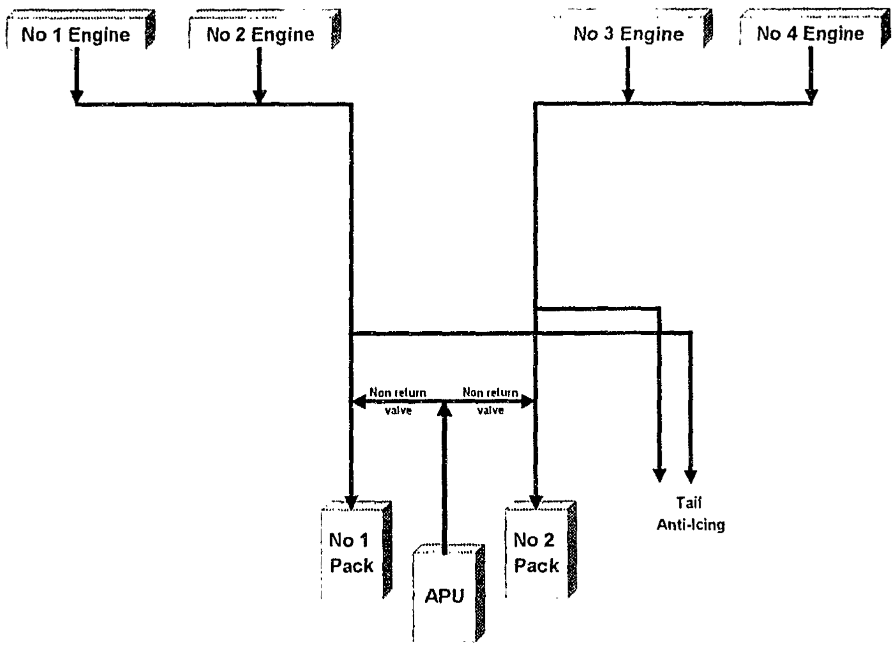
The BAe 146 also contains a Garrett/Sunstream auxiliary power unit (APU) which primarily supplies compressed air for ground operation of the air conditioning system and is also used during take off and landing. Both the engines and APU have been implicated as sources of the fumes/mists that have entered the flight deck and cabin, although the engines are considered the main source of the problem.

A schematic of the engine, APU and air conditioning packs is shown in the next figure.

One engine oil used in the BAe 146 in Australia is Jet Oil II, a synthetic phosphate ester product manufactured by Mobil USA and marketed in Australia by Mobil Australia. Obtaining details about the composition of this product and its safety information has proved difficult (see Appendix 2).

The compressor section of the engine contains lubricating oils (such as Mobil Jet Oil II). Engine maintenance manuals note *Do not keep the oil on the skin for a long time. If you do not clean the oil off, the oil can cause injury* and *Do not let the oil stay on your skin. You can absorb poisonous materials from the oil through your skin* This suggests that oil is not harmless. This information is obviously aimed at maintenance personnel, and presumably envisages that no one else will come into contact with the oil. Further, new notices warning against the inhalation of mists were added in 1997-8.

Schematic of Air System in the BAe 146



Sources of Exposure Events on the BAe 146

There are a range of ways in which exposure events can occur.

Leaking oil seals in the compressor section of the engine suggest that oil would enter the high-pressure bleed to the air conditioning packs and APU, and therefore, into the passenger cabin. Leaking oil seals leak at different rates and therefore different planes will have different levels of contamination. The APU also can suffer from the same problem of leaking compressor bearing oil seals. Filters were introduced between the air conditioning packs and the cabin distribution outlets some time after 1992 (and not by Ansett Australia until much later), but are of unknown effectiveness if not regularly serviced.

Therefore, one probable source of exposure events is engine oil leaks, which are re-circulated through the plane in its air conditioning system. These leaks were not uncommon on this model of plane.

Another source of exposure events, fortunately rare, is an engine fire, leading to emission of smoke into the cabin. However, with high engine operating temperatures and leaks of engine materials into the air conditioning system, the possibility of leaks of partly combusted or pyrolised products into the cabin cannot be excluded. Exposure incidents that report smoke or black mist may indicate such events.

In a study of 89 incidents of smoke/fumes in the cockpit during the flight of USAF aircraft from 1970 to 1980, a broad spectrum of symptoms were reported, including:[3]

dizzy, light headed	42;	visual acuity	10;
irritated eyes and mucous membranes	31;	Parathesias	8;
nausea/vomiting	31;	chest pain, heaviness	6;
confusion, disorientation, performance decrement	23;	loss of consciousness	4;
headache	22;	Cough	2.

Often more than one symptom was reported

Further, an engineering procedure called a APU Pack Burnout Procedure, by which the air conditioning system is heated with hot air to remove (burn out) any oil contamination in the system was used routinely till 1998. This would have produced substantial exposure to exposed personnel.

Lastly, the emission of oil vapours/smoke/mists into the passenger cabin would produce contamination of the cabin. Aerosols would settle out onto surfaces, which would thereafter slowly vaporise, the rate of evaporation being dependent on individual contaminant vapour pressures. This residual contamination would continue until cleaned off or until it had evaporated.

Therefore sources of exposure events on BAe 146 planes may be due to:

- oil leaks to the air conditioning system;
- smoke from combustion/pyrolysis events;
- contamination following pack burn outs;
- exposures during times when contaminated engines/APU are being used;
- residual contamination.

Leaks of engine oil contaminants into the passenger cabin of an aircraft in flight appear to be a significant problem necessitating a prompt response. It is apparent that the airlines in Australia knew about the problem from at least 1992 (see Appendix 3). However, attempts to deal with the situation, such as establishing an odour committee or "panel of experts" seem to be more about addressing industrial relations issues, rather than establishing genuine efforts to rectify the problem through design or engineering solutions.

Issues Related to Vapours and Particulates

Airborne contaminants are generally divided into two types: gas/vapour and particulates.

Gases/Vapours: A vapour is the gas phase of a liquid at room temperature. That is, a vapour is that amount of liquid that evaporates into air (or dissolves into air).

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3 RAYMAN, R.B. AND MCNAUGHTON, G.B. Smoke/fumes in the cockpit. *Aviation, Space and Environmental Medicine* **54:** 738-740, 1983.

The amount of evaporation is dependent on the individual vapour pressure of the contaminant. Where vapour pressure is low, only a small amount of the contaminant will evaporate. Generally, vapour pressure increases with temperature.

Where volatile organic chemicals (VOCs) have high vapour pressures, they will be present in air in high concentrations, and are amenable to sample collection and analysis using sorbent or gas collection methods. Where semi-volatile or poorly volatile chemicals have low vapour pressures, sorbent or gas collection methods are less useful.

Particulates: These are materials suspended, not dissolved, in air, and include fumes, smoke, mists, aerosols, dusts, fibres and so on. Particulates may be in liquid phase (such as mists), solid phase (smokes, fumes and dusts) or mixed phases (aerosols). Precise criteria for these terms exist based on particle size and phase, but are unnecessary for the present discussion.

Where a particulate is present in air, the volatile components will evaporate at a rate dependent on individual vapour pressures. However, depending on the amount of particulate present in air, it is possible to exceed the vapour pressure of an individual contaminant. Where a contaminant has a low vapour pressure, particulate exposure is more important than exposure to vapour.

Therefore, particulates containing a large proportion of volatile components will evaporate quickly (sometimes even before settling), indicating that the vapour phase of the contaminant is more important. Particulates containing poorly volatile components will stay in particulate form for a long time. until gravity or turbulence causes them to settle. Once settled, particles coalesce onto surfaces, and become subject to evaporation through vapour pressure. Where evaporative pressures are low, long term, low-level contamination leading to residual exposures will occur.

Further, because particulates can settle on exposed skin and be subject to absorption through skin, sometimes after airborne exposure has ceased, it is important to consider both the inhalational and skin routes when estimating exposure.

Particulates are not amenable to the same sampling and collection methods that are required for gases and vapours. They require specialised sampling, usually by filtration or gravimetric methods. Further, because particulates can exist in different sizes and diameters, an estimate of that fraction of the particulate that is taken into the respiratory system may be more critical than an estimation of the total concentration of particulate.

Consideration of the type of airborne contaminants, whether in vapour, particulate or mixed phases is quite critical for the success and relevance of a monitoring program

AIR MONITORING STUDIES

During the last fifteen years there has been a number of studies carried out in relation to oil contaminants entering the cabins of aircraft (see below). Not all of this research has been carried out on the BAe 146, or in engines containing the oil used on the BAe 146 (Mobil Jet Oil II). Therefore the usefulness of this information is

limited. Much of this research is not available in the public domain, and it is difficult to critically examine its findings:

- Studies by the US Transportation Board in April 1983 investigated the potential problem of turbine oil by product contamination of an aircraft's cabin from a cracked front main shaft compressor carbon seal element in a Garrett TPE-331 turboprop engine might allow engine oil to leak into the cabin.[4] This issue had arisen from several accident investigations. Test procedures were simulated on the ground using Exxon Turbo 2380 lubricating oil in a Garrett TPE 331 Turboprop engine on a test stand at the Garrett plant in Arizona in 1981 (two years before the BAe 146 was flying commercially). The study concluded that pilot incapacitation from engine oil contamination was without validity, although the extrapolation of ground based studies to flying conditions is highly dubious. The report noted "the results of the test program are applicable only to aircraft using Garrett TPE 331 engine compressor bleed air for cabin environment system." This engine model is not used on the BAe 146.

- A study of the inhalation toxicity of six commercially available products (including Mobil Jet Oil II) was conducted by the US Federal Aviation Administration (FAA) in 1983.[5] This report was linked to the Wizniak 1983 study (see above) and investigated exposure of rats and chickens to decomposition products. The toxicity endpoints measured were time to incapacitation or time to death. These are crude measures of toxicity which do not measure effects such as irritancy or sensitisation. Results suggest that the toxicity of decomposition products were related to production of Carbon monoxide. Also, while three products were tested in aerosol exposure experiments, Mobil Jet Oil II was not one of the products tested. The results of this study, again carried out at ground level, provide little about exposures at altitude, and nothing about exposure to mists of Mobil Jet Oil II.

- A 1989 study by Dickey and Wilson investigated contaminants arising from air flowing over a vessel of heated synthetic oil.[6] The oil was Mil L 23699, heated at 250°, 450° and 700°F (120°, 230° and 370°C), and from a cabin air sample taken from an UN-named aircraft over the UK with a "slight odour of oil". Results indicate that the oil found in the cabin is not chemically altered from the oil in the engine. This oil is not used on the BAe 146, but serves to indicate that (at least one) synthetic oil is stable.

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4 WIZNIAK, E.P. *Special Investigation - An Evaluation of the Potential for Turbine Oil By-product Contamination of an Aircraft's Cabin Environmental System*. National Transportation Safety Board, 25 April 1983.

5 CRANE, C.R., SANDERS, D.C., ENDECOTT, B.R. AND ABOTT, J.K. *Inhalation Toxicology: III Evaluation of Thermal Degradation Products from Aircraft and Autombile Engine Oils, Aircraft Hydraulic Fluid and Mineral Oil.* Report No FAA-AM-83-12. US Federal Aviation Administration/US Department of Transportation, Washington, 1983.

6 DICKEY, T.A. AND WILSON, D.E. *Contamination of cabin air by synthetic oil and breakdown products.* SAE Technical Paper, 19th Intersociety Conference on Environmental Systems, San Diego, California, 24-26 July, 1989.

- In 1990, a Discussion Paper on developing a limit for total organic material in cabin bleed air was prepared for the SAE E31 Cabin Air SubCommittee.[7] This paper recognised that "contamination of the cabin bleed air by engine generated organic material may occur". Further, it noted various ways of expressing such contamination, eventually recommending that the maximum allowable concentration of total organic material should be in the order of 0.1 parts per million by weight, or 0.2 parts per million by volume (0.2 ml/m^3). This is an exceptionally low level, compared with the conventional exposure standard for oil mist (at 5 mg/m^3).
- A 1991 microbiological study by Pall Europe of an objectionable odour arising in the APU of a Dan-Air BAe 146 failed to find anything unusual.[8] The authors concluded that the APU related odour was not caused by microbial contamination.
- A 22 July 1991 report prepared by Richard Fox of Allied Signal Aerospace reports the results of air quality testing for Dan-Air London. This report notes that "several BAe 146 aircraft are having reports of objectionable odours described as "dirty socks or musty"." The report also notes that "no contaminant appeared to be that great, but they do act in synergism and their combined effect could be enough to trigger the odour complaints".
- In 1992, Vladimir Vasak, consultant occupational hygienist to Qantas in Sydney, investigated APU filter samples and air quality samples from revenue flights.[9] There are a number of procedural and methodological problems with these studies, and in some cases, suitable conclusions could not be made. However, these studies report oil mist levels in the cockpit of 1.5 mg/m^3, and in the cabin of 1.3 mg/m^3, with a similarity between the oil in the cabin and Mobil Jet II. The exposure standard for conventional hydrocarbon oil mist is 5 mg/m^3, although the applicability of the standard for synthetic oils containing phosphate esters used in aircraft is questionable (see[7]). This study is the first to report oil contamination of the cabin, although no tricresyl phosphate was detected.
- Two 1995 studies conducted by Ansett[10] collected air for oil mist assessment for 15 minutes in a plane on the ground following a report of passenger and crew vomiting, and for 360 and 497 minutes on later days in other planes on scheduled services. Oil mist concentration was below the level of detectability (below 0.02 mg/m^3) in all samples. Again, with the exception of a 15 minute sample after a plane had landed after some passenger and crew symptoms (insufficient for detecting anything other than massive levels of oil) no monitoring was carried out during an exposure event.

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7 WALKER, P.H. *Discussion Paper: Discussion on the Specification Limit for Total Organic Material in Cabin Bleed Air.* Rolls Royce, Williamsburg, 1990.

8 WILKINS, K AND KENDALL, K. *Dan-Air BAe 146 Odour – Microbial Analysis.* Pall Europe, Portsmouth, July 1991.

9 VASAK, V. *Cabin Air Contamination in BAe 146 in EastWest Airlines.* Industrial Hygiene and Environmental Service Laboratories, St Ives, July 1992.

10 CURRIE, K. *Oil Mist Assessment. BAe 146 200 Aircraft Rear Flight Attendant Seat.* Ansett Engineering Health and Safety Report, 7 August 1995 and 4 September 1995.

- A 1997 report carried out by George Lee of the Queensland Health Scientific Services actually installed a gas chromatograph on a BAe 146 (all other studies collect samples for later laboratory analysis).[11] Basically, these analyses report "nothing untoward was detected by the gas chromatograph, and none of the crew complained of any unusual smell". Again, this indicates monitoring was conducted in the absence of an exposure event. Using a somewhat novel technique, air sampling was also conducted during a pack burn out, by pumping cabin air through a vessel cooled with liquid nitrogen, in an attempt to capture everything in the air sample. Subsequent analysis identified tricresyl phosphate in the sample. The possibility that all other monitoring studies were unable to detect tricresyl phosphate as the chemical is poorly volatile, or eludes sorption onto sampler, or for some other reason makes virtually all monitoring carried out to date highly questionable. A later report of this study indicates "on one occasion, tricresyl phosphate was detected at low ppm level in an aircraft cabin during a pack burn".[12] This again suggests that even in the absence of exposure events, low levels of tricresyl phosphates are possible.

- A report on air quality measurements on BAe 146 aircraft in service at Ansett Airlines was prepared by Richard Fox of Allied Signal in 25 November 1997.[13] The investigations took place on revenue flights on planes with and without new filters. Planes had levels of contaminants, which were within an order of magnitude (30-40%) of recommended exposure standards, and above such values (100-130%) in the aft galley. This finding applied to contaminants with exposure standards and not to those contaminants that do not have exposure standards – the majority of detected compounds did not have such values, suggesting that the unacceptability of exposure would have been increased even further if all contaminants were considered. This report strongly criticised the practice of pack burnouts, suggesting damage to filters and increased off gassing of contaminants. Recommendations for suspension of pack burn outs as an acceptable operation procedure date from this report. While no tri-orthocresyl phosphate was found, another phosphate ester Tributyl phosphate was detected. There is some doubt that the monitoring techniques used in this investigation (summa canisters) could capture poorly volatile contaminants such as the tricresyl phosphates, and overall, the monitoring in this study was not associated with a definable exposure event. Further, in air monitoring for volatile organic vapours, this study notes concentrations were at, or below 3,000 µg/m^3. This is not a concentration "orders of magnitude" below anything that could be considered a problem, but is at the lower level of a "discomfort range".[14]

- Finally, a report by van Netten on air quality on the BAe-146 carried out air monitoring on the BAe 146 during non-revenue flights on a plane the day after

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11 LEE, G. *BAe 146, Interim Report.* Queensland Health Scientific Services, Brisbane, 4 June 1997.

12 LEE, G. *Investigations into Odours in the Cabins of BAe 146 Aircraft.* Queensland Health Scientific Services, Brisbane, 15 December 1997.

13 FOX, R. Allied Signal, November 1997.

14 HOLCOMB, L.C. AND PEDELTY, J.F. *Volatile Organic Compounds Reported Concentrations and Criteria for Health and Comfort.* Holcomb Environmental Services.

an exposure event.[15] The author notes that the problem in this plane relates to leaks of seals in engine bearings one and nine. The plane used Castrol 5000, which was replaced with Exxon 2380 after the incident (note that Mobil Jet Oil II was not used in this particular aeroplane). Air monitoring used techniques for volatile organic chemicals and "potential aerosolised oils". It is likely that the day after an oil fume event that volatile components or aerosol mists will have dispersed. This proved to be the case.

It is difficult to extract useful information from these studies. Methodological considerations indicate that many are flawed. One of the most serious problems is sample collection for later analysis. If an exposure event occurred, and a sample of the cabin air was collected, then any mists in the sample would coalesce to the surfaces of the sample collector device (such as a bag or canister). The concentration of the mist would therefore drop dramatically, leaving only a very low vapour residual. Subsequent extraction of this sample for analysis would be as the residual vapour, and only very low levels would be measured Any sampling method that relies on sample collection of an air sample containing a mist, and analysis of a residual vapour (when all the mist has settled) could underestimate exposure by orders of magnitude. Virtually all monitoring outlined above which relies on sample collection for later analysis is severely flawed. Tricresyl phosphates are detected only in a method where the entire sample is captured and not allowed to disperse (such as the cryogenic sampling outlined in the Lee studies[11,12]).

Therefore, there are methodological problems with these studies:

- the monitoring was carried out using inappropriate conditions, such as testing at ground level;
- the monitoring was carried out using inappropriate methods, such as analyses of samples collected in summa canisters or Tedlar bags, when mists could coalesce onto the surface of the sample container;
- storage of sample containers was too long (for example, over 72 hours after sample collection when some compounds could be lost, or semi-volatile compounds would adhere to the inside of the bag);
- some studies are not relevant to the BAe 146, or to Mobil Jet Oil II;
- little evidence is presented to indicate if monitoring was carried out after scheduled maintenance, or seal, oil or filter changes, so it is difficult to assess whether the monitoring was representative of typical exposures;
- most importantly, no monitoring was conducted out at a time when an odour incident had occurred.

A last point should be made, that airborne monitoring ignores exposure from skin absorption, known to be a significant route of exposure for at least some organic phosphates, including tri-orthocresyl phosphate.[16]

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15 VAN NETTEN, C. Air quality and health effects associated with the operation of the BAe 146-200 aircaft. *Applied Occupational and Environmental Hygiene* **13:** 733-739, 1998.

16 HODGE, H.C AND STERNER, J.H. The skin absorption of triorthocresyl phosphate as shown by radioactive phosphorus. *Journal of Pharmacology and Experimental Therapeutics* **79:** 225-234, 1943.

TOXIC SYMPTOMS FROM EXPOSURE EVENTS

In terms of toxicity, a growing number of crew are developing symptoms following both short term and long term repeated exposures to leak/smoke/fume events.[15,17]

Routes of Exposure

In any given exposure event, the magnitude of exposure will be related to the airborne form of the contaminant, as well as the concentration in air:

- inhalation of vapours, fumes, and mists and smoke is an important route of exposure;
- exposure of uncovered skin to mists and aerosols is a second, less significant route;
- ingestion seems an unlikely route of exposure.

Measures of rates of exposure remain problematic. An algorithm has been developed for estimating exposure from data available on engine oil top up rates, taking into account factors such as leak flow rate, bleed air flow, re-circulation rates, oil retention ratios, concentration of contaminants in oil, inspiratory rates, numbers of passengers, exposure duration and so forth.[18] Worst case calculations using this model indicate significant exposure to toxic contaminants.

Toxic Symptoms

Symptoms may be possible from single/short term or longer-term exposures.

Symptoms from short term exposure

Symptoms from single or short-term exposures include:

- neurotoxic symptoms: blurred or tunnel vision, nystagmus, disorientation, shaking and tremors, loss of balance and vertigo, seizures, loss of consciousness, parathesias;
- psychotoxic symptoms: memory impairment, headache, light-headedness, dizziness, confusion and feeling intoxicated;
- gastro-intestinal symptoms: nausea, vomiting;
- respiratory symptoms: cough, breathing difficulties (shortness of breath), tightness in chest, respiratory failure requiring oxygen;
- cardiovascular symptoms: increased heart rate and palpitations;
- irritation of eyes, nose and upper airways.

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17 BALOUET, J.-C. AND WINDER, C. Aerotoxic syndrome in air crew as a result of exposure to airborne contaminants in aircraft. American Society of Testing and Materials (ASTM) *Symposium on Air Quality and Comfort in Airliner Cabins*, New Orleans, USA, 27-28 October 1999.

18 Balouet, J.-C., Hoffman, H., Winder, C. Aviation and exposure to toxic chemicals. SAE *First World Aviation Congress*, Los Angeles, USA, 20-22 October 1999.

Neurotoxicity is a major flight safety concern, especially where exposures are intense.

One case which supports the problem of neurotoxicity in flight crew occurred in July 1997, when a pilot experienced difficulties (difficulty in concentration and loss of situational awareness) following the presence of strong oily odours and fumes in the cockpit while landing a plane, whereby the pilot had to hand over the plane to the first officer. This incident was subject of a report to the Bureau of Air Safety.[19] One extract of this report is: *At 3,000 ft on approach to Melbourne Airport, the pilot suffered vertigo and handed control of the aircraft to the co-pilot. At the same time a check pilot suffered from nausea. The incapacitation occurred after the crew smelt oil fumes in the cockpit air supply.* The onboard maintenance record noted that an oil smell had been reported 23 days prior to this incident, and that the repair had been noted for repair at company convenience, indicating even in 1997, the lack of importance that the airlines gave to oil fume problems. The consequences of what might have occurred if oil fumes had affected two of two pilots, rather than two of three pilots are unthinkable.

The similarity of the symptoms listed above to complaints of ill health from BAe 146 flight crews in Canada over a four-month period reported by van Netten[15] is quite striking. These symptoms include:

burning throat	48;	light-headedness	6;
headache	29;	watery eyes	6;
burning eyes	27;	gagging and coughing	3;
disorientation	17;	tingling of nose and lips	3;
nausea	9;	breathing problems requiring oxygen	2;
chest pains	7;		
dizziness	7;	numbness	2;
sinus congestion	6;	blurred vision	1.

Symptoms from long term exposure

Symptoms from long term low-level exposure or residual symptoms from exposure events include:

- neurotoxic symptoms: numbness (fingers, lips, limbs), parathesias;
- psychotoxic symptoms: memory impairment, forgetfulness, lack of co-ordination, severe headaches, dizziness, sleep disorders;
- gastro-intestinal symptoms: salivation, nausea, vomiting, diarrhoea;
- respiratory symptoms: breathing difficulties (shortness of breath), tightness in chest, respiratory failure, susceptibility to upper respiratory tract infections;
- cardiovascular symptoms: chest pain, increased heart rate and palpitations;
- skin symptoms: skin itching and rashes, skin blisters (on uncovered body parts), hair loss;

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19 BASI. *British Aerospace plc BAE 146-300 10 July 1997: Preliminary Report 9702276.* Bureau of Air Safety Inspection, 23 October 1997.

- irritation of eyes, nose and upper airways;
- sensitivity: signs of immunosupression, chemical sensitivity leading to acquired or multiple chemical sensitivity
- general: weakness and fatigue (leading to chronic fatigue), exhaustion, hot flashes, joint pain, muscle weakness and pain.

Symptom duration

It is also apparent that some symptoms occur immediately or soon after exposure, for example, many of the irritant, gastric, nervous and respiratory effects. However, others, such as nervous system impairment, immunosupression and chemical sensitivity, develop later, perhaps months after exposures may have ceased Further, while some of these symptoms are fully reversible, others appear to persist for longer. Debate is also continuing about the links between exposure and some of longer-term symptoms (such as chemical sensitivity).

Symptom severity

Symptom severity depends on a number of factors, including the range of contaminants present, the intensity, duration and frequency of exposure, toxicity of compounds (expectedly influenced by cabin environment factors such as humidity, decreased oxygen concentration and contaminants such as carbon monoxide), and individual susceptibility.

While single/long term exposure to aircraft engine lubricants and hydraulics (basically due to their chemical content and possible thermal decomposition products) is diagnosed as responsible for the reported symptoms, air crew or passengers exposed to same events or similar doses do not necessarily develop same symptom severity. The variation in symptoms severity is attributed to individual susceptibility, may also depend on other potentiation factors, including prior exposure events.

Aerotoxic Syndrome

The symptoms reported by individuals showing symptoms from exposure events are sufficiently consistent to indicate the development of a discrete occupational health condition, and the term aerotoxic syndrome is introduced to describe it.[16] Features of this syndrome are that it is associated with air crew exposure at altitude to atmospheric contaminants from engine oil or other aircraft fluids, temporally juxtaposed by the development of a consistent symptomology of irritancy, sensitivity and neurotoxicity. This syndrome may be reversible following brief exposures, but features are emerging of a chronic syndrome following significant exposures.

Other Critical Issues Related to Toxicity of Contaminants at Altitude

While there has been an impressive number of studies attempting to deal with the BAe 146 exposure event issue, none have been able to deal with all the necessary methodological requirements for an adequate study. Further, there have been a number of critical issues that some of these studies have not addressed.

The impact of altitude

A number of studies report that the concentration of oxygen at altitude remains constant, at 20.9%. This suggests that oxygen levels are unchanged. This is not true. Basically, as the plane increases in altitude, the atmospheric pressure declines. While the proportion of oxygen in air remains unchanged, the actual amount of oxygen in air declines.

Atmospheric pressure at sea level is 760 mm Hg, with the corresponding partial pressure of oxygen in air is 159 mm Hg (20.9% of 760 mm Hg). The minimum O_2 concentration for work is considered to be about 136 mm Hg (18 kPa or 18%) O_2 in air at sea level.[20] The altitude at which the partial pressure of 136 mm Hg is reached is also approximately the pressure at which aeroplane cabins are pressurised (an altitude equivalent to 2,000-2,500 m). Therefore, there is little margin of safety in people working at altitude, and in many cases, such workers may be beginning to become hypoxic (see the Figure below, where the area bounded by the dashed partial pressure of Oxygen in Air curve, and the dotted line representing the minimum physiological demand line represents the margin of safety at which workers can be considered to have sufficient oxygen to work safely.

Further, the position of the cabin pressurisation line shows that in some cases, workers at altitude may not be obtaining enough oxygen for their physiological requirements.

Other problems with lowered oxygen concentrations include changes in sensitivity to toxic exposures (for example, the toxicity of carbon monoxide is 50% higher at 8000 ft than at sea level), and the possibility that incipient hypoxia may lead to higher respiratory rates and therefore increased exposure.

Other problems with lowered oxygen concentrations include changes in sensitivity to toxic exposures (for example, the toxicity of carbon monoxide is 50% higher at 8000 ft than at sea level), and the possibility that incipient hypoxia may lead to higher respiratory rates and therefore increased exposure.

Therefore tests that simulate conditions but are carried out at ground level are unlikely to be representative of operational conditions.

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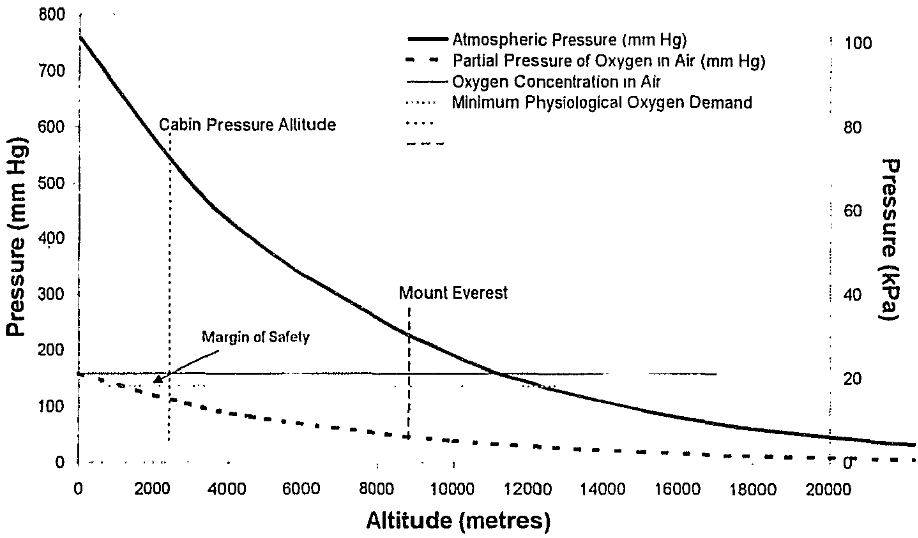
20 NOHSC. *Exposure Standards for Contaminants in the Occupational Environment* National Occupational Health and Safety Commission, Canberra, 1995.

Pressures and Oxygen Concentrations at Altitude[†]



The impact of physical properties of oil

Another critical factor is the vapour pressure of the oil. The vapour pressure for Triorthocresyl phosphate is very low, at 0.02 mm Hg at 150°C. It is unlikely to reach high concentrations in air as a vapour, and therefore unlikely to be toxic as a vapour The development of inhalational toxicity is more likely to arise from exposure to mists and aerosols. As noted above, attempts at collecting aerosol samples that coalesce on collector surface, leaving a residual vapour that is extracted for analysis, severely underestimates exposure.

CONCLUSIONS

Direct exposure to hydraulics and lubricants are known to be toxic, causing effects such as blurred vision, disorientation, memory loss, lack of co-ordination, nausea, that if they occurred in flight crew, are direct threats to flight safety. Further, cabin air contamination by engine oil and hydraulic fluids is well documented by aircraft environmental control systems engineers, either as logged incidents, or in repair/maintenance records. This provides a factual basis that flight deck, cabin crew and passengers can be directly exposed to trace chemicals on aircraft in sufficient concentrations to cause immediate to long term symptoms.

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† **Assumptions:**
Atmospheric pressure: 101 kPa (760 mm Hg) at sea level
Proportonal concentration of O_2 in air: 20.9% (21 kpa or 159 mm Hg) at sea level)
Minimum O_2 concentration for work: 135 mm Hg (18 kPa or 18%) O_2 in air at sea level (Worksafe Australia, 1995).
Aircraft Pressurisation Pressure: Equivalent to an altitude of 2500 m (about 8000 ft).

A number of recommendations, some of which have earlier been addressed by international organisations, governmental bodies, or industry (airline companies, aircraft manufacturer) have been made in response to the leak/fume/smoke events These include:

- **Design:** engine/seal design should be improved, less toxic chemicals should be used in aircraft operations, operation of ECS to be improved to more efficiently remove contaminants in normal operations and in abnormal situations.
- **Maintenance:** improved maintenance procedures should be instituted (including consideration of more intense maintenance of ageing aircraft), inappropriate maintenance and operational procedures (such as pack burn outs) should be reviewed for effectiveness or abandoned, leak/fume/smoke control procedures should be developed and implemented.
- **Incident reporting:** incident reporting systems should be developed, implemented and reviewed, especially with regard to under-reporting of incidents.
- **Procedures for leak/fume/smoke events:** Staff should be advised of appropriate action to be taken in the case of exposure events, for example:
    - the flight deck to be informed of the safety issues of smoke/fume events,
    - use of oxygen or of blankets as a respiratory filter for smoke inhalation,
    - advice on recommended medical tests (prompt check of cholinesterase/ carboxyhemoglobin levels),
    - medical treatment to include advice regarding the possibility or organophosphorus poisoning,
    - document details of exposure event including duration of exposure, reported symptoms, number of crew and passengers complaints before landing,
    - inform company management, medical and maintenance divisions of the incident and associated hazards as soon as is practicable.
- **Monitoring:** Sources of contamination in the cabin environment should be better identified and evaluated using appropriate sampling and analytical technologies[†] for contaminants of known toxicity.
- **Toxicity:** Symptoms that are reported should be documented along with other relevant factors, such as toxicity as a function of altitude, the possibility of synergistic or potentiation factors (for example, carbon monoxide, humidity, hypoxia).
- **Medical:** institute more stringent surveillance programs, illnesses in staff should be subject to closer medical surveillance, better staff counselling procedures should be developed, the possibility of an occupational source as a possible cause of symptoms should be acknowledged.

[†] Most monitoring studies use inappropriate sampling techniques (such as air collection of poorly volatile contaminants) or inadequate methodologies (such as sample collection time, sample volume, storage of samples, not taking account of altitude).

- **Inter-company:** Companies could pool data to evaluate any possible world-wide impact.

Attempts by airlines to address this problem through design, maintenance and operational improvements and through staff support and medical care have not been successful, and in the main, continue to be reactive and piecemeal.

Obviously, in some cases, options such as improving engine design are not within the sphere of activity of airline operators. However, the adversarial and acrimonious manner in which some airlines have pursued workers compensation cases brought by staff with aerotoxic syndrome indicates a confrontational approach which is unlikely to be beneficial to all parties in the long term.

These exposures can produce symptoms of toxicity. Symptoms associated with aerotoxic syndrome clearly include neurotoxicity as neuropsychological effects, as well as other symptoms typically correlated to chemical intoxication. Links between neurotoxic effects and certain contaminants known to be neurotoxic (such as the phosphate esters) are suspected.

Aerotoxic syndrome presents significant issues with regard to the health of pilots, cabin crew and passengers, but most notably with regard to air safety if pilots are incapacitated and cabin crew cannot supervise cabin evacuations during emergencies. Health effects include short term irritant, skin, gastro-intestinal, and respiratory and nervous system effects, and long term central nervous and immunological effects. Some of these effects are transient, others appear more permanent. The exacerbation of pre-existing health problems by toxic exposures is also highly probable.

This is a hidden issue. Staff of the airlines are worried about job security and what might happen to them if they complain about working conditions and make their symptoms public. At present, with only a few cases proceeding in the courts, little compensation has been awarded to airline workers affected by toxic fumes. Therefore, staff are reluctant to come forward until their health in jeopardised sufficiently that they can no longer fly without compromising their health and safety.

In workers' compensation court proceedings in Australia, one airline has admitted that exposure events are significant enough to produce irritation. Debate about other effects, and about the significance of long term sequelae continues.

APPENDIX 1: PERSONAL DETAILS OF THE AUTHOR OF THIS REPORT

My name is Christopher Winder, of 22 Peebles Avenue, Kirrawee NSW 2232. I am an Associate Professor in Chemical Safety and Head of the School of Safety Science, at the University of New South Wales. I am also Principal Consultant in Chemical Safety with AusTox CCS plc.

My qualifications are:

- a BA (Hons) Biology and Psychology from the Open University, UK (1979);
- a MSc in Neurophysiology from the City of London Polytechnic, London, UK (1981);
- a PhD in Toxicology and Pathology from the Royal Postgraduate Medical School, University of London, London, UK (1983).

I have also attended the University of Sydney/Worksafe Australia Intensive Course in Occupational Hygiene (1990).

I have held the following appointments and positions:

Senior Research Fellow	Royal Postgraduate Medical School, University of London	1979-83
Post-Doctoral Research Fellow	Cot Death Research Laboratories, University of Sydney	1983-84
Principal Toxicologist	Commonwealth Department of Health, Canberra	1984-85
Visiting Research Fellow	Australian National University, Canberra	1984-85
Director and Chief Toxicologist	Chemicals Section, Worksafe Australia, Sydney	1985-87
Senior Lecturer in Toxicology	National Institute of Occupational Health and Safety, Sydney	1987-92
Co-ordinator	Hazard Evaluation Program, Worksafe Australia, Sydney	1987-92
Senior Lecturer in Occupational Health	Department of Occupational Health, University of Sydney, Sydney	1990-95
Senior Lecturer/ Associate Professor/ Head of School	School of Safety Science, University of New South Wales, Kensington	1992-95 from 1995 from 1998
Principal Consultant in Chemical Safety	AusTox Consultants in Chemical Safety, Kirrawee	from 1992
Visiting Sabbatical Fellow	School of Biological Sciences, University of Surrey, Guilford, Surrey, UK	1999

I have written three books, twelve chapters in books, and over seventy papers, reviews and abstracts in toxicology and chemical safety.

Of particular reference to the subject of chemical sensitivity from chemicals in the workplace is the following publication:

- Winder C. Chemically related chronic fatigue syndrome. *International Journal of Occupational Medicine and Toxicology* **3**: 253-278 (1994).

- Winder C and others. *Hazard Alert: Managing Workplace Hazardous Substances.* CCH International, Sydney (1995).

My first professional involvement with exposure of workers to chemicals was in 1984-1985 as a toxicologist with the Commonwealth Department of Health in Canberra. At that time I began reading the medical and scientific literature and evaluating data on, among other things, the health effects of chemicals such as metals, solvents, pesticides, toxic gases, neurotoxicants and carcinogens.

Thereafter I continued my involvement in this area when I began working as Chief Toxicologist and Director of the Chemicals Section, Worksafe Australia (the National Occupational Health and Safety Commission). My role at this section was to direct the work of the section and to investigate the effects of chemicals on the health of workers.

I also organised and ran training courses on chemical safety for Worksafe Australia from 1988 onwards and lectured at the University of Sydney, University of New South Wales and the NSW College of Nursing since at least 1989. In addition, I have undertaken research projects and supervised doctorate and masters students undertaking research projects in a wide variety of toxicological and chemical safety topics. I continued in teaching and research in chemical safety and toxicology on my appointment to the University of New South Wales in 1992 In 1995, I was promoted from senior lecturer to associate professor, and in 1998, I was appointed Head of the School of Safety Science.

I have been reading, researching, teaching, and providing advice on the health effects of chemicals since the late 1970's.

APPENDIX 2: MOBIL JET OIL II

Common to many similar products, organic phosphate esters are being used in the manufacture of fire-resistant hydraulic fluids and lubricants There is some evidence on the neurotoxicity of jet engine lubricants containing phosphorus additives.[21] Some of this evidence is from animal studies, showing effects on adrenal, ovarian and testicular function.[22]

There are two types of organic phosphate hydraulic fluids being manufactured - phosphate ester oil blends and "pure synthetics". Mobil Jet II is presumed to be of the first type.

Mobil Jet Oil II is a synthetic oil product imported into Australia. The product is not labelled in accordance with Australian requirements under the Hazardous Substances Regulation, but probably complies by default.

The supplier's label on the cardboard box the cans are shipped in lists the following ingredients:

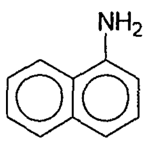
- Synthetic esters
- Phoshoric acid, tris(methylphenyl) ester (CAS No 1330-78-5)
- Benzenamine, 4-Octyl-*N*-(4-Octylphenyl) (CAS No 101-67-7)
- 1-Naphthalenamine, N-phenyl (CAS No 90-30-2)
- 1-Naphthalenamine (CAS No 134-32-7)
- 2-Naphthalenamine (CAS No 91-59-8)
- a last entry "ingredients partially unknown" is also present.

The ingredients are not listed by amount present in the formulation.

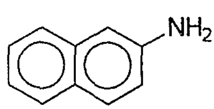
There are a number of issues relevant to these ingredients:

- 2-Naphthalenamine is better known as the established carcinogen β-Naphthylamine or 2-Naphthylamine (similarly 1-Naphthalenamine is better known as α-Naphthylamine or 1-Naphthylamine);

  The Naphthylamines



1-Naphthylamine



2-Naphthylamine

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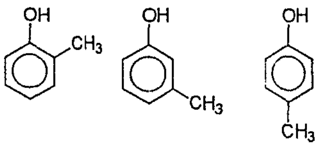
[21] CENTERS, P.W. Potential neurotoxin formation in thermally degraded synthetic ester turbine lubricants. *Archives of Toxicology* **66:** 679-680, 1992.

[22] LATENDRESSE, J.R., BROOKS, C.L AND CAPEN, C.C. Pathologic effects of butylated triphenyl phosphate-based hydraulic fluid and tricresyl phosphate on the adrenal gland, ovary and testis in the Fisher-344 rat. *Toxicologic Pathology* **22:** 341-352, 1994.

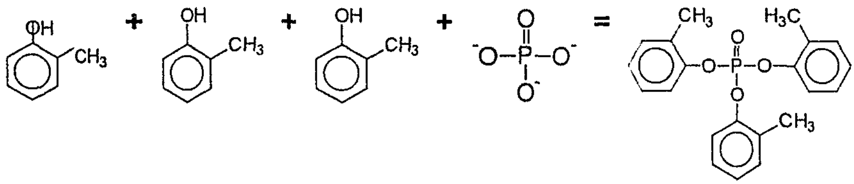
- 2-Naphthalenamine (CAS No 91-59-8) is not listed on the 1992 Australian inventory of Chemical Substances (AICS), and dependent on the amount present in the formulated product, could technically breach the requirements of the Commonwealth Industrial Chemicals (Notification and Assessment) Act 1989. However, the Mobil material safety data bulletin for this product notes that "all components in this product comply with AICS";
- Phoshoric acid, tris(methylphenyl) ester (CAS No 1330-78-5) is better known as Tricresyl phosphate (TCP) or Tritolyl phosphate. This is a chemical, which formed from the cresols (an aromatic group of compounds), combined with a phosphate group, making an organophosphate molecule:

  The Cresols



  o-Cresol p-Cresol m-Cresol

  The Chemical Makeup of Tri-ortho-Cresyl phosphate (TOCP)



  o-Cresol o-Cresol o-Cresol phosphate Triorthocresyl phosphate

  Generally, tricresyl phosphate (TCP) normally comprises a mixture of unspecified o- p- and m-cresyl groups, of which Tri-orthocresyl phosphate (CAS No 78-30-8, TOCP) is highly toxic, causing irreversible nerve damage. However, the toxic potential of the other isomers in Tricresyl phosphate should not be ignored;
- the reasons for inclusion of three Naphthylamine based ingredients in this product seem obscure. However inclusion of 2-Naphthylamine as an ingredient in this product seems unnecessary. The presence of Tricresyl phosphate is for its property as a lubricant and flame retardant. However, inclusion of a chemical which contains TOCP as a contaminant (Tricresyl phosphate) also seems unnecessary.

The Classification of Jet Oil II as a Hazardous Substance

In Australia, classification of materials as being hazardous substances under the Hazardous Substances Regulation use a list of hazardous substances[23] and approved criteria,[24] with reference to the list being the primary step.

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23 NOHSC. *List of Designated Hazardous Substances*. National Occupational Health and Safety Commission, Canberra, 1994.

24 NOHSC. *Approved Criteria for Classification of Hazardous Substances*. National Occupational Health and Safety Commission, Canberra, 1994.

- these processes classify as hazardous substances –
  - → 2-Naphthylamine (a NOHSC Category 1 carcinogen),
  - → Tricresyl phosphates, and
  - → Triorthocresyl phosphate (as Tritolyl phosphate, for its neurotoxic effects),
- it should be noted that classification for hazardous substances for the Tricresyl phosphates also have entries for "Tricresyl phosphates containing less than 1% o-cresol" and "Tricresyl phosphates containing more than 1% o-cresol". o-Cresol is a separate compound from tri-orthocresyl phosphate. An incorrect assumption is made in applying these two entries in the classification of Tricresyl phosphates because it is assumed that the term "containing less (or more) that o-cresol" means "containing less (or more) than tri-orthocresyl phosphate". As the amount of o-Cresol in Mobil Jet II is not known, these two entries cannot be used in the hazard classification process, and must not be used in classifying on the basis of tri-orthocresyl phosphate.
- the Hazardous Substances Regulation also classifies formulated products as hazardous substances if they contain hazardous ingredients above cut off values recommended by Worksafe Australia. For 2-Naphthylamine, the value is 0.01%; for Triorthocresyl phosphate the value is between 0.2% and 1%, for classification as "Harmful" and above 1% for classification as "Toxic". Formulated products containing at least these amounts are classified as hazardous substances which then fall into the requirements of the regulation.
- the proportion of ingredients listed as "ingredients partially unknown" is not known.

It is critical to note that the issue of the classification of Jet Oil II as a hazardous substance in Australia requires specific and nonequivocal information about identity of ingredients and amounts present in the formulated product (neither of which is easily available).

It should also be noted that cases of exposure on the BAe 146 still continue, with at least one exposure event in 1999.

The Material Safety Data Bulletin (MSDB)

The material safety data bulletin (MSDB) for Mobil Jet Oil II is issued by Mobil Australia, but is based on that issued by the US parent company, in Princeton, New Jersey, with some minor amendments added locally for Australian requirements. As such, it is written to the US MSDS requirements and not those required in Australia under the hazardous substances regulation. However, it is possible that the information in this document satisfies Australian requirements, again by default.

A range of MSDB have been released over the past decade, with various versions being issued either in the USA or Australia in 1988, 1992, 1994, 1997 and 1998. The information is these versions have varied substantially, and in some cases, has been inconsistent from version to version.

In each version, the MSDB has made the point that the chemical is "safe under normal conditions of use" but does not provides an opinion of safety under conditions that are not normal. The MSDB further recommends the use of respiratory protection in exposures and cholinesterase monitoring for cases of overexposure.

The 1998 MSDB classifies Jet Oil II as being non-hazardous in Australia. This entry is incorrect. This MSDB contains an entry which identifies a specific ingredient by name and CAS Number, and by amount present, as:

CAS No 1330-78-5	Tritolyl phosphate	1-5%

This exceeds the cut-off concentration for this ingredient (of 1%) stipulated in the Designated List of Hazardous Substances for classification as "Toxic" (and hazardous).

The Label

As a result of this incorrect hazard classification, the MSDB also includes incorrect risk and safety phrases:

R40	Possible risk of irreversible effects.
R20/R21/R22	Harmful by inhalation, in contact with skin and if swallowed.

A product containing more than 1% Tritolyl phosphate should contain the risk phrases:

R39	Danger of very serious irreversible effects.
R23/R24/R25	Toxic by inhalation, in contact with skin and if swallowed.

These are significant differences, and serve to show that users of Mobil Jet II may be unaware of the significance of the material they are using, and serve to illustrate why staff in the Airlines continue to be misinformed about the hazard of this material. Other parts of the MSDS, such as "This product is not expected to produce ... effects under normal conditions of use and appropriate personal hygiene practices" perpetuates the notion that Mobil Jet Oil II is not a harmful material.

Further, these risk phrases are not specific inclusions on the label, as required by the hazardous substances legislation in Australia.

The label for the pre-1998 container contained the following risk and safety phrases

Caution: Avoid spilling on insulation. plastic, rubber or paint

> *Warning! Contains Tricresyl Phosphate.*
> *Produces paralysis if taken internally.*
> *Do not use as medicine or food product.*
> *Wash thoroughly after handling.*

The label for the post-1998 container contained the following risk and safety phrases:

Avoid spilling on insulation. plastic, rubber or paint

WARNING!

Contains Tricresyl Phosphate.

Swallowing this product can cause nervous system disorders, including paralysis

Prolonged or repeated breathing of oil mist, or prolonged or repeated skin contact can cause nervous system defects.

PRECAUTIONS:

Never swallow. Wash hands after handling and before eating. Never use in or around food. Avoid prolonged or repeated overexposure to skin or lungs.

FIRST AID:

If swallowed, seek immediate medical attention. If medical attention is delayed, induce vomiting. In case of contact, wash skin with soap and water. Remove contaminated clothing.

FOR INDUSTRIAL USE ONLY

Not intended or suitable for use in or around a household or dwelling. Never use empty container to carry water or food. Do not cut or weld on empty container.

(In thirteen languages) *When using do not eat, drink or smoke. After contact with skin, was immediately with plenty of soap and water.*

The change in warning information in the two labels is quite significant. While the general meaning of R39 may be covered by the specific risk statements on the post 1998 label above, the classification of "Toxic" (R23/24/25) is absent. Indeed, in the European Community, the toxic classification is required to be accompanied by a pictogram of the skull and crossbones (not mandatory in Australia).

No reason was given to maintenance workers handling Mobil Jet II for the new label when it was introduced in 1998.

Discussions between the National Occupational Health and Safety Commission and Mobil Australia about labelling and MSDS issues were initiated in 1999.

APPENDIX 3: HOW LONG HAVE THE AIRLINES KNOWN ABOUT THE PROBLEM OF EXPOSURE EVENTS ON THE BAE 146?

Documentation, some of it confidential, has been provided to the author indicating that the airlines in Australia were aware of the problem of exposure events on the BAe 146 from at least 1991. The likelihood that other documentation exists is highly probable:

- A 10 July 1991 letter written by Mr RW Sands, Services Support Manager, British Aerospace, to Mr J Nicholson, Engineering Manager, East West Airlines, provides an update on the BAe 146 APU smell problem. This letter also notes that problems are reported in another airline, Dan-Air.
- A July 1991 letter written by Mobil Australia notes that Mobil Jet Oil II does not pose a problem in normal use, a position taken in virtually all subsequent correspondence. The application of this phrase in unusual working conditions seems dubious: a seal leak could hardly be considered a "normal use". Further, a pack burn out would not be considered a "normal use".
- A 22 July 1991 report prepared by Richard Fox of Allied Signal Aerospace reports the results of air quality testing for Dan-Air London (see above). Here is a report of odour problems of another airline flying the BAe 146.
- A 3 July 1992 circular to all LAMEs employed at Ansett written by Chris Ryan of the Australian Licenced Aircraft Engineers Association makes a number of important points:
    - "The Association is concerned at the potential health and safety risks involved in carrying out pack burn-outs on the air-conditioning systems on the BAe 146 aircraft";
    - the circular advises that members should utilise on board oxygen "during the phases of the pack burn outs when vapour/mist is produced";
- A 7 August 1992 circular written by Mr Ken Crawford, Assistant General Manager, EastWest Airlines makes a number of important points:
    - "The issue of odour on the BAe 146-300 series is of course a world-wide problem with similar occurrence in other airlines operating this type and series aircraft." This is a clear admission that EastWest knew about this problem from at least that time;
    - "the results of four independent overseas research reports into cabin odours and our own air sampling conducted on EastWest aircraft by Dr Vasak" indicates significant activity investigating this problem. These reports have not been made available to those workers who are exposed to cabin odours;
    - "major equipment modification and operating procedural changes have been made to the APUs and air conditioning systems", and the availability in November [1992] of totally new prototype air filtration units" indicate that changes in the planes were made in an attempt to deal with this problem;

- an intense occurrence of odour in a flight from Sydney resulted from a seal failure.

- A 16 May 1992 letter written by Mr Vladimir Vasak, occupational hygienist with Qantas, Sydney, advises that personnel exposed to oil fumes should be sent for cholinesterase monitoring.

- In a later circular (18 August 1992) Mr Crawford notes:
  - the development of the new filtration unit was running to schedule;
  - that the first units would be available in November 1992; and
  - that the Mr Alan Harrison (General Manager - Technical, Ansett Australia) and John Playford (of the FAAA) were departing to the UK for discussions about the new filtration unit.

- In flight health surveys throughout 1992 reported problems of odours in flight. In some cases, these report passengers and flight attendants vomiting, and flight attendants with visible signs of sickness (such as sore eyes, bad heart palpitations, headaches, fatigue, and nausea).

- Ansett were aware of monitoring results in other airlines and then their own commissioned monitoring from 1992.

- Ansett were also aware that new filtration systems which could reduce odours were available in 1992, however, the urgency in which Ansett Australia gave to this matter could hardly be considered speedy. A 14 July 1995 circular from Ms Jennifer Shepperd, National Manager Flight Attendants, Ansett Australia to Cairns and Perth Crews notes:
  - "JJJ is at present in the hangar having major work on the engines and will be back on line with new filtration units". This was nearly three years after the initial circular, and two and a half years when the filtration units were said to be available;
  - "air testing will continue to plan and the results analysed". Again the results of this testing has not been made available.

- An incident occurred in 1994, where three flight attendants became quite ill (all three eventually gave up flying).

- A 28 March 1996 internal memo from Mr P Symons to Mr S Murphy (both at Allied Signal) prepares a message for the Ansett Cabin Odour Study, noting out of 77 flights in and out of Cairns over seventeen months (from November 1994 to March 1996) there were 49 flights on which fumes and/or smells were reported, and 42 flights on which crew reported sickness.

- Ansett formed a BAe 146 Odour Enquiry Committee from at least 1996. As part of the process of obtaining information about fume incidents, a fume report form was generated. Ansett BAe 146 Fume Occurrence Report Forms from 24 March 1996 to 11 February 1998 indicate:
  - they were submitted from fifteen BAe 146 aircraft - JJ# aircraft are BAe 146 200 series and EW# are BAe 146 300 series aircraft operating in Australia,
  - 92 reports were submitted from 68 cabin crew, 10 flight crew and 5 passengers at a rate of about 17-19 a month,

- 59 reports were about odour problems and 77 reports noted symptoms,

Plane ID	Odour	Symptoms	Comments
EWI	3	5	"Crew felt dizzy by end of 4th leg"
EWM	4	11	"Cabin filled with smoke on pushback. Controlled evacuation"
EWR	3	7	"dizzy on descent"
EWS	5	21	Captain on 0_2 a/c grounded
JJI	4	2	
JJK	1	0	
JJP	8	8	
JJQ	6	4	
JJS	6	3	
JJT	9	7	
JJU	4	1	
JJW	4	7	"Purser still off flying"
JJY	1	0	
Unidentified (or EW or JJ)	1	3	

- while the significance of these reports can be debated, the number of reports indicates a serious and persisting problem, and some of these reports (captain on O_2 while landing, crew reporting dizziness and evacuation when cabin filled with smoke on pushback) can be regarded as highly significant in terms of health and/or safety;

Throughout this period, Ansett Engine Defect Reports note -

- "oil in cabin"
- "smoke in cabin"
- "cabin filled with smoke"
- "oil smell in cabin"

Defect reports also not the possible cause of such problems as -

- "flattened no 2 bearing package gaskets"
- "blow out of thermocouple gasket"
- "external surfaces of APU were very dirty indicating a hot gas leak"
- "evidence of oil leakage in seal housing, the seal carbon was not damaged or cracked, however when the seal was pushed into the housing it tended to stick, causing the carbon seal to 'hang' in the housing"
- "leaking front compressor bearing oil possibly due to stiction",
- "Oil smell/smoke in the cabin is a well documented defect"

A 26 March 1996 circular from Ms Jennifer Shepperd, National Manager Flight Attendants, Ansett Australia notes "extensive air sampling, testing and analysis were undertaken over a long period of time by an independent consultant and the NSW WorkCover Authority." A 12 January 1998 letter from Mr Graham Saunders, Co-ordinator Chemical Safety Unit, NSW WorkCover to Mr L Cox of the AFAP notes "A number of years ago we carried out sampling for oil mist in this model aircraft but found only a low levels of

contamination. The testing was not carried out in flight and the comment was made at the time that the contamination is spasmodic so the results of our testing may not necessarily be representative of actual situations". This suggests that its authors did not share Ms Shepperd's belief in the results of such monitoring.

- In 11 April 1997, a letter from Mr PO Clark of Mobil to Mr Trevor Jensen, General manager, Operations at Ansett Australia provides advice that Mobil Jet Oil II is not toxic under normal conditions of use. A similar letter was sent to Barry Lodge at National Jet Systems, the other airline using BAe 146 aircraft on 25 August 1997.

- In April 1997, a Brisbane crew walked off a BAe 146 after suffering extreme nausea and vomiting.

- An April 1997 Mobil customer service Request Internal Report from Mr Martin Webb (EH&S Manager) notes "a problem may emerge with Mobil Jet II with Ansett as a confidential air safety report has been submitted to BASI and there is the potential of the FA union to blackban the aircraft".

- An April 1997 Aviation Medicine Advisory Circular (No 47), prepared by Dr Dai Lewis, Medical Director, Occupational Health Department, Ansett Australia also discusses BAe 146 Cockpit Odours. This circular notes that two, possibly three, BAe 146 Technical Crew, have experienced the symptom of vertigo. The loss of ability to fly an aeroplane because of symptoms which can influence ability during flying is a serious safety issue and an advisory of this nature seems appropriate. However, rather than explore the issue in some depth, the advisory discusses clinical causes of vertigo, and indicates that there is no known toxicological agent that produces vertigo. However, the circular ignores symptoms other than vertigo, and the possible safety implications of pilots affected by fumes.

- In April 1997, Ansett Engineering revised the instructions for air conditioning pack burn outs. These new procedures:

  - had to be carried out after the last flight of the day or at least one and a half hours before crews attended aircraft for the first flight of the day,
  - had to be carried out every day;
  - no person was allowed to be on board during the procedure except the person carrying out the task (usually the pilot);
  - all doors and cockpit windows were to be kept open (except the front passenger door leading to the air terminal if the plane was parked at an aerobridge);
  - the procedure was to be continued if an oil smell was detected;
  - the procedure had to be recorded in the maintenance log;
  - signoff time was fifteen minutes after completion of pack burnout.

  This suggests that previous pack burn out procedures were considered problematic.

- A 15 April 1997 Circular to all pilots from Captain Trevor Jensen, General Manager - Operations, Ansett Australia notes "Queensland Department of Health have an air sample machine that may be able to assist in the

identification of the odours and officers of that Department will be flying with us over the next few days with a view to taking air samples" (see above);

- In August 1997, Ansett and National Jet Systems agree to share information relating to the oil mist problem;

- Ansett Flight Attendants Department began issuing a BAe 146 Updates. Update No 7 (November 1997) notes that "the procedure of a daily pack burn will cease from Wednesday 24 December 1997." The update also notes that pack burn outs will continue to be carry out, "when an odour is reported" but only "in conjunction with changing the air conditioning filters";

- Ansett Australia convened an "Expert Panel of Specialists for the BAe 146 Odour Occurrences". The panel reviewed information supplied by Ansett (including the studies outlined above). On the 25 March 1998, this panel prepared a draft "Consensus Statement" which states, among other things:

    - "The panel ... is of the opinion that the air conditioning contaminants at the levels detected for both in flight and the worst case scenario of 'pack burn-offs' will not cause long them health effects";
    - "The panel accepts that the short term symptoms associated with odours that have been reported on the BAe 146 and other types are substantiated. These have generally been linked with inadequate ventilation and with aircraft system defects";
    - "Contaminant levels were found to be well below internationally accepted occupational health standards";

  The status of the draft consensus statement remains unclear, and it is not known if it has been finalised, and apparently has not been signed by all parties. However, the draft consensus statement:

    - notes the presence of symptoms of exposure in Ansett BAe 146 crew at measured exposures within recommended exposure standards;
    - ignores the evidence of the development of long term health effects from exposed individuals such as Flight attendants Ms Leanne Chew and Ms Judy Cullinane and pilots such as Ms Leanne Harper with chronic symptoms and development of chemical sensitivity;
    - ignores aspects of dose response and the definition of exposure standard (see Appendix 4) and exposures to mixtures of chemicals (Appendix 5) and makes assertions about "internationally accepted occupational health standards" that not even a government agency such as the National Occupational Health and Safety Commission support;
    - contains a statement of absolute certainty that the panel considers that exposure events have occurred, and that the cause of these events was problems with the BAe 146;

- A 16 April 1998 operational notice written by Kingsley Hughes, Chief Pilot BAe 146, Ansett Australia, outlines recommended practices for engine/APU selection during flights and suggests that if there is an incident of odour or fumes, that pilots experiment with engine/APU configuration not to reduce the intensity of exposure, but to find the source of contamination - "should an

aircraft develop a Cabin Odour or Fumes incidence, endeavour to vary the switching order in an endeavour to localise the source." A similar operational notice was made to National Jet pilots in August 1997.

- In November 1998, a new directive regarding medical examinations of staff affected by fumes was issued by Dr Dai Lewis.
- On 27 January 1999, after another oil fumes incident in Cairns, a Safety Bulletin was issued by Mr Pieter Rienks, General Manager of the Safety Department of Ansett Australia, noting that "Ansett Engineering, in conjunction with the manufacturer, will accelerate a preventive maintenance program to substantially reduce the incidence of oil leaks." Even seven years after Ansett became aware of the problem with oil fumes and mists in the BAe 146, documentation is available to suggest that a preventive maintenance program was not yet suitable that its introduction had to be accelerated.

SUBMISSION TO THE SENATE REFERENCES COMMITTEE
RURAL AND REGIONAL AFFAIRS AND TRANSPORT

ON THE INQUIRY INTO

AIR SAFETY - BAE 146
CABIN AIR QUALITY

SUBMISSION NUMBER 7

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GCAT

GENETIC CONSULTING AND TESTING

Consistently going further to reveal the hidden evidence

2-Aug-99

The Secretary,
Senate Rural & Regional Affairs & Transport References Committee,
SG.62
Parliament House,
Canberra ACT 2600

Dear Mr. Snedden,

I am accepting the invitation to make a submission in regard to the "Inquiry into Airspace 2000 and other related issues".

My comments relate solely to part (d) the examination of air safety, with particular reference to cabin air quality in BAE-146 aircraft.

Thank you for offering me this opportunity.

Dr. Judith Ford
CEO & Chief Scientist
Genetic Consulting & Testing

Genetic Consulting and Testing Pty Ltd ACN 067 111237 **Postal Address** Box 210 Port Adelaide South Australia 5015
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GCAT
GENETIC CONSULTING AND TESTING

Consistently going further to reveal the hidden evidence

INQUIRY INTO AIRSPACE 2000 –
(D) CABIN AIR QUALITY IN BEA-146 AIRCRAFT

My name:	Judith Helen Ford
Qualifications:	BSc with first class Honours in Genetics, University of Sydney, 1967 Ph.D in Genetics, University of Sydney, 1971 HGSACC (Certified Cytogeneticist, Human Genetics Society of Australasia, 1964
My Company:	Genetic Consulting & Testing (GCAT) Pty Ltd. Accredited Pathology Authority, Accredited Pathology Laboratory (under Medicare Act), NATA accredited.

Interest in this Inquiry:

Background:

GCAT frequently performs chromosomal tests on the blood of persons who are suffering from a range of debilitating illnesses whose onset have been attributed to one of more exposures to a genotoxic agent.

Genotoxic agents are commonly radiations or chemicals that are known to alter DNA (mutagens), break chromosomes (clastogens) or cause disturbances of cell division leading to changes in chromosome number (aneuploidogens).

There is considerable literature identifying certain substances as genotoxins. There is also a significant body of knowledge that links chromosomal changes to cancers, congenital abnormalities, miscarriage and infertility. It is well established that chromosome abnormalities can survive in lymphocytes many decades after the exposure to the genotoxic agent.

It is also well recognised that individuals differ in their ability to withstand exposure to genotoxic agents. This difference is largely genetic but is influenced by diet.

We have recently published a manuscript entitled "*Sporadic chromosome abnormalities in human lymphocytes and previous exposure to chemicals", Cytobios 96: 179-192, 1998*

In this manuscript we establish that "detection of 0.38% or more, structural abnormalities (of chromosomes) was 27.2 times more likely in exposed persons than in controls. The finding of a single autosomal trisomy (a gain of a chromosome other than an X or Y chromosome) was 14.4 times more likely in exposed persons". Trisomy of the X chromosome (one extra X chromosomes in one or more cells) was 5.06 times more likely in exposed women, aged 31 or older than in non exposed women, despite the fact that sex chromosome aneuploidy increases with age in all women.

To our knowledge there is no other human cytogenetics laboratory in Australia that has demonstrated any knowledge or expertise in the area of mutagenesis. By comparison, my own interest in mutagenesis, especially in aneuploidy, is internationally recognised.

Our Investigations:

Studies on Cabin Crew and Pilots from BAE-146

Specimens of blood were received by GCAT from persons identified as Susan Michaelis, Leanne Harper, Lesley Williams, Judy Cullinane and Robyn May. The details of the referrals and the results are given in the following Table.

GCAT

GENETIC CONSULTING AND TESTING

Consistently going further to reveal the hidden evidence

Lab No.	Name	Date of Referral	Clinical Notes	Result
G2718	Michaelis, Susan	01/09/97	BAE 146-100 & 200 chemical exposure	50 cells analysed; 49 were normal 46,XX, 1 was abnormal 46,XX,der(1). In one cell there was a structural abnormality involving one chromosome 1.
G2947	Harper, Leanne	03/11/97	Exposure to solvents and VOCs as well as tricresyl phosphate, and who is now suffering from multiple chemical sensitivity and gut related disorders	50 cells analysed; 50 were normal 46,XX.
G3220	Williams, Lesley	06/02/98	Toxic exposure (then illegible)	50 cells analysed; 50 were normal 46,XX.
G3436	Cullinane, Judy	09/04/98	Exposure as flight attendant on BAE 146	50 cells analysed; 48 were normal 46,XX, 2 were abnormal, one was 46,XX,del(4)(p11) and one was a complex aneuploid, 47,X,+4,+8,-10,+12.

Genetic Consulting and Testing Pty Ltd ACN 067 111237 **Postal Address** Box 210 Port Adelaide South Australia 5015
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				Part of this blood sample was sent to a Perth laboratory. They also performed cytogenetic analysis and analysed 50 cells. They found 49 were normal 46,XX and one had a structural abnormality involving chromosomes 12 and 18, 46,XX,t(12;18)(p12.2;q23)
G4736	May, Robyn	02/06/99	Previously pilot on BAE 146 off sick from September 1994 with unexplained chest pain and nausea and vertigo.	50 cells analysed. 46 cells were normal 46,XX. One cell was 45,X and 3 cells had an extra X chromosome and each was 47,XXX.

Our Interpretation:

If each of these persons had been referred separately, we would have concluded that both Michaelis and Cullinane had evidence of significant exposure to clastogenic and/or aneuploidogenic chemicals. We would have concluded that May had results compatible with accelerated ageing that might be due to chemical exposure.

The finding of notable disturbances in three people from the same environment is compelling evidence that there was significant toxic exposure.

The absence of findings in the other two persons could be explained either by sampling error (we did not happen to detect abnormal cells because of the relatively small number of cells sampled) or that the two people did not have chromosome abnormalities. In our experience of repeat analyses (see Cullinane's results as an example), these results are most likely to mean that these two people do not have chromosome abnormalities. The finding of chromosome abnormalities is influenced by three factors. (1) The exposure (2) The person's genetic make-up and (3) The person's diet at the time of exposure; some foods are known to be protective.

Our Conclusions:

The chromosomes analyses performed on these 5 persons show evidence of exposure to significant levels of chemical toxins, sufficient to cause grave, short and long term health consequences.

SUBMISSION TO THE SENATE REFERENCES COMMITTEE
RURAL AND REGIONAL AFFAIRS AND TRANSPORT

ON THE INQUIRY INTO

AIR SAFETY - BAE 146
CABIN AIR QUALITY

SUBMISSION NUMBER 8

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August 17, 1999.

The Secretary
Senate Rural and Regional Affairs and
Transport References Committee
S.G.6Z Parliament House
CANBERRA ACT 2600

Dear Sir/Madam

I have been asked, by a variety of sources, to make a submission to the "Inquiry into Airspace 2000 and Related Issues" .

As my expertise and experience is related to the operation of the BAe-146 aircraft, my submission will deal with item (d) of the list of matters to be investigated by the committee i.e. "The examination of air safety, with particular reference to cabin air quality in BAe-146 aircraft."

My submission is based on 5 scientific articles (attached) that I have authored, 3 of which have already been peer reviewed and have been published, 2 articles are currently under review for publication. The last two are stamped confidential and cannot be released until these have been accepted for publication.

My observations, concerns, and conclusions are clearly identified in these articles and can be summarized as follows:

The engines used by the BAe-146 aircraft appear to have an inherent problem with leaking oils seals, specifically in the compressor section of the engine at bearing locations 1 and 9.

Bleed air, used for pressurization of the aircraft, from the compressor stage of the engine can become contaminated with engine oil constituents. The temperature of the bleed air can be in excess of 500° Celsius. At this temperature any oil constituents will pyrolize resulting in smoke formation. The presence of smoke in the cabin has been well documented in these aircraft.

The constituents of the oil at normal temperatures and at elevated temperatures (in excess of 500°C) are not fully disclosed by the manufacturer for the former and are not known for the latter.

My research indicates that all engine oils tested to-date contain, among many other compounds, tricresyl phosphate (TCP) isomers. Tricresyl phosphates have been associated with neurotoxic properties. The American matrial safety data sheets (MSDSs) do identify TCP isomers as a constituent whereas the Australian MSDS i. e. for Mobil jet oil II, for instance, does not specify these as constituents.

Pyrolized oils release a large number of constituents into the air including TCP isomers. It has been argued that these compounds have low volatility i.e. they do not evaporate readily and likely would condense out when cooler surfaces are encountered such as throughout the aircraft ventilation system, making the exposure unlikely. My laboratory research indicates that these compounds are found in the air at room temperature. A possible explanation is that these isomers condense out on smoke particles which travel through the air allowing exposure to occur at normal cabin temperatures. To date no actual inflight data during incidents of smoke in the cabin have either identified or eliminated the presence of TCP isomers.

Pyrolysis of these jet engine oils under laboratory conditions also will release substantial amounts of carbon monoxide (CO). Some of the symptoms reported by flight crews experienced during an in flight incident appear to be consistent with CO exposure. Again the presence of CO during an in-flight incident has not been clearly confirmed or eliminated. As CO exposure can have acute effects on flight crew performance with potential serious consequences, monitoring for this agent on an on-going basis is a priority until enough in-flight incidents have been captured to either eliminate or identify this agent as a problem.

As noted in my papers I have also investigated the constituents of hydraulic fluids used in aircraft. Under certain conditions hydraulic fluid can enter the ventilation system through a number of ways including the auxiliary power unit (APU) and expose flight crew and passengers to their components. Although pyrolized hydraulic fluids do not appear to be as great a source of CO, they are a source of air contamination and their constituents are likely to gain access to cabin air directly or through their association with smoke particles similar to engine oils. Again this potential route of exposure needs further experimental clarification during actual in-flight conditions.

If further clarification of this submission is required, or if I can be of assitance to the inquiry, do not hesitate to contact me.

Yours sincerely

C. van Netten, MSc, PhD,
Associate Professor and Head
Division of Occupational and
Environmental Health.

Air Quality and Health Effects Associated with the Operation of BAe 146-200 Aircraft

Christiaan van Netten

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Poor air quality and health complaints from flight crews operating BAe-146 aircraft, requiring admission to emergency departments on several occasions, led to an investigation into the source of these problems. Health complaints could be classified as those consistent with exposure to carbon monoxide, respiratory irritants, and possible neurological agents. Cabin air is bled off from the engine's combustion air, passes through a catalytic converter to clean the air from oil contaminants, is cooled from 550° to 50°C, and enters the cabin after it passes through an airpack unit which conditions the air as appropriate. Excessive oil leakage from oil seals overloaded the catalytic converter, allowing smoke and lubricating oil components to enter the cabin. A complaint aircraft air, during a test flight, was found to contain oil contaminants including siloxane lubricating oils, as well as methylated propane and butane ester derivatives. Tricresyl phosphates, known to be neurotoxic, were identified in bulk oil samples, but could not be demonstrated in the cabin air. Air quality measurements in a problem aircraft tested on the tarmac indicated carbon monoxide at 3 ppm and carbon dioxide at 900 ppm. Air quality measurements during normal commercial flights of three noncomplaint aircraft (two BAe-146s and one de Haviland Dash 8-100) showed no detectable levels of carbon monoxide, 800 to 2700 ppm for carbon dioxide, and 19.6 to 21.9 percent for oxygen. Carbon dioxide and oxygen levels would change predictably during takeoff and landing for the former and pressurization and depressurization for the latter. Carboxyhemoglobin levels in four individuals admitted to emergency departments ranged from 0.7 to 2.0 percent. Since no direct carbon monoxide measurements were available during these incidents, it was recommended that potential problem aircraft be equipped with datalogging carbon monoxide monitors to identify or eliminate carbon monoxide exposure as a problem. VAN NETTEN, C.: AIR QUALITY AND HEALTH EFFECTS ASSOCIATED WITH THE OPERATION OF BAE 146-200 AIRCRAFT. APPL OCCUP ENVIRON. HYG. 13(10):733–739; 1998 © 1998 AIH.

Complaints of ill health from flight crews operating the British Aerospace BAe-146 series aircraft, followed by threats of a walkout, initiated an investigation into the complaints and the history and operation of these aircraft.

The aircraft was conceived in 1973 and designed for short-range transport. In 1981 it was test flown and acquired the name "the quiet trader" as a reflection of the quiet operation of its four turbofan engines.[1] At the end of 1993 a total of 217 BAe 146 aircraft were in use worldwide. Of these, 193 were being operated by 59 different airlines; 19 by manufacturers, brokers, and leasing companies; 4 by a number of governments; and 1 by a private operator.[2] The majority of these aircraft (199) are propelled with four Textron Lycoming turbojet engines (ALF 502R5). These engines are not used in any other aircraft. A total of 18 aircraft are outfitted with the LF507 engines, but none of these are operating in Canada.

As with other aircraft, the ventilation and heating system is dependent on the engines for the in-flight cabin air, which is bled off from the compressed combustion air just prior to the combustion chamber at location E in Figure 1. At this point the temperature of the air is in excess of 500°C and normally contains minor contaminants from the upstream engine lubrication system. For this reason the BAe-146 aircraft also makes use of catalytic converters, situated on the engines, which are responsible for converting any oil contaminant in the air destined for the cabin to carbon dioxide, water, and nitrogen. The air then passes through a heat exchanger, located in the engine pylons, which cools the air to around 200°C before it is ducted through the spine of the aircraft to the rear into an airpack unit. There are separate airpack units for the right and left sides of the aircraft. The airpack units condition the air before it is ducted into the cabin at temperatures between 50° and 60°C, depending on requirements. Engine air is also used to control the pressure within the aircraft.

In addition, there is an auxiliary power unit (APU; Allied Signal 36-100 or 36-150) situated in the tail section of the aircraft, which is also jet powered and provides electrical power to the aircraft when operating on the ground. On the ground and during takeoff, when combustion air cannot be spared from the engines, the APU is also responsible for the cabin air. Under these conditions cabin air can become contaminated from external sources such as engine exhaust when the APU is operating when taxiing at the airport or while waiting in line for takeoff behind other aircraft.

Under normal conditions, when the ventilation system is switched on, there usually is a momentary smell that disappears within seconds and which is consistent with the operation of most air ventilation systems. The flight deck has control over the cabin air and can choose which airpack to use and whether to use 100 percent fresh air or recirculated air. The latter is generally a mix of 40 percent recirculated and 60 percent fresh air.

In the past there have been sporadic complaints from flight crews of some BAe-146 aircraft operating in Canada regarding poor air quality. Although a nonsmoking policy has been in place for several years, the number of complaints has increased dramatically since January 1996 and appears to be coincident with the aircraft company switching the aircraft jet engine oil

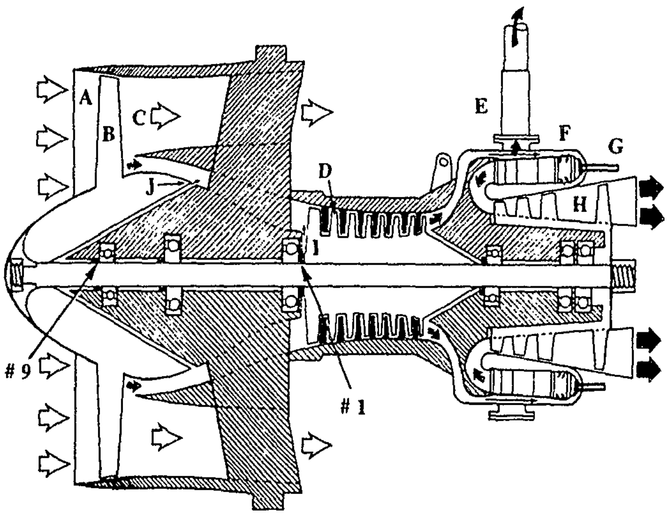

FIGURE 1. Simplified diagram of the turbo ALF 502R5 turbojet engine showing the general location of bearings 1 and 9 and the source of cabin air contamination due to leaking oil seals. (Adapted from Textron Lycoming, ALF 502, Student Workbook, pp. 1–8, Engine Bearing Locations.) Air enters the engine at location A and is compressed by the turbofan (B), allowing most of the air to bypass the rear section of the engine at C. Some air is funneled into the engine and is further compressed by the compressor blades at D. Some air is diverted into the catalytic convertor (E) before it is directed toward the cabin. Highly compressed air is forced into the combustion chamber (F), where it is mixed with fuel from the fuel supply (G) and is combusted. High pressure exhaust gases exit the engine, passing the turbine blades at H, driving the engine. Improper seals at the locations of bearings 1 and 9 allow oil constituents to enter the combustion air at I and J, respectively, contaminating the air destined for the cabin.

from Exxon 2380 to Castrol 5000. Since then, the air quality complaints have been traced to leaky oil seals associated with bearings 1 and 9 of the jet engines (Figure 1). Once the source of air contaminants was known, a rigorous daily inspection regime was initiated, followed by immediate replacement of the oil seals if this was indicated. This approach prevented some, but not all, exposures. Although there were health complaints prior to the oil switching, the complaints appeared to be more numerous after this had taken place, and a variety of symptoms have been reported ranging from itchy, red eyes to flight attendants requiring oxygen during flight followed by admission to the local emergency department at the port of arrival. The complaints appeared to be more frequent among flight attendants than among pilots.

This article reports on the health complaints by the flight crews as well as the findings regarding air quality measurements taken during flight and test conditions of two of the aircraft that had experienced oil seal failure. It also reports on the problems encountered when these exposures occur in flight, the warning system present, and the approach taken by medical personnel when these flight crews reported to the emergency department of a local hospital. To show that BAe-146 aircraft with properly functioning oil seals have air quality comparable to other aircraft, in-flight comparisons of the air quality of one BAe-146, another BAe-146 outfitted with an experimental activated charcoal air filter, and a Dash-8 aircraft that had never been associated with any complaints were also made.

Methods

Exposure description and health complaints were taken from the accident reports filled out by the individuals involved, as well as from clinical assessments. Aircraft 1, of the BAe 146-200 fleet, had come in on the previous night with complaints from the flight crew regarding air that made them ill. The aircraft had been operating on Castrol 5000. That evening the oil was removed and replaced with Exxon 2380. The next day this aircraft was tested during flight for air contaminants such as volatile organic compounds (VOCs) and higher molecular weight oils. VOCs were measured using activated charcoal adsorbent tubes and portable sampling pumps running at calibrated air flows of 0.1 L/min, according to the Worker's Compensation Board of British Columbia method 3301.[3] The higher molecular weight hydrocarbons, such as potential aerosolized oils, were collected on a filter cassette and attached to portable pumps running at calibrated air flows of 2 L/min. The cassette filters were extracted with acetonitrile and analyzed on a high pressure liquid chromatograph (HPLC). The activated charcoal adsorbent tubes were extracted with carbon disulfide and analyzed on a GC–mass spectrometer with detection limits for VOCs in air ranging from 1 to 15 ng/m^3. Two sets of air samples for both analyses were taken during flight, one set behind the copilot's seat and the other set at the rear of the cabin at head height. Bulk and head space samples of the two oils at room temperature were analyzed with HPLC.

The flight crew of aircraft 2 BAe-146) had experienced air quality problems on a 2-hour flight, requiring the pilots to remain at the destination of that flight for 24 hours. This aircraft was brought back to its port of origin and tested on the tarmac the following day for carbon monoxide and carbon dioxide. Both gases were measured using direct-reading instruments in the galley, situated behind the cockpit, as well as the rear of the cabin. The APU and each of the engines were tested separately under a number of conditions, including pressurization, as high as a 0.2 atm (3 psi) pressure differential, and depressurization.

A BAe-146 (aircraft 3) equipped with a standard air handling system was monitored for the duration of a 3-hour, one-stop round trip with 28 and 35 individuals on board, respectively. A second BAe-146 (aircraft 4 outfitted with an experimental activated charcoal air filter was monitored on a 4-hour, one-stop round trip. This flight had 80 and 35 individuals on board, respectively. The reference aircraft was a de Haviland Dash 8-100 (aircraft 5). This aircraft was monitored for the duration of a 3-hour, two-stop flight with 23, 16, and 13 individuals on board, respectively. All measurements were made in the rear seat section of each aircraft.

Carbon dioxide and carbon monoxide (detection limits of 5 and 1 ppm, respectively) as well as relative humidity and temperature were measured using a Q-Track indoor air quality monitor (TSI Incorporated) The instrument was set to record the environmental parameters every 5 minutes and was calibrated for carbon dioxide using nitrogen as the zero gas and 900 ppm carbon dioxide calibration gas (Matheson). Nitrogen oxides were measured using an Odyssey 2001 gas monitor (Transducer Research Inc.). Oxygen and additional carbon monoxide concentrations were measured using a TMX 410 datalogger (Industrial Scientific Corporation) with detection limits of 0.1 percent and 1 ppm, respectively. All equipment had datalogging capabilities, and the information was downloaded into an IBM 486 computer..

Results

Exposure descriptions by flight crews over a 4-month period included the following: sharp odor in cabin, assault by toxic fumes, heavy exhaust smell, deicing smell, soapy smell, detergent smell, dirty sock smell during takeoff, oven cleaner smell, peroxide smell, acrid noxious fumes filling cabin on descent, aircraft filled with heavy blue haze, and strong smoke odor. Flight attendents generally noted an odor during takeoff and landing They reported that, as their flight progressed, they frequently experienced burning eyes, nasal congestion, sore throat, and tingling lips. Several experienced disorientation, were unable to continue with their duties, and were administered oxygen A summary of the symptoms reported during the 4-month period is shown in Table 1.

Carboxyhemoglobin (COHB) levels obtained 4 hours after these incidents in four individuals were 0.7, 0.7, 1.0, and 2.0 percent The latter individual was a smoker. Most of the symptoms resolved within 24 hours postexposure, and no ongoing residual health problems related to these exposures have been reported.

Aircraft 1 was test flown for 1.5 hours the day after the flight crew had made the complaints. Samples for analysis were taken during this period Two minutes after takeoff an oily smell with a distinct detergent and sour smell overtone, which changed to a hot oil smell after a few minutes, came into the cabin. The aircraft went through a number of ascents and descents in order to simulate takeoff and landing conditions. The ventilation air source was also checked during the flight by isolating each engine. It was found that air from engine 4 definitely resulted in a stronger smell in the cabin, and confirmed an earlier observation that seal 9 of this engine was found to be leaking.

TABLE 1 Symptoms Reported by Flight Crew During a 4 Month Period

Symptom	No. of Individuals
Headache	29
Burning eyes	27
Burning throat	48
Watery eyes	6
Sinus congestion	6
Light headedness	6
Nausea	9
Chest pains	7
Dizziness	7
Disorientation	16
Breathing problems requiring oxygen	2
Gagging, coughing	3
Blurred vision	1
Tingling of nose and lips	3
Numbness	2

Five aircraft, involving 35 flights each Total individuals with symptoms = 112, total flight crew present = 200

The results from the VOC analyses of samples taken during these conditions indicated the presence of a number of agents in the samples from the cockpit and the rear of the cabin when compared with the laboratory blank. These included alpha pinene, long-chain hydrocarbon derivatives such as, 3,7-dimethyl-1,3,6 octatriene (fit 881), and 3-isopropoxy-1,1,1,7,7,7 hexamethyl-3,5 (fit 797), as well as a number of siloxane derivatives including, 1,1,1,3,5,7,9,9,9,-nonamethylpentasiloxane (fit 882), decamethyl cyclopentasiloxane (fit 817), dodecamethyl cyclohexasiloxane (fit 859), tetradecamethyl-hexasiloxane (fit 714), hexadecamethyl heptasiloxane (fit 664), and hexadecamethyl heptasiloxane (fit 759). The results from the cockpit and the rear of the aircraft were virtually identical except for the presence of hexadecamethyl heptasiloxane, which was found only in the rear of the aircraft. The levels of contaminants measured in the rear of the aircraft were three times higher than in the cockpit.

The results of the analyses for VOCs in the head space of the bulk oil samples showed that there was virtually no difference between these samples and the laboratory blank (air) at room temperature (i.e., no volatiles were present under these conditions). HPLC analyses of filter cassettes for potential aerosolized oil components in the cabin did not indicate their presence.

The results of the bulk oil samples analyzed by HPLC indicated that the two oils were very similar, with Exxon showing a small additional peak. Castrol showed two small additional peaks. These peaks have not been identified since the ingredients of these oils are not revealed and are deemed

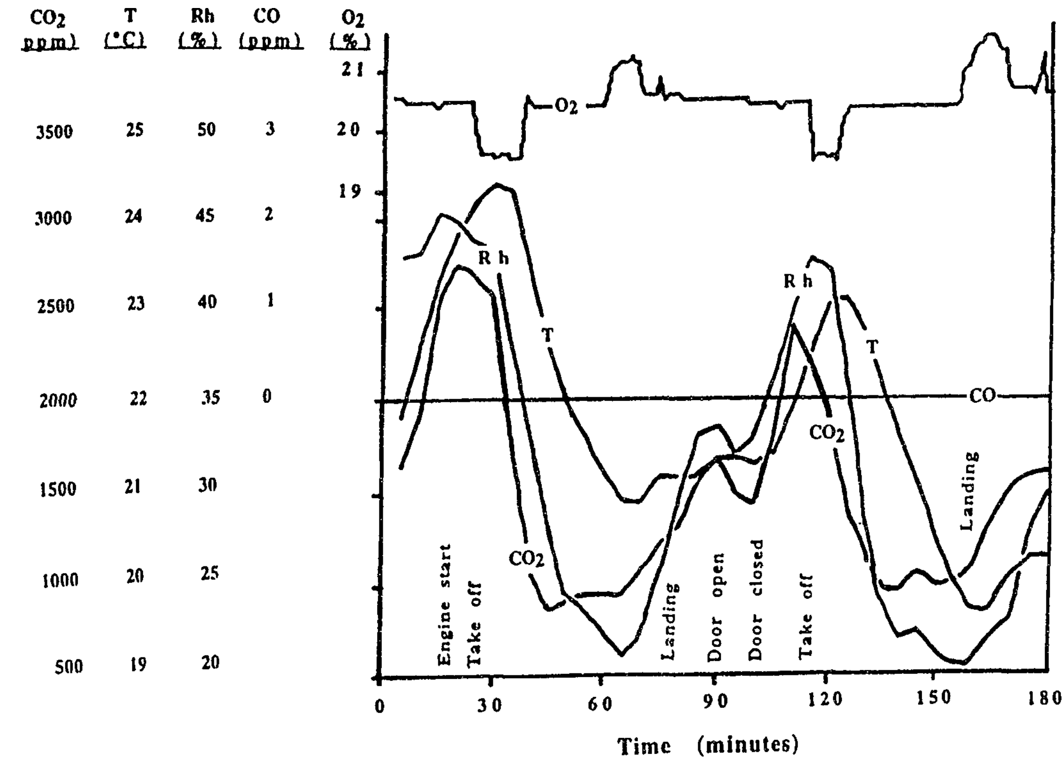

FIGURE 2. Graph showing the transients in carbon dioxide (CO_2), temperature (°C), percent relative humidity (Rh), and carbon monoxide (CO), and percent oxygen during a commercial flight of aircraft 3. All measurements were made in the rear of the passenger cabin

proprietary information by the two companies. Standards are therefore not obtainable for identification. The two companies did acknowledge the fact that these jet engine oils do contain 2 to 3 percent of tricresyl phosphates, which are high pressure lubricants. A standard for the o,m,p isomers of this agent was obtained, and, upon further analysis, the retention time of the para isomer coincided with one of the peaks present in each of the bulk oils.

When aircraft 2 was tested on the tarmac in the absence of other aircraft, there was a distinct oil odor which became highly pronounced when the air supply from engine 2 was introduced into the cabin. The cabin temperature was 22°C with a duct temperature of 63°C. Under these conditions it was very noticeable that a distinct stratification of the cabin air was present. At the upper levels where the air registers are located, and coinciding with head level of a standing individual, the air was quite difficult to deal with (i.e., blue smoke that irritated the upper respiratory tract and eyes). When seated, however, head level would be in a stratum of colder, more acceptable air. The carbon dioxide levels ranged throughout the testing period, with three individuals present, from 528 ppm at the start to a high of 900 ppm when engine 2 was tested under full takeoff power with 100 percent fresh air with duct and cabin temperatures of 69° and 26°C, respectively, and at a 0.2 atm (3 psi) pressure differential Under these conditions carbon monoxide reached a level of 3 ppm During the testing exercise the carbon monoxide levels hovered between 1 and 2 ppm and rarely went up to 3 ppm. There were no major differences between levels measured at the front of the cabin compared to the back for either gas Under the test conditions, switching from 100 percent fresh air to the 60/40 percent mix recirculated air did not result in any significant differences

The results from the in-flight air quality comparisons of three aircraft indicated that the air of properly maintained BAe-146 aircraft was similar to the air quality in the Dash 8-100. As an example of the various environmental parameters that were monitored over the duration of each flight, the results from aircraft 3 are presented in Figure 2. The trends shown were similar for aircraft 4 and 5.

In general, it can be noted that carbon dioxide concentrations, along with temperature and relative humidity in the aircraft, rose sharply after loading of passengers and before takeoff, at which time these parameters decreased until landing Again a rise in these parameters was noted during the interval between landing and the unloading of the passengers After a short decrease in these parameters, when all passengers have

left, a sharp increase can again be observed between loading of new passengers and takeoff. This general cycle repeated itself. The carbon dioxide levels measured in aircraft 3 (BAe-146) ranged from 850 to 2700 ppm. In aircraft 4 (BAe-146) these ranged from 800 to 2300 ppm. Similar transients were obtained in aircraft 5 (Dash 8-100), where carbon dioxide levels ranged from 1100 to 2500 ppm. In all aircraft no carbon monoxide was detected above the detection limit of 1 ppm using two independent sensing systems.

Oxygen concentrations appear to change rather predictably, with a decrease after takeoff and an increase prior to landing. In aircraft 3 oxygen levels ranged from 19.6 to 21.8 percent. In aircraft 4 these ranged from 19.6 to 21.2 percent. Both aircraft maintained a relatively stable 21.7 percent oxygen level during flight. Aircraft 3 maintained a more steady oxygen level compared with aircraft 4. Aircraft 5 generally maintained an oxygen level of 20.8 percent, which ranged during takeoff and landing from 19.71 to 21.9 percent.

Discussion

When confronted with complaints of a "bad smell" in an air quality situation such as this, it is very difficult to zero in on a particular agent and monitor it. This was further aggravated, after the oil seals were identified as the problem, by the fact that the manufacturers of the jet engine oil do not disclose the composition and ingredients of their product in the required material safety data sheets, claiming that this is proprietory information. In situations like this, one has to rely on the symptoms of the individuals involved and check for classes of agents that are most likely to be present and which could be the cause of these symptoms.

Some of the reported symptoms appeared consistent with those associated with low level carbon monoxide exposure, including headaches, nausea, light-headedness, and disorientation.[4] Some of the other symptoms, including burning eyes, burning throat, watery eyes, and sinus congestion,[5] appeared more consistent with exposure to an irritant such as smoke or VOCs. The tingling and numbness experienced by some individuals appear to indicate some neurological involvement, indicating possible exposure to volatile neurotoxic hydrocarbons such as hexane and octane,[6] as well as tricresyl phosphates (TCPs),[7] known ingredients in jet engine oils.

At the time of the test flight of aircraft 1, it was learned from the British aircraft manufacturer representative, that the air destined for the cabin is passed through a catalytic converter in order to oxidize any oil contaminants to carbon dioxide and water. Catalytic converters operate at maximum efficiency under highly specific conditions of temperature and contaminant to air ratio. As an example, the Engelhard TWX catalytic converter[8] used for automobiles operates best at a contaminant to air ratio of 1/14.7. Under these conditions it is 95 percent efficient in changing carbon monoxide to carbon dioxide, hydrocarbons to water and carbon dioxide, and nitrogen oxides to nitrogen and carbon dioxide. For this reason an oxygen sensor is often present in the exhaust stream to provide feedback to the carburetor to keep this ratio as ideal as possible. The catalytic converters in the aircraft are probably subject to similar principles for efficient operation. When the contaminant to air ratio is drastically altered, as in an aircraft with leaky oil seals, one can expect a number of contaminants to pass through the converter in an original or semialtered state. This makes it even more difficult to zero in on a particular agent for testing. For this reason it was decided to monitor for the most acute toxic agent that could potentially be generated if the catalytic converter was not operating efficiently (i.e., carbon monoxide, since it lacks an odor which could act as an early warning system.

Under the test conditions of aircraft 2, the highest level obtained was 3 ppm, which is well below the 25 ppm level which is the exposure limit set by the American Conference of Governmental Industrial Hygienists (ACGIH) for an occupational setting.[9] Although both aircraft had a "dead stop" carbon monoxide detector (Houston Atlas, an Enviro Tech Company, Kingswood, Texas) stuck to the galley wall, these did not appear to be effective. Statements on the indicator such as "CO present when spot turns dark," without provision of a clear reference color, are not helpful. Similarly, the directions for use were printed on the back of the sensor, which was glued to the wall of the galley. In addition, no information was available to the personnel present whether these indicators were reversible or not. The indicators in both aircraft had turned dark at some time in the past, had not been renewed, and had been scratched by frustrated individuals to see what the original color had been so that an assessment could be made regarding exposure. An identical or similar device was present in an aircraft that recently crashed when it ran out of fuel over New Hamshire after its pilots had already expired from carbon monoxide poisoning.[10]

During the testing of aircraft 2 on the tarmac, no difference was observed in air quality when the air source was switched from 100 percent fresh air to a 60/40 percent mix of fresh to recirculated air (i.e., in this aircraft decreasing the source of the contaminants to 60%, while at the same time recirculating 40% of this contaminated air). A difference would probably have been observed if the 100 percent fresh air had been clean and the test cycle for the 60/40 percent mix had been long enough for pollutants to build up.

To "remove excess oil and odor that, under certain failure conditions, may exist within the air conditioning system" (i.e., the airpack units,[11] a new experimental activated charcoal filtration system was installed on aircraft 4. Activated charcoal filters are capable of cleaning the air from a large variety of agents, but are not known to be effective for carbon monoxide and carbon dioxide.[12,13] Unless there are other undisclosed components in the new filtration system capable of scrubbing out carbon monoxide, these new air filter units could potentially be quite dangerous in the absence of a carbon monoxide warning system (i.e., they remove the early warning signals for potential carbon monoxide presence, such as the smell of smoke, leaving an odorless, toxic gas in the air).

None of the flight measurements in aircraft 3, 4, and 5 indicated the presence of carbon monoxide. It was therefore concluded that under normal operating conditions the bleed air from the engine in the 146 aircraft did not contain, or the action of the catalytic converter did not result in, any measurable carbon monoxide above the minimum detection levels inside the cabin.

Attempts to obtain direct evidence of carbon monoxide exposure by measuring COHB levels in the blood in exposed individuals who had to be taken to the emergency department

failed for a number of reasons. Although the flight crews had a copy of a recommended set of tests in case an exposure occurred, as suggested by the occupational health physician, this was not followed by most of the attending physicians in the emergency departments. When COHB levels were measured in four individuals, relatively low levels (0.7 to 2.0%) were obtained. This could be due to the administration of pure oxygen in the aircraft as well as the time delay (4 hours) between exposure and measurement. Based on the 4-hour half-life of COHB in the blood under normal breathing conditions,[4] these values could have been 1.4, 1.4, 2.0, and 4 percent immediately after exposure. These values could double once again when one takes in consideration that pure oxygen was administered during exposure, which reduces the half-life to 60 to 90 minutes.[4] These calculations are based on simple models, and accurate prediction of COHB at the time of exposure can be difficult because of likely elevated carbon dioxide levels and the administration of oxygen.[14]

It has been shown that sedentary breathing of a nonsmoker exposed to 35 ppm of carbon monoxide in the air (the Environmental Protection Agency standard) for 2 hours will result in a 2.5 percent COHB level in the blood.[15] Based on the above information, the possibility of elevated COHB levels in the flight crews at the time of arrival of some of these flights cannot be ruled out. The biological exposure indices from the ACGIH[9] recommend that COHB levels measured at the end of a shift should not exceed 3.5 percent.

As it is virtually impossible for a technician to be present with monitoring equipment when these incidents occur, it was recommended that a datalogging carbon monoxide monitor be present on the aircraft, ready to be activated by the flight crew when required to either clearly identify or eliminate carbon monoxide as a contaminant.

The VOCs and long-chain hydrocarbons that were measured during the test flight of aircraft 1 were present in small quantities and can be classified as methylated siloxane derivatives as well as methylated propane and butane derivatives. The identification of these compounds has to be done with caution as the mass spectra of these compounds are not ideal and could represent other compounds with similar molecular structure. Since aircraft 1 had recently been refurbished with new carpets, it should be noted that siloxane derivatives are sometimes released from new carpets (personal observation). They are also used in extreme temperature lubricating oil formulations and consequently could be a reflection of lubricating oil components contaminating the aircraft air. The methylated propane and butane ester derivatives are also probably the actual or the thermal breakdown products of the ingredients of the oil formulations.

HPLC analyses for potential aerosolized oils indicated that major oil components could not be observed in the cabin air. It would appear, when oil leakage occurs, that these probably have been filtered out in the APU or condensed out somewhere in the ventilation system, which has a decreasing temperature differential from above 500° to 50°C.

Carbon dioxide gas is also produced by the catalytic converter as well as by each individual in the aircraft. The levels measured on the ground in aircraft 2, with only three individuals present, was as high as 900 ppm. The carbon dioxide levels measured in flight in each of the aircraft tested were comparable and ranged from a low of 800 to a high of 2700 ppm Aircraft 5 (Dash 8-100) reached its lowest reading of 1100 ppm. This was about 250 to 300 ppm higher than the BAe-146 aircraft. This is probably due to a combination of factors, including its occupancy, the time interval between loading and takeoff, the time at which the engines are started, the duration of the flight, and the size of the aircraft The carbon dioxide levels were in general very comparable between the three aircraft and were well below the threshold limit value for carbon dioxide of 5000 ppm and the short-term exposure limit of 30,000 ppm.[9] It should be noted that these levels are meant for occupational settings and do not necessarily apply to passengers. One study indicates that psychomotor and mental performance is not impaired at carbon dioxide levels as high as 50,000 ppm.[16] Another study found that the ability to detect coherent motion is impaired at carbon dioxide levels of 25,000 ppm.[17] It would therefore be prudent to reduce carbon dioxide levels to as low as possible.

The oxygen concentrations during flight of all three aircraft were highly comparable and ranged from 19 6 to 21 9 percent It should be appreciated that when it is stated that the airplane is pressurized, it really means that upon takeoff from sea level the plane is actually depressurized to an air pressure equivalent to 2133 m (7000 ft) in the BAe-146 aircraft, and consequently a decrease in oxygen content is observed Upon landing at an airport situated at sea level, the reverse is observed and the aircraft is repressurized. The steady oxygen concentration in the Dash 8-100 was slightly lower than the 146s at 20.8 percent and reached a high of 21 9 percent This aircraft was probably pressurized to a slightly higher altitude than the BAe-146 aircraft.

Nitrogen dioxide levels within the aircraft were generally not detectable for most of the time during each flight. Some minuscule transients in the parts per billion range could be observed during takeoff and landing in all aircraft.

The most important potential chronic effects that one should be aware of are due to exposure to one of the jet oil ingredients that both companies admitted to be constituents in their oil, TCP. TCP is used in a number of commercial applications including the manufacture of plastics, as a flame retardant, as a lead scavenger in gasoline, and as a high pressure lubricant.[18] TCP is a mixture of three isomers, called ortho, meta, and para cresyl phosphate. Of these, the ortho isomer is the most toxic and is often removed as much as possible from the mixture. In 1959 a mass poisoning occurred in Morocco when 10,000 individuals fell ill after consuming cooking oil that had been adulterated with turbojet engine oil[19] In general, ortho-cresyl-phosphate is a neurotoxin and causes peripheral neuropathies.[7] It has also been concluded, based on hen experiments using lubricating oils containing up to 3 percent TCP, that these lubricating oils had low neurotoxic potential under normal conditions of exposure[20] Rats exposed to a daily oral dose of TCP indicate that this compound also has effects on the adrenal glands, ovaries, and seminiferous tubules.[21]

There is no information available regarding inhalation exposure of this agent. The turbojet oils used on the BAe-146 aircraft were analyzed and found to contain 2.8 percent cresyl phosphates. The oil manufacturers claim that less than 1 percent of this is the ortho isomer In-flight measurements in a complaint aircraft could not demonstrate the presence of this

agent in the air above the detection limit of 80 $\mu g/m^3$ of air. A recent article indicates that turbojet oils can also contain a number of other agents such as the trimethylolpropane esters (TMPEs) of carboxylic acids.[22] At temperatures between 350° and 700°C, TMPE and TCP can react together to form *trimethylolpropane phosphate* (TMPP). As TMPP is a potent neurotoxin, it was suggested that "extreme caution should be exercised in applications of these lubricants where these are thermally degraded."[22] It would appear that the current situation, where turbojet oils are being thermally degraded in a catalytic converter that is prone to be overloaded, could be one of these applications and requires further investigation.

The air quality of BAe-146 aircraft appears to have been a long-standing problem, as is apparent from the many modifications, additions, and deletions to the air-conditioning system recommended by British Aerospace over the years.[11] If one expects the flight crews to have confidence in the decision-making processes and operate these aircraft, the best argument that can be presented is to show that the air in suspected aircraft with properly functioning oil seals is comparable to that in other aircraft that have never been associated with complaints and have always been quite acceptable. If the air quality is not comparable, then the differences should be identified and evaluated, and, if deemed necessary, appropriate changes should be made. For this reason, in-flight comparisons were made of three aircraft.

When one compares the two BAe-146 aircraft with properly functioning oil seals, no distinct differences in the air quality parameters measured can be noted. A faint hydrocarbon combustion smell was noted in aircraft 3 (BAe-146, no charcoal filter) at the times of takeoff. A similar smell was noted in aircraft 5 (Dash 8-100) at the time when the engines were started. This was not noticed in aircraft 4 (BAe-146 with activated charcoal filter).

It appears, therefore, that the activated carbon filter does improve the air quality during normal operating conditions. Whether it is capable of performing under a challenging load such as failure conditions remains to be seen.

Conclusions

In-flight oil seal failure in turbojet engines of BAe-146 aircraft was traced as the source of smoke in the cabin. The diverted engine combustion air passes through catalytic converters, which tend to become overloaded, resulting in the potential production of carbon monoxide. Although the reported symptoms appeared consistent with carbon monoxide exposure, only slight elevations in COHB levels were measured in flight attendants, which was probably the result of the time delay since exposure. Oxygen administration and carbon dioxide levels are known to shorten the half-life of COHB. To identify or eliminate carbon monoxide as a problem, the use of data-logging instruments for carbon monoxide was recommended, to be activated when accidental exposures occur. Although cresyl phosphates are present in engine oils, these were not found in the cabin air of problem aircraft. The air quality of normal BAe-146 aircraft compared favorably with that of a Dash-8 not associated with problems.

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Comparison of the constituents of two jet engine lubricating oils and their volatile pyrolytic degradation products.

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Comparison of the constituents of two jet engine lubricating oils and their volatile pyrolytic degradation products.

Abstract

Leaking oil seals in jet engines, at locations prior to the compressor stage, can be a cause of smoke in the cabins of BAe-146 aircraft. Compressed combustion air is bled off to pressurize the cabin and to provide a source of fresh air. Bleed air is diverted from a location just prior to the combustion chamber at a temperature around 500 °C. To prevent oil breakdown products from entering the cabin air, catalytic converters have been used to clean the air. During an oil seal failure this device becomes overloaded and smoke is observed in the cabin. Some aircraft companies have removed the catalytic converters and claim an improvement in air quality. During an oil seal failure, however, the flight crew is potentially exposed to the thermal breakdown products of the engine oils. Since very little is known regarding the thermal breakdown products of jet engine lubrication oils, two comercially available oils were investigated under laboratory conditions at 525 °C to measure the release of CO, CO_2, NO_2, HCN as well as volatiles which were analyzed using GC-Mass spectrometry in an attempt to see if the neurotoxic agents tricresyl phosphates (TCPs) and trimethyl propane phosphate (TMPP) would be present or formed. TMPP was not found in these experiments. Some CO_2 was generated along with CO which reached levels in excess of 100 ppm. HCN and NO_2 were not detected. GC composition of the two bulk oils and their breakdown products were almost identical. The presence of TCPs were confirmed in the bulk oils and in the volatiles. Localized condensation in the ventilation ducts and filters in the air conditioning packs are likely why the presence of TCPs has not been demonstrated in cabin air. It was recommended that this needed to be verified in aircraft.

Key words: jet engine lubricating oils, tricresylphosphates,TCP, TMPP, pyrolysis, neurotoxins, inhalation exposure, aircraft air, air quality.

Introduction.

The presence of smoke in the cabin has been classified as a pilot's nightmare. [1] It was therefor not surprising that episodes of smoke in the cabin during flight of a number of BAe-146 aircraft raised the anxiety of the flight crews exposed.[2] Eventually the source of the smoke coincided with the recent use of a less expensive engine oil, Castrol 5000, which was did not appear to be as compatible with the engine oil seals as Exxon 2380 which was used prior to oil switching. This resulted in excessive amounts of engine oil leaking into the compressed airstream. Under normal conditions air from the compressed engine combustion air is bled off and used for ventilation air and cabin pressurization. Because minor oil contaminants are unavoidable, air destined for the cabin passes through catalytic converters which, at a temperature of 500 °C, are capable of oxidizing sporadic contaminants to carbon dioxide and water. When abnormal amounts of oil enter the ventilation air, however, the system is likely to become overloaded resulting in a number of contaminants entering the cabin air. These potentially include elevated carbon monoxide and carbon dioxide levels, as well as the presence of unconverted, or semi converted, hydrocarbon oil constituents which present themselves in the form of smoke. In addition, a heavy chemical load on the catalytic converters is likely to increase their oxygen demand at the expense of the oxygen concentration in the air delivered to the cabin.

Some companies operating the BAe-146 have removed the catalytic converters and claim an improvement of air quality. In these aircraft the presence of leaking oil seals would result in the direct contamination of air destined for the cabin. As this air is diverted from the engine combustion air

stream immediately prior to entering the combustion chamber, the temperature is estimated to be in excess of 500 °C. This air is cooled in the engine pylons to 200 °C before it is ducted through the spine of the aircraft to two air pack units situated in the rear of the aircraft. These units filter and condition the air to 50-60 °C before it enters the cabin.

Since both jet engine lubricants of interest contain up to 3% tricresyl phosphates (TCPs) as an antiwear agent, (3) inhalation exposure to these agents cannot be ruled out.

It has been reported that inhalation exposure to TCPs in a manufacturing plant has resulted in toxic polyneuritis. (4) Long-term inhalation exposure of chickens to concentrations between 23 and 110 mg/m^3 produced neurotoxic effects. (5) It has also been suggested that humans are 10 to 100 times more sensitive than chickens. (6) Although the neurotoxic effects of TCPs have been associated with the ortho isomer which, for that reason, has been kept below 1 % in these lubricants(3), the observed neurotocicity in laboratory studies cannot be explained by the presence of the ortho isomer alone. This has been demonstrated by one recent study which reported an unexpected high neurotoxic potency associated with aviation engine lubricants containing 3% TCP levels and less than 0.02% of the ortho isomer.(7)

There also has been a recent report (8) that has drawn the attention to the potential generation of an additional neurotoxin, trimethyl propane phosphate (TMPP, i.e. 4-ethyl-1-oxo-2,6,7-trioxy-1-phospha-bicyclo(2.2.2) octane, CAS Registry Number 1005-93-2) that is produced at temperatures between 350-650 °C (9) from TCP and trimethylolpropane esters (TMPE), both of which are common constituents in jet engine oils.

This article would like to report on the constituents of two commonly used jet engine lubricating oils, their volatile components, and their pyrolytic products at 525 °C, the optimum temperature that has been reported by Wyman et al. for TMPP production. (9) Little information is available that describes how under these circumstances the oxygen, carbon monoxide, carbon dioxide levels may be affected. Wyman et al.(9) did report an increase in CO and CO_2 that was co-incident with a decrease in O_2. The source of these observations was thought to be the diesel fuel used to generate the elevated temperature conditions rather than the lubricant oil under investigation. Another investigation of the pyrolysis of Exxon 2380 under non-flaming conditions, using an electric heating unit, indicated that high levels of CO can be generated under these conditions. (10)

As it was not possible to make measurements during a flight with leaking oil seals and without the presence of catalytic converters on the engine, a laboratory simulation was done using both oils.

Methods

Two commercially available jet engine oils were compared, Castrol 5000 which had been implicated in the air quality problems, and Exxon 2380 which had been used without major problems until it was temporarily replaced with Castrol 5000.

The general behavior of each oil was investigated by visual observation after a 0.5-mL sample of the oil was placed on a piece of aluminum foil on top of a ceramic hotplate which was heated to temperatures beyond 250 °C at a rate of approximately 10 °C/min. until only charred material remained.

The generation of potential volatile oil components at 525 °C was investigated using a stainless steel chamber 54x64x71cm (WxLxH). A hotplate with a ceramic top was put at the bottom of this chamber and allowed to reach 525°C while the top lid was open. A surface thermometer (Model 573C Pacific Transducer Corporation) was placed on top of the hotplate to monitor the temperature. A direct reading multigas monitor TMX-412 (Industrial Scientific Corporation, Oakdale PA) with data logging capabilities for NO_2, O_2, CO, and LEL was suspended at the top and inside the chamber as well as a YES-204A monitor (Young Environmental Systems, Richmond, B.C.), capable of recording temperature, relative humidity, and CO_2 concentration.

Both instruments were turned on before a 0.5-mL sample of the oil to be investigated was introduced onto a 5cm x 5cm piece of aluminum foil with the edges slightly curled up. This sample was put directly on top of the hot plate at 525 °C. The lid was closed and, in order to prevent the direct reading instruments from thermal damage, the hot plate was kept at this temperature for one additional minute, at which time it was allowed to cool off. Sampling for volatiles was done using a midget impinger filled with a 10- mL ethanol and isopropyl alcohol mixture (95/5%) kept at 0 °C and using an air sampling pump running at 1 L/min. Hydrogen cyanide (HCN) was measured using Workers' Compensation Board of BC laboratory procedure 0700 [11]using midget impingers and sampling pumps running at 1.6 L/min. The chamber had a 10-mm entry port, allowing free access to laboratory air, and a 8-mm exit port to which the impinger was attached. Sampling for all agents was continued for a period of 15 minutes after the introduction of the oil sample. Prior to each experiment a control sample was taken using the identical procedure, as described above, except that no oil was present on the aluminum foil.

The impinger and bulk oil samples were analyzed using GC/MS. The GLC (Varian model 3400) was equipped with a Supelco PTE-5 column 30 meters in length and .25-mm ID. The injector temperature started at 60 °C, was held for 1 minute, followed by 180 °C/min. increments up to 280 °C where it was maintained to the end of the run, 50 minutes. The column temperature started at 70 °C, was held for 2 minutes followed by 15 °C/min. increments up to 280 °C where it was maintained at that temperature to the end of the run. The Mass spectra obtained (Varian Saturn 2) were compared to the National Institute of Standards and Technology library.[12] A para-tri-cresyl phosphate standard was obtained from ACROS chemicals (Fisher).

Results

Both oils had similar appearance and consistency with Castrol 5000 being slightly more orange in color. Close observation of the oils during heating from room temperature showed white smoke from Exxon 2380 at 275 °C, darkening of the oil at 300 °C with the beginning of charring at 310 °C. For Castrol 5000 visible white smoke appeared at 285 °C, with darkening of the oil at 310 °C but no charring was observed until the temperature was above 350 °C.

When oil samples were introduced onto the hotplate with its surface at 525 °C inside the chamber, smoke was liberated which was similar in smell to what was noticed in aircraft with leaking oil seals. At the end of the experiments, except for some charred brown material, no oil was remaining on the aluminum foil.

The results obtained from the data logging monitors for CO_2, CO, NO_2, LEL, temperature and relative humidity as well as HCN have been summarized in Table 1.

As can be observed in this table no evidence was found for the generation of NO_2 and HCN. CO_2 levels increased throughout the 15-minute experimental regime from a low of 365 (control) to a high of 509 ppm(Castrol 5000). Similarly CO reached a high of 141 ppm when Castrol 5000 was investigated compared to a high of 120 ppm for Exxon 2380.

The GC traces for the two bulk oil sample analyses and their corresponding traces for the volatiles released at temperatures of 525 °C have been summarized in Figure 1. The bulk oil traces showed virtually identical patterns as well as the relative proportions of their constituents. The pyrolized oils were very similar in general but differed somewhat between scan number 1200 and 1350 which showed more pronounced peaks for Castrol 5000.

The corresponding GC/MS analyses of the peaks in Figure 1 have been summarized in Table 2. The various peaks show virtually identical retention times and mass spectra. The corresponding compounds that match these mass spectra have also been identified in Table 2 along with their fit and CAS number. Where possible, only those compounds that were identical in both analyses as being present in peaks of comparable retention times have been shown. Other possible compounds can therefore not be excluded.

Discussion

Visual observation of the two oils during heating indicated slightly different behavior, Castrol 5000 appeared to generate smoke at a slightly higher temperature than Exxon 2380, i.e. 285 vs. 275 °C. The major difference was that Castrol 2000 did not produce charred remains until 350 °C compared to 310 °C for Exxon 2380. A Published report[10] on an 1983 Exxon 2380 sample indicates visible traces of condensate at 208° C with a dramatic

increase in smoke at 306 °C which was coincident with the generation of CO which reached a high of 10600 ppm at 533 °C. A level of 14,300 ppm of CO was reported when an Exxon 2380 oil sample was placed directly in an environment at 375 °C under non-flaming conditions. The CO concentration in our current experiments indicated a high CO concentration of 120 ppm for Exxon 2380. When one takes the different loading characteristics into account, i.e. 4.2 L/cc of oil [10] compared to 490 L/cc of oil in our experiments, the concentration of 14,300 ppm referred to above corresponds to 123 ppm under the loading condition that we used. This shows good agreement with the value of 120 ppm CO that we measured at 525 °C. There is a possibility that some of the constituents of Exxon 2380 might have been modified or replaced since 1983, and could be responsible for small differences in the CO concentration generated as well as the difference in temperature at which visible smoke was observed in our experiments, i.e. 208 °C vs. 275 °C. The levels of CO_2 also increased during the experiment whereas O_2 decreased slightly as expected. These results indicate that these oils, when exposed to elevated temperatures, are sources of CO and CO_2. The CO produced could become a hazard to the flight crew when operating aircraft with leaking engine oil seals. It could be argued that the production of CO in these experiments is a result of limiting oxygen conditions which are not likely to be present in the combustion air of the aircraft. The oxygen measurements during pyrolysis do not appear to support this argument since only a .2% change in oxygen concentration was noted. In contrast, much wider variations in aircraft oxygen concentrations have been reported.[2]

NO_2 and HCN were not produced under the conditions of the experiment which is consistent with the fact that these gasses are produced from atmospheric nitrogen only at temperatures associated with actual flame

conditions which are well in excess of 1000 °C. [13] HCN can also be formed at lower temperatures from combustion of nitrogen-rich materials such as wool, silk, polyurethane, and polyacrylonitrile. [14] Based on our analysis of the two oils the nitrogen content appears to be minimal.

It is also apparent from Figure 1 that the process of heating the oils to above 500 °C produces volatile compounds that are not present in the oil itself. These volatiles appeared to be similar between the two oils. In addition some of the components in the bulk oils that were retained at 1950 and longer retention times were not found in the pyrolized samples.

The chamber experiments indicate that the cresyl phosphates were volatilized and could therefore potentially enter the cabin of an aircraft. It is interesting to note that previously reported HPLC analysis of aircraft air with leaking oil seals could not demonstrate the presence of cresyl phosphates above 80 ug/m^3 [2]. It is therefore likely that under the conditions present in an aircraft one expects that a number of oil constituents that were pyrolized and/or volatilized will condense out of the air stream at different locations along the ventilation ducts depending on the local temperature. The more volatile components are expected to travel through the ventilation system and enter the cabin resulting in exposure to the passengers as well as the flight crew. The principle of localized condensation has also been observed by Rubey [15] during the incineration of engine oils containing TCP. In that investigation the neurotoxic TMPP was not found in the gaseous effluent but was identified in the scrapings of the boiler walls. Since the incinerator temperature was likely higher than what would be encountered in an aircraft ventilation system it is unlikely that TMPP, if it were produced, would be encountered in the aircraft supply air. It would appear therefore that the catalytic converters on the engines, localized condensation along the

ventilation system, and conditioning by the airpack units of the aircraft are capable of modifying and filtering out most compounds that could potentially contaminate the cabin air. It would nevertheless be prudent to verify these hypotheses under the conditions present in an aircraft with either actual or simulated engine oil leakage.

Localized condensation will lead to accumulation of the condensation products in the ventilation system. This could result in the release of these agents into the air when duct temperatures, for some reason, become elevated causing an air quality problem at a time when there is nothing wrong with the mechanical system of the aircraft.

It should be emphasized that the compounds identified in Table 1 should be interpreted with caution because other compounds not shown had similar, or closely related, mass spectra. Since the ingredients of these two oils are proprietary information the accuracy of our analysis could not be confirmed with appropriate standards for most of the components identified and their retention times could not be compared. For this reason some of the compounds in Table 2 may have been associated with quite different retention times such as, for instance, 1,8-dihydroxyanthraquinone for the Exxon 2380 analysis. Only a standard would identify the correct peak and its retention time, the other peaks, which were identified with the same compound, are likely associated with closely related derivatives of the compound identified. This was particularly apparent with the large numbers of phosphoric acid derivatives with retention times between 1274 and 1381. Each one of these refers to one of the 10 possible isomers of TCP. The companies did indicate that TCP is present at a 2-3% level. This was confirmed in our analyses with a p-cresyl phosphate standard. Identification of the other components was mainly done to identify similarities and to

search for the presence of TMPP which could not be demonstrated under the conditions of the experiment and using the NIST library which does contain a spectrum for TMPP. The identification of TMPP was also hampered by the fact that a standard for this compound could not be obtained.

It has been pointed out (10) that the resulting products from the thermal breakdown of agents is highly dependent on the conditions under which this is achieved. The current observations should therefore be interpreted with caution. Nevertheless it was also suggested by the same authors that the non-flaming conditions provided by an electric heating system is a reasonable model to study the degradation of turbo engine oils.

Conclusions

The two jet engine oils investigated appear almost identical in their chemical composition. Pyrolysis at 525 °C resulted in the release of CO_2, CO, as well as a large number of volatiles. Of these CO and volatilized components as well as pyrolysis products could pose a potential hazard to the flight crews of BAe-146 aircraft experiencing engine oil seal failure. Although TCPs were found in both bulk oils as well as in the air, the presence of neurotoxic TMPP could not be demonstrated. It was postulated that some of the volatilized components, as well as pyrolysis products that were generated in our experiments, would likely condense out of the airstream onto the interior surface of the aircraft ventilation system and not reach the cabin unless the duct temperature is increased. It was therefore recommended that this hypothesis needed to be investigated under actual aircraft conditions.

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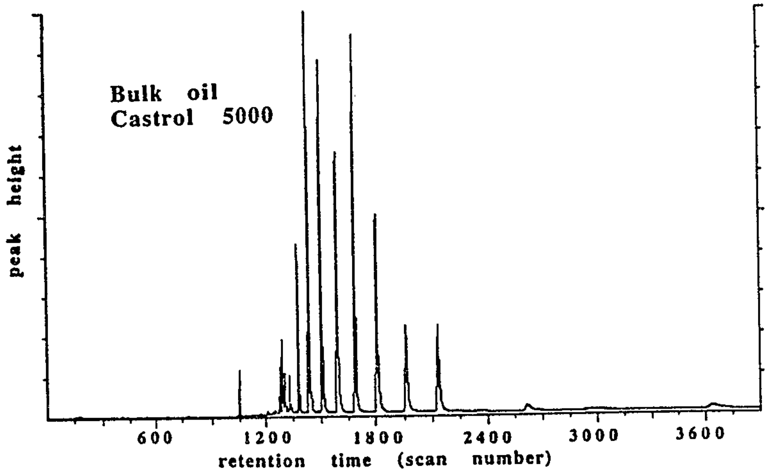
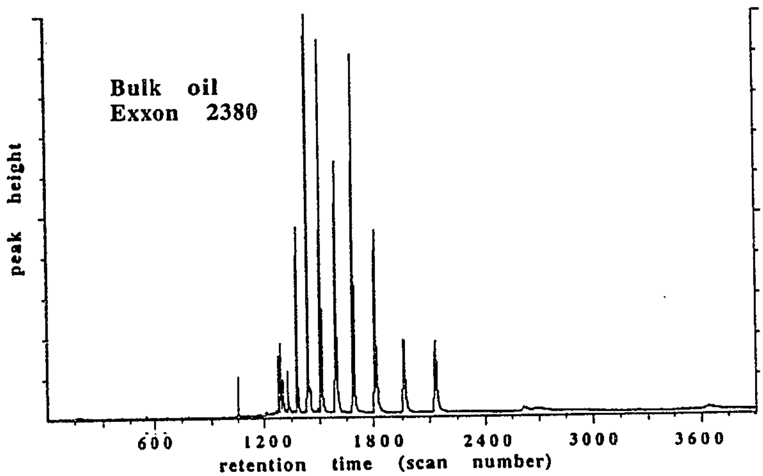

Bulk oil
Castrol 5000
peak height
600
1200
1800
2400
3000
3600
retention time (scan number)


Bulk oil
Exxon 2380
peak height
600
1200
1800
2400
3000
3600
retention time (scan number)

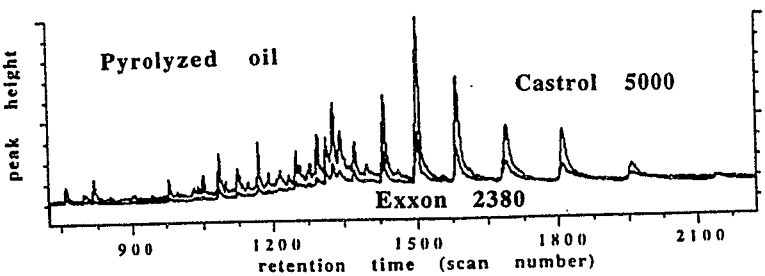

Pyrolyzed oil
Castrol 5000
Exxon 2380
peak height
900
1200
1500
1800
2100
retention time (scan number)

Table 2. Bulk oil constituents and volatile products at 525°C from two turbo jet engine oil lubricants.

Castrol 5000

Bulk oil analysis

Ret. time	Compound	Fit	Cas #
1049	8-Benzylquinoline	972	28748-19-8
	2-naphthylamine, N-phenyl-	963	135-88-6
1274	Phosphoric acid, tris(3-methylphenyl)ester	989	563-04-2
1287	Phosphoric acid, tris(3-methylphenyl)ester	986	563-04-2
1301	Phosphoric acid, tris(3-methylphenyl)ester	984	563-04-2
1316	Phosphoric acid, tris(4-methylphenyl)ester	968	78-32-0
	Phosphoric acid, tris(3-methylphenyl)ester	966	563-04-2
1328	1,3-Dioxane, 5-(hexadecyloxy)-2-pentadecyl-,trans-	892	34315-34-9
1378	3,3-dimethyl-5-(2,2-dimethylpropyl)tetrahydrofuran-2-one	978	0-00-0
1436	Gallium, tetraethyl-di.mu.-1-piperidinyldi-	899	42777-03-7
	Silane derivative	845	56771-62-1
1504	1,8-Dihydroxyanthraquinone	897	7336-68-7
1590	Decanoic acid, 1,2,3-propanetriyl ester	864	621-71-6
1690	Decanoic acid, 1,2,3-propanetriyl ester	813	621-71-6
1807	1,8-Dihydroxyanthraquinone	891	7336-68-7
1957	8-methoxy-2-(p-methoxyphenyl)-1,2,4,5-tetrahydro-1-benzazocine-3,6-dione	903	90732-26-6
	Decanoic acid, 1,2,3-propanetriyl ester	837	621-71-6
2132	4-hydroxyanthraquinone-2-carboxylic acid, di-TMS	868	0-00-0
2615	Methanone, (4-ethoxy-3-methoxyphenyl)(6-methyl-1,3-benzodioxol-5-yl)-	863	52828-42-9
3639	Octadecanoic acid, 8,9,11,12-tetrakis[trimethylsilyl)oxy]-, methyl ester	840	35437-04-8

Exxon 2380

bulk oil analysis

Ret. time	Compound	Fit	Cas #
1051	8-Benzylquinoline	973	28748-19-8
	3-Benzylquinoline	970	37045-16-2
	2-naphthylamine, N-phenyl-	958	135-88-6
1275	Phosphoric acid, tris(3-methylphenyl)ester	987	563-04-2
1288	Phosphoric acid, tris(3-methylphenyl)ester	987	563-04-2
1303	Phosphoric acid, tris(3-methylphenyl)ester	984	563-04-2
1318	Phosphoric acid, tris(4-methylphenyl)ester	968	78-32-0
	Phosphoric acid, tris(methylphenyl)ester	966	1330-78-5
1330	1,3-Dioxane, 5-(hexadecyloxy)-2-pentadecyl-,trans-	890	34315-34-9
1379	3,3-dimethyl-5-(2,2-dimethylpropyl)tetrahydrofuran-2-one	975	0-00-0
1438	Gallium, tetraethyl-di.mu.-1-piperidinyldi-	898	42777-03-7
	Silane derivative	845	56771-62-1
1506	1,8-Dihydroxyanthraquinone	900	7336-68-7
1591	Decanoic acid, 1,2,3-propanetriyl ester	851	621-71-6
1693	Decanoic acid, 1,2,3-propanetriyl ester	824	621-71-6
1809	1,8-Dihydroxyanthraquinone	924	7336-68-7
1958	8-methoxy-2-(p-methoxyphenyl)-1,2,4,5-tetrahydro-1-benzazocine-3,6-dione	882	90732-26-6
	Decanoic acid, 1,2,3-propanetriyl ester	827	621-71-6
2133	Naphthalene, 2-(1,1-dimethyl)decahydro-4a-methyl	873	54934-96-2
	4-hydroxyanthraquinone-2-carboxylic acid, di-TMS	871	0-00-0
2615	Methanone, (4-ethoxy-3-methoxyphenyl)(6-methyl-1,3-benzodioxol-5-yl)-	887	52828-42-9
3639	Octadecanoic acid, 8,9,11,12-tetrakis[trimethylsilyl)oxy]-, methyl ester	843	35437-04-8

Castrol 5000

Pyrolyzed oil analysis

Ret. time	Compound	Fit	Cas #
737	diethyl phthalate	967	84-66-2
793	hexane, 1,1'-oxybis	815	112-58-3
958	hexane,2,2,3,4,5,5-hexamethyl-, meso	848	55258-16-7
1059	3-benzoquinoline	937	37045-16-2
1098	2-t-butyl-2,3-dimethyl-3-buten-1-ol	906	0-00-0
1144	5,6-decanedione	847	5579-73-7
1166	Butanimidamide, N-(1-chloro-2-methyl-1-butenyl)-2-monochloride	938	40645-73-6
1189	5-decen-1,ol (Z)-	977	51652-47-2
1269	anthraquinone, 1-p-tolyl	943	20600-74-2
1288	Phosphoric acid, tris(methylphenyl)ester	937	1330-78-5
1301	Phosphoric acid, tris(methylphenyl)ester	961	1330-78-5
1317	Phosphoric acid, tris(methylphenyl)ester	942	1330-78-5
1349	dodecane,1-isocyanate	790	4202-38-4
1375	piperazine,1-(aminoacetyl)-	868	77808-88-9
1409	3,3-dimethyl-5-(2,2-dimethylpropyl)tetrahydrofuran-2-one	947	0-00-0
1478	Silane, methyltriphenoxy	801	3439-97-2
1562	1,8-Dihydroxyanthraquinone	818	7336-68-7
1664	1,1,3-Tri(alloxy)propane	822	0-00-0
1789	Phenylethylamine, N-Methyl-.beta.,3,4-tris-(trimethylsiloxy)	824	10538-85-9
1933	Benzo[g][I]benzothiopyrano[4,3]-indole	752	10023-23-1

Exxon 2380

Pyrolyzed oil analysis

Ret. time	Compound	Fit	Cas #
739	diethyl phthalate	969	84-66-2
794	hexane, 1,1'-oxybis	844	112-58-3
958	hexane,2,2,3,4,5,5-hexamethyl-, meso	902	55258-16-7
1056	3-benzoquinoline	970	37045-16-2
1099	2-t-butyl-2,3-dimethyl-3-buten-1-ol	913	0-00-0
1145	5,6-decanedione	872	5579-73-7
	2-nitro-2-methylcyclohexanone	954	0-00-0
1268	anthraquinone, 1-p-tolyl	927	20600-74-2
1286	Phosphoric acid, tris(methylphenyl)ester	817	1330-78-5
1301	Phosphoric acid, tris(methylphenyl)ester	859	1330-78-5
1317	Phosphoric acid, tris(methylphenyl)ester	946	1330-78-5
1350	1-piperidinecarboxaldehyde	897	2591-86-8
1407	3,3-dimethyl-5-(2,2-dimethylpropyl)tetrahydrofuran-2-one	977	0-00-0
1475	Silane, methyltriphenoxy	755	3439-97-2
1559	1,8-Dihydroxyanthraquinone	845	7336-68-7
1665	1,1,3-Tri(alloxy)propane	750	0-00-0
1789	Phenylethylamine, N-Methyl-.beta.,3,4-tris-(trimethylsiloxy)	677	10538-85-9
1931	Benzo[g][I]benzothiopyrano[4,3]-indole	764	10023-23-1

Table 1. Summary of gaseous constituents, and conditions, in the air from two turbo jet engine oils at 525 °C

Agent/condition	Castrol 5000		Exxon 2380	
	Control	Oil	Control	Oil
NO_2 (ppm)	<0.09	<0.09	<0.09	<0.09
CO_2 (ppm)	370-420	390-509	365-420	395-510
CO (ppm)	0.0	0.0-141	0.0	0.0-120
O_2 (%)	21.6-21.6	21.6-21.4	21.6-21.6	21.6-21.4
LEL (%)	0.0	2	0.0	3
Temp, (°C)*	35.7	34.5	36.8	35.7
% RH	20-25	21-28	20-28	20-25
HCN (ppm)	<1.1	<1.1	<1.1	<1.1

* Temperature at the top of the chamber at the location of the recording instruments.

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Short communication

Multi-elemental analysis of jet engine lubricating oils and hydraulic fluids and their implication in aircraft air quality incidents

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Abstract

The flight crews of aircraft often report symptoms including dizziness, nausea, disorientation, blurred vision and tingling in legs and arms. Many of these incidents have been traced to contamination of cabin air with lubricating oil, as well as hydraulic fluid, constituents. Considering that these air contaminants are often subjected to temperatures in excess of 500°C, a large number of different exposures can be expected. Although the reported symptoms are most consistent with exposures to volatile organic compounds, carbon monoxide, and the organophosphate constituents in these oils and fluids, the involvement of these agents has not been clearly demonstrated Possible exposure to toxic elements, such as lead, mercury, thallium and others, have not been ruled out. In order to assess the potential of exposure to toxic elements a multi-elemental analysis was done on two hydraulic fluids and three lubricating oils which have been implicated in a number of air quality incidents. A secondary objective was to establish if the multi-elemental concentrations of the fluids tested are different enough to allow such an analysis to be used as a possible method of identifying the source of exposure that might have been present during aircraft air quality incidents. No significant concentrations of toxic elements were identified in any of the oils or hydraulic fluids The elemental compositions of the samples were different enough to be used for identification purposes and the measurement of only three elements was able to achieve this. Whether these findings have an application, in aircraft air quality incident investigations, needs to be established with further studies.

Keywords: Aircraft; Air quality; Hydraulic fluid; Engine oil; Multi-elemental analysis

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1. Introduction

Jet engine oils and hydraulic fluid contamination of aircraft air has resulted in a large number of complaints from the flight crew who experienced a wide number symptoms including dizziness, nausea, disorientation, confusion, lethargy, tremors, and tingling of the arms and legs (Bigelow, 1998; Seattle Post-Inteligencer, 1998a,b; The News Tribune, 1998; The Seattle Times, 1998). As bleed air from the compressor section of the jet engines is used to pressurize and ventilate the cabin, any contaminant in this air can cause exposure to the flight crew present (van Netten, 1998). When there is an engine oil seal failure, lubricating oils can enter the combustion air-stream from which ventilation air is bled of at a location next to the combustion chamber where temperatures in excess of 500°C are present. Any oil contaminant in this air will therefore be subjected to a pyrolyzing environment (van Netten, 1998). Hydraulic fluids have also been shown to contaminate the cabin air resulting in numerous complaints from flight crews and passengers alike. It appears that in certain aircraft, hydraulic fluid can leak onto the shell of the aircraft at a location immediately in front of the air intake of the auxiliary power unit (APU) (The Seattle Times, 1998). This unit provides ventilation air to the cabin under conditions when the jet engines are not operating or when combustion air cannot be spared from the engines, such as during high power requirements at takeoff.

A number of articles (Labour Canada, 1980; Crane et al., 1983; Daughtrey et al., 1996; van Netten, 1998) have attempted to describe the constituents of these oils and fluids as well as their pyrolytic degradation products in an effort to find a likely agent(s) that might be responsible for the symptoms experienced by flight crews. A number of possible agents were identified including carbon monoxide, volatile organic compounds, tricresyl phosphates, and tributyl phosphates.

The material safety data sheets (MSDSs), provided by the manufacturers, do not include elemental analyses of their products or disclose the nature of all the additives. For this reason one is not certain that exposure to a number of elements, or organo-elemental derivatives, could also be the cause off, or a contributor to, the symptoms experienced by flight crews during air quality incidents.

Although the elemental composition of crude oils has been well documented and have been shown to be a potential source of nickel and vanadium, as well as mercury (Filby, 1994), the elemental composition of these synthetic oils and lubricants and hydraulic fluids is difficult to predict.

It is known that a number of elements can be present in these oils as lubricant additives including zinc dialkyl dithiophosphates (ZDTPs), calcium alkyl phenates, magnesium, sodium and calcium sulphonates, as well as barium and molybdenum (Hewstone, 1994).

Some of these organo-elemental additives are known to have toxic effects. Repeated exposure to ZDTPs has been shown to cause skin and eye damage in experimental animals as well as inhibiting spermatogenesis and causing tubular hypoplasia in male rabbits (Hewstone, 1994). Similar effects were observed with high doses of calcium alkyl phenates. There appears to be some confusion regarding the skin and eye irritation that has been associated with exposure to sodium sulphonates (Hewstone, 1994). There also appears to be some evidence that a mixture of these additives, as they occur in some oils, are considerably less toxic than the sum of the individual components (Hewstone, 1994).

A multi-elemental analysis of two hydraulic fluids and three jet engine lubrication oils was done in order to determine their elemental composition in an effort to identify, or eliminate, the possibility that exposure to certain elements could explain the symptoms experienced by the flight crews.

In addition, the elemental composition of these oils and fluids, if significantly different enough, could be useful as an elemental fingerprint and an indicator of the type of agent that might be involved in aircraft air quality incidents.

2. Methods

Unopened quart cans of Skydrol LD-4, fire-resistant hydraulic fluid (Monsanto Company, St. Louis, Missouri 63167, USA); HyJet IV-A^{plus}, phosphate ester aviation hydraulic fluid (Chevron International Oil Company, 555 Market street, PO Box 7146, San Francisco, 94120-7146 USA); Mobil Jet Oil 254, synthetic jet engine oil (Mobil Oil Corporation); Castrol 5000; and Exxon 2380 were obtained from the appropriate suppliers.

The samples were analyzed using 0.1-ml aliquots added to a Parr Bomb reaction vessel along with 1 ml of Seatar nitric acid. The vessels were capped and heated overnight at 120°C. The resulting solutions were analyzed directly by conventional ICPMS. Other samples were diluted as is, in a 60% propanol/0.1% triton mixture and analyzed by 'ultra-sonic nebulization/membrane desolvation' ICPMS.

The samples were analyzed for the following elements: Li, Be, B, Na, Mg, Al, Si, P, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Rb, Sr, Y, Zr, Nb, Mo, Ru, Rh, Pd, Ag, Cd, Sn, Sb, Te, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, W, Re, Ir, Pt, Au, Hg, Ti, Pb, Bi, Th and U.

3. Results

Many of the elements in the oils and hydraulic fluids investigated were found to be present at concentrations below the various limits of detection. Only those elements which showed differences in their concentrations are reported on.

A summary of these elements is provided in Table 1. It appears that there are major elemental concentration differences between the hydraulic fluids and the jet engine oils. The former category was consistently higher in phosphorus and potassium by at least one order of magnitude.

Table 1
Summary of elemental concentrations of two hydraulic fluids and three jet engine lubrication oils[a]

Element	Hydraulic fluids		Jet engine lubricating oils		
	Skydrol	HyJet	Exxon	Castrol	Mobil
B	< 5000	5000	< 5000	< 5000	< 5000
Na	3000	4000	< 3000	< 3000	3000
Mg	900	1900	1500	500	1100
Al	1100	1200	1400	1000	1000
Si	56 000	58 000	54 000	63 000	64 000
P (%)	11.1	11.3	0.23	0.28	0.29
K	22 000	38 000	< 5000	< 5000	< 5000
Ca	< 10 000	110 000	< 10 000	< 10 000	< 10 000
Ti	20	60	100	110	< 10
V	600	700	700	800	9000
Cr	2190	900	3360	2230	115 000
Mn	300	< 100	200	< 100	2200
Co	50	30	50	20	520
Zn	13 900	12 300	14 300	10 900	5400
Rb	< 3	4	< 3	< 3	< 3
Sr	12	58	14	10	13
Y	3	4	< 3	< 3	< 3
Cd	< 2	< 2	< 2	< 2	7
Sb	< 5	5	< 5	< 5	15
Ba	7	390	5	9	10
W	< 5	< 5	< 5	< 5	57

[a]All concentrations are in ppb except where otherwise noted.

Differences, by one order of magnitude, can also be observed between the two hydraulic fluids for barium, which was highest in HyJet. Concentrations that were at least double the difference between the two hydraulic fluids were associated with magnesium, titanium, chromium, manganese and strontium.

Differences of one order of magnitude between the three jet engine lubricating oils could be observed for titanium, chromium, manganese, cobalt, zinc and tungsten. All of these were associated with Mobil relative to the two other oils. Differences between these two oils, Exxon and Castrol, became evident when a doubling of the concentrations was used. Elements in this category included Mg, Mn and Co.

4. Discussion

Of the elements analyzed for, none of the toxic elements that could possibly be related to some of the symptoms experienced by the flight crews were present in these fluids and oils above the detection limits of < 20, < 10, < 2 and < 200 ppb for lead, mercury, thallium and arsenic, respectively. Cadmium concentrations in the oils and fluids were also below the detection limit of < 2 ppb except for Mobil, which registered a concentration of 7 ppb. It appears therefore that these fluids are not a major source of heavy metals and consequently can be ruled out as possible contributors to the symptoms experienced by flight crew personnel during air quality incidents involving these oils and hydraulic fluids.

Whether the relatively high levels of zinc that were found are associated with ZDTPs cannot be determined from this data. The same holds true for calcium alkyl phenate and the sulphonate derivatives of calcium, magnesium and sodium. Whether any of the other elements were linked to organic moieties can also not be established from the data presented here.

Based on the information provided by the material safety data sheets (MSDSs) provided by the manufacturers as well as published information, hydraulic fluids can contain high levels of tributyl phosphates (79%) and mixtures of phenyl dibutyl phosphates, diphenyl butyl phosphates and tricresyl phosphates. Lubricant engine oils are allowed to contain 3% cresyl phosphates of which only 0.1% can be the neurotoxic ortho isomer. In hydraulic fluids this isomer can be as high as 1% (Hewstone 1994). It is therefore not surprising that the hydraulic fluids were found to contain levels of phosphorus orders of magnitude higher than those present in any of the lubricating oils. The high levels of potassium in the hydraulic fluids were not expected.

It appears from the elemental analyses done on the hydraulic fluids and the oil samples that concentration differences between phosphorus and potassium can be used to clearly separate the two hydraulic fluids from the three lubricating oils. Between the two hydraulic fluids it appears that barium alone can clearly differentiate between them.

Mobil oil appears quite different in its composition compared to Exxon and Castrol and can be clearly identified by any one of the seven elements: titanium, vanadium, chromium, manganese, cobalt, zinc and tungsten. Differences between Exxon and Castrol are less clearly defined and need to be based on relatively minor differences, i.e. doubling, of elemental concentrations regarding magnesium, manganese and cobalt.

The minimum number of elements that need to be determined in any of the five samples investigated capable of identifying each is only three, i.e. phosphorus or potassium, barium, and cobalt or magnesium.

Whether these elemental differences are reflected in aircraft air during exposure incidents involving any of these fluids needs verification. Since these elemental analyses were done on unopened cans of oil and fluid, the possibility exists that the elemental composition of these oils could change somewhat, based on the number of hours they have been used in the aircraft. Whether some of the elemental concentrations referred to above are affected by this needs to be assessed in used oils and fluids.

Since the production of these synthetic oils and fluids are based on a tightly controlled batch process (Hewstone, 1994) major differences in

elemental concentrations between batches are not expected. Only additional analyses for the elements referred to above, however, will identify the extent of elemental concentration variation between batches.

5. Conclusions

It can be concluded that no toxic heavy metals are present in the fluids and oils examined. The elemental composition of each of the fluids and oils investigated are different enough to identify each one based on an analysis of only three elements, phosphorus or potassium, barium, and cobalt or magnesium.

It should be investigated if these differences could be used as indicators of exposure to these fluids and oils during air quality incidents in aircraft.

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Al	1100	1200	1400	1000	1000
Si	56 000	58 000	54 000	63 000	64 000
P (%)	11.1	11.3	0.23	0.28	0.29
K	22 000	38 000	< 5000	< 5000	< 5000
Ca	< 10 000	110 000	< 10 000	< 10 000	< 10 000
Ti	20	60	100	110	< 10
V	600	700	700	800	9000
Cr	2190	900	3360	2230	115 000
Mn	300	< 100	200	< 100	2200
Co	50	30	50	20	520
Zn	13 900	12 300	14 300	10 900	5400
Rb	< 3	4	< 3	< 3	< 3
Sr	12	58	14	10	13
Y	3	4	< 3	< 3	< 3
Cd	< 2	< 2	< 2	< 2	7
Sb	< 5	5	< 5	< 5	15
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[a]All concentrations are in ppb except where otherwise noted.

Differences, by one order of magnitude, can also be observed between the two hydraulic fluids for barium, which was highest in HyJet. Concentrations that were at least double the difference between the two hydraulic fluids were associated with magnesium, titanium, chromium, manganese and strontium.

Differences of one order of magnitude between the three jet engine lubricating oils could be observed for titanium, chromium, manganese, cobalt, zinc and tungsten. All of these were associated with Mobil relative to the two other oils. Differences between these two oils, Exxon and Castrol, became evident when a doubling of the concentrations was used. Elements in this category included Mg, Mn and Co.

4. Discussion

Of the elements analyzed for, none of the toxic elements that could possibly be related to some of the symptoms experienced by the flight crews were present in these fluids and oils above the detection limits of < 20, < 10, < 2 and < 200 ppb for lead, mercury, thallium and arsenic, respectively. Cadmium concentrations in the oils and fluids were also below the detection limit of < 2 ppb except for Mobil, which registered a concentration of 7 ppb. It appears therefore that these fluids are not a major source of heavy metals and consequently can be ruled out as possible contributors to the symptoms experienced by flight crew personnel during air quality incidents involving these oils and hydraulic fluids.

Whether the relatively high levels of zinc that were found are associated with ZDTPs cannot be determined from this data. The same holds true for calcium alkyl phenate and the sulphonate derivatives of calcium, magnesium and sodium. Whether any of the other elements were linked to organic moieties can also not be established from the data presented here.

Based on the information provided by the material safety data sheets (MSDSs) provided by the manufacturers as well as published information, hydraulic fluids can contain high levels of tributyl phosphates (79%) and mixtures of phenyl dibutyl phosphates, diphenyl butyl phosphates and tricresyl phosphates. Lubricant engine oils are allowed to contain 3% cresyl phosphates of which only 0.1% can be the neurotoxic ortho isomer. In hydraulic fluids this isomer can be as high as 1% (Hewstone 1994). It is therefore not surprising that the hydraulic fluids were found to contain levels of phosphorus orders of magnitude higher than those present in any of the lubricating oils. The high levels of potassium in the hydraulic fluids were not expected.

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The minimum number of elements that need to be determined in any of the five samples investigated capable of identifying each is only three, i.e. phosphorus or potassium, barium, and cobalt or magnesium.

Whether these elemental differences are reflected in aircraft air during exposure incidents involving any of these fluids needs verification. Since these elemental analyses were done on unopened cans of oil and fluid, the possibility exists that the elemental composition of these oils could change somewhat, based on the number of hours they have been used in the aircraft. Whether some of the elemental concentrations referred to above are affected by this needs to be assessed in used oils and fluids.

Since the production of these synthetic oils and fluids are based on a tightly controlled batch process (Hewstone, 1994) major differences in

elemental concentrations between batches are not expected. Only additional analyses for the elements referred to above, however, will identify the extent of elemental concentration variation between batches.

5. Conclusions

It can be concluded that no toxic heavy metals are present in the fluids and oils examined. The elemental composition of each of the fluids and oils investigated are different enough to identify each one based on an analysis of only three elements, phosphorus or potassium, barium, and cobalt or magnesium.

It should be investigated if these differences could be used as indicators of exposure to these fluids and oils during air quality incidents in aircraft.

References

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SUBMISSION TO THE SENATE REFERENCES COMMITTEE
RURAL AND REGIONAL AFFAIRS AND TRANSPORT

ON THE INQUIRY INTO

AIR SAFETY – BAE 146 CABIN AIR QUALITY

SUBMISSION NUMBER 9

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25th August, 1999

The Secretary,
Senate Rural and Regional Affairs and Transport References Committee,
SG. 62
Parliament House,
CANBERRA ACT 2600.

Dear Sir,

1. Re: Proposal to replace Pressure Altitude and Mean Tracheal Partial Pressure of Oxygen as the criteria for flight crew capacity to act at altitude, with Blood Oxygen Saturation Level.

Surveys of accident investigation records attribute about 70% of aircraft accidents and incidents to human error. Of these, the greatest number occur in the later phases of flight, during the descent, approach, and landing. This is, recent research suggests, when the crew are most likely, even when complying with current regulations, to be subject to a degree of incapacitation due to hypobaric hypoxaemia, or lack of sufficient oxygen.

The degree of incapacitation is determined by the deficit in the amount of oxygen transferred from the alveoli (air sacs) in the lung to the pulmonary capillaries, which in turn reduces the amount available for uptake by the tissues. Whilst this may present no difficulty if it occurs over one or two minutes, it will result in impairment of higher cerebral function if it continues over more prolonged periods.

The amount of oxygen in arterial blood can now be easily measured with a pulse oximeter. This instrument can provide a reliable measure of blood oxygen levels spectrophotometrically. This is performed by placing a small probe onto a finger and transmitting light through the finger. A sensor in the probe then measures the wavelength of the transmitted light and compares it to known values of blood oxygen levels. It indicates the result as a percentage of the value that would be recorded if the blood oxygen levels were at a maximum. This value, known as the saturation level, is then displayed on the oximeter screen. Pulse oximeters are small, reliable, consistent, cheap and can be used with accuracy after only a few minutes training. Flight crew can monitor their own levels in flight, and take corrective action to maintain these above the required minimum.

Under the present rules (CAO 20.4) all flight crew can operate in a cabin pressure up to 10,000' without supplemental oxygen for up to 8 hours, day or night.

The July, 1998 issue of the CASA Publication, Flight Safety Australia, carried an article[1] which stated that hypoxia could affect flight crew's night vision, at altitudes as low as 4000', and concentration and judgement were likely to be affected on long flights, well below 10,000'. It further suggests that the accompanying sense of well being ensures that pilots without training and experience will not recognise their intoxication.

Other published work tends to confirm the belief of many pilots, that crew capacity is impaired in subtle ways well below 10,000'. Above this level, the effects are obvious to an observer, and if you are exposed long enough, you lose consciousness. At lower altitudes, you don't pass out, but fatigue accumulates quickly. Studies indicate that cognitive, decision making and calculating abilities and short term memory all begin to deteriorate from 5000' to 8000'[2,3,4], though well learned skills remain[2,5]. Work in 1997 at the FAA's Civil Aeromedical Institute, found pilots continuing to make more procedural errors on descent from altitude and approach[5], indicating that impairment does persist for some time after returning to a lower level..

This presents less of a problem to a pilot carrying out a well rehearsed routine. The problem comes when he is presented with new information, or a new or different situation requiring the application of cognitive skills. Then there is a greater risk of an error or delay in judgement and or decision making. Usually the new situation arises towards the end of a flight. The still partially hypoxic crew have to plan and execute an Approach and landing, often with significant differences to what they may have been expecting.

The physiological response to altitude of fit young men has been found to vary widely, both between individuals, and in the same individual, depending on his physical condition and level of arousal[2,4,10]. The pilot population , particularly in General Aviation, is not composed of fit young men. After 50 the arterial plasma oxygen tension, which alone governs oxygen transfer to the tissues, normally drops[7]. As with the rest of the population, some pilots are smokers, which limits their lung performance[6]. Length of exposure at altitude also plays a significant part. Lactic acid accumulates in hypoxic tissues, which shows up as fatigue, which further magnifies the effects of the hypoxia.

Current ideas on safety emphasise the chain of multiple causes, which together end up in an accident. At the wrong time, perceptual error, or a delay in responding, may make the difference between a non-event and an accident. Most pilots are unaware of the effect of low levels of hypoxia on their performance and fatigue. There is no requirement for them to be told, and the nature of the effect makes it unlikely that they will work it out for themselves. It usually takes some experience, both without and with Supplemental Oxygen, to demonstrate the difference.
This proposal is to require flight crew to monitor their Blood Oxygen Saturation level with pulse oximeters, or use estimates from records established for each crew member under similar conditions, and maintain a minimum level, by use of additional supplementary oxygen, or lower cabin altitude. There should in particular be a minimum Saturation level maintained during descent and instrument approach.

2. Re: Low level Hypoxia and Oil Mist.

The oil mist problem probably presents a hazard that is a bit subtle, and there should be some advice given to pilots on the dangers and appropriate procedures in the event that they encounter it.

A fine oil mist entering the cockpit or cabin of a pressurised or unpressurized aircraft has the potential to incapacitate the crew and passengers, probably without their realising it is happening.

Oil and lungs don't get on well together. The wall of the alveoli, or air sacs, is coated with a surfactant film. It has a low surface tension which is required to maintain the open geometry of the air sacs. Any small quantity of oil (or lipids) alters the surface tension. That can cause distortion or partial collapse, and affect ventilation and blood flow matching. It may even upset the sac's ability to remain open, and will provoke a reaction that fills the sacs with fluids and makes the damage more permanent. The references provide examples of this. The net result is that the lung's capacity to transfer oxygen from the air breathed in, is reduced, and probably fairly quickly.

In an aircraft cockpit or cabin, the crew will already be partially hypoxic, because the cabin pressure is well below that of sea level. A pressurized cabin is normally maintained at a pressure equivalent to 6000' to 8000'. A loss of some lung capacity will drop their blood oxygen saturation levels further, so they will probably experience hypoxia equivalent to a much higher cabin altitude. If the loss is severe enough they may become incapacitated, without realising what is happening.

If a person breathes smoke, the large particles are intercepted in the nose and airways, where their deposition causes chemical or mechanical irritation, manifested usually by cough, chest tightness and sometimes breathlessness, so he knows that he is in trouble. Particles, including fluid droplets below 5 micron in diameter, will largely pass through the mechanical defenses on the lung and reach the alveoli without there being much of a physical cue. There are no nerves in the lung itself.

There appear to be no training or emergency procedures appropriate to handling the entry of oil mist into an aircraft cockpit or cabin. It is probably not a common occurrence, but there are stories of an oil mist entering in several aircraft types. It deserves some consideration..

We recommend that advisory material be provided to flight crew on the hazard presented by oil mist entry to the cockpit or cabin. This should at least cover identification and emergency procedures.

Yours sincerely,

Andrew Thom

Jonathon Burdon.

Annex 1. List of references.

Annex 2. Authors' background.

Annex 1.

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Annex 2.

Authors' background.

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Chief Pilot, Melbourme Air Taxis,
Authorized Person under CAR35 and 36, and holder of Weight Control Authority AV15.

Dr Jonathan Burdon MBBS, FRACP, FCCP, FACLM, Grad Dip Health & Med Law (Melb)
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Chairman, Respiratory Physicians, Medical Panels Victoria
Member of Council, Medical Defense Association of Victoria
Senior Associate, department of Medicine, University of Melbourne

SUBMISSION TO THE SENATE REFERENCES COMMITTEE
RURAL AND REGIONAL AFFAIRS AND TRANSPORT

ON THE INQUIRY INTO

AIR SAFETY - BAE 146
CABIN AIR QUALITY

SUBMISSION NUMBER 10

Ms Deborah Carter
48 Clinton Street
YORKEYS KNOB QLD 4878

Phone:
Fax:
Email:

RECEIVED
- 1 SEP 1999
Senate Rural and Regional Affairs and Transport Committee

48 Clinton Street
Yorkeys Knob
4878

25 August 1999

To Secretary, Senate of Rural & Regional Affairs & Transport Reference Committee,

My name is Deborah Carter & I am an ex Flight Attendant who flew for Ansett Australia.

I would like to make a submission to the senate inquiry into the BAE 146 air contamination.

After a fourteen year career as a flight attendant I became extremely ill after being exposed to toxic chemicals on The BAE 146 which I was constantly flying based in Cairns.

The fumes in this aircraft were coming through the airconditioning on take off & landing. They varied in strength from a light odour to smoke filling the cabin.

On the 14th November 1994 whilst crewing a four leg journey these fumes were so strong the 3 flight Attendants, including myself put portable oxygen on for all take offs & landing. The passengers were projectile vomiting & were very distressed.

I was so ill I attended the doctor with burning eyes, nausea, headaches, sore throat & numbness down the right side of my body.

From that day I was ill for 2 years.

I attended a number of specialists & I have strong medical evidence that my condition was caused by toxic chemical exposure. I would be happy to provide these documents if you require them.

I resigned on Medical grounds in 1995
I was able to obtain a job answering telephones in July 96. I still have effects from this exposure but I manage to keep employment as I can sit down at work.

My career had been cut short & my health has suffered from these fumes.

yours sincerely
Deborah Carter.

P.S
All 3 Flight Attendants who flew on the 14th November 1994 had to resign from their jobs, due to illness.

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SUBMISSION TO THE SENATE REFERENCES COMMITTEE
RURAL AND REGIONAL AFFAIRS AND TRANSPORT

ON THE INQUIRY INTO

AIR SAFETY - BAE 146
CABIN AIR QUALITY

SUBMISSION NUMBER 11

British Aerospace Australia Limited

Mr Bruce Jones
Senior Vice President Australasian Support
PO Box 312
BOTANY NSW 1455

Phone:
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Regional Aircraft
L1, 2B Lord Street
Botany, NSW 2019

PO Box 312, Botany
NSW 1455

Telephone +61 2 9666 8200
Facsimile +61 2 9666 8065

3rd September 1999

The Secretary
Rural and Regional Affairs and Transport References Committee
Parliament House
Canberra ACT 2600

Dear Sir,

The planned Australian Government Senate Committee Inquiry into airspace 2000 and related issues incorporates a "term of reference" on the examination of air safety, with particular reference to cabin air quality in the BAe 146 aircraft.

On behalf of British Aerospace I would like to provide our submission in response to that particular term of reference. The enclosed submission and attachments provide background information on the BAe146 aircraft and on the subject of cabin air quality. The submission includes the following attachments:

- Australian BAe146 route map
- Countries where the BAe146 is certificated
- Report dated July 11 1992 prepared by Dr V. Vasak
- Published report dated October 1996 prepared by C. van Netten
- Report dated August 1997 prepared by Richard Fox

I would like to register the point that British Aerospace reserves the right to submit further supplementary submissions to the Senate Inquiry. In particular we reserve the right to make a further written or verbal submission on the BASI Occurrence Report relating to an in-flight cabin air quality incident on an Australian registered BAe146, which was released yesterday.

British Aerospace would also welcome the opportunity to brief Committee members on its company and the BAe 146 aircraft and we look forward to hearing from committee members in this regard.

British Aerospace looks forward to contributing to the Senate Committee Inquiry and assisting the Committee in addressing any issues relating to the BAe146 aircraft.

Yours sincerely

Bruce Jones
Senior Vice President
Australasian Support

BRITISH AEROSPACE
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Parliament House
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Bruce Jones
Senior Vice President
Australasian Support

BRITISH AEROSPACE
Regional Aircraft

3rd September 1999

British Aerospace Submission To The Senate Rural and Regional Affairs and Transport References Committee

Inquiry into Airspace 2000

Introduction

The planned Australian Government Senate Committee Inquiry into airspace 2000 and related issues incorporates a "term of reference" on the examination of air safety, with particular reference to cabin air quality in the BAe 146 aircraft. This briefing paper provides the British Aerospace submission in response to that particular term of reference.

1 Summary

- In excess of 350 BAe146 type aircraft are in service, with 52 airlines. The aircraft is certificated in 37 countries.
- The BAe 146 air conditioning system is conventional, similar to most jet airliners and conforms to international standards.
- Reports of cabin air odours have been received from time to time and have predominantly been determined to be due to minor systems failures such as leaks from oil seals on the aircraft engines or auxiliary power unit (APU). The engine and APU manufacturers introduced modifications in 1992 that are designed to prevent oil leakage into the air conditioning system. These are being embodied in aircraft all over the world with excellent results.
- During 1998 CASA undertook a review of the BAe 146 air conditioning system's compliance with certification and airworthiness requirements and were satisfied with the results.
- 3 independent analyses (see paragraph 4) of the air supply have been carried out and no health or toxicity issues have been identified with the air supply on board the BAe146 aircraft.
- In recent times the subject of cabin air quality has become an industry issue and several aircraft types have been investigated principally in the United States and in Australia.
- Recently a judgment has been made in the case of Alysia Chew and Ansett Australia. In this judgment, Moran J quoted evidence from a panel of medical experts that the levels of measured chemical contaminants in the cabin air were not a threat to the health of aircrew or passengers.

2 The BAe 146 Series

- It is a regional aircraft designed and built by British Aerospace in the UK.
- It is available in three versions ranging from 70 to 100 seats.
- It is powered by 4xTurbofan engines manufactured by Allied Signal.
- It was initially certificated by the UK Civil Aviation Authority in 1984.
- In excess of 350 BAe146 type aircraft are in service, with 52 airlines currently operating in 27 countries.
- The BAe146 has never suffered a passenger fatality or a fatal accident due to technical failure in more than 4.5 million hours of operation.
- The BAe146 type is in worldwide operation with leading national and mainline customers such as Lufthansa, Sabena, City Flyer/British Airways, Mesaba/Northwest Airlines, Crossair, KLM and Turkish Airlines.
- The BAe146 aircraft started operations in Australia in 1985
- 42 x BAe146 aircraft operate within Australia and New Zealand with the major airline carriers
- The BAe146 operates to every State and Territory in Australia.

3 Design and Certification

- The BAe 146 type is certificated to operate in 37 countries including the UK, USA and Australia.
- The BAe146 aircraft in Australia are typical of the rest of the world fleet.
- Australian certification was granted following a detailed technical review of the Airworthiness Requirements and the design of the aircraft.
- The BAe 146 Air Conditioning System is conventional, similar to most jet airliners and conforms to International Standards
- There are no national differences in requirements for the air conditioning system and the Australian Department of Aviation accepted compliance concurring with both the CAA and FAA.
- The BAe146 is designed to operate with the air conditioning system recirculating a proportion of the air. This is normal for all aircraft types and the recirculated air improves humidity levels and helps reduce the symptoms of watering eyes and nasal and throat dryness caused by dry air.
- During 1998 in the light of cabin odour reports, CASA reconsidered the BAe146 air conditioning standards and its compliance with certification and airworthiness requirements, in the course of which it consulted with the UK CAA. BAe understands that CASA was satisfied with the results of that exercise.

4 Independent Analysis of the Air Supply

- In 1992 Dr V. Vasak conducted an analysis of air in BAe146 aircraft operated by Eastwest Airlines (now part of Ansett Australia). **The report stated that there was no evidence which would support the opinion that reported cabin odour would have lasting adverse health effects on flight crew or passengers. (A copy of this report is attached)**

- In 1996 Chris van Netten of the British Colombia University conducted a comparison of air quality in various types in the Air BC fleet. **No health or toxicity issues were identified and his published report stated that the air quality of a normal BAe146 compared favourably with that of a Dash 8 aircraft not associated with cabin air problems. (A copy of this report is attached)**

- In 1997 Allied Signal in conjunction with Ansett undertook toxicity testing on Ansett aircraft. **The report concluded that the air supply was within safety limits. (A copy of this report is attached)**

5 Cabin Air Quality

- In 1992 reports of cabin odours appeared in Australia and investigation established that small quantities of oil could migrate through Auxiliary Power Unit (APU) and engine bearing seals into the air conditioning system. (Independent analysis of the cabin air indicated there was no danger to passengers, cabin crew or flight deck crew).
- In response the engine and APU manufacturers have since introduced modifications, which are being embodied world wide with excellent results.
- In 1992 Domnick Hunter, a UK specialist company worked with BAe and analysed air samples as part of the work which led to the definition and introduction of the BAe cabin air filtration system. No toxicity issues were identified.
- BAe assisted Ansett by providing an Oil Coalescer and Air Filtration System for its BAe 146 fleet during the engine and APU modification phase.
- In July 1997 a BAe146 pilot suffered vertigo following selection of an engine air source on a system previously diagnosed as faulty owing to a failed engine oil seal. British Aerospace has responded to two draft reports prepared by BASI and is aware that BASI is currently in the process of issuing an Occurrence Report on the incident. Those draft reports are classified as confidential and British Aerospace is unable to respond publicly to the BASI report until it is officially released.
- The aircraft design provides an in-flight means to shut off contaminated air supply if this occurs during flight.
- 3 independent analyses of the air supply have been carried out and have found that no health or toxicity issues are identified with the air supply on board BAe146 aircraft.
- British Aerospace is not aware that any of the events, which have been investigated since 1992, have established any risk to the safety of either the passengers or the crew relating to any BAe146 during flight.

6 Recent air quality issues

- In recent times the subject of cabin air quality has become an industry issue and several aircraft types have been investigated principally in the United States and in Australia
- Recent world wide cabin air quality events on many aircraft types, not just the BAe 146, have included the use of anti-icing fluid on the airframe prior to take off and the use of excessive amounts of dry ice in the galley.
- During 1998 British Aerospace and Ansett reviewed a number of options to enhance the working environment within the vestibule (galley) area of the BAe146. Subsequently optional modifications have been introduced as follows:

  - Removal of potential odours from the toilet compartment and the reduction in carbon dioxide levels (caused by the use of dry ice) by installing an electrically operated toilet extraction system.
  - Improved air movement in the vestibule (galley) through an additional air outlet in the forward and rear vestibule.
  - Improved lighting within the vestibule area.
  - Extension of the conditioned air tubes in order to provide air outlets in the roof panels between the overhead luggage lockers.

Note 1. (The above modifications are customer optional and have no effect on the certification standard of the aircraft).

Note 2. (British Aerospace has recommended to operators that they use recirculation mode to increase the humidity in the cabin in order to reduce the effects of watering eyes plus nasal and throat dryness caused by dry air).

7 Industry Awareness

- Cabin air quality periodically becomes an industry issue with cabin crew and flight crew (and very rarely with passengers). Several aircraft types have been investigated principally in the United States and in Australia.
- Recently a judgment was made in the case between Alysia Chew and Ansett Airlines which arose out of her work as a flight attendant on the BAe146 of Eastwest Airlines between January 1992 and October 1993. In his judgment, Moran J quoted evidence from a panel of medical experts:-

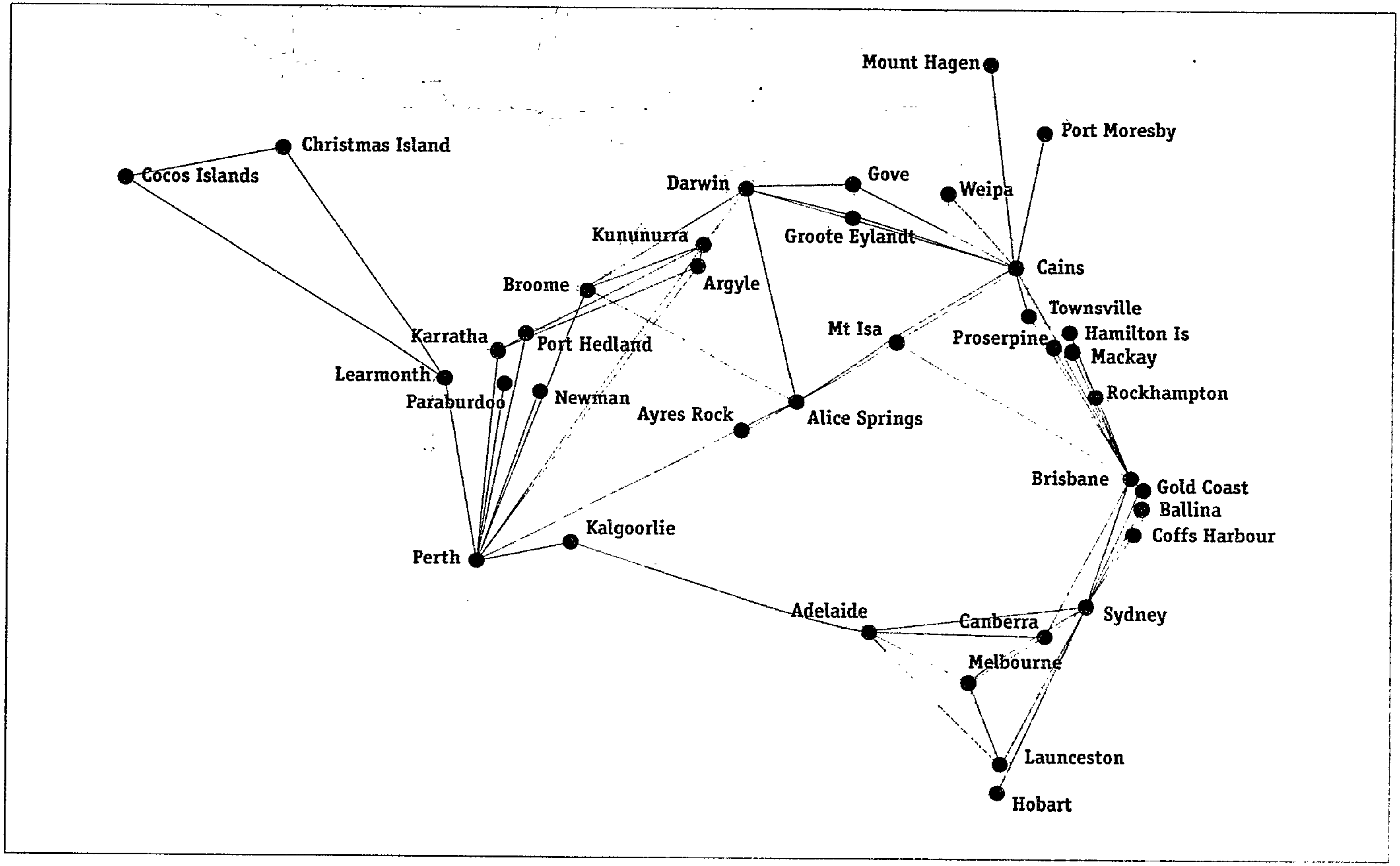
1. The levels of measured chemical contaminants in the cabin air were not a threat to the health of aircrew or passengers.
2. Contaminant levels were well below internationally accepted occupational health standards and cannot precipitate any chronic disorders.
3. The levels of contaminants were hundreds to thousands of times below those levels known to cause neurotoxic sequelae.

It should be noted that Moran J acknowledged that Ms Chew's had a pre-existing viral condition, which made her particularly sensitive to irritants.

8 Conclusion

- There has never been any evidence of any toxicity in the BAe146 cabin air, and since 1992 there have been a number of independent analyses into the BAe146 air quality, and none of them have established any risk to the safety of either the passengers or the crew or breach of accepted safety standards.
- Nevertheless, British Aerospace has throughout remained sensitive to its customer needs and concerns, and has in particular worked with the manufacturers of the engines and the APU to produce a package of optional modifications in 1992, and more recently working with Ansett to produce a suite of customer enhancements to improve the cabin environment.

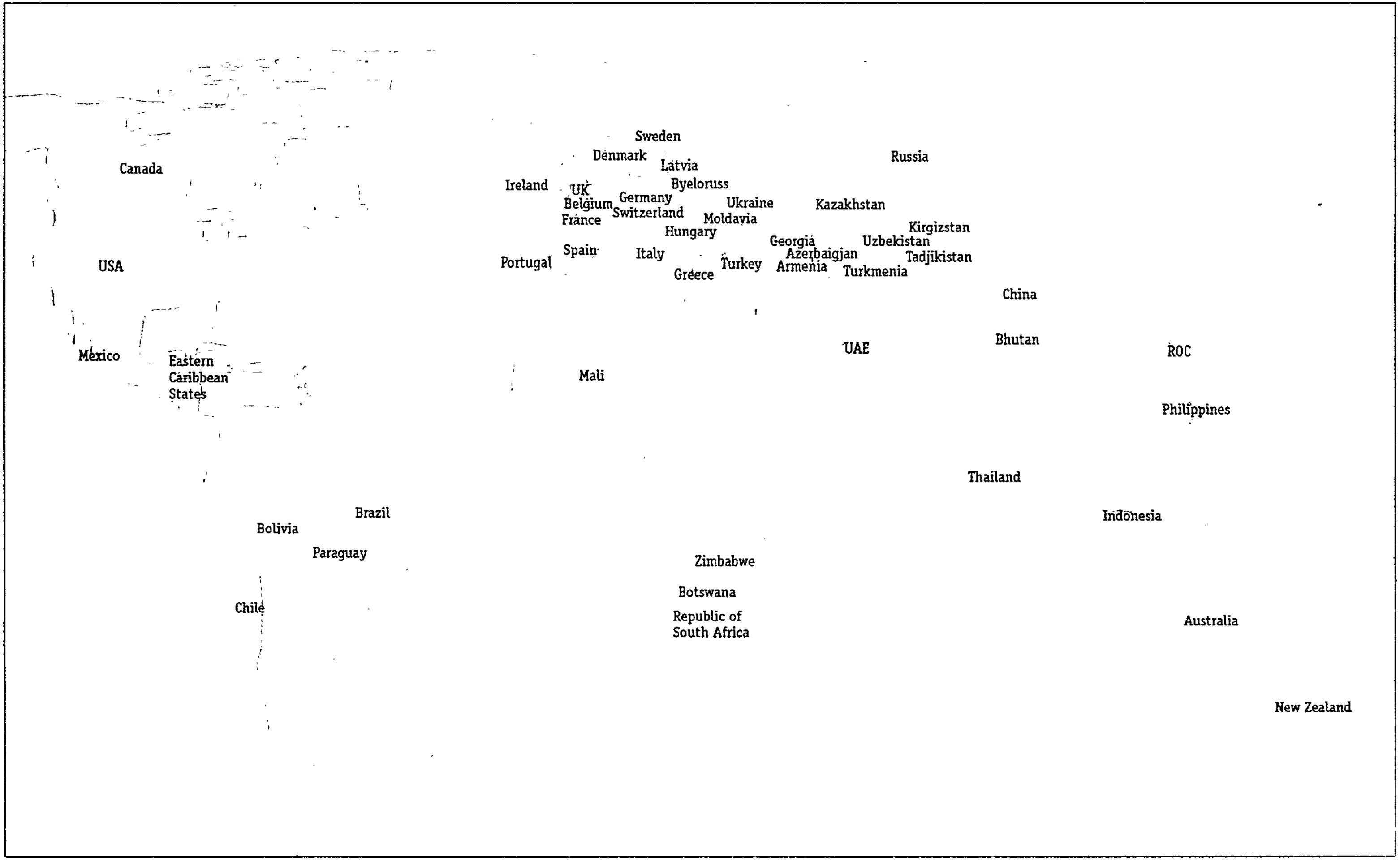
BAe 146 Series Aircraft Services in Australia



BRITISH AEROSPACE
Regional Aircraft

September 1999

BAe 146 Series Aircraft World Wide Certification



INDUSTRIAL HYGIENE AND
ENVIRONMENTAL SERVICE LABORATORIES P/L.
25 Hunter Ave, ST. IVES NSW 2075
Principal Consultant Dr V. Vasak

CABIN AIR CONTAMINATION IN BAe 146 in EASTWEST AIRLINES

In addition to my preliminary report of June 21, 1992, I am presenting the "Results of analyses" No 201986-1 and 202310-4 by the WorkCover Authority laboratory. These documents refer to samples collected on the test flight on May 15, 1992 in Sydney and June 4, 1992 Sydney-Coolangatta and Brisbane-Sydney.
Included are my conclusions drawn from the laboratory results and general comments.

SAMPLING PROCEDURES AND DESCRIPTION OF SAMPLES

The samples No 201986 and 201987 were portions from the original polyurethane filters removed from the outlet of the air duct into the cabin. As these filters must have been in situ for considerable time it was expected that they are representative of the oily contaminant entering the cabin.

The extracts from these filters were analysed by an infrared spectrophotometry as well as by a fluorimetric scan. The similarity with the unused MOBIL JET Oil II was also investigated, as this lubricant is expected to enter the turbine compressor section which is the source of the bleed air used to pressurise the cabin.

The samples No 201988, 201989 and 201990 were absorbent tubes with the XAD polymer and the sample No 201991 was an activated charcoal tube. Air in the cabin was drawn through these tubes by battery driven pumps (Spectrex PAS-3000 Personal Air Sampler) calibrated for the correct flow rate. The pumps were situated in the aircraft at the locations described in the report (cockpit and seats 1/C, 8/C and 18/A).

The WorkCover Authority report No 201986-1 states that no similarity has been found between the collected samples and the unused Mobil Jet Oil II. This fact made the quantitative evaluation of the samples impossible.

The dissimilarity between the contaminants collected on the sorbents and the unused Mobil Jet Oil II indicated that the lubricant has underwent some change. It is well known from other literature sources that more than 50 individual components could be present in such synthetic oils. The thermal degradation or partial decomposition of the oil mist in a catalytic converter can occur.
The gradual stripping of the more volatile components from the hot oil in the air duct may also contribute to a somewhat changed analytical spectrum of contaminants in the cabin.

A full identification of the individual odorous trace components could not be carried out by the WorkCover laboratory mainly because of the low volatility of the lubricant ingredients which makes the GC separation difficult.

All six samples were further analysed for the presence of tricresyl phosphate which is known to be present in minute quantities in the Mobil Jet Oil. The presence of tricresyl phosphate would be of considerable concern as one of the isomers (ortho) is known for its neurotoxic properties. Using high performance liquid chromatography (HPLC) the tricresyl phosphate could not be detected in any of the six samples.

The report No 302310-4 refers to air samples taken on the aircraft EWS in flight Sydney-Coolangatta and the EWR from Brisbane to Sydney.

Samples of used oil from EWI aircraft were also collected and labeled with the engine numbers 1, 2, 3, 4 and APU.

The gauze inserted for a number of days into the air duct came from the aircraft EWR and is described in the report as "swab".

The sampling train consisted of a Millipore membrane filter of porosity 0.9 micrometres followed by a charcoal absorption tube. Spectrex pumps were calibrated for the flow with the resistance of the sorption unit.

In the sample No 201310 collected in the cockpit, the absolute amount of oil was 0.12 mg. With the flow rate of 0.75 L/min and operation time 113 minutes, the total volume of air sampled was 85 litres and the calculated concentration of oil in the air was 1.4 mg per meter cub.

In the sample No 202313 collected mid cabin on the EWR flight Brisbane-Sydney, the amount of oil collected was 0.09

mg. With the flow rate of 0.9 L/min and the operation time 79 min, the total volume of air was 71 litres and the calculated concentration of oil was 1.3 mg per meter cub.

In both of these cases the similarity between the used Mobil Jet Oil II and the contaminant in the aircraft was confirmed by a spectrofluorimetric scan.

In the samples No 20211 and 20212 from the flight of EWS SYD-BRS at locations 13L/H and 20 L/H the scan could not be matched with the submitted used oils and therefore the quantification was not possible.

The charcoal tubes were analysed separately for volatile components. In the cockpit the concentration of 0.01 mg of toluene could be detected. In the sampled volume of 85 litres, this corresponds to a concentration of 0.11 mg of toluene per meter cub of air.

In the remaining three samples of air taken in the cabin, toluene was not detectable.
The Exposure Standard for toluene as a time weighted average for an 8 hour shift is 377 mg/m cub. The short term exposure limit is 565 mg/meter cub. The concentration of toluene in the cockpit (0.11 mg/meter cub) was considered negligible.

The minute quantities of ethyl alcohol found in the samples No 202310, 202311, 202312 and 302313 were 0.03, 0.04, 0.09, 0.01 mg respectively. Expressing these absolute figures as concentration of ethyl alcohol in milligrams per meter cub. in air, all these results are negligibly low (less than 1 mg/meter cub, while the Exposure standard would allow concentration for ethyl alcohol 1 880 mg/m cub).

The source of the ethyl alcohol, according to the maintenance personnel, may be the methylated spirit used in the cleaning of the cabin interior.

CONCLUSIONS

The quantitative determination of the air contaminants in the cabin poses analytical problems as the levels are low and the composition of the highly complicated mixture varies. The emission can be affected by the operational conditions of the aircraft, temperature of the turbine air, performance of the catalytic converter and other factors.

In the case where the spectral match between the contaminant and the Mobil Jet Oil II was found, the concentration of the oil mist in the cockpit was 1.4 mg/m cub and in the cabin

1.3 mg/meter cub. This is within the recommended Worksafe Exposure Standard of 5 mg per meter cub (TWA for 8 hours inhalation exposure in workroom atmosphere). The same limit for oil mist is suggested in the Material Safety Data Sheet by Mobil.

The analyses have shown that the potentially toxic tricresyl phosphate could not be detected in any of the samples collected in the air duct, cabin and cockpit.
The detection limit of 0.01 mg quoted by the WorkCover Authority laboratory is adequate for this determination.

As reported previously the carbon monoxide could not be detected in the cabin air either on the ground or in the flight during various operational modes. The carbon dioxide measured at various occasions during the flight as well as during the testing of the engines on the ground was well within the hygiene standard.

While the contaminants in the cabin air can cause discomfort and be considered a nuisance there is at present no evidence which would support the opinion that the odour would have lasting adverse health effects on the flight crew or passengers. On the other hand providing a clean cabin atmosphere as far as technically possible will always be the principal aim of the occupational hygiene.

COMMENTS

The reason that only a limited number of quantitative results for concentration of the oil mist were produced up to now lies in the methodical difficulties of quantification of this type of air contaminants.
It took more than a month of the WorkCover Authority laboratory effort to provide the first results as various analytical approaches had to be tested.

Unless the problem of the cabin air contamination is satisfactorily resolved soon by technical means e.g new catalytic converters, electrostatic precipitators, filters or a "burn off" procedure, further tests should be carried out. Greater number of representative samples is required to confirm a low concentration of oil mist in the cabin as this can vary with operation of the aircraft and its maintenance.

Strong suggestion was made that the aircraft manufacturer provides the testing procedure believed to be developed by the American SAE E31 Committee for testing the cabin air for contamination by lubricants and their degradation products.

The above procedure recommends a portable flame ionisation detector (FID) as a "carbon counter". This technique would

not allow the separation of individual components but could instantly evaluate the total level of all organic contaminants in the cabin air.

Parallel to the efforts of EastWest Airlines to resolve the problem by technical means, a literature search is continuing for any further information on toxicity of degradation products of the lubricant. Contact with the overseas manufacturer, Mobil Oil, has already been initiated.

Dr Vladimir Vasak
Fellow of the Australian Institute of Occup. Hygienists
Member of the British Institute of Occup. Hygienists

St Ives, July 11, 1992

Enclosure
2 WorkCover Authority reports

WORKCOVER AUTHORITY

Reference
201986-1

Mr V Vasak
25 Hunter Avenue
ST IVES NSW 2075

RESULTS OF ANALYSIS

Samples Analysed as Received

SAMPLE ORIGIN: East West Airline

SAMPLES: Air Filter (201986, 201987);
XAD Tube (201988, 201989, 201990);
Charcoal Tube (201991)

DATE OF INVESTIGATION: 15/5/92 **DATE RECEIVED:** 18/5/92

ANALYSIS REQUIRED: Spectrofluorimetry Scan and Tricresyl Phosphate by HPLC

Reg No	Sample Ib	Spectrofluorimetric Scans of Extracts
201986	Air Filter	The scans for all of these extracts were not similar to that of the Mobil Jet Oil II
201987	Air Filter	
201988	I - 1/C	
201989	II - cockpit	
201990	III - 8/C	
201991	IV - 18/A	

COMMENTS: Both airfilter extracts (201986 and 201987) were checked by infrared scans as well, and were also found to be not similar to an infrared spectrum of Mobil Jet Oil II. The above six sample extracts were also tested for tricresyl phosphate by HPLC and nothing was detected in any of the samples. Our detection limit for tricresyl phosphate by HPLC is 0.05 mg/sample.

Robert Geyer
Manager
Laboratory Services
Date: 6/7/92

LABORATORY SERVICES 5A Pioneer Avenue Thornleigh NSW 2120
Phone (02) 484 6655 Fax(02) 980 6649

WorkCover Authority

Reference
202310-4

Mr. V Vasak
25 Hunter Avenue
ST IVES NSW 2075

RESULTS OF ANALYSIS
Samples Analysed as Received

SAMPLE ORIGIN: East West Airlines

DATE OF INVESTIGATION: 1/6/92 **DATE RECEIVED:** 10/6/92

ANALYSIS REQUIRED: Spectrofluorimetric Scans, and Qualitation and Quantitation of Oil Mist

Reg No	Sample	Sample ID	Spectrofluorimetric Scans of Extracts	mg Oil
202310	Filter	Ia	Both Scans were similar to engine oil 2 and 4	0.12
202313	Filter	IVa		0.09
202311	Filter	IIa	Scans were similar but could not be matched with any of the submitted oils	
202312	Filter	IIIa		
202314	Swab	EWR		

COMMENTS: The oil mist loadings on the filters were very light. Hence, the charcoal tubes were not analysed for oil mist but rather, individual solvent compounds. None of the above filter sample scans were similar to the scan for the APU oil. Engine oils 1 and 3 had similar scans.

	Charcoal Tubes	
Reg No	Ethanol mg	Toluene mg
202310	0.03	0.01
202311	0.04	N/D
202312	0.09	N/D
202313	0.01	N/D

N/D: Not Detected

DETECTION LIMIT: Single Substances - 0.01 mg/sample; Complex & Grouped Substances - 0.1 mg/sample.

Robert Geyer - Manager
Laboratory Services
Date: 6/7/92

Air Quality and Health Effects Associated with the Operation of BAe 146-200 Aircraft

Christiaan van Netten

Department of Health Care and Epidemiology, University of British Columbia, James Mather Building, 5804 Fairview Avenue, Vancouver, British Columbia, Canada V6T1Z3

Poor air quality and health complaints from flight crews operating BAe-146 aircraft, requiring admission to emergency departments on several occasions, led to an investigation into the source of these problems. Health complaints could be classified as those consistent with exposure to carbon monoxide, respiratory irritants, and possible neurological agents. Cabin air is bled off from the engine's combustion air, passes through a catalytic converter to clean the air from oil contaminants, is cooled from 550° to 50°C, and enters the cabin after it passes through an airpack unit which conditions the air as appropriate. Excessive oil leakage from oil seals overloaded the catalytic converter, allowing smoke and lubricating oil components to enter the cabin. A complaint aircraft air, during a test flight, was found to contain oil contaminants including siloxane lubricating oils, as well as methylated propane and butane ester derivatives. Tricresyl phosphates, known to be neurotoxic, were identified in bulk oil samples, but could not be demonstrated in the cabin air. Air quality measurements in a problem aircraft tested on the tarmac indicated carbon monoxide at 3 ppm and carbon dioxide at 900 ppm. Air quality measurements during normal commercial flights of three noncomplaint aircraft (two BAe-146s and one de Haviland Dash 8-100) showed no detectable levels of carbon monoxide, 900 to 2700 ppm for carbon dioxide, and 19.6 to 21.9 percent for oxygen. Carbon dioxide and oxygen levels would change predictably during takeoff and landing for the former and pressurization and depressurization for the latter. Carboxyhemoglobin levels in four individuals admitted to emergency departments ranged from 0.7 to 2.0 percent. Since no direct carbon monoxide measurements were available during these incidents, it was recommended that potential problem aircraft be equipped with datalogging carbon monoxide monitors to identify or eliminate carbon monoxide exposure as a problem. van Netten, C.: Air Quality and Health Effects Associated with the Operation of BAe 146-200 Aircraft. Appl. Occup. Environ. Hyg. 13(10):733–739; 1998. © 1998 AIH.

Complaints of ill health from flight crews operating the British Aerospace BAe-146 series aircraft, followed by threats of a walkout, initiated an investigation into the complaints and the history and operation of these aircraft.

The aircraft was conceived in 1973 and designed for short-range transport. In 1981 it was test flown and acquired the name "the quiet trader" as a reflection of the quiet operation of its four turbofan engines.[1] At the end of 1993 a total of 217 BAe 146 aircraft were in use worldwide. Of these, 193 were being operated by 59 different airlines; 19 by manufacturers, brokers, and leasing companies; 4 by a number of governments; and 1 by a private operator.[2] The majority of these aircraft (199) are propelled with four Textron Lycoming turbojet engines (ALF 502R5). These engines are not used in any other aircraft. A total of 18 aircraft are outfitted with the LF507 engines, but none of these are operating in Canada.

As with other aircraft, the ventilation and heating system is dependent on the engines for the in-flight cabin air, which is bled off from the compressed combustion air just prior to the combustion chamber at location E in Figure 1. At this point the temperature of the air is in excess of 500°C and normally contains minor contaminants from the upstream engine lubrication system. For this reason the BAe-146 aircraft also makes use of catalytic converters, situated on the engines, which are responsible for converting any oil contaminant in the air destined for the cabin to carbon dioxide, water, and nitrogen. The air then passes through a heat exchanger, located in the engine pylons, which cools the air to around 200°C before it is ducted through the spine of the aircraft to the rear into an airpack unit. There are separate airpack units for the right and left sides of the aircraft. The airpack units condition the air before it is ducted into the cabin at temperatures between 50° and 60°C, depending on requirements. Engine air is also used to control the pressure within the aircraft.

In addition, there is an auxiliary power unit (APU; Allied Signal 36-100 or 36-150) situated in the tail section of the aircraft, which is also jet powered and provides electrical power to the aircraft when operating on the ground. On the ground and during takeoff, when combustion air cannot be spared from the engines, the APU is also responsible for the cabin air. Under these conditions cabin air can become contaminated from external sources such as engine exhaust when the APU is operating when taxiing at the airport or while waiting in line for takeoff behind other aircraft.

Under normal conditions, when the ventilation system is switched on, there usually is a momentary smell that disappears within seconds and which is consistent with the operation of most air ventilation systems. The flight deck has control over the cabin air and can choose which airpack to use and whether to use 100 percent fresh air or recirculated air. The latter is generally a mix of 40 percent recirculated and 60 percent fresh air.

In the past there have been sporadic complaints from flight crews of some BAe-146 aircraft operating in Canada regarding poor air quality. Although a nonsmoking policy has been in place for several years, the number of complaints has increased dramatically since January 1996 and appears to be coincident with the aircraft company switching the aircraft jet engine oil

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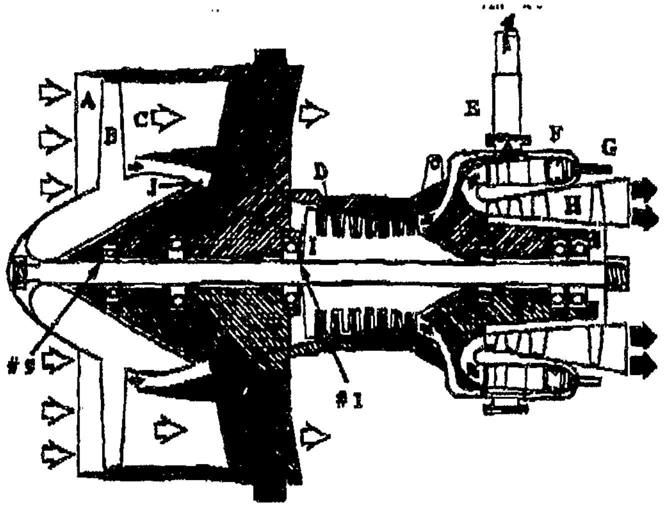

FIGURE 1. Simplified diagram of the turbo ALF 502R5 turbojet engine showing the general location of bearings 1 and 9 and the source of cabin air contamination due to leaking oil seals. (Adapted from Textron Lycoming, ALF 502, Student Workbook, pp. 1–8, Engine Bearing Locations.) Air enters the engine at location A and is compressed by the turbofan (B), allowing most of the air to bypass the rear section of the engine at C. Some air is funneled into the engine and is further compressed by the compressor blades at D. Some air is diverted into the catalytic convertor (E) before it is directed toward the cabin. Highly compressed air is forced into the combustion chamber (F), where it is mixed with fuel from the fuel supply (G) and is combusted. High pressure exhaust gases exit the engine, passing the turbine blades at H, driving the engine. Improper seals at the locations of bearings 1 and 9 allow oil constituents to enter the combustion air at I and J, respectively, contaminating the air destined for the cabin.

from Exxon 2380 to Castrol 5000. Since then, the air quality complaints have been traced to leaky oil seals associated with bearings 1 and 9 of the jet engines (Figure 1). Once the source of air contaminants was known, a rigorous daily inspection regime was initiated, followed by immediate replacement of the oil seals if this was indicated. This approach prevented some, but not all, exposures. Although there were health complaints prior to the oil switching, the complaints appeared to be more numerous after this had taken place, and a variety of symptoms have been reported ranging from itchy, red eyes to flight attendants requiring oxygen during flight followed by admission to the local emergency department at the port of arrival. The complaints appeared to be more frequent among flight attendants than among pilots.

This article reports on the health complaints by the flight crews as well as the findings regarding air quality measurements taken during flight and test conditions of two of the aircraft that had experienced oil seal failure. It also reports on the problems encountered when these exposures occur in flight, the warning system present, and the approach taken by medical personnel when these flight crews reported to the emergency department of a local hospital. To show that BAe-146 aircraft with properly functioning oil seals have air quality comparable to other aircraft, in-flight comparisons of the air quality of one BAe-146, another BAe-146 outfitted with an experimental activated charcoal air filter, and a Dash-8 aircraft that had never been associated with any complaints were also made.

Methods

Exposure description and health complaints were taken from the accident reports filled out by the individuals involved, as well as from clinical assessments. Aircraft 1, of the BAe 146-200 fleet, had come in on the previous night with complaints from the flight crew regarding air that made them ill. The aircraft had been operating on Castrol 5000. That evening the oil was removed and replaced with Exxon 2380. The next day this aircraft was tested during flight for air contaminants such as volatile organic compounds (VOCs) and higher molecular weight oils. VOCs were measured using activated charcoal adsorbent tubes and portable sampling pumps running at calibrated air flows of 0.1 L/min, according to the Worker's Compensation Board of British Columbia method 3301.[3] The higher molecular weight hydrocarbons, such as potential aerosolized oils, were collected on a filter cassette and attached to portable pumps running at calibrated air flows of 2 L/min. The cassette filters were extracted with acetonitrile and analyzed on a high pressure liquid chromatograph (HPLC). The activated charcoal adsorbent tubes were extracted with carbon disulfide and analyzed on a GC–mass spectrometer with detection limits for VOCs in air ranging from 1 to 13 ng/m^3. Two sets of air samples for both analyses were taken during flight, one set behind the copilot's seat and the other set at the rear of the cabin at head height. Bulk and head space samples of the two oils at room temperature were analyzed with HPLC.

The flight crew of aircraft 2 (BAe-146) had experienced air quality problems on a 2-hour flight, requiring the pilots to remain at the destination of that flight for 24 hours. This aircraft was brought back to its port of origin and tested on the ramp the following day for carbon monoxide and carbon dioxide. Both gases were measured using direct-reading instruments in the galley, situated behind the cockpit, as well as the rear of the cabin. The APU and each of the engines were tested separately under a number of conditions, including pressurization, as high as a 0.2 atm (3 psi) pressure differential, and depressurization.

A BAe-146 (aircraft 3) equipped with a standard air handling system was monitored for the duration of a 3-hour, one-stop round trip with 28 and 35 individuals on board, respectively. A second BAe-146 (aircraft 4) outfitted with an experimental activated charcoal air filter was monitored on a 4-hour, one-stop round trip. This flight had 80 and 35 individuals on board, respectively. The reference aircraft was a de Haviland Dash-1(aft 5). This aircraft was monitored for the duration of a 3-hour, two-stop flight with 23, 16, and 13 individuals on board, respectively. All measurements were made in the rear or section of each aircraft.

Carbon dioxide and carbon monoxide (detection limits of 5 and 1 ppm, respectively) as well as relative humidity and temperature were measured using a Q-Track indoor air quality monitor (TSI Incorporated). The instrument was set to record the environmental parameters every 5 minutes and was calibrated for carbon dioxide using nitrogen as the zero gas and 0 ppm carbon dioxide calibration gas (Matheson). Nitrogen oxides were measured using an Odyssey 2001 gas monitor (Transducer Research Inc.). Oxygen and additional carbon monoxide concentrations were measured using a TMX 410 datalogger (Industrial Scientific Corporation) with detection limits of 0.1 percent and 1 ppm, respectively. All equipment had datalogging capabilities, and the information was downloaded into an IBM 486 computer.

Results

Exposure descriptions by flight crews over a 4-month period included the following: sharp odor in cabin, assault by toxic fumes, heavy exhaust smell, deicing smell, soapy smell, detergent smell, dirty sock smell during takeoff, oven cleaner smell, peroxide smell, acrid noxious fumes filling cabin on descent, aircraft filled with heavy blue haze, and strong smoke odor. Flight attendants generally noted an odor during takeoff and landing. They reported that, as their flight progressed, they frequently experienced burning eyes, nasal congestion, sore throat, and tingling lips. Several experienced disorientation, were unable to continue with their duties, and were administered oxygen. A summary of the symptoms reported during the 4-month period is shown in Table 1.

Carboxyhemoglobin (COHB) levels obtained 4 hours after the incidents in four individuals were 0.7, 0.7, 1.0, and 2.0 percent. The latter individual was a smoker. Most of the symptoms resolved within 24 hours postexposure, and no residual health problems related to these exposures were reported.

as test flown for 1.5 hours the day after the flight the complaints. Samples for analysis were taken . Two minutes after takeoff an oily smell with

TABLE 1. Symptoms Reported by Flight Crew During a 4-Month Period

Symptom	No. of Individuals
Headache	29
Burning eyes	27
Burning throat	48
Watery eyes	6
Sinus congestion	6
Light headedness	6
Nausea	9
Chest pains	7
Dizziness	7
Disorientation	16
Breathing problems requiring oxygen	2
Gagging, coughing	3
Blurred vision	1
Tingling of nose and lips	3
Numbness	2

Five aircraft, involving 35 flights each. Total individuals with symptoms = 112; total flight crew present = 200.

a distinct detergent and sour smell overtone, which changed to a hot oil smell after a few minutes, came into the cabin. The aircraft went through a number of ascents and descents in order to simulate takeoff and landing conditions. The ventilation air source was also checked during the flight by isolating each engine. It was found that air from engine 4 definitely resulted in a stronger smell in the cabin, and confirmed an earlier observation that seal 9 of this engine was found to be leaking.

The results from the VOC analyses of samples taken during these conditions indicated the presence of a number of agents in the samples from the cockpit and the rear of the cabin when compared with the laboratory blank. These included alpha pinene, long-chain hydrocarbon derivatives such as, 3,7-dimethyl-1,3,6 octatriene (fit 881), and 3-isopropoxy-1,1,1,7,7,7 hexamethyl-3,5 (fit 797), as well as a number of siloxane derivatives including, 1,1,1,3,5,7,9,9,9,-nonamethylpentasiloxane (fit 882), decamethyl cyclopentasiloxane (fit 817), dodecamethyl cyclohexasiloxane (fit 859), tetradecamethyl-hexasiloxane (fit 714), hexadecamethyl heptasiloxane (fit 664), and hexadecamethyl heptasiloxane (fit 759). The results from the cockpit and the rear of the aircraft were virtually identical except for the presence of hexadecamethyl heptasiloxane, which was found only in the rear of the aircraft. The levels of contaminants measured in the rear of the aircraft were three times higher than in the cockpit.

The results of the analyses for VOCs in the head space of the bulk oil samples showed that there was virtually no difference between these samples and the laboratory blank (air) at room temperature (i.e., no volatiles were present under these conditions). HPLC analyses of filter cassettes for potential aerosolized oil components in the cabin did not indicate their presence.

The results of the bulk oil samples analyzed by HPLC indicated that the two oils were very similar, with Exxon showing a small additional peak. Castrol showed two small additional peaks. These peaks have not been identified since the ingredients of these oils are not revealed and are deemed

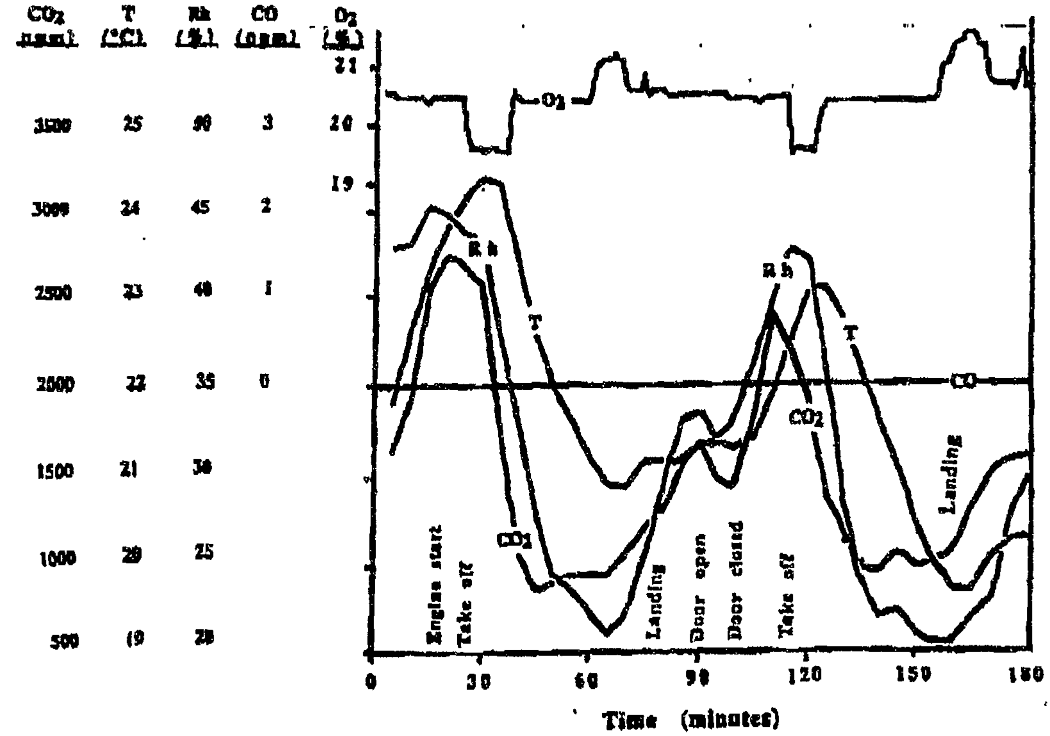

FIGURE 2. Graph showing the transients in carbon dioxide (CO_2), temperature (°C), percent relative humidity (Rh), and carbon monoxide (CO), and percent oxygen during a commercial flight of aircraft 3. All measurements were made in the rear of the passenger cabin.

proprietary information by the two companies. Standards are therefore not obtainable for identification. The two companies acknowledge the fact that these jet engine oils do contain 2 to 3 percent of tricresyl phosphates, which are high pressure lubricants. A standard for the o,m,p isomers of this agent was obtained, and, upon further analysis, the retention time of the para isomer coincided with one of the peaks present in each of the bulk oils.

When aircraft 2 was tested on the tarmac in the absence of other aircraft, there was a distinct oil odor which became highly pronounced when the air supply from engine 2 was introduced into the cabin. The cabin temperature was 22°C with a duct temperature of 63°C. Under these conditions it was very noticeable that a distinct stratification of the cabin air was present. At the upper levels where the air registers are located, and coinciding with head level of a standing individual, the air was quite difficult to deal with (i.e., blue smoke that irritated the upper respiratory tract and eyes). When seated, however, head level would be in a stratum of colder, more acceptable air. The carbon dioxide levels ranged throughout the testing period, with three individuals present, from 528 ppm at the start to a high of 900 ppm when engine 2 was tested under full takeoff power with 100 percent fresh air with duct and cabin temperatures of 69° and 26°C, respectively, and at a 0.2 atm (3 psi) pressure differential. Under these conditions carbon monoxide reached a level of 3 ppm. During the testing exercise the carbon monoxide levels hovered between 1 and 2 ppm and rarely went up to 3 ppm. There were no major differences between levels measured at the front of the cabin compared to the back for either gas. Under the test conditions, switching from 100 percent fresh air to the 60/40 percent mix recirculated air did not result in any significant differences.

The results from the in-flight air quality comparisons of three aircraft indicated that the air of properly maintained BAe-146 aircraft was similar to the air quality in the Dash 8-100. As an example of the various environmental parameters that were monitored over the duration of each flight, the results from aircraft 3 are presented in Figure 2. The trends shown were similar for aircraft 4 and 5.

In general, it can be noted that carbon dioxide concentrations, along with temperature and relative humidity in the aircraft, rose sharply after loading of passengers and before takeoff, at which time these parameters decreased until landing. Again a rise in these parameters was noted during the interval between landing and the unloading of the passengers. After a short decrease in these parameters, when all passengers have

left, a sharp increase can again be observed between loading of new passengers and takeoff. This general cycle repeated itself. The carbon dioxide levels measured in aircraft 3 (BAe-146) ranged from 850 to 2700 ppm. In aircraft 4 (BAe-146) these ranged from 800 to 2300 ppm. Similar transients were obtained in aircraft 5 (Dash 8-100), where carbon dioxide levels ranged from 1100 to 2500 ppm. In all aircraft no carbon monoxide was detected above the detection limit of 1 ppm using two independent sensing systems.

Oxygen concentrations appear to change rather predictably, with a decrease after takeoff and an increase prior to landing. In aircraft 3 oxygen levels ranged from 19.6 to 21.8 percent. In aircraft 4 these ranged from 19.6 to 21.2 percent. Both aircraft maintained a relatively stable 21.7 percent oxygen level during flight. Aircraft 3 maintained a more steady oxygen level compared with aircraft 4. Aircraft 5 generally maintained an oxygen level of 20.8 percent, which ranged during takeoff and landing from 19.71 to 21.9 percent.

Discussion

When confronted with complaints of a "bad smell" in an air quality situation such as this, it is very difficult to zero in on a particular agent and monitor it. This was further aggravated, after the oil seals were identified as the problem, by the fact that the manufacturers of the jet engine oil do not disclose the composition and ingredients of their product in the required material safety data sheets, claiming that this is proprietary information. In situations like this, one has to rely on the symptoms of the individuals involved and check for classes of agents that are most likely to be present and which could be the cause of these symptoms.

Some of the reported symptoms appeared consistent with those associated with low level carbon monoxide exposure, including headaches, nausea, light-headedness, and disorientation.[4] Some of the other symptoms, including burning eyes, burning throat, watery eyes, and sinus congestion,[5] appeared to be consistent with exposure to an irritant such as smoke or VOCs. The tingling and numbness experienced by some individuals appear to indicate some neurological involvement, indicating possible exposure to volatile neurotoxic hydrocarbons such as hexane and octane,[6] as well as tricresyl phosphates (TCPs),[7] known ingredients in jet engine oils.

At the time of the test flight of aircraft 1, it was learned from the British aircraft manufacturer representative, that the air destined for the cabin is passed through a catalytic converter in order to oxidize any oil contaminants to carbon dioxide and water. Catalytic converters operate at maximum efficiency under highly specific conditions of temperature and contaminant to air ratio. As an example, the Engelhard TWX catalytic converter[8] used for automobiles operates best at a contaminant to air ratio of 1/14.7. Under these conditions it is 95 percent efficient in changing carbon monoxide to carbon dioxide, hydrocarbons to water and carbon dioxide, and nitrogen oxides to nitrogen and carbon dioxide. For this reason an oxygen sensor is often present in the exhaust stream to provide feedback to the carburetor to keep this ratio as ideal as possible. The catalytic converters in the aircraft are probably subject to similar principles for efficient operation. When the contaminant to air ratio is drastically altered, as in an aircraft with leaky oil seals, one can expect a number of contaminants to pass through the converter in an original or semialtered state. This makes it even more difficult to zero in on a particular agent for testing. For this reason it was decided to monitor for the most acute toxic agent that could potentially be generated if the catalytic converter was not operating efficiently (i.e., carbon monoxide, since it lacks an odor which could act as an early warning system.

Under the test conditions of aircraft 2, the highest level obtained was 3 ppm, which is well below the 25 ppm level which is the exposure limit set by the American Conference of Governmental Industrial Hygienists (ACGIH) for an occupational setting.[9] Although both aircraft had a "dead stop" carbon monoxide detector (Houston Atlas, an Enviro Tech Company, Kingswood, Texas) stuck to the galley wall, these did not appear to be effective. Statements on the indicator such as "CO present when spot turns dark," without provision of a clear reference color, are not helpful. Similarly, the directions for use were printed on the back of the sensor, which was glued to the wall of the galley. In addition, no information was available to the personnel present whether these indicators were reversible or not. The indicators in both aircraft had turned dark at some time in the past, had not been renewed, and had been scratched by frustrated individuals to see what the original color had been so that an assessment could be made regarding exposure. An identical or similar device was present in an aircraft that recently crashed when it ran out of fuel over New Hampshire after its pilots had already expired from carbon monoxide poisoning.[10]

During the testing of aircraft 2 on the tarmac, no difference was observed in air quality when the air source was switched from 100 percent fresh air to a 60/40 percent mix of fresh to recirculated air (i.e., in this aircraft decreasing the source of the contaminants to 60%, while at the same time recirculating 40% of this contaminated air). A difference would probably have been observed if the 100 percent fresh air had been clean and the test cycle for the 60/40 percent mix had been long enough for pollutants to build up.

To "remove excess oil and odor that, under certain failure conditions, may exist within the air conditioning system" (i.e., the airpack units,[11] a new experimental activated charcoal filtration system was installed on aircraft 4. Activated charcoal filters are capable of cleaning the air from a large variety of agents, but are not known to be effective for carbon monoxide and carbon dioxide.[12,13] Unless there are other undisclosed components in the new filtration system capable of scrubbing out carbon monoxide, these new air filter units could potentially be quite dangerous in the absence of a carbon monoxide warning system (i.e., they remove the early warning signals for potential carbon monoxide presence, such as the smell of smoke, leaving an odorless, toxic gas in the air).

None of the flight measurements in aircraft 3, 4, and 5 indicated the presence of carbon monoxide. It was therefore concluded that under normal operating conditions the bleed air from the engine in the 146 aircraft did not contain, or the action of the catalytic converter did not result in, any measurable carbon monoxide above the minimum detection levels inside the cabin.

Attempts to obtain direct evidence of carbon monoxide exposure by measuring COHB levels in the blood in exposed individuals who had to be taken to the emergency department

failed for a number of reasons. Although the flight crews had a copy of a recommended set of tests in case an exposure occurred, as suggested by the occupational health physician, this was not followed by most of the attending physicians in the emergency departments. When COHB levels were measured in four individuals, relatively low levels (0.7 to 2.0%) were obtained. This could be due to the administration of pure oxygen in the aircraft as well as the time delay (4 hours) between exposure and measurement. Based on the 4-hour half-life of COHB in the blood under normal breathing conditions,[4] these values could have been 1.4, 1.4, 2.0, and 4 percent immediately after exposure. These values could double once again when one takes in consideration that pure oxygen was administered during exposure, which reduces the half-life to 60 to 90 minutes.[4] These calculations are based on simple models, and accurate prediction of COHB at the time of exposure can be difficult because of likely elevated carbon dioxide levels and the administration of oxygen.[14]

It has been shown that sedentary breathing of a nonsmoker exposed to 35 ppm of carbon monoxide in the air (the Environmental Protection Agency standard) for 2 hours will result in a 2.5 percent COHB level in the blood.[15] Based on the above information, the possibility of elevated COHB levels in the flight crews at the time of arrival of some of these flights cannot be ruled out. The biological exposure indices from the ACGIH[9] recommend that COHB levels measured at the end of a shift should not exceed 3.5 percent.

As it is virtually impossible for a technician to be present with monitoring equipment when these incidents occur, it was recommended that a datalogging carbon monoxide monitor be present on the aircraft, ready to be activated by the flight crew when required to either clearly identify or eliminate carbon monoxide as a contaminant.

The VOCs and long-chain hydrocarbons that were measured during the test flight of aircraft 1 were present in small quantities and can be classified as methylated siloxane derivatives as well as methylated propane and butane derivatives. The identification of these compounds has to be done with caution as the mass spectra of these compounds are not ideal and could represent other compounds with similar molecular structure. Since aircraft 1 had recently been refurbished with new carpets, it should be noted that siloxane derivatives are sometimes released from new carpets (personal observation). They are also used in extreme temperature lubricating oil formulations and consequently could be a reflection of lubricating oil components contaminating the aircraft air. The methylated propane and butane ester derivatives are also probably the actual or the thermal breakdown products of the ingredients of the oil formulations.

HPLC analyses for potential aerosolized oils indicated that major oil components could not be observed in the cabin air. It would appear, when oil leakage occurs, that these probably have been filtered out in the APU or condensed out somewhere in the ventilation system, which has a decreasing temperature differential from above 500° to 50°C.

Carbon dioxide gas is also produced by the catalytic converter as well as by each individual in the aircraft. The levels measured on the ground in aircraft 2, with only three individuals present, was as high as 900 ppm. The carbon dioxide levels measured in flight in each of the aircraft tested were comparable and ranged from a low of 800 to a high of 2700 ppm. Aircraft 5 (Dash 8-100) reached its lowest reading of 1100 ppm. This was about 250 to 300 ppm higher than the BAe-146 aircraft. This is probably due to a combination of factors, including its occupancy, the time interval between loading and takeoff, the time at which the engines are started, the duration of the flight, and the size of the aircraft. The carbon dioxide levels were in general very comparable between the three aircraft and were well below the threshold limit value for carbon dioxide of 5000 ppm and the short-term exposure limit of 30,000 ppm.[9] It should be noted that these levels are meant for occupational settings and do not necessarily apply to passengers. One study indicates that psychomotor and mental performance is not impaired at carbon dioxide levels as high as 50,000 ppm.[16] Another study found that the ability to detect coherent motion is impaired at carbon dioxide levels of 25,000 ppm.[17] It would therefore be prudent to reduce carbon dioxide levels to as low as possible.

The oxygen concentrations during flight of all three aircraft were highly comparable and ranged from 19.6 to 21.9 percent. It should be appreciated that when it is stated that the airplane is pressurized, it really means that upon takeoff from sea level the plane is actually depressurized to an air pressure equivalent to 2133 m (7000 ft) in the BAe-146 aircraft, and consequently a decrease in oxygen content is observed. Upon landing at an airport situated at sea level, the reverse is observed and the aircraft is repressurized. The steady oxygen concentration in the Dash 8-100 was slightly lower than the 146s at 20.8 percent and reached a high of 21.9 percent. This aircraft was probably pressurized to a slightly higher altitude than the BAe-146 aircraft.

Nitrogen dioxide levels within the aircraft were generally not detectable for most of the time during each flight. Some minuscule transients in the parts per billion range could be observed during takeoff and landing in all aircraft.

The most important potential chronic effects that one should be aware of are due to exposure to one of the jet oil ingredients that both companies admitted to be constituents in their oil, TCP. TCP is used in a number of commercial applications including the manufacture of plastics, as a flame retardant, as a lead scavenger in gasoline, and as a high pressure lubricant.[18] TCP is a mixture of three isomers, called ortho, meta, and para cresyl phosphate. Of these, the ortho isomer is the most toxic and is often removed as much as possible from the mixture. In 1959 a mass poisoning occurred in Morocco when 10,000 individuals fell ill after consuming cooking oil that had been adulterated with turbojet engine oil.[19] In general, ortho-cresyl-phosphate is a neurotoxin and causes peripheral neuropathies.[7] It has also been concluded, based on hen experiments using lubricating oils containing up to 3 percent TCP, that these lubricating oils had low neurotoxic potential under normal conditions of exposure.[20] Rats exposed to a daily oral dose of TCP indicate that this compound also has effects on the adrenal glands, ovaries, and seminiferous tubules.[21]

There is no information available regarding inhalation exposure of this agent. The turbojet oils used on the BAe-146 aircraft were analyzed and found to contain 2.8 percent cresyl phosphates. The oil manufacturers claim that less than 1 percent of this is the ortho isomer. In-flight measurements in a complaint aircraft could not demonstrate the presence of this

agent in the air above the detection limit of 80 $\mu g/m^3$ of air. A recent article indicates that turbojet oils can also contain a number of other agents such as the trimethylolpropane esters (TMPEs) of carboxylic acids.[22] At temperatures between 350° and 700°C, TMPE and TCP can react together to form trimethylolpropane phosphate (TMPP). As TMPP is a potent neurotoxin, it was suggested that "extreme caution should be exercised in applications of these lubricants where these are thermally degraded."[22] It would appear that the current situation, where turbojet oils are being thermally degraded in a catalytic converter that is prone to be overloaded, could be one of these applications and requires further investigation.

The air quality of BAe-146 aircraft appears to have been a long-standing problem, as is apparent from the many modifications, additions, and deletions to the air-conditioning system recommended by British Aerospace over the years.[11] If one ...ects the flight crews to have confidence in the decision-...aking processes and operate these aircraft, the best arguments that can be presented is to show that the air in suspected aircraft with properly functioning oil seals is comparable to that in other aircraft that have never been associated with complaints and have always been quite acceptable. If the air quality is not comparable, then the differences should be identified and evaluated, and, if deemed necessary, appropriate changes should be made. For this reason, in-flight comparisons were made of three aircraft.

When one compares the two BAe-146 aircraft with properly functioning oil seals, no distinct differences in the air quality parameters measured can be noted. A faint hydrocarbon combustion smell was noted in aircraft 3 (BAe-146, no charcoal filter) at the times of takeoff. A similar smell was noted in aircraft 5 (Dash 8-100) at the time when the engines were started. This was not noticed in aircraft 4 (BAe-146 with activated charcoal filter).

It appears, therefore, that the activated carbon filter does improve the air quality during normal operating conditions. Whether it is capable of performing under a challenging load ...h as failure conditions remains to be seen.

Conclusions

In-flight oil seal failure in turbojet engines of BAe-146 aircraft was traced as the source of smoke in the cabin. The diverted engine combustion air passes through catalytic converters, which tend to become overloaded, resulting in the potential production of carbon monoxide. Although the reported symptoms appeared consistent with carbon monoxide exposure, only slight elevations in COHB levels were measured in flight attendants, which was probably the result of the time delay since exposure. Oxygen administration and carbon dioxide levels are known to shorten the half-life of COHB. To identify or eliminate carbon monoxide as a problem, the use of data-logging instruments for carbon monoxide was recommended, to be activated when accidental exposures occur. Although cresyl phosphates are present in engine oils, these were not found in the cabin air of problem aircraft. The air quality of normal BAe-146 aircraft compared favorably with that of a Dash-8 not associated with problems.

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AlliedSignal

Final Report

Air Quality testing aboard Ansett Airlines BAe146 Aircraft

August 23-25, 1997

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SCOPE

Air quality complaints have been noted on the BAe146 aircraft fleet in service at Ansett Airlines in Australia. The root cause for these complaints has been a matter of speculation for some time. The purpose of the AlliedSignal testing at Ansett Airlines was to provide technical assistance in the area of air quality measurement and help identify areas where improvements could be made to enhance the perceived quality of air on board the aircraft.

It should be noted that current safety standards differ from air quality levels that will provide a perceived acceptable level of customer and crew satisfaction. Contaminant levels may be well below recommended levels in currently accepted safety standards, yet generate complaints because they can act in synergy with other contaminants or because some standards may be outdated and not have incorporated more recent scientific and medical evidence . In addition, extenuating circumstances on board aircraft (including humidity and cabin pressure) have not been studied to the extent that a new standard can be proposed which incorporates these factors or identifies interactions between factors.

This report presents the findings from air quality measurements taken on the ground and in flight, contaminant identification from the air filters used to clean the cabin supply air, and findings from measurements taken during pack burnouts.

SUMMARY

*Testing indicates that on a system with properly installed and serviced air filters that air quality is acceptable throughout the aircraft during revenue flights, with the exception of the aft galley when dry ice is present. In non revenue flights, with no dry ice present in the aft galley, carbon dioxide levels were acceptable throughout all areas of the aircraft. The aft galley is a confined space and changes should be implemented to provide carbon dioxide removal or ventilation for this area.

*Contaminant levels in supply air to the cabin approach current safety standards during pack burnouts. Irritating and carcinogenic compounds present include formaldehyde, tetrahydrofuran, and cumene. These compounds cause skin, respiratory system, and eye irritation as well as nausea and narcosis if present in excessive levels. These compounds are concentrated on the filters and are released when breakthrough occurs during use.

*Test results indicate that heating up the packs do not fully remove the buildup of hydrocarbon contaminants. Physical observation of the filters indicated that filter temperatures reach a level high enough to melt the thermoset glue adhering the filter pleats to the support screen of the cabin filter. (see photo at front of appendix)

*A contaminant breakthrough test for air filters needs to be developed and implemented. Current method of measuring delta P across filter checks for particulate contamination and gives no indication as to actual efficiency of filter for hydrocarbon contaminant removal.

* Pack burnouts may cause premature failure of charcoal impregnated filters by heating up contaminants only enough to cause them to migrate further into the filter media, blocking filter surface area that might otherwise be available for hydrocarbon adsorption. They may in fact create an elevation of hydrocarbon offgasing for a time during the first flight after performing this cleaning procedure. Test results indicated that performance of high time filter was similar to a new filter for hydrocarbon removal.

*Providing 40% recirculated cabin air would provide an increased level of humidity in the cabin and reduce discomfort from watering eyes and dry nasal tissue. In conjunction with the use of properly serviced air filtration, a clean more comfortable cabin atmosphere would be provided.

* Perception of temperature gradients was not supported by temperature and relative humidity measurements. Air flow is minimal in the center of the cabin and can generate these perceptions. Improving airflow to the center of the cabin is recommended to reduce stagnation and the accompanying perception of poor air quality and hot spots.

* During normal flights, with filters having over 1000 hours of service as well as with new filters, levels of contaminants in the air provided to the cabin and cockpit were found to be 30 % to 40 % of currently accepted safety standards (NIOSH). During all revenue segments, contaminant levels were 100% to 130 % of accepted safety standards. No evidence was found from either the cabin air quality measurements or filter analyses to support a former claim that tricresylphosphate isomers are present in the air. Other phosphate isomers were detected, however.

Schedule of testing:

Friday 8/22/97 s/n VH-JJY freighter
Pack burns only APU s/n unavailable

Saturday 8/23/97 s/n VH-EWI passenger

This aircraft was chosen for testing because it had the worst record for odor in the cabin at the time.

Pack burns and air quality sampling in cabin during pack burn

APU Model # GTCP 36-150M			
APU MFG. part no. 3800216-2		s/n P162AUC	Ansett s/n 026
Engine Model #'s ALF502R5 (141100)			
Engine s/n 's	LHI	Mfr. # LF05154	Ansett s/n 014
	LHO	Mfr. # LF05691A	Ansett s/n 066
	RHI	Mfr. # LF05852A	Ansett s/n 082
	RHO	Mfr. # LF05816A	Ansett s/n 081

Sunday/Monday 8/24/97& 8/25/97 s/n VH-EWI passenger

One 2 hour Non revenue flight in the A.M. with old filter having service life of over 1000 hours. Cabin full fresh air was selected for entire flight. 7 persons were on board for test. Also 2 90 minute legs of revenue flight on Sunday P.M. and 2 120 minute legs on Monday A.M. After changing out air filters and installing new, cabin full fresh air was selected for outbound legs and 40% recirculated air was selected for return legs. Flights were near 100% passenger loading.

Monday **8/25/97** **s/n VW-EWS** passenger , APU model 36-150M, s/n P304
Pack Burn only

PROCEDURE

A variety of analytical methods were used to evaluate aircraft air quality. These are briefly described along with the target of the analysis.

1. Bleed air contamination monitor:
This device converts organic material such as fuel, oil, or hydraulic fluids to carbon dioxide and measurs the increase compared with carbon dioxide levels in the engine or APU inlet air. This instrument was used in this application to look at pack burnouts and evaluate their effectiveness using the standard Ansett operating procedure as the test sequence.

2. Carbon Dioxide Analyzer: On line monitoring of carbon dioxide levels in the supply air to the cockpit, cabin, and within the aft galley adjacent to the flight attendant seat at approximately head height.

3. Carbon monoxide, Oxygen, and methane analyzer: On line monitoring of analyzer levels of contaminants in the supply air to the cockpit, cabin, and within the cabin (aft galley).

4. Temperature / Relative Humidity: Measurements of temperature and relative humidity were obtained to determine potential causes for reports of stuffiness and temperature gradients in the aircraft cabin. Human comfort perception requires that temperature and humidity fall within a certain range to satisfy the 80th percentile of the population.

The following analyses were performed by Performance Analytical Laboratories in Canoga Park California. A list of the states that they have been certified in is in the appendix.

5. DNPH Cartridges for EPA TO-11 analyses of Aldehydes and Ketones: sampling media for aldehydes and ketones in the supply air and aft galley. A minimum of 20 liters

of air is drawn through the cartridge at a calibrated flow rate not to exceed two liters per minute.

Aldehydes and ketones have previously been shown to be a potential cause of complaints dealing with burning, watering eyes. It should be noted that burning, watering eyes can also be caused by low humidity.

6. Summa canister analyses: Summa canisters are evacuated, precleaned, polished and conditioned, stainless steel cylinders used to trap air samples for later analysis. Samples may be collected by either a "grab" type method whereby the valve on the cylinder is opened and a sample immediately captured, or by a time weighted method using a calibrated mass flow controller. In this testing application, mass flow controllers were used to collect samples over the flight test intervals of 30, 60, 90, and 120 minutes.

A variety of tests were performed on the summa samples.

A. EPA method 25C: This method is used to quantify levels of carbon dioxide, carbon monoxide, methane, and total nonmethane hydrocarbons by gas chromatography. It provided a cross check for the on board analyzers as well as a way to obtain a relative total hydrocarbon measurement in flight.

B. EPA analysis for ozone precursors: This method is used to quantify levels of target compounds which are usually fuel combustion products. It provides a more specific target list than other methods.

C. EPA method TO-14 plus 15 tentatively identified compounds: This test method specifically looks for 43 compounds on the EPA target list using Gas Chromatography/ Mass Spectroscopy. In addition, the 15 compounds of highest concentration not previously analyzed in the target list are tentatively identified.

This method provides an intensive look into the remaining air constituents that have not been analyzed by other methods. Often, there will be fragments of other compounds that have been thermally decomposed. These compounds will not have any safety standards derived for them, but can help identify the source of contamination based on the type and size of the fragments detected.

7. EPA TO-13 Analyses: This method identifies compounds which are usually too heavy to be captured by summa canisters, typically known as semivolatile compounds. Some of these compounds generate foul odors. A large volume of air is required to obtain low detection limits. This makes testing for these contaminants during revenue flight tests impractical. As an option, the filters were removed from the ECS system and the captured contaminants identified. This provides a very large sample volume, with the filters having

over 1000 hours of service, but makes it impossible to quantify mass per unit of air volume.

This method is used to identify the ortho, meta, and para isomers of tricresylphosphate (TCP). This compound is too large to be detected by the gas analysis techniques used for summa canisters. Four TCP isomers were evaluated during the analysis process.

It was determined during test planning that the only accurate way to assess the presence of triorthocresyl phosphate would be to analyze a portion of the filter elements from the aircraft. The filter elements would capture any semivolatile material in the air supply before it reached the main cabin and therefore any in-cabin measurements of semivolatile material would most likely detect contaminants from non-supply air sources, i.e. passengers and baggage brought on board, etc.

TEST OUTLINE:

Bleed air contamination monitoring was conducted on 3 separate aircraft during pack burnouts. The goal was to assess the effectiveness of the pack burnouts by comparing the hydrocarbon level of air entering the APU with the air being supplied by the packs to the cockpit and cabin.

This equipment was set up for ground use at the hangar. Sample lines were run to the APU inlet and a cabin supply air grill. Throughout the test, a variety of selections were chosen from the control panel. These included single and dual pack operation, and temperatures ranging from 0 to 70 degrees C. Some of this selection was involuntary, as packs at times tripped off due to fault controls of the ECS system. During the testing of the aircraft used for the flight testing, samples were collected with no filters install as well as with high time air filters.

Air quality samples were also collected from the aircraft used for flight testing to determine operator[1] exposure levels when inside an aircraft performing pack burnouts.

A non-revenue flight was scheduled to provide a time when comprehensive testing of temperature and airflow could be conducted without any impact on passenger comfort during a revenue flight. The non-revenue flight provided an opportunity to capture Summa Canister samples during separate phases of flight. This could not be done on revenue flights due to potential passenger curiosity and operational inconvenience during canister changes. The flight also provided a comparison of contaminant levels aboard an empty aircraft to compare with levels aboard an aircraft with 100% loading. Comprehensive air flow, temperature, and humidity measurements were collected by Ansett Airlines and AI(R) personnel during the time interval that the gaseous air quality measurements were obtained. In addition, Ansett Airlines personnel ignited a smoke candle in the forward cabin to observe air flow patterns in the cabin.

[1] Operator refers to the Engineer or Technical crew carrying out the pack burn procedure.

The ECS was run in full fresh mode during the entire non revenue flight.

Testing was also conducted on four revenue flight segments. These segments were 90 to 120 minutes in length. Passenger loading was near or at 100% during all segments. The two outbound segments were tested with full fresh air supplied to the cabin. The two return segments were tested with a 40 % cabin recirculation rate.

Testing with this aircraft loading allowed an accurate assessment to be made regarding the impact of recirculating cabin air on total air quality.

RESULTS:

1. Cabin and Cockpit air filtration test results:

Findings from the bleed air contamination monitor indicate that full hydrocarbon clean out of the ECS systems on the three aircraft never occurred. The test period for these aircraft was at least 1/2 hour for each aircraft. A typical pack burnout will only heat the duct for a period of five minutes. On the aircraft used for the revenue flight testing, the filters were removed and the tests repeated. No improvement was seen on the analyser over air quality with filters in place. Hydrocarbons from synthetic oil do not begin to oxidize and decompose until they reach approximately 200 degrees C. The pack temperature of 70 degrees C may begin the cleanout procedure but will always leave a residue of high molecular weight hydrocarbons behind. Analysis of the filters indicated a significant amount of high molecular weight residues which could not be identifed.

The high time filters allowed odors to pass through them on takeoff during the non-revenue flight. These odors were not detected with new cockpit and cabin filters installed on subsequent takeoffs the same day or the next. Neither set of filters was effective at removing the ethanol that was present from alcohol consumption on board the aircraft.

A table is included in the appendix indicating that activated charcoal has selective adsorption capabilities. The filters on board this aircraft operate on a similar pricniple, but may have slightly different adsorption characteristics. Formaldehyde has a potentially low adsorptivity. Ethanol should have a high adsorptivity. Neither contaminant appeared to be reduced to any great extent when operating in a 40% recirculation mode. Total volatile organic compounds as measured using EPA TO-14 in all legs of revenue flight were at or below 3000 ug/ cubic meter, even when taking passenger generated contamination. This level is where Molhave indicates that complaints may begin to occur due to high levels of VOC's.[2,3]

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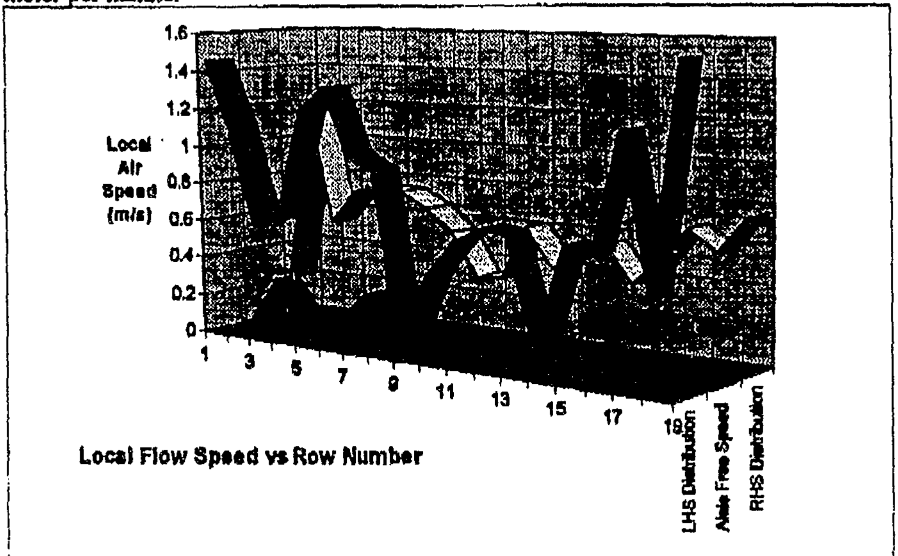
[2] Molhave, L. "Volatile Organic Compounds, Indoor Air Quality and Health" *Indoor Air, 1991a. 4:357-376.*

[3] Holcomb, L., Pedelty, J. Volatile Organic Compounds: Reported Concentrations and Criteria for Health and Comfort. Environment Professional, 2:9,pp1-14,Sept, 1996.

Generally, levels of VOC's in the air supplied to the cabin are very low when compared with other aircraft in use. Contamination originating in the aircraft air supply system is typical with that seen in airframes of other manufacturing origin.

2. Flight Test :

Airflow: Airflow measurements in the cabin indicated that outlet flows were highest at the forward 3 rows of the cabin. (1.3 m/s) . On average, outlet flow was 0.7 m/s. through the remainder of the cabin, with flows of approximately 0.4 m/s being recorded in rows 9&10, 12, and 15. Flows in the aisle were taken at head height of seated passengers. These flow rates were much lower, being generally well below 0.1 m/s. A smoke candle that was ignited at the front of the cabin indicated that the flow pattern was from the front to the rear of the aircraft. The rate of travel of the smoke was roughly estimated at less than one meter per minute.



Temperature: Temperature in the cabin appeared to be very stable throughout the flights. No isolated pockets of hot air were noticed. Stability appeared to be independent of passenger loading.

Relative humidity: The relative humidity of the air in the cabin dropped to nearly zero on the non revenue flight with no passenger load when the aircraft was operated in full fresh mode. With a passenger load, the relative humidity reached lows of 1 to 3 % . When operated in a 40% recirculation mode. The achievable humidity levels were on the order of 9 to 13 %. See data and charts in appendix for more detailed test data.

Carbon Dioxide:

Carbon Dioxide levels were monitored by on-line measurements taken during flight from cockpit supply air, cabin supply air, and air within the aft galley. During the final revenue

sectors, levels were also measured within the aft cabin. The levels of carbon dioxide were also measured from the summa canister samples taken from the cockpit supply, cabin supply and aft galley.

Results of these measurements indicate that carbon dioxide levels are within acceptable levels, with the exception of the aft galley where dry ice is present. When dry ice is present, concentrations of carbon dioxide were observed to reach unacceptable levels after takeoff[4].

The summa canister concentration of carbon dioxide agreed with the on line analyzer findings, even though the summa samples were a time weighted average.

Carbon Monoxide:

Carbon monoxide was not detected in flight. Samples analyzed from the summa canisters were in agreement with these findings.

Oxygen:

Oxygen levels remained at 20.9 % throughout the flight. There was a slight drop in oxygen levels in the galley to 19.9 % during takeoff for a period of approximately one minute

DNPH Aldehyde Samples:

Results from aldehyde testing indicated that Formaldehyde was around 30% of NIOSH levels in the supply air and aft galley during pack burnouts. In flight, levels of formaldehyde were within accepted safety standards. It does not appear that new cabin air filters make a significant improvement over the 1000 + hour filters in reducing total levels of formaldehyde.

Summa canister samples:

Levels of other contaminants measured by the summa canisters do not have as significant an impact on the Threshold Limit Values (TLV's) as formaldehyde. Many of the compounds detected have not been assessed for exposure limits. They could add to occurrences of odor or physiological complaints if present in significant quantities.

Carbon monoxide appears to have been detected by this method, but was not detected with the on line analyzers during flight. The method detection limit for carbon monoxide is 1 ppm, which is very near levels which are being reported on the summa canister samples. It is doubtful that carbon monoxide is present in any significant levels.

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[4] Carbon dioxide levels within the aft galley were seen to exceed OSHA and ASHRAE recommendations for 8 hour continuous exposure in a workplace environment.

EPA TO-13 analyses of cabin and cockpit filters:

A substantial number of contaminants were detected on the filter samples. These contaminants were significantly different than those reported by Asdor to myself in a memo dated March 13, 1997. It appears that the general contaminant list that they used for their analysis was similar to the TO-11 list without analysis of tentatively identified compounds. The AlliedSignal analysis identifies a number of odor producing compounds that have not been previously reported.

A search referenced against a calibrated standard was made for isomers of tricresyl phosphate. None were detected in the sample.

Conclusions:

1. Pack Burn outs:

Pack burnouts are reported to reduce the number of odor complaints when they are performed on a daily basis. However, test data indicate that operators are exposed to levels of hydrocarbons approaching the recommended allowable limits. This exposure can continue for some time after completion of this procedure.

Findings from the in flight test indicate that hydrocarbons are breaking through the filter, even though a pack burnout is performed before the departure(ethanol). Pack burn outs very likely accelerate the loading up of the surfaces on the filter and accelerate the process of hydrocarbon breakthrough. Higher molecular weight molecules occupy available filter surface area necessary for trapping other compounds such as formaldehyde and ethanol and prevent the filter from effectively removing odors for its calculated life expectancy.

Physical damage was observed on the cabin filter from excessive heat melting the thermoset adhesive holding the filter pleats to the inner screen. The thermoset adhesive starts to soften at 85 degrees C. The filters are rated for operation at temperatures of over 100 degrees C. It has not yet been determined if the adhesive used on this particular set of filters is faulty or if the bleed temperature exceeded the filter temperature limit. (See photaograph in appendix)

Bleed air contamination monitor results indicate other areas of the system are contaminated. On this aircraft, all four engines and the APU have modifications installed to prevent oil leakage into the bleed air. It is not known if the ECS system and ductwork were cleaned since these modifications were made to the main engines and the APU. Ansett Airlines informed me that this cleaning usually occurs during the C-Check every couple of years.

	EPA METHOD TO-13	Cabin Filter	Cockpit Filter	TWA mg/m^3
GC/MS	COMPOUND mg/Kg			
Ret. Time	weight of compound per unit of filter mass			
5.21-.25	Napthalene	41	51	50
5.69	Nonane	40	50	1050
5.76	2-Butoxyethanol	30	50	24
6.8	Ethylmethyl Benzene isomer		50	D/A
7.16	Octamethyl Cyclotetrasiloxane	200	300	D/A
7.4	Trimethylbenzene isomer	60	50	123
7.5	Decane	200	500	D/A
7.89	Trimethylbenzene isomer	50	200	123
7.99	Unidentified Hydrocarbon		50	D/A
8.05	Limonene		50	D/A
8.12	Eucalyptol	100	300	D/A
8.41	1-Methyl-3-Propylbenzene		50	D/A
8.51	Diethylbenzene isomer	40		D/A
8.55	Unidentified Hydrocarbon		100	D/A
8.64	2-Methyldecane	50	100	D/A
8.75	3-Methyldecane	40		D/A
9.01	Dimethylethyl Benzene Isomer		170	D/A
9.11	Heptanoic Acid	100		D/A
9.26	Undecane	600	600	D/A
9.63	Tetramethylbenzene isomer	80	100	D/A
9.86	Decamethylcyclopentasiloxane	200	300	D/A
10.16	Ethyl-dimethylbenzene isomer	60		D/A
10.25	Unidentified Hydrocarbon	60		D/A
10.34	2-Methyl-undecane	80		D/A
10.44	Unidentified Hydrocarbon	80		D/A
10.93	Dodecane	600	500	D/A
11.13-12.05	Unidentified Hydrocarbons	300	400	D/A
12.33	Bornyl Acetate	100	100	D/A
12.49	Tridecane	600	400	D/A
12.86	1,3,5-Tris(1-Methylethyl)Benzene		60	D/A
13.41-13.51	Unidentified Hydrocarbons	100	200	D/A
13.94	Tetradecane	300	400	D/A
14.78	Unidentified Hydrocarbon	40	70	D/A
14.86	2,6-Bis(1,1-Dimethylethyl)-2,5-cyclohexadiene-1,4-dione	40	70	D/A
15.31	Pentadecane	200	300	D/A
16.86	Unidentified Acid	100	10	D/A
16.66	Hexadecane		100	D/A
17.17	Tributyl Phosphate	200	300	2200
17.5	Unidentified Hydrocarbon	40	50	D/A
18.02	Heptadecane	80	90	D/A
18.33	2,4-Diphenyl-4-Methyl-2(Z)-Pentene	100	200	D/A
19.57	Isopropyl Myristate	100	200	D/A
21.49	Unidentified Phthalate		50	D/A
22.91	n-Octyl-4-Hydroxybenzoate	100	200	D/A
30.37	Bis(2-ethylhexyl)phthalate		50	D/A
31.27-37.71	Unidentified Compounds	2000	800	D/A
31.76, 32.10, 32.43	Tricresylphosphate isomers	ND	ND	

2. Cabin Supply air quality:

The quality of the supply air for the cabin and cockpit is within safety limits. Based on the filter analysis, there is no evidence to back claims of symptoms of triorthocresyl phosphate exposure. The manufacturer of the oil in use on the aircraft backs this claim as evidenced in his attached memo. Odors were detected in the air on the flights where the filters had hydrocarbon breakthrough. Changing the filters immediately corrected this problem.

Carbon dioxide levels in the main cabin were very low compared with other aircraft models. Based on an improvement in humidity levels and reduction in organic contaminants seen while operating in a recirculation mode, it would be recommended to operate the aircraft in this mode.

Low humidity levels can cause some of the sensible heat complaints. By operating in a recirculation mode, the effect of sensible heat on occupants of the aircraft will be reduced by increasing the humidity to buffer the rate of evaporation of perspiration.

Air flow rates throughout the cabin were very low near the center aisle. Increasing airflow has been found to give improved perception of air quality.

Carbon dioxide levels in the aft galley were acceptable when no dry ice was present. During the final flight leg the observation was made that the punkalouvre in the lavatory was closed. This louver was opened on the return trip, causing toilet odors to migrate forward to the rear row of seating. Indications are that there is not enough air exchange in the aft galley area. High carbon dioxide levels, coupled with low humidity could cause the sensation of burning eyes as well as muscle aches, headaches, etc. An additional scrubber in the aft galley to remove carbon dioxide and odors may solve the comfort problems experienced by working in this area.

RECOMMENDATIONS

In summation there appear to be five key areas to make improvements on this aircraft:

1. Improve the filtration maintenance procedure and possibly use more readily cleanable filters.

Recommendations from this test would be that pack burn outs be discontinued and a method of cleaning filters external to the aircraft be developed. It has been found that steam cleaning reduces the efficiency of the filter (75% filtration efficiency post steam cleaned). At this time it appears that the most viable method for cleaning the filters will be the use of supercritical fluid (Carbon dioxide). Asdor filters is currently developing cleanable filters and techniques to be used in their regeneration. Current results are that the new process is yielding 97% efficiency on cleaned filters. [5]

A method of assessing filter life needs to be developed. The current procedure only examines the pressure drop across the filter. Hydrocarbon breakthrough is occurring,

[5] Asdor filters have a shelf life of six months due to their hygroscopic nature. It is not recommended that they be kept on the shelf due to a loss in efficieny with water adsorption.

even though there is not a high pressure drop. As currently used, the standard filter does not consistently provide 1000 hours of service before rejection due to pressure drop criteria.

The use on a real time formaldehyde analyzer would allow operators to quickly check for formaldehyde and other hydrocarbons to determine if breakthrough is occurring.

2. Reinstate the use of recirculated air in the cabin.

3. Increase air movement in the cabin.

4. Reduce the amount of carbon dioxide in the aft galley.

These changes and improvements will make the aircraft environment safer and enhance the perceived air quality for the crew and passengers of the aircraft.

Richard Fox

AlliedSignal Aerospace

Biographical Information regarding Principal Investigator

Richard B. Fox
Senior Engineer
AlliedSignal Aerospace Company
AlliedSignal Engine Division
Materials Engineering Laboratory

1. Basic Data

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Date Bio Prepared:	October 28, 1997

2. Educational Record **(begin with High School)**

Institution	*Course*	*Years Completed*	*Date of Graduation*	*Degree*
Washington High	Sciences	4	May 1974	Diploma
Glendale Community College	Chemistry, Physics Biology, Mathematics	2	May 1997	AA Liberal Arts
Arizona State University	Zoology, Chemistry	2	May 1978	BS Zoology

3. Professional Experience

From	*to*	*Employer*	*Title*	*Duties*
12-96	Pres	AlliedSignal	Engineer III	Air quality and Emissions measurement team leader
5-90	12-96	AlliedSignal	Engineer II	Air quality and Emissions measurement team leader
7-88	5-90	AlliedSignal	Engineer I	Chemistry analysis, air quality and emissions measurement
4-86	7-88	AlliedSignal	Engineering Assoc.	Chemistry analysis, air quality and emissions measurement
4-85	4-86	Ross Laboratory Div of Abbott Pharmaceutical	Lab Technician	Assist in new plant startup and chemical analysis

3. Professional Experience, continued

From	*to*	*Employer*	*Title*	*Duties*
1-79 &8-84	10-83 4-85	Phelps Dodge Corp.	Senior Chemist	Analytical group leader Laboratory budgeting
10-83	8-84	Phelps Dodge Corp.	Assistant Shift Foreman	Coordinate smelter operations to maximize production without violating air quality standards

4. Memberships and activities in Societies

Society	*Grade*	*Committee*	*Year*	*Position*
American Society of Heating ,Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE)				
	Associate Member	ASHRAE Aviation Subcommittee	1997	Co- Chairman of Research Subcommittee
		SPC161	1996	Standard for air quality in commercial aircraft- represent aircraft engine manufacturers
Society of Automotive Engineers (SAE)				
	Member	E-31 Engine Emissions Measurement	93-97	Main Committee Chairman
		1987-present	91-97	Cabin air quality subcommittee chairman
	Consultant	AC-9 Aircraft Environmental Systems 1990- present		

5. Principal Technical Interest Areas

Aircraft cabin air quality, engine exhaust and smoke measurement, smoke plume visibility, engine lubricant and fuels certification.

6. Honors

Award	*Organization*	*Date*
Premier Achievement Award	AlliedSignal	1997
Alpha Epsilon Delta Premedical Honor Society	Arizona State University	1977-1978
Deans List	Glendale Community College	1976
National Honor Society	Washington High	1973-1974

7. Publications

Sponsor of the following Aerospace Standards

SAE ARP4418	Measurement of Air Quality in Aircraft Cabins	1995
SAE ARP1533C	Calculation of Emission Indices from Aircraft Emissions	1995
SAE ARP 1179C	Smoke Emission Measurement Procedures	1997

Documents in Process

SAE AIR 4476	Aircraft Cabin Air Quality	1990-1997
ASHRAE SPC161	Standard for Air Quality in Commercial Aircraft	1996-1997

8. Patents
U.S. and Foreign Patents pending on Bleed Air Contamination Monitor.

9. Projects
Technical Liaison and Project Monitoring subcommittee chairman for ASHRAE Research Project 959. Determine Aircraft Supply System Contaminants for Aircraft of Varying age and Types. Project goes out for bids on November 11, 1997. Research to be completed within one year.

AlliedSignal project to identify thermal decomposition products of fluids used on board aircraft when exposed to hot bleed air temperatures. Project completion , January 1998.

10. Certifications
EPA Sections 608 and 609 Universal ground equipment and transportation certification for freon recovery from air-conditioning systems.

ACKNOWLEDGMENTS

The following key people contributed many hours of their time and resources to allow this project to be performed in a time efficient and effective manner:

1. Don Love- Technical Director Australia **Aero International (Regional) AI(R)**
2. Peter Gibbs- Fleet Technical Officer **Ansett Australia**
3. Kevin Currie- Occupational Risk Manager **Ansett Australia**
4. Karen Skehan- Purser **Ansett Australia**
5. Judy Schache- Purser **Ansett Australia**
6. Dr. David Lewis- Medical Director **Ansett Australia**
7. Dr. Kevin Sleigh- Medical Doctor **Ansett Australia**
8. George Lee- Chemist, Occupational Hygiene **Queensland Health Scientific Services**

In addition, the following contributions were made:

Ansett Australia- provided flight crews and mechanics and aircraft to expedite setup and flight testing during both non revenue and revenue flights.

AlliedSignal Aerospace- provided air quality testing equipment and manpower as well as funding for laboratory analysis of samples.

AI(R)- provided manpower and funding for laboratory analyses

ASDOR FILTERS- provided a new set of cabin and cockpit filters to allow testing of both new and high time filters.

SUBMISSION TO THE SENATE REFERENCES COMMITTEE
RURAL AND REGIONAL AFFAIRS AND TRANSPORT

ON THE INQUIRY INTO

AIR SAFETY – BAE 146
CABIN AIR QUALITY

SUBMISSION NUMBER 11A

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22nd October 1999

The Secretary
Rural and Regional Affairs and Transport Reference Committee
Parliament House
Canberra ACT 2600

Dear Sir,

On September 3rd 1999 British Aerospace Regional Aircraft made a submission to the Senate Committee in response to the reference to cabin air quality in the BAe 146 aircraft.

The submission comprised of a number of attachments including a report dated August 1997 prepared by Richard Fox. This particular issue of the report has been superseded by a more complete and formally approved "Final Report" dated November 25th 1997. As a result I kindly request that the copies of the report provided to you on September 3rd be substituted with the enclosed issue of the "Final Report" dated November 1997. I have enclosed 8 copies of the report for distribution to the committee members.

Thank you for your assistance in this matter.

Yours sincerely

Bruce Jones
Senior Vice President
Australasian Support

AIR-QUALITY TESTING
ABOARD ANSETT AIRLINES
BAe146 AIRCRAFT

FINAL REPORT

21-9910 **November 25, 1997**

Approved By: ______________________

D. Sullivan
Manager
Regional Airlines Enterprise
AlliedSignal Engine Division

Approved By: ______________________

R. B. Fox
Senior Engineer (Principal Investigator)
Materials Engineering Laboratory
AlliedSignal Engine Division

AlliedSignal
AEROSPACE

REPORT NO.: 21-9910

ATTACHMENTS: 1—Mobil Oil Australia Limited (1 page)
2—Holcomb Environmental Services (17 pages)
3—Boeing (2 pages)
4—Dustfree, Inc. (3 pages)

Revision	By	Approved	Date	Pages and/or Paragraphs Affected
New	WMC	D. Sullivan	11-25-97	All (Initial Issue)
		R. Fox	11-25-97	

TABLE OF CONTENTS

LIST OF ABBREVIATIONS AND ACRONYMS[1]

ACGIH	American Conference of Governmental Industrial Hygienists
AI(R)	Aero International (Regional), Australia
APU	Auxiliary Power Unit
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
C-Check	Heavy-Maintenance Overhaul Procedure
DNPH	Dinitrophenylhydrazine
ECS	Environmental Control System(s)
EPA	Environmental Protection Agency
NIOSH	National Institute of Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
TCP	Tricresylphosphate
TLV	Threshold Limit Values
TVOC	Total Volatile Organic Compounds
VOC	Volatile Organic Compounds

[1](See Attachment 2 for additional abbreviations, acronyms, and references.)

DEFINITION OF TERMS[2]

Operator—In this report, the operator is defined as the engineer or technical crew who is performing the pack burn procedure.

Recirculation Mode—On the BAe146 aircraft, the recirculation mode is defined as the delivery of a mixture of 60% conditioned outside air, and 40% air, drawn from the cabin—through the ECS-cabin and cockpit-filtration and distribution system.

[2](See Attachment 2 for additional definitions of terms and references.)

AlliedSignal
AEROSPACE

AIR-QUALITY TESTING
ABOARD ANSETT AIRLINES
BAe146 AIRCRAFT

1. SCOPE

Air-quality complaints have been noted on the BAe146 aircraft fleet in service at Ansett Airlines in Australia. The root cause for these complaints has been a matter of speculation for some time. The purpose of the AlliedSignal testing at Ansett Airlines was to provide technical assistance in the area of air-quality measurement, and to help identify areas where improvements could be made, to enhance the perceived quality of the air on-board the aircraft.

This report presents the findings from air-quality measurements taken on the ground, and in flight, contaminant identification—from the air filters used to clean the cabin supply air, and findings from measurements taken during pack burn out's.

2. SUMMARY

Testing on a system, with correctly installed and serviced air filters, indicates that air quality is acceptable throughout the aircraft during revenue flights—with the exception of the aft galley, when dry ice is present. In non revenue flights, with no dry ice present in the aft galley, carbon-dioxide levels were acceptable throughout all areas of the aircraft. The aft galley is a confined space, and changes to the airframe or operations could be implemented to reduce carbon dioxide in this area.

Total contaminant levels, in supply air to the cabin, exceed 50% of the current safety standard limits (NIOSH, ACGIH) during pack burn out's. Compounds present include formaldehyde, tetrahydrofuran, and cumene. These compounds cause skin, respiratory system, and eye irritation, as well as nausea and narcosis, if present in excessive levels. NIOSH recommends that exposure to these compounds be reduced as much as practicable. These compounds are concentrated—and are released from the filters—if break-through occurs during use. The majority of the currently detected compounds do not have established exposure limits.

Test results indicate that heating up the packs does not fully remove the build-up of hydrocarbon contaminants. Observing the filters reveals that filter temperatures reach a high level—high enough to melt the thermoplastic glue that adheres the filter pleats to the cabin-filter support screen (see photo at front of Appendix 1).

A contaminant-breakthrough test for air filters needs to be developed and implemented. The current method used to measure delta P across the filter, checks for particulate contamination, and gives no indication for actual, hydrocarbon contaminant removal from the filter.

Pack burn out's may cause premature failure of charcoal-impregnated filters by heating up contaminants—only enough to cause them to migrate further into the filter media, blocking filter surface area—that might otherwise be available for hydrocarbon adsorption. They may, in fact, create an elevation of hydrocarbon offgasing, for a time during the first flight, after performing this cleaning procedure. Test results indicated that the filters performed better at removing the supply-system contaminants, than removing passenger-generated contaminants.

Providing recirculated cabin air would provide an increased level of humidity in the cabin, and reduce discomfort from watering eyes and dry nasal tissue. In conjunction with the use of correctly serviced air filtration, a clean, more comfortable, cabin atmosphere would be provided.

Perception of temperature gradients was not supported by temperature and relative-humidity measurements. Sensible air flow is minimal in the center of the cabin, and can generate these perceptions. Increasing airflow to the center of the cabin would reduce the perception of poor air quality and hot spots.

During normal flights, with filters having over 1000 hours of service, as well as with new filters, levels of air contaminants—provided to the cabin and cockpit—were found to be 30 % to 40 % of currently accepted safety standards (NIOSH, ACGIH). During all revenue segments—total contaminant levels, whose TLVs have been identified—were 100% to 130 % of accepted safety standards in the aft galley. Total TLVs are determined by summing the ratio of the measured concentrations of contaminants, versus their individual TLV limits. No evidence was found of any tricresyl phosphate isomers having been present in the cabin air-supply system. Tributylphosphate, however, was detected in trace quantities. Its TLV values cannot be assessed, because there is no way to determine the quantity of air that has passed through the analyzed filters

2.1 Schedule Of Testing:

Friday **8/22/97** **S/N——VH-JJY** (Freighter)

Pack burns only APU S/N—unavailable

Saturday **8/23/97** **S/N——VH-EWI** (Passenger)

This aircraft was chosen for testing because it had the worst record for odor in the cabin at the time.

Pack burns and air-quality sampling in cabin during pack burn.

APU Model Number GTCP 36-150M

APU MFG. P/N—3800216-2		S/N—P162AUC	Ansett S/N—026
Engine Model Numbers ALF502R5 (141100)			
Engine S/Ns—LHI		Mfr. # LF05154	Ansett S/N— 014
	LHO	Mfr. # LF05691A	Ansett S/N— 066
	RHI	Mfr. # LF05852A	Ansett S/N— 082
	RHO	Mfr. # LF05816A	Ansett S/N— 081

Sunday/Monday 8/24/97& 8/25/97, S/N—VH-EWI (Passenger)

One, two-hour, non-revenue flight, in the A.M—with the old filter having service life of over 1000 hours. Cabin full-fresh air was selected for entire flight. Seven persons were on board for test.

Also, two, 90-minute legs of revenue flight on Sunday P.M., and two, 120-minute legs on Monday A.M. After changing out air filters and installing new, cabin full-fresh air was selected for outbound legs, and 40% recirculated air was selected for return legs. Flights were near 100% passenger loading.

Monday 8/25/97 S/N—VH-EWS (Passenger , APU Model 36-150M, S/N—P304)

Pack Burn only

3. PROCEDURE

A variety of analytical methods were used to evaluate aircraft air quality. These are briefly described, along with the target of the analysis.

3.1 Bleed-Air Contamination Monitor

This device converts organic material such as fuel, oil, or hydraulic fluids to carbon dioxide, and measures the increase—compared with carbon-dioxide levels in the engine or APU inlet air. This instrument was used in this application to look at pack burn outs, and evaluate their effectiveness, using the standard Ansett operating procedure as the test sequence.

3.2 Carbon Dioxide Analyzer

On-line monitoring of carbon-dioxide levels in the supply air to the cockpit, cabin, and within the aft galley—adjacent to the flight attendant seat, at approximately head height.

3.3 Carbon Monoxide, Oxygen, And Methane Analyzer

On-line, analyzer-level monitoring of contaminants in the supply air to the cockpit, cabin, and within the cabin (aft galley).

3.4 Temperature And Relative Humidity

Measurements of temperature and relative humidity were taken in the aircraft cabin to determine potential causes for reports of stuffiness and temperature gradients. Human comfort perception requires that temperature and humidity fall within a certain range to satisfy the 80th percentile of the population.

The following analyses were performed by Performance Analytical Laboratories in Canoga Park, California. See the appendixes for the list of the states in which they have been certified:

3.5 DNPH Cartridges For EPA TO-11 Analyses Of Aldehydes And Ketones

These are the sampling media, for aldehydes and ketones, in the supply air and aft galley. A minimum of 20 liters of air is drawn through the cartridge, at a calibrated flow-rate, not to exceed two-liters per minute.

Aldehydes and ketones have previously been shown to cause burning and watering eyes. These compounds are common, thermal-decomposition products of fuel combustion, internal- and external-system lubrication oils, and hydraulic fluids. It should be noted that these symptoms can also be caused by low humidity.

3.6 Summa-Canister Analyses

Summa canisters are evacuated, precleaned, polished and conditioned, stainless-steel cylinders used to trap air samples for later analysis. Samples may be collected by either a *grab type* method—whereby the valve on the cylinder is opened, and a sample is immediately captured—or by a time-weighted method, using a calibrated, mass-flow controller. In this testing application, mass-flow controllers were used to collect samples over the flight-test intervals of 30, 60, 90, and 120 minutes.

A variety of tests were performed on the summa samples:

(a) EPA Method 25C: This method is used to quantify levels of carbon dioxide, carbon monoxide, methane, and total nonmethane hydrocarbons by gas chromatography. It provides a cross check for the on-board analyzers, as well as a way to obtain a relative, total-hydrocarbon measurement in flight.

(b) EPA Analysis For Ozone Precursors: This method is used to quantify levels of target compounds, which are usually fuel-combustion products. It provides a more specific target list than other methods.

(c) EPA Method TO-14, Plus 15 Tentatively Identified Compounds: This test method specifically looks for 43 compounds on the EPA target list, using Gas Chromatography and Mass Spectroscopy. In addition, the 15 compounds of highest concentration, not previously analyzed in the target list, are tentatively identified.

This method provides an intensive look into the remaining air constituents that have not been analyzed by other methods. Often, there will be fragments of other compounds that have been thermally decomposed. These compounds will not have any safety standards derived for them, but they can help identify the source of contamination—based on the type and size of the fragments detected.

3.7 EPA TO-13 Analyses

This method identifies compounds that are usually too heavy to be captured by summa canisters, typically known as semivolatile compounds. Some of these compounds generate foul odors. A large volume of air is required to obtain low-detection limits. This makes testing for these contaminants impractical during revenue flight tests. As an option, the filters were removed from the ECS system, and the captured contaminants identified. This provides a very large sample volume, with the filters having over 1000 hours of service, but makes it impossible to quantify mass-per-unit of air volume.

This method is used to identify the ortho, meta, and para isomers of tricresylphosphate (TCP). This compound is too large to be detected by the gas-analysis techniques used for summa canisters. Four TCP isomers were evaluated during the analysis process.

Test planning revealed that the only accurate way to assess the presence of triorthocresyl phosphate, is to analyze a portion of the filter elements from the aircraft. The filter elements would capture any semivolatile material in the air supply, before it reached the main cabin. Therefore, any in-cabin measurements of semivolatile material, would most likely detect contaminants from non-supply air sources—that is, passengers and baggage brought on board, and so on.

4. TEST OUTLINE

Bleed-air contamination monitoring was conducted on three, separate, aircraft during pack burn out's. The goal was to assess the effectiveness of the pack burn out's by comparing the hydrocarbon level of air entering the APU, with the air being supplied by the packs to the cockpit and cabin.

This equipment was set up for ground use at the hangar. Sample lines were run to the APU inlet and a cabin-supply air grill. Throughout the test, a variety of selections were chosen from the control panel. These included single- and dual-pack operation, and temperatures ranging from 0- to 70-degrees C. Some of this selection was involuntary, as packs, at times, tripped off—due to fault controls of the ECS system. During the testing of the aircraft, that is used for flight testing, samples were collected with no filters installed, as well as with high-time air filters.

Air-quality samples were also collected from this same aircraft—to determine the operator-exposure levels—when inside an aircraft performing pack burn out's.

A non-revenue flight was scheduled to provide a time when comprehensive testing of temperature and airflow could be conducted, without any impact on passenger comfort, during a revenue flight. The non-revenue flight provided an opportunity to capture summa-canister samples during separate phases of flight. This could not be done on revenue flights due to potential passenger curiosity, and operational inconvenience during canister changes.

The flight also provided a comparison of contaminant levels, aboard an empty aircraft, to compare with levels aboard an aircraft with 100% loading. Comprehensive air flow, temperature, and humidity measurements were collected by Ansett Airlines, and AI(R) personnel, during the time interval that the gaseous air-quality measurements were obtained. In addition, Ansett Airlines personnel ignited a smoke candle in the forward cabin to observe air-flow patterns in the cabin.

The ECS was run in full-fresh mode during the entire non-revenue flight.

Testing was also conducted on four, revenue-flight segments. These segments were 90 to 120 minutes in length. Passenger loading was near, or at 100%, during all segments. The two, outbound segments were tested with full, fresh air supplied to the cabin. The two return segments were tested with a 40 % cabin-recirculation rate.

Testing with this aircraft loading allowed an accurate assessment to be made, regarding the impact of recirculating cabin air on total air quality.

5. RESULTS

5.1 Cabin And Cockpit Air-Filtration Test Results:

Findings from the bleed-air contamination monitor indicate that full, hydrocarbon clean-out of the ECS systems, on the three aircraft, never occurred during the pack-burnout process. The test period for these aircraft was at least one-half hour for each aircraft. A typical pack burn out will only heat the duct for a period of five minutes. On the aircraft used for the revenue flight testing, the filters were removed, and the tests repeated. The analyzer did not indicate any air-quality improvement with the filters in place.

Hydrocarbons from synthetic oil do not begin to oxidize and decompose, until they reach approximately 200-degrees C. The pack temperature of 70-degrees C may begin the cleanout procedure—by vaporizing and oxidizing lower-molecular-weight hydrocarbons—but will always leave a residue of high-molecular-weight hydrocarbons behind. The higher-molecular-weight residue can be the cause of the *dirty-sock* odors that are sometimes encountered. Analysis of the filters indicated a significant amount of high-molecular-weight residues that could not be identified.

The high-time filters allowed odors to pass through them, on takeoff, during the non-revenue flight. These odors were not detected, with new cockpit and cabin filters installed, on

subsequent takeoffs—the same day or the next. Neither set of filters were effective at removing the passenger-generated contaminants present from alcohol consumption on board the aircraft.

Appendix 1 contains a table that indicates that activated charcoal has selective-adsorption capabilities. The filters on board this aircraft operate on a similar principle, but may have slightly different adsorption characteristics. Formaldehyde has a potentially low adsorptivity. Ethanol should have a high adsorptivity. Neither contaminant was reduced to any great extent when operating in recirculation mode. The total VOCs—as measured using EPA TO-14, in all legs of revenue flight—were at, or below, 3000 ug/cubic meter—even when taking passenger-generated contamination into account. This level, is where Hogston indicates that complaints may begin to occur because of high levels of VOCs. Though ethanol levels are very low, the fact that they did not decrease, during recirculation modes of operation, raises the question of their overall adsorption efficiency for other substances.

Generally, levels of VOCs in the air supplied to the cabin are very low, when compared with other models of aircraft in use. Contamination originating in the aircraft air-supply system is similar to that seen in airframes of other manufacturing origin.

5.2 Flight Test

Airflow: Cabin-airflow measurements indicated that outlet flows were highest (1.3 m/s) at the forward three rows of the cabin (see Figure 1.). On average, outlet flow was 0.7 m/s. through the remainder of the cabin, with flows of approximately 0.4 m/s being recorded in rows 9 and 10, 12, and 15. Flows in the aisle were taken at head-height of seated passengers. These flow rates were much lower, being generally well below 0.1 m/s. An ignited smoke candle, in front of the cabin, indicated that the flow pattern was from the front to the rear of the aircraft.

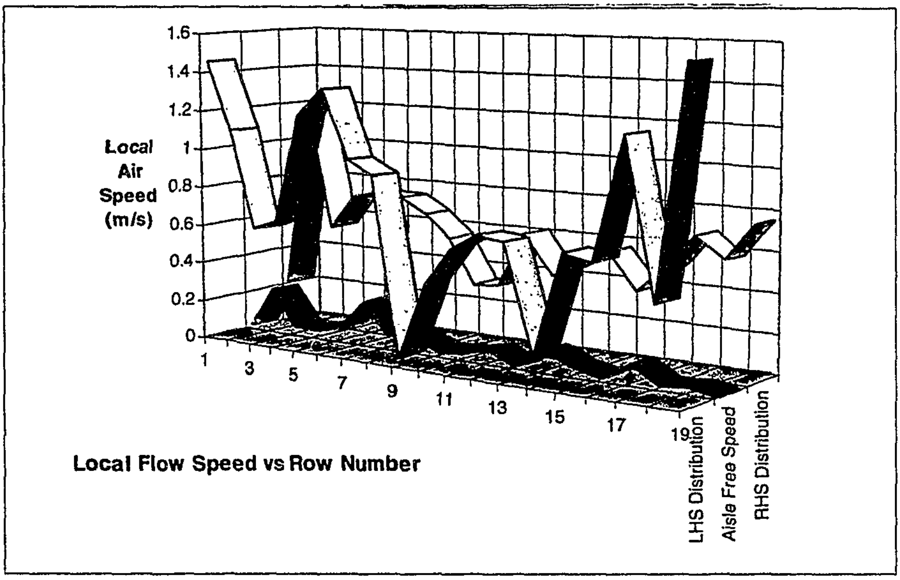

Figure 1. Cabin Airflow Measurements

Temperature: Cabin air temperature was very stable throughout the flights. No isolated pockets of hot air were detected. Stability appeared to be independent of passenger loading.

Relative Humidity: The cabin-air relative humidity dropped to nearly zero—on the non-revenue flight, with no passenger load—when the aircraft was operated in full-fresh mode. With a passenger load, operating in a full-fresh mode, the relative humidity reached lows of one-to-three percent. When operating in recirculation mode, the achievable humidity levels ranged from nine to thirteen percent. (See the appendixes for more detailed test data.)

Carbon Dioxide: The carbon-dioxide levels were monitored by on-line measurements—taken during flight—from cockpit supply air, cabin supply air, and air within the aft galley. During the final-revenue sectors, levels were also measured within the aft cabin. The levels of

carbon dioxide were also measured from the summa-canister samples—taken from the cockpit supply, cabin supply, and aft galley.

Results of these measurements indicate that carbon-dioxide levels are below comfort and safety limits, with the exception of the aft galley, where dry ice is present. When dry ice is present, concentrations of carbon dioxide were observed to reach unacceptable levels—after takeoff—when its TLV ratio is added to other compounds. (Carbon dioxide levels, in the aft galley, exceeded OSHA and ASHRAE recommendations for an eight-hour continuous exposure in a workplace environment.)

The summa-canister concentration of carbon dioxide corresponded with the on-line analyzer findings—even though the summa samples were based on a time-weighted average.

Carbon Monoxide: Carbon monoxide was not detected in flight. Samples analyzed from the summa canisters were in agreement with these findings.

Oxygen: Oxygen levels remained at 20.9 % throughout the flight. The oxygen levels in the galley dropped slightly—to 19.9 %, during takeoff—for a period of approximately one minute.

DNPH Aldehyde: Sample results from aldehyde testing indicated that formaldehyde was around 30% of NIOSH levels, in the supply air, and aft galley, during pack burn out's. Levels in flight were also within accepted safety standards. The new cabin-air filters do not make a significant improvement over the 1000+ hour filters in reducing total levels of formaldehyde.

Summa Canister: Levels of other contaminants measured by the summa-canister samples do not have as significant an impact on the TLVs as formaldehyde. Many of the compounds detected have not been assessed for exposure limits. They could add to occurrences of odor, or physiological complaints, if present in significant quantities.

Carbon Monoxide: Carbon monoxide appears to have been detected by this method, but was not detected with the on-line analyzers during flight. The method-detection limit for carbon monoxide is one ppm, which is very near levels that are being reported on the summa-canister samples. It is doubtful that carbon monoxide is present in any significant levels.

EPA TO-13 Analyses Of Cabin And Cockpit Filters: A substantial number of contaminants were detected on the filter samples. These contaminants were significantly different than those reported by Asdor in a memo dated March 13, 1997. The general-contaminant list that they used for their analysis was similar to the TO-11 list—without analysis of tentatively identified compounds. The AlliedSignal analysis identifies a number of odor-producing compounds that have not been previously reported.

A search, referenced against a calibrated standard, was made for isomers of tricresyl phosphate. None were detected in the sample.

5.3 Conclusions

5.3.1 Pack Burn Outs

Pack burn out's are reported to reduce the number of odor complaints, when they are performed on a daily basis. However, test data indicates that operators are exposed to levels of hydrocarbons over half the total TLV. This exposure can continue for some time after completion of this procedure.

Findings from the in-flight test indicate that hydrocarbons (ethanol) are breaking through the filter, even though a pack burnout is performed before the departure. Pack burn outs very likely accelerate the loading up of the surfaces on the filter, and accelerate the process of hydrocarbon breakthrough. Higher molecular-weight molecules occupy the available filter surface area necessary for trapping other compounds—such as formaldehyde and ethanol—and prevent the filter from effectively removing odors for its calculated life expectancy.

Physical damage—from excessive heat melting the thermoplastic adhesive that holds the filter pleats to the inner screen—was observed on the cabin filter. The thermoplastic adhesive starts to soften at 85-degrees C. The filters are rated for operation at temperatures of over 100-degrees C. It has not been determined if the adhesive used on this particular set of filters is faulty, or if the bleed temperature exceeded the filter-temperature limit (see the photograph in Appendix 1).

Bleed-air contamination-monitor results indicate other areas of the system are contaminated. On this aircraft, all four engines, and the APU, have modifications installed to minimize oil leakage into the bleed air. It is not known if the ECS system and ductwork were cleaned since these modifications were made to the main engines and the APU.

Ansett Airlines states that this cleaning usually occurs during the C-Check every 1000 hours, or approximately two years.

5.3.2 Cabin-Supply Air Quality

Note that current safety standards differ from air-quality levels, that will provide a perceived, acceptable level of customer and crew satisfaction. Contaminant levels may be well below recommended levels in currently accepted safety standards—yet generate complaints, because they can act in synergy with other contaminants—or because some standards may be outdated and not have incorporated more recent scientific and medical evidence . In addition, extenuating circumstances on board aircraft (including humidity and cabin pressure), have not been studied to the extent that a new standard can be proposed—that incorporates these factors—or identifies interactions between factors.

The quality of the supply air for the cabin and cockpit is within safety limits. Based on the filter analysis, there is no evidence to back claims of triorthocresyl phosphate exposure. The manufacturer of the oil-in-use on the aircraft backs this claim, as evidenced in the manufacture's

attached memo. Odors were detected in the air on the flights where the filters had hydrocarbon breakthrough. Changing the filters immediately corrected this problem.

Carbon-dioxide levels in the main cabin were very low, compared with other aircraft models. Based on an improvement in humidity levels—and reduction in organic contaminants seen while operating in a recirculation mode—it is recommended that the aircraft be operated in this mode.

Low-humidity levels can cause some of the sensible heat complaints. By operating in a recirculation mode, the effect of sensible heat on occupants of the aircraft, will be reduced by increasing the humidity—to buffer the rate of evaporation of perspiration .

Air-flow rates throughout the cabin were perceived to be very low near the center aisle. Increasing airflow has been found to give improved perception of air quality.

Carbon-dioxide levels in the aft galley were acceptable when no dry ice was present. During the final flight leg, the observation was made that the punkalouvre in the lavatory was closed. This louver was opened on the return trip, causing toilet odors to migrate forward to the rear row of seating. Indications are, that there is not enough air exchange in the aft-galley area. High carbon-dioxide levels, coupled with low humidity, could cause the sensation of burning eyes, as well as muscle aches, headaches, and so on.

6. RECOMMENDATIONS

In summation, there are five, key areas to improve air quality:

(1) Improve the filtration maintenance procedure and possibly use more readily cleanable filters.

Results from this test, suggest that pack burn outs should be discontinued, and a method of cleaning filters, external to the aircraft, be developed. Steam cleaning reduces the efficiency of the filter (75% filtration efficiency, post steam-cleaned). At this time, the most viable method for cleaning the filters is the use of supercritical fluid (carbon dioxide). Asdor Filters is currently developing cleanable filters and techniques to be used in their regeneration. Currently, the new process is yielding 97% efficiency on cleaned filters.

(2) A method of assessing filter life should be developed. The current procedure only examines the pressure drop across the filter. Hydrocarbon breakthrough is occurring, even though there is not a high-pressure drop. In the current application, the standard filter does not consistently provide 1000 hours of service—before rejection—due to pressure-drop criteria. Using a hydrocarbon monitor would allow operators to quickly check for hydrocarbons, to determine if breakthrough is occurring.

(3) Reinstate the use of recirculation mode in normal operation of the ECS.

(4) Increase sensible air movement in the cabin.

(5) Reduce the amount of carbon dioxide in the aft galley.

These changes and improvements will enhance the air quality for both the crew and the passengers of the aircraft.

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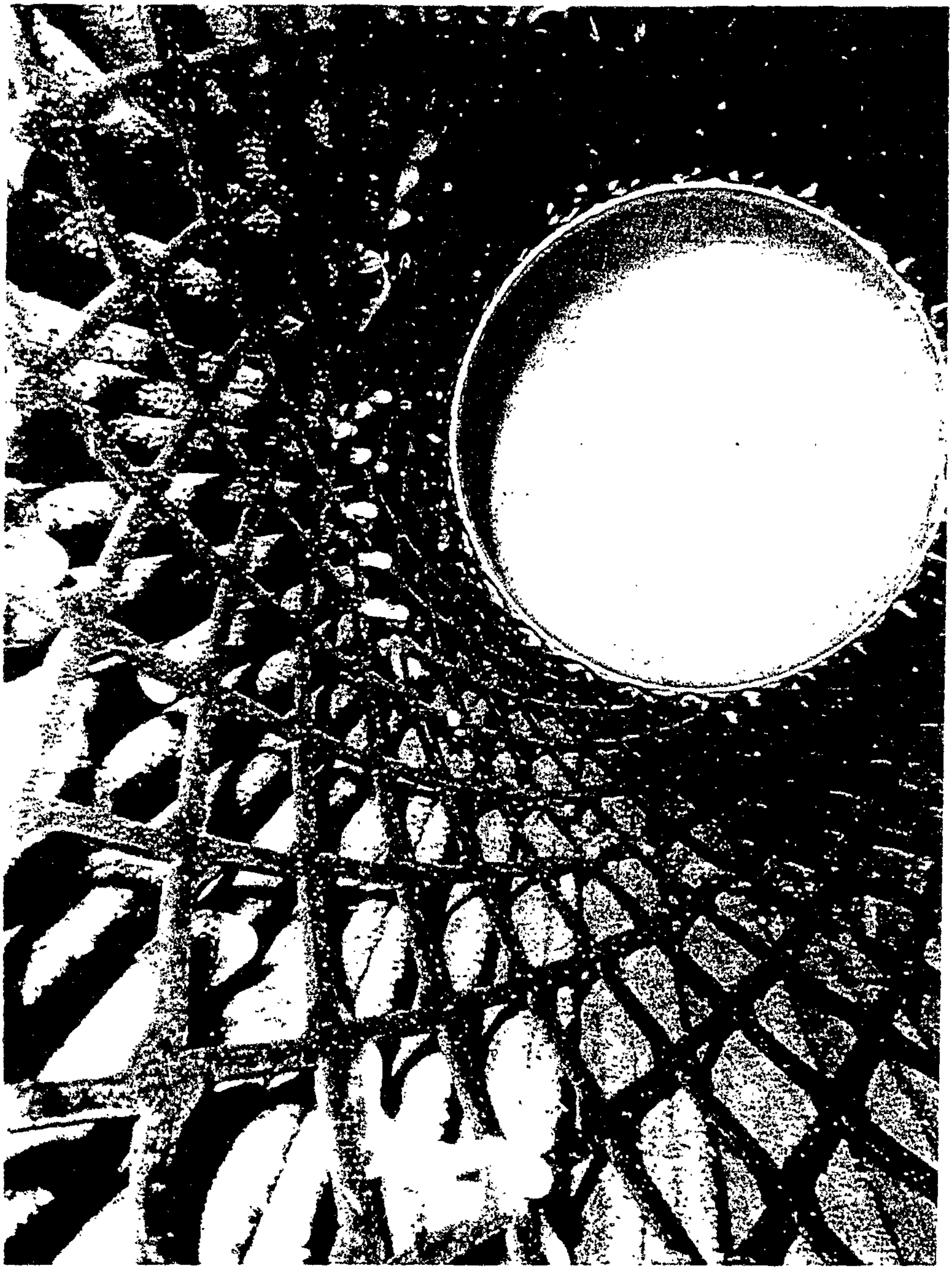
APPENDIX I

AIR-QUALITY TESTING ABOARD ANSETT AIRLINES BAe146 AIRCRAFT

SUPPORTING DATA

(18 pages)



		Cabin Filter	Cockpit Filter	TWA mg/m^3
EPA method TO-13				
GC/MS	COMPOUND mg/Kg			
Ret. Time	weight of compound per unit of filter mass			
5.21-.25	Napthalene	41	51	50
5.69	Nonane	40	60	1050
5.76	2-Butoxyethanol	30	50	24
6.8	Ethylmethyl Benzene Isomer		50	D/A
7.16	Octamethyl Cyclotetrasiloxane	200	300	D/A
7.4	Trimethylbenzene Isomer	60	50	123
7.5	Decane	200	500	D/A
7.89	Trimethylbenzene Isomer	50	200	123
7.99	Unidentified Hydrocarbon		50	D/A
8.05	Limonene		50	D/A
8.12	Eucalyptol	100	300	D/A
8.41	1-Methyl-3-Propylbenzene		50	D/A
8.51	Diethylbenzene Isomer	40		D/A
8.55	Unidentified Hydrocarbon		100	D/A
8.64	2-Methyldecane	50	100	D/A
8.75	3-Methyldecane	40		D/A
9.01	Dimethylethyl Benzene Isomer		170	D/A
9.11	Heptanoic Acid	100		D/A
9.26	Undecane	600	600	D/A
9.63	Tetramethylbenzene Isomer	80	100	D/A
9.86	Decamethylcyclopentasiloxane	200	300	D/A
10.16	Ethyl-dimethylbenzene Isomer	60		D/A
10.25	Unidentified Hydrocarbon	60		D/A
10.34	2-Methyl-undecane	90		D/A
10.44	Unidentified Hydrocarbon	80		D/A
10.93	Dodecane	600	500	D/A
11.13-12.05	Unidentified Hydrocarbons	300	400	D/A
12.33	Bornyl Acetate	100	100	D/A
12.49	Tridecane	600	400	D/A
12.86	1,3,5-Tris(1-Methylethyl)Benzene		60	D/A
13.41-13.51	Unidentified Hydrocarbons	100	200	D/A
13.94	Tetradecane	300	400	D/A
14.78	Unidentified Hydrocarbon	40	70	D/A
14.86	2,6-Bis(1,1-Dimethylethyl)-2,5-cyclohexadiene-1,4-dion	40	70	D/A
15.31	Pentadecane	200	300	D/A
16.66	Unidentified Acid	100	90	D/A
16.66	Hexadecane		100	D/A
17.17	Tributyl Phosphate	200	300	2200
17.5	Unidentified Hydrocarbon	40	50	D/A
18.02	Heptadecane	80	90	D/A
18.33	2,4-Diphenyl-4-Methyl-2(Z)-Pentene	100	200	D/A
19.67	Isopropyl Myristate	100	200	D/A
21.49	Unidentified Phthalate		50	D/A
22.91	n-Octyl-4-Hydroxybenzoate	100	200	D/A
30.37	Bis(2-ethylhexyl)phthalate		50	D/A
31.27-37.71	Unidentified Compounds	2000	800	D/A
31.76, 32.10, 32.4	Tricresylphosphate isomers	ND	ND	

ANSETT AIRLINES TEST- 8/23-25/97

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OLD FILTERS: G.T. Pack Burn (Full Fresh); NRF-Tkoff/climb, NRF-Cruise (Full Fresh); NRF-Descend/Land (Full Fresh). NEW FILTERS: Bris to Rkhptn (Full Fresh); Rkhptn to Bris (40% RECIRCULATED); Bris to Mackay (Full Fresh); Mackay to Bris (40% RECIRCULATED).

CAS # / R.T.	Compound	Units	G.T. Pack Burn Cockpit Supply	G.T. Pack Burn Cabin Supply	G.T. Pack Burn Galley	G.T. Pack Burn Field Blank	NRF-Tkoff/climb Cockpit	NRF-Tkoff/climb Cabin Supply	NRF-Tkoff/climb Galley	NRF-Cruise Cockpit Supply	NRF-Cruise Cabin Supply	NRF-Cruise Galley	NRF-Descend/Land Cockpit Supply	NRF-Descend/Land Cabin Supply	NRF-Descend/Land Galley	NRF-Descend/Land Field Blank	Bris to Rkhptn Cockpit Supply	Bris to Rkhptn Cabin Supply	Bris to Rkhptn Galley	Rkhptn to Bris Cockpit Supply	Rkhptn to Bris Cabin Supply	Rkhptn to Bris Galley	Rkhptn to Bris Field Blank	Bris to Mackay Cockpit Supply	Bris to Mackay Cabin Supply	Bris to Mackay Galley	Mackay to Bris Cockpit Supply	Mackay to Bris Cabin Supply	Mackay to Bris Galley	Mackay to Bris Field Blank	TWA ug/m³
DNPH Aldehyde Samples																															
EPA method TO-11			All Results reported in ug/m3																												
50-00-0	Formaldehyde		25.0	41.0	32.0		2.1	7.6	7.5	1.5	2.4	1.7	2.0	5.4	4.1		0.9	1.1	3.9	1.2	1.5	2.5		1.7	4.6	7.5	0.8	1.4	3.4		20.0
75-07-0	Acetaldehyde		26.0	36.0	30.0	2.8	5.6	13.0	12.0	3.0	5.0	4.4	4.1	6.4	5.6	2.6	3.7		30.0	6.3	6.4	18.0	4.8	3.1	6.8	22.0	3.4	4.6	18.0	0.9	360000.0
67-64-1	Acetone		23.0	21.0	24.0			17.0	34.0	9.0	7.1	16.0	87.0	20.0	26.0	7.6	12.0		34.0	14.0	16.0	45.0		6.6	8.5		11.0	9.6	33.0	3.1	1780000.0
107-02-8	Acrolein					9.8	16.0																								D/A
123-38-6	Propionaldehyde		4.7	4.8	5.1			2.4											1.8			1.7							1.5		D/A
123-72-8	Butyraldehyde		3.0	4.9	4.1														1.4			0.7									D/A
110-62-3	Valeraldehyde			4.0																						2.2					175000.0
66-25-1	Hexaldehyde		7.3						5.7													4.8			3.3	4.2			4.8		D/A
5779-94-2	2,5-Dimethyl Benzaldehyde		6.3																												D/A
SUMMA CANISTER SAMPLES																															
EPA Method 25C																															
	Carbon Monoxide	ppm	4.8	4.6	4.5		4.6	4.1	4.2	5.3	4.5	4.5	3.8	4.1	3.8		4.1	3.6	3.7	3.5	4.2	4.1		4.3	4.5	4.3	4.4		4.6		35
	Methane	ppm	2.2	2.1	2.0		2.0	2.5	2.3	2.2	2.0	1.8	2.1	1.7	2.2		2.1	2.0	2.0	2.1	2.3	2.1		2.1	1.6	2.2	2.0		2.6		D/A
	Carbon Dioxide	ppm	570	490	500		530	470	810	500	480	690	550	470	790		920	780	4700	1400	1200	3800		930	800	3100	1400		3500		5000
	Total Non-Methane Hydrocarbons	ppm	1.80	1.4	1.6		1.3	1.2	1.80		1.40	1.20							1.8	0.97		2.3				1.5			1.6		D/A
Analysis for Ozone Precursors																															
CAS #	COMPOUND																														
00074-85-1	Ethylene	ppb	2.2						2.1				0.2	2.1			1.7	1.9	1.5	2.3	13.0	2.1		5.2	5.8	5.4	1.3		2.4		D/A
00074-84-0	Ethane	ppb	8.7																												D/A
00074-98-6	Propane	ppb							4.1		3.7														3.3						980000
00075-28-5	Isobutane	ppb																2.0													785000
00078-78-4	Isopentane	ppb	3.1															3.9													D/A
00078-79-5	Isoprene	ppb																	2.4			2.4				2.0			2.4		D/A
00109-67-1	1 Pentene	ppb							6.7								6.1	1.6		4.5											D/A
00142-82-5	n-Heptane	ppb															5.1	4.2	5.4												350000
00108-87-2	Methylcyclohexane	ppb															3.8		4.1												1600000
00110-54-3	n-Hexane	ppb									3.3																				180000
00589-34-4	3-Methylhexane	ppb															4.4	3.8	4.8												D/A
EPA METHOD TO-14																															
CAS #	COMPOUND ug/m3																														
74-87-3	Chloromethane		3.4	3.5	3.3		2.6	2.3	2.5	7.1	8.2	5.3	2.5	2.1	2.4		2.2	2.8	3.3	2.7	2.5	3.1		3.2	2.7	4.8	2.4		3.5		D/A
75-00-3	Chloroethane		2.0	4.2	1.2					2.4	2.0													1.3	1.2	2.4			1.2		D/A
67-64-1	Acetone		35.0	23.0	35.0		21.0	28.0	32.0	11.0	7.4	31.0	40.0	25.0	23.0		13.0	14.0	45.0	20.0	32.0	70.0		18.0	18.0	48.0	24.0		64.0		1780000
75-69-4	Trichlorofluoromethane		1.8	1.8	1.8		1.5	1.5	1.9	1.6	1.5	1.7	2.0	2.1	2.1		1.8	1.3	1.6	1.7	1.4	1.7		1.1	1.9	2.9	5.3		30.0		D/A
75-09-2	Methylene chloride		1.4	2.4	1.3		1.0		4.5								1.5	2.1	5.1	1.4	1.0	1.4							1.4		1765000
75-15-0	Carbon Disulfide		9.0	24.0	12.0		3.6	3.1	2.5	3.6	5.0							5.0	6.4		3.0	5.5		3.4	4.5	9.8	3.4		3.4		300
76-13-1	Trichlorotrifluoroethane								1.1																						7600000
156-59-2	cis 1,2 Dichloroethene		1.3																												
1634-04-4	Methyl Tert-Butyl Ether																		0.8												D/A
108-05-4	Vinyl Acetate		2.5	5.3			1.4	2.4	3.1			2.2			1.3				6.2		2.0	1.0		1.5		4.3			5.0		15000
78-93-3	2-Butanone		15.0	12.0	13.0		7.4	9.1	20.0		1.9	12.0	6.6	8.5	5.8		2.9	5.4	5.7	3.7	11.0	8.4		4.7	4.3	9.2	4.9		8.8		590000
67-66-3	Chloroform																	3.0													9780
107-06-2	1,2-Dichloroethane									36.0	1.3									1.5	1.1										D/A
71-55-6	1,1,1-Trichloroethane								1.6										0.8	1.5		1.0									D/A
71-43-2	Benzene		1.9	1.7	1.2				1.3																						1600
56-23-5	Carbon Tetrachloride		2.0	1.7																											10000
79-01-6	Trichloroethene		5.8	6.2			4.0	3.8				1.1	3.5						3.4			3.3			5.0	5.1					546000
108-10-1	4-Methyl-2-pentanone		2.4	1.4	1.9		1.1		8.1			2.1						1.2	2.1		1.1	0.9				1.4					D/A
108-88-3	Toluene		15.0	11.0	16.0		7.0	5.6	22.0	4.5	3.1	9.2	3.0		5.6		30.0	23.0	32.0	4.4	2.8	11.0		4.5	3.7	13.0	2.9		6.9		375000
591-78-6	2-Hexanone								1.3			1.4									1.1										410000
127-18-4	Tetrachloroethene		3.6	4.6	3.9		2.5	2.0	6.6			3.0	1.3		2.4		2.1		3.0	1.3		4.0		1.4	1.6	6.3	1.3		3.6		170000
100-41-4	Ethylbenzene		2.4		1.0			2.8	2.4		1.3	1.6			1.2		1.1	1.3	2.0			1.2				1.3			1.5		435000
1330-20-7	m,p-Xylenes		7.1	4.0	4.5		3.0	3.7	7.6		3.7	6.1	1.0		4.8		4.2	5.2	6.5	3.3	1.4	4.7		2.7		4.5	1.6		5.6		435000
95-47-6	o-Xylene		2.3	1.4	1.5				2.5			1.9			1.5		0.9	1.7	1.9			1.8				1.6			1.8		435000
R.T. (min)	Identification																														
3.63	norflurane								200.0								3.0	70.0													
4.02	Propene									2.0																					D/A
4.03	Carbonyl Sulfide																								20.0		3.0				D/A
4.08	sulfur dioxide						30.0	200.0			20.0				3.0			70.0			10.0			200.0	8.0						5200
4.38	Dichlorodifluoromethane							4.0		4.0	4.0		4.0	4.0	4.0		6.0			4.0	44.0			4.0	4.0		40.0	100.0			4950000
4.58	1-chloro-1-fluoroethane																5.0			3.0											D/A
4.74	Isobutane																	70.0													1900000
4.75	Acetaldehyde		30.0	20.0	20.0		10.0	20.0	20.0	8.0	7.0	10.0	10.0	10.0	7.0		7.0		40.0	10.0	20.0	40.0		10.0	30.0	30.0	10.0		45.0		360000
5.01	Isobutene									2.0			2.0												4.0						D/A
5.40	Butane																								8.0						1900000
5.76	Ethanol		80.0	70.0	70.0		30.0	20.0	200.0			40.0	6.0	7.0	20.0		90.0	100.0	2000.0	500.0	300.0	3000.0		100.0	40.0	900.0	200.0		2000.0		1900000
6.63	Unidentified Chlorofluorocarbon								9.0								40.0	10.0	6.0	30.0	7.0	10.0									D/A
6.73	Acetonitrile		20.0	10.0	20.0			20.0				20.0		5.0	30.0		10.0	10.0	70.0	7.0		50.0		7.0	20.0	50.0	10.0		70.0		34000
7.54	Isopropyl Alcohol							3.0	30.0			4.0	2.0	2.0	3.0									8.0	10.0	200.0	10.0		30.0		980000
7.61	Isopentane		7.0				2.0		20.0									10.0									2.0				D/A
8.70	Pentadiene																		9.0	2.0		9.0				5.0	2.0		9.0		D/A
8.93	Butanol		7.0	4.0	6.0		6.0	7.0			5.0	4.0	4.0	7.0	4.0						5.0	3.0		30.0	8.0		3.0		7.0		D/A
10.80	Trimethylsilanol																									60.0			15.0		D/A
12.39	2-Methylhexane																20.0	10.0	10.0												D/A
12.50	Ethyl Acetate																					5.0							10.0		1400000
12.51	2,3-Dimethylpentane																5.0	5.0	5.0												D/A
12.68	tetrahydrofuran		30.0	50.0			5.0	4.0					10.0						9.0						50.0	8.0					590000
12.68	Pentanol						4.0	4.0			5.0			3.0	3.0					2.0	4.0	3.0		6.0	5.0		2.0				175000
12.75	3-Methylhexane				7.0				10.0			4.0					20.0	20.0	20.0												D/A
13.67	n-Heptane									2.0	2.0	3.0					30.0	20.0	20.0	2.0											350000
14.70	1-Butanol			5.0	6.0		5.0		8.0			5.0		2.0	3.0						3.0	5.0		20.0			2.0		6.0		D/A
14.66	Methylcyclohexane		8.0	5.0	9.0				9.0	4.0	3.0	4.0					20.0	10.0	20.0						5.0						1600000
14.85	Dimethyl Disulfide																			1.0											[illegible]
15.66	Isooctane																														D/A
16.57	C7-H14 Alkene																4.0	3.0													D/A
16.79	Hexanol						3.0	3.0	9.0		7.0	3.0		1.0							3.0			5.0		10.0	2.0		5.0		D/A
20.12	Hexamethylcyclotrisiloxane		10.0	40.0	20.0		20.0				8.0								10.0					3.0		200.0					D/A
22.67	2-Ethylhexanol										30.0																				D/A
22.72	Chloro(trifluoromethyl)benzene		70.0	70.0																						60.0					D/A
23.07	Nonane						2.0	3.0																							D/A
23.70	cyclohexanone		20.0	40.0	30.0		8.0	6.0	100.0		3.0	30.0		1.0	10.0		5.0	20.0	10.0		5.0	4.0		30.0	8.0	80.0	30.0		30.0		100000
23.90	1,2,4-Trimethylbenzene			5.0								1.0								1.0		2.0									D/A
23.96	Unidentified Silane or Siloxane			8.0			5.0																			40.0					D/A
23.97	Heptanol																				2.0										D/A
24.11	n-Decane		10.0				3.0	4.0	4.0		2.0																				D/A
24.17	2-butoxy-ethanol								20.0																						121000
24.44	Propylcyclohexane+C10 Alkene																														D/A
24.60	Benzaldehyde																	2.0			2.0										D/A
24.62	C11H24 Branched Alkane																														D/A
24.75	D-Limonene								10.0		3.0	8.0							10.0	2.0		10.0				7.0	1.0				D/A
24.91	n-butyl ether																							4.0							D/A
25.68	Nonanol														4.0																D/A
25.78	alpha-pinene								4.0	1.0		2.0										1.0									D/A
26.22	camphene									2.0										8.0	1.0						1.0				D/A
26.72	Azobisisobutyronitrile				10.0																										D/A
27.25	1-dichloromethyl-2,6-difluorobenzene			7.0																						20.0					D/A
27.43	Cymene		10.0							20.0							3.0			6.0	4.0								5.0		D/A
27.94	C11-C12 Branched Alkane																					4.0		3.0	5.0				4.0		D/A
27.73	Eucalyptol																		10.0			30.0							5.0		D/A
28.96	C12-C13 Branched Alkane		20.0	5.0	5.0						3.0	3.0																			D/A
29.17	dichlorotoluene		10.0	6.0																						8.0					D/A
	Sum of all TO-14 VOC's		446.1	453.2	300.6		180.3	362.3	774.0	111.2	137.4	217.4 ####	97.9	79.7	141.1		327.7	496.0	2374.9	675.5	470.4	3295.1		171.8	267.9	1795	363.8	n/s	2477		
	Sum of TO14 VOC's w/o ethanol and sample artifacts(teflon)		366.1	383.2	230.6		159.3	338.3	565.0	107.2	133.4	179.6 ####	87.9	68.7	117.1		186.7	386.0	368.9	88.5	119.4	285.0		162.8	223.9	895.6	123.8	n/s	377		

AlliedSignal

ANSETT AIRLINES TEST- 8/23-25/97

DNPH Aldehyde Samples

CAS	Compound	TWA ug/m³	Full Fresh, Old Filters: Park Burn – Cockpit Supply (15min STEL)	Park Burn – Cockpit Supply/TWA	Full Fresh, Old Filters: NRF Taxi/climb – Cockpit Supply	NRF Taxi/climb – Cockpit Supply/TWA	Full Fresh: NRF Cruise – Cockpit Supply	NRF Cruise – Cockpit Supply/TWA	Full Fresh: NRF Descend/Land – Cockpit Supply	NRF Descend/Land – Cockpit Supply/TWA	Full Fresh: Bris to Rkhptn – Cockpit Supply	Bris to Rkhptn – Cockpit Supply/TWA	40% RECIRC, New Filters: Rkhptn to Bris – Cockpit Supply	Rkhptn to Bris – Cockpit Supply/TWA	Full Fresh, New Filters: Bris to Mackay – Cockpit Supply	Bris to Mackay – Cockpit Supply/TWA	40% RECIRC, New Filters: Mackay to Bris – Cockpit Supply	Mackay to Bris – Cockpit Supply/TWA
	EPA method TO-11																	
	All Results reported in ug / m3																	
50-00-0	Formaldehyde (15min=100ug/m3 & 8hr=20ug/m3)	20.0	21.0	0.25	2.3	0.12	1.5	0.08	2.0	0.10	0.9	0.04	1.2	0.06	1.7	0.09	0.77	0.04
75-07-0	Acetaldehyde	360000.0	26.0		5.6		3.0		4.1		3.7		5.3		3.1		3.4	
67-64-1	Acetone	1780000.0	23.0				9.0		87.0		12.0		14.0		6.6		11.0	
107-02-8	Acrolein	D/A			16.0													
123-38-6	Propionaldehyde	D/A	14.7															
123-72-8	Butyraldehyde	D/A	13.0															
110-62-3	Valeraldehyde	175000.0																
66-25-1	Hexaldehyde	D/A	7.3															
5779-94-2	2,5-Dimethyl Benzaldehyde	D/A	6.3															
	SUMMA CANISTER SAMPLES																	
	EPA Method 25C																	
	All Results reported in ppm																	
	Carbon Monoxide	35	4.8	0.14	4.5	0.13	5.3	0.15	3.8	0.11	4.1	0.12	3.5	0.10	4.3	0.12	4.4	0.13
	Methane	D/A	2.2		2.0		2.2		2.1				2.1		2.1		2.0	
	Carbon Dioxide	5000	570.0	0.11	530.0	0.11	500.0	0.10	550.0	0.11	920.0	0.18	1400.0	0.28	930.0	0.19	1400.0	0.28
	Total Non-Methane Hydrocarbons ppm	D/A	1.8		1.3								1.0					
	Analysis for Ozone Precursors																	
	All Results reported in ppb																	
CAS #	COMPOUND																	
00074-85-1	Ethylene	D/A	2.2						3.2		1.7		2.3		5.2		1.3	
00074-84-0	Ethane	D/A	8.7															
00074-98-6	Propane	980000																
00075-28-5	Isobutane	785000																
00078-78-4	Isopentane	D/A	3.1															
00078-79-5	Isoprene	D/A																
00109-67-1	-Pentene	D/A									6.1		4.5					
00142-82-5	n-Heptane	350000									5.1							
00108-87-2	Methylcyclohexane	1600000									3.8							
00110-54-3	n-Hexane	180000																
00589-34-4	3-Methylhexane	D/A									4.4							
	EPA METHOD TO-14																	
	All Results reported in ug / m3																	
CAS #	COMPOUND																	
74-87-3	Chloromethane	D/A	3.4				7.1		2.5		2.2		2.7		3.2		2.4	
75-00-3	Chloroethane	D/A	2.0				2.4								1.3			
67-64-1	Acetone	1780000	[illegible]				11.1		40.0		11.0		21.0		18.0		24.0	
75-69-4	Trichlorofluoromethane	D/A	1.9				1.6		2.0		1.8		1.7		1.1		5.3	
75-09-2	Methylene chloride	1765000	1.6								1.6		1.4					
75-15-0	Carbon Disulfide	300	[illegible]	0.03			3.6	0.01							3.4	0.01	3.4	0.01
76-13-1	Trichlorotrifluoroethane	7600000																
156-59-2	cis-1,2-Dichloroethene		1.1															
1634-04-4	Methyl tert-Butyl Ether	D/A																
108-05-4	Vinyl Acetate	15000	2.5												1.5			
78-93-3	2-Butanone	590000	[illegible]						6.6		2.9		3.7		4.7		4.2	
67-66-3	Chloroform	9780																
107-06-2	1,2-Dichloroethane	D/A					36.0						1.5					
71-55-6	1,1,1-Trichloroethane	D/A											1.5					
71-43-2	Benzene	1600	1.2															
56-23-5	Carbon Tetrachloride	10000	1.0															
79-01-6	Trichloroethene	546000	5.8						1.5									
108-10-1	4-Methyl-2-pentanone	D/A	2.4															
108-88-3	Toluene	375000	15.0				4.5		3.0		[illegible]		4.4		4.5		2.9	
591-78-6	2-Hexanone	410000																
127-18-4	Tetrachloroethene	170000	3.6						1.3		2.1		1.3		1.4		1.3	
100-41-4	Ethylbenzene	435000	2.4								1.1							
1330-20-7	m,p-Xylenes	435000	7.7						1.0		4.2		3.3		2.7		1.6	
95-47-6	o-Xylene	435000	2.3								[illegible]							
R.T. (min)	Identification																	
3.63	norflurane										3.0							
4.02	Propene	D/A					2.0											
4.03	Carbonyl Sulfide	D/A															3.0	
4.08	sulfur dioxide	5200													200.0	0.04		
4.38	Dichlorodifluoromethane	4950000					4.0		4.0		6.0		4.0		4.0		40.0	
4.58	1-chloro-1-fluoroethane	D/A									5.0		3.0					
4.74	Isobutane	1900000																
4.75	Acetaldehyde	360000	30.0				8.0		10.0		7.0		10.0		10.0		10.0	
5.01	Isobutene	D/A					2.0		2.0									
5.40	Butane	1900000																
5.76	Ethanol	1900000	80.0						6.0		90.0		500.0		100.0		200.0	
6.63	Unidentified Chlorofluorocarbon	D/A									40.0		30.0					
6.73	Acetonitrile	34000	20.0								10.0		7.0		7.0		10.0	
7.54	Isopropyl Alcohol	980000							2.0						8.0		10.0	
7.61	Isopentane	D/A	7.0														2.0	
8.70	Pentadiene	D/A											2.0				2.0	
8.93	Butanal	D/A	7.0						4.0						30.0		3.0	
10.80	Trimethylsilanol	D/A																
12.39	2-Methylhexane	D/A									20.0							
12.50	Ethyl Acetate	1400000																
12.51	2,3-Dimethylpentane	D/A									5.0							
12.68	Tetrahydrofuran	590000	30.0						10.0									
12.68	Pentanal	175000											2.0		6.0		2.0	
12.75	3-Methylhexane	D/A									20.0							
13.67	n-Heptane	350000					2.0				10.0		2.0					
14.70	1-Butanol	D/A													20.0		2.0	
14.66	Methylcyclohexane	1600000	8.0				4.0				20.0							
14.85	Dimethyl Disulfide	D/A											7.0					
15.66	Isooctane	D/A																
16.57	C7H14 Alkene	D/A									4.0							
16.79	Hexanal	D/A													5.0		2.0	
20.12	Hexamethylcyclotrisiloxane	D/A	10.0												3.0			
22.67	2-Ethylhexanol	D/A																
22.72	Chloro(trifluoromethyl)benzene	D/A	70.0															
23.07	Nonane	D/A																
23.70	cyclohexanone	100000	20.0								5.0				30.0		30.0	
23.90	1,2,4 Trimethylbenzene	D/A											1.0					
23.96	Unidentified Silane or Siloxane	D/A																
23.97	Heptanal	D/A																
24.11	n-Decane	D/A	10.0															
24.17	2-butoxy-ethanol	121000																
24.44	Propylcyclohexane+C10 Alkene	D/A																
24.60	Benzaldehyde	D/A																
24.62	C11H24 Branched Alkane	D/A																
24.75	D-Limonene	D/A											2.0				1.0	
24.91	n-butyl ether	D/A													4.0			
25.68	Nonanal	D/A																
25.78	alpha pinene	D/A					1.0											
26.22	camphene	D/A					2.0						8.0				1.0	
26.72	Azobisisobutyronitrile	D/A																
27.25	1-dichloromethyl-2,6-difluorobenzene	D/A																
27.43	Cymene	D/A	10.0				20.0				3.0		6.0					
27.94	C11-C12 Branched Alkane	D/A													3.0			
27.73	Eucalyptol	D/A																
28.96	C12-C13 Branched Alkane	D/A	[illegible]															
29.17	dichlorotoluene	D/A	10.0															
	Total Concentrations/TWA's			0.5		0.3		0.3		0.3		0.3		0.4		0.4		0.5

AIR-QUALITY TESTING
ABOARD ANSETT AIRLINES
BAe146 AIRCRAFT

FINAL REPORT

21-9910 November 25, 1997

AlliedSignal
AEROSPACE

ANSETT AIRLINES TEST- 8/23-25/97

			Full Fresh				Full F esh						40% REC'RC.		Full Fresh		40% RE'IRC.	
			'OLD FILTERS								NEW FILTERS							
			G.T. Pack Burn		NRF-Ikoff/clmb		NRF-Cruise		NRF-Descend/Land		Bris to Rkhpln		Rkhpln to Bris		Bris to Mackay		Mackay to Bris	
DNPH Aldehyde Samples		TWA ug/m³	Cabin Supply (15min STEL)	Cabin Supply/TWA	Cabin Supply	Cabin Supply/TWA	Cabin Supply	Cabin Supply/TWA	Cabin Supply	Cabin Supply/TWA	Cabin Supply	Cabin Supply/TWA	Cabin Supply	Cabin Supply/TWA	Cabin Supply	Cabin Supply/TWA	Cabin Supply	Cabin Supply/TWA
EPA method TO-11																		
All Results reported in ug / m3																		
50-00-0	Formaldehyde (15 min=100ug/m3 & 8 hr = 20 ug/m3	20 0	41.0	0.41	7.6	0.38	2.4	0.12	5.4	0.27	0.9	0.04	1.2	0.06	4.6	0.23	1.4	0.07
75-07-0	Acetaldehyde	360000 0	36.0		13.0		5.0		6.4		3.7		5.3		6.8		4.6	
67-64-1	Acetone	1780000.0	21.0		17.0		7.1		20.0		12.0		14.0		8.5		9.6	
107-02-8	Acrolein	D/A																
123-38-6	Propionaldehyde	D/A	4.8		2.4													
123-72-8	Butyraldehyde	D/A	4.9															
110-62-3	Valeraldehyde	175000 0	4.0															
66-25-1	Hexaldehyde	D/A													3.3			
5779-94-2	2,5-Dimethyl Benzaldehyde	D/A																
SUMMA CANISTER SAMPLES																		
EPA Method 25C																		
All Results reported in ppm																		
Carbon Monoxide		35	4.6	0.13	4.1	0.12	4.5	0.13	4.1	0.12	4.1	0.12	3.5	0.10	4.5	0.13		0.00
Methane		D/A	2.1		2.5		2.0		1.7		2.1		2.1		1.6			
Carbon Dioxide		5000	490	0.10	470	0.09	480	0.10	470	0.09	920.0	0.18	1400.0	0.28	800	0.16		0.00
Total Non-Methane Hydrocarbons ppm		D/A																
Analysis for Ozone Precursors																		
All Results reported in ppb																		
CAS #	COMPOUND																	
00074-85-1	Ethylene	D/A							2.1		1.9		2.3		5.8			
00074-84-0	Ethane	D/A																
00074-98-6	Propane	980000					3.7								3.3			
00075-28-5	Isobutane	785000									2.0							
00078-78-4	Isopentane	D/A									3.9							
00078-79-5	Isoprene	D/A																
00109-67-1	1-Pentene	D/A									1.6		4.5					
00142-82-5	n-Heptane	350000									4.2							
00108-87-2	Methylcyclohexane	1600000																
00110-54-3	n-Hexane	180000					3.3											
00589-34-4	3-Methylhexane	D/A									3.8							
EPA METHOD TO-14																		
All Results reported in ug / m3																		
CAS #	COMPOUND ug/m3																	
74-87-3	Chloromethane	D/A	3.5		2.3		8.2		2.1		2.8		2.7		2.7			
75-00-3	Chloroethane	D/A	4.2				2.0								1.2			
67-64-1	Acetone	1780000	23.0		28.0		7.4		25.0		14.0		20.0		18.0			
75-69-4	Trichlorofluoromethane	D/A	1.8		1.5		1.5		2.1		1.3		1.7		1.9			
75-09-2	Methylene chloride	1765000	2.4								2.1		1.4					
75-15-0	Carbon Disulfide	300	24.0	0.08	3.1	0.01	5.0	0.02			5.0	0.02			4.5	0.02		
76-13-1	Trichlorotrifluoroethane	7600000																
156-59-2	cis-1,2-Dichloroethene																	
1634-04-4	Methyl tert-Butyl Ether	D/A																
108-05-4	Vinyl Acetate	15000	5.3		2.4													
78-93-3	2-Butanone	590000	12.0		9.1		1.9		8.5		5.4		3.7		4.3			
67-66-3	Chloroform	9780									3.0							
107-06-2	1,2-Dichloroethane	D/A					1.3						1.5					
71-55-6	1,1,1-Trichloroethane	D/A											1.5					
71-43-2	Benzene	1600	1.7															
56-23-5	Carbon Tetrachloride	10000	1.7															
79-01-6	Trichloroethene	546000	6.2		3.8										5.0			
108-10-1	4-Methyl-2-pentanone	D/A	1.4								1.2							
108-88-3	Toluene	375000	11.0		5.6		3.1				23.0		4.4		3.7			
591-78-6	2-Hexanone	410000																
127-18-4	Tetrachloroethene	170000	4.6		2.0								1.3		1.6			
100-41-4	Ethylbenzene	435000			2.8		1.3				1.3							
1330-20-7	m,p-Xylenes	435000	4.0		3.7		3.7				5.2		3.3					
95-47-6	o-Xylene	435000	1.4								1.7							
RT (min)	Identification										70.0							
3.63	norflurane																	
4.02	Propene	D/A																
4.03	Carbonyl Sulfide	D/A			200.0						70.0				20.0			
4.08	sulfur dioxide	5200			4.0		20.0								8.0			
4.38	Dichlorodifluoromethane	4950000					4.0		4.0				4.0		4.0			
4.58	1-chloro-1-fluoroethane	D/A									70.0		3.0					
4.74	Isobutane	1900000			20.0													
4.75	Acetaldehyde	360000	20.0				7.0		10.0				10.0		30.0			
5.01	Isobutene	D/A													4.0			
5.40	Butane	1900000			20.0						100.0				8.0			
5.76	Ethanol	1900000	70.0						7.0		10.0		500.0		40.0			
6.63	Unidentified Chlorofluorocarbon	D/A			20.0						10.0		30.0					
6.73	Acetonitrile	34000	10.0		3.0				5.0				7.0		20.0			
7.54	Isopropyl Alcohol	980000							2.0		10.0				10.0			
7.61	Isopentane	D/A																
8.70	Pentadiene	D/A			7.0								2.0					
8.93	Butanol	D/A	4.0				5.0		7.0						8.0			
10.80	Trimethylsilanol	D/A									10.0							
12.39	2-Methylhexane	D/A																
12.50	Ethyl Acetate	1400000									5.0							
12.51	2,3-Dimethylpentane	D/A			4.0													
12.68	tetrahydrofuran	590000	50.0		4.0										50.0			
12.68	Pentanol	175000					5.0		3.0		20.0		2.0		5.0			
12.75	3-Methylhexane	D/A									20.0							
13.67	n-Heptane	350000					2.0						2.0					
14.70	1-Butanol	D/A	5.0						2.0		10.0							
14.66	Methylcyclohexane	1600000	5.0				3.0								5.0			
14.85	Dimethyl Disulfide	D/A											7.0					
15.66	Isooctane	D/A									3.0							
16.57	C7 H14 Alkene	D/A			3.0													
16.79	Hexanol	D/A					7.0		1.0									
20.12	Hexamethylcyclotrisiloxane	D/A	40.0				8.0											
22.67	2-Ethylhexanal	D/A					30.0											
22.72	Chloro(trifluoromethyl)benzene	D/A	70.0		3.0													
23.07	Nonane	D/A			6.0						20.0							
23.70	cyclohexanone	100000	40.0				3.0		1.0						8.0			
23.90	1,2,4 Trimethylbenzene	D/A	5.0										1.0					
23.96	Unidentified Silane or Siloxane	D/A	8.0															
23.97	Heptanal	D/A			4.0													
24.11	n-Decane	D/A					2.0											
24.17	2-butoxy ethanol	121000																
24.44	Propylcyclohexane+C10 Alkene	D/A									2.0							
24.60	Benzaldehyde	D/A																
24.62	C11H24 Branched Alkane	D/A																
24.75	D-Limonene	D/A					3.0						2.0					
24.91	n-butyl ether	D/A																
25.68	Nonanal	D/A																
25.78	alpha-pinene	D/A																
26.22	camphene	D/A											8.0					
26.72	Azobisisobutyronitrile	D/A																
27.25	?-dichloromethyl-2,6-difluorobenzene	D/A	7.0															
27.43	Cymene	D/A											6.0					
27.94	C11-C12 Branched Alkane	D/A													5.0			
27.73	Eucalyptol	D/A																
28.96	C12-C13 Branched Alkane	D/A	5.0				3.0											
29.17	dichlorotoluene	D/A	6.0															
Total Concentrations/TWA's				0.7		0.6		0.4		0.5		0.4		0.4		0.5		0.1

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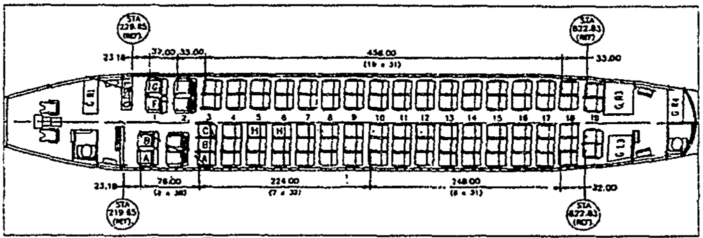
ANSETT AIRLINES TEST- 8/23-25/97

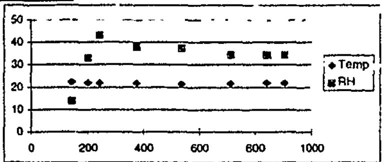
			Full Fresh				Full Fresh				Full Fresh		40% RECIRC.		Full Fresh		40% RECIRC.	
			"OLD FILTERS								NEW FILTERS							
			G.T. Pack Burn		NRF-tkoff/climb		NRF-Cruise		NRF-Descend/Land		Bris to Rkhptn		Rkhptn to Bris		Bris to Mackay		Mackay to Bris	
DNPH Aldehyde Samples		TWA ug/m^3	Galley Air (15 min STEL)	Galley Air/TWA	Galley Air	Galley Air/TWA	Galley Air	Galley Air/TWA	Galley Air	Galley Air/TWA	Galley Air	Galley Air/TWA	Galley Air	Galley Air/TWA	Galley Air	Galley Air/TWA	Galley Air	Galley Air/TWA
EPA method TO-11																		
All Results reported in ug / m3																		
50-00-0	Formaldehyde(15min=100ug/m3 & 8hr=20ug/m3	20.0	32.0	0.32	7.5	0.38	1.7	0.09	4.1	0.21	3.9	0.20	2.5	0.13	7.5	0.38	3.4	0.17
75-07-0	Acetaldehyde	360000.0	30.0		12.0		4.4		5.6		30.0		18.0		22.0		18.0	
67-64-1	Acetone	1780000.0	24.0		34.0		16.0		26.0		34.0		45.0				33.0	
107-02-8	Acrolein	D/A																
123-38-6	Propionaldehyde	D/A	5.1								1.8		1.7				1.5	
123-72-8	Butyraldehyde	D/A	4.1								1.4		0.7					
110-62-3	Valeraldehyde	175000.0													2.2			
66-25-1	Hexaldehyde	D/A			5.7								4.8		4.2		4.8	
5779-94-2	2,5-Dimethyl Benzaldehyde	D/A																
SUMMA CANISTER SAMPLES																		
EPA Method 25C																		
All Results reported in ppm																		
Carbon Monoxide		35	4.6	0.13	4.2	0.12	4.5	0.13	3.8	0.11	3.7	0.11	4.1	0.12	4.3	0.12	4.6	0.13
Methane		D/A	2.1		2.3		1.8		2.2		2.0		2.1		2.2		2.6	
Carbon Dioxide		5000	490	0.10	810	0.16	690	0.14	790	0.16	4700	0.94	3800	0.76	3100	0.62	3500	0.70
Total Non-Methane Hydrocarbons ppm		D/A	1.4		1.80		1.20				1.8		2.3		1.5		1.6	
Analysis for Ozone Precursors																		
All Results reported in ppb																		
CAS #	COMPOUND																	
00074-85-1	Ethylene	D/A			2.1						1.5		2.1		5.4		2.4	
00074-84-0	Ethane	D/A																
00074-98-6	Propane	980000			4.1													
00075-28-5	Isobutane	785000																
00078-78-4	Isopentane	D/A																
00078-79-5	Isoprene	D/A									2.4		2.4		2.0		2.4	
00109-67-1	1-Pentene	D/A			6.7													
00142-82-5	n-Heptane	350000									5.4							
00108-87-2	Methylcyclohexane	1600000									4.1							
00110-54-3	n-Hexane	180000																
00589-34-4	3-Methylhexane	D/A									4.8							
EPA METHOD TO-14																		
All Results reported in ug / m3																		
CAS #	COMPOUND ug/m3																	
74-87-3	Chloromethane	D/A	3.3		2.5		5.3		2.4		3.3		3.1		4.8		3.5	
75-00-3	Chloroethane	D/A	1.2												2.4		1.2	
67-64-1	Acetone	1780000	35.0		32.0		31.0		23.0		45.0		70.0		48.0		64.0	
75-69-4	Trichlorofluoromethane	D/A	1.8		1.9		1.7		2.1		1.6		1.7		2.9		30.0	
75-09-2	Methylene chloride	1765000	1.3		4.5						5.1		1.4				1.4	
75-15-0	Carbon Disulfide	300	12.0	0.04	2.5	0.01					6.4	0.02	5.5	0.02	9.8	0.03	3.4	0.01
76-13-1	Trichlorotrifluoroethane	7600000			1.1													
156-59-2	cis-1,2-Dichloroethene																	
1634-04-4	Methyl tert-Butyl Ether	D/A									0.8							
108-05-4	Vinyl Acetate	15000			3.1		2.2		1.3		6.2		1.0		4.3		5.0	
78-93-3	2-Butanone	590000	13.0		20.0		12.0		5.8		5.7		8.4		9.2		8.8	
67-66-3	Chloroform	9780																
107-06-2	1 2-Dichloroethane	D/A																
71-55-6	1,1,1-Trichloroethane	D/A			1.6						0.8		1.0					
71-43-2	Benzene	1600	1.2		1.3													
56-23-5	Carbon Tetrachloride	10000																
79-01-6	Trichloroethene	546000					1.1				3.4		3.3		5.1			
108-10-1	4-Methyl-2-pentanone	D/A	1.9		8.1		2.1				2.1		0.9		1.4			
108-88-3	Toluene	375000	16.0		22.0		9.2		5.6		32.0		11.0		13.0		6.9	
591-78-6	2-Hexanone	410000			1.3		1.4											
127-18-4	Tetrachloroethene	170000	3.9		6.6		3.0		2.4		3.0		4.0		6.3		3.6	
100-41-4	Ethylbenzene	435000	1.0		2.4		1.6		1.2		2.0		1.2		1.3		1.5	
1330-20-7	m,p-Xylenes	435000	4.5		7.6		6.1		4.8		6.5		4.7		4.5		5.6	
95-47-6	o-Xylene	435000	1.5		2.5		1.9		1.5		1.9		1.8		1.6		1.8	
R.T. (min)	Identification																	
3.63	norflurane				200.0													
4.02	Propene	D/A																
4.03	Carbonyl Sulfide	D/A																
4.08	sulfur dioxide	5200							3.0									
4.38	Dichlorodifluoromethane	4950000							4.0								100.0	
4.58	1-chloro-1-fluoroethane	D/A																
4.74	Isobutane	1900000																
4.75	Acetaldehyde	360000	20.0		20.0		10.0		7.0		40.0		40.0		30.0		45.0	
5.01	Isobutene	D/A																
5.40	Butane	1900000																
5.76	Ethanol	1900000	70.0		200.0		40.0		20.0		2000.0		3000.0		900.0		#####	
6.63	Unidentified Chlorofluorocarbon	D/A			9.0						6.0		10.0					
6.73	Acetonitrile	34000	20.0				20.0		30.0		70.0		50.0		50.0		70.0	
7.54	Isopropyl Alcohol	980000			30.0		4.0		3.0						200.0		30.0	
7.61	Isopentane	D/A			20.0													
8.70	Pentadiene	D/A									9.0		9.0		8.0		9.0	
8.93	Butanal	D/A	6.0				4.0		4.0				3.0				7.0	
10.80	Trimethylsilanol	D/A													60.0		15.0	
12.39	2-Methylhexane	D/A									10.0							
12.50	Ethyl Acetate	1400000											5.0				10.0	
12.51	2,3-Dimethylpentane	D/A									5.0							
12.68	tetrahydrofuran	590000									9.0				8.0			
12.68	Pentanal	175000							3.0				3.0					
12.75	3-Methylhexane	D/A	7.0		10.0		4.0				20.0							
13.67	n-Heptane	350000					3.0				20.0							
14.70	1-Butanol	D/A	6.0		8.0		5.0		3.0				5.0				6.0	
14.66	Methylcyclohexane	1600000	9.0		9.0		4.0				20.0							
14.85	Dimethyl Disulfide	D/A																
15.66	Isooctane	D/A																
16.57	C7-H14 Alkene	D/A																
16.79	Hexanal	D/A			9.0		3.0								10.0		5.0	
20.12	Hexamethylcyclotrisiloxane	D/A	20.0								10.0				200.0			
22.67	2-Ethylhexanol	D/A																
22.72	Chloro(trifluoromethyl)benzene	D/A													60.0			
23.07	Nonane	D/A																
23.70	cyclohexanone	100000	30.0		100.0		30.0		10.0		10.0		4.0		80.0		30.0	
23.90	1,2,4-Trimethylbenzene	D/A					1.0						2.0					
23.96	Unidentified Silane or Siloxane	D/A													40.0			
23.97	Heptanal	D/A																
24.11	n-Decane	D/A			4.0													
24.17	2-butoxy-ethanol	121000			20.0													
24.44	Propylcyclohexane+C10 Alkene	D/A																
24.60	Benzaldehyde	D/A																
24.62	C11H24 Branched Alkane	D/A																
24.75	D-Limonene	D/A			10.0		8.0				10.0		10.0		7.0			
24.91	n-butyl ether	D/A																
25.68	Nonanal	D/A							4.0									
25.78	alpha-pinene	D/A			4.0		2.0						1.0					
26.22	camphene	D/A																
26.72	Azobisisobutyronitrile	D/A	10.0															
27.25	1-dichloromethyl-2,6-difluorobenzene	D/A													20.0			
27.43	Cymene	D/A															5.0	
27.94	C11-C12 Branched Alkane	D/A											4.0				4.0	
27.73	Eucalyptol	D/A									10.0		30.0				5.0	
28.96	C12-C13 Branched Alkane	D/A	5.0				3.0											
29.17	dichlorotoluene	D/A													8.0			
	Total Concentrations/TWA's			0.6		0.7		0.4		0.5		1.3		1.0		1.2		1.0

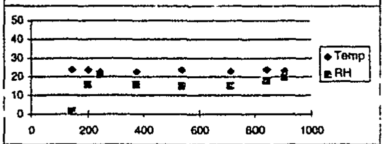
Temperature and Humidity Measurements

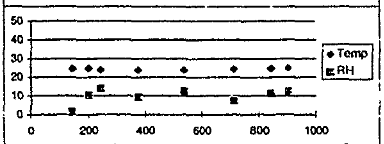
Non Revenue Test Flight 24 August 1997 BNE-BNE

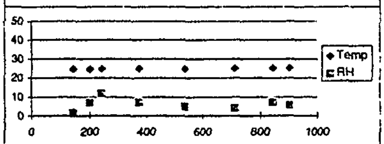


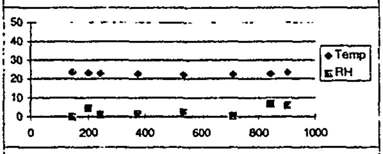
Phase	Time	Location	X (Approx)	Temp	RH	Comments
Climb	9:30	1B	242	21.7	43.1	
	9:30	5C	375	21.7	38.2	
	9:31	10C	535	21.3	37.5	
	9:32	15C	715	21.4	34.5	
	9:33	19B	840	21.8	34.6	
	9:34	AG	900	21.9	34.6	
	9:35	FG	200	21.8	33	
	9:36	CP	144	22.1	14	
Climb	9:40	1B	242	22.4	21.6	
	9:41	5C	375	22.5	16	
	9:42	10C	535	23.6	15.1	
	9:43	15C	715	22.7	15.4	
	9:44	19B	840	23.8	18.1	
	9:45	AG	900	23.2	20	
	9:46	FG	200	23.6	16	
	9:48	CP	144	23.6	1.6	
Cruise	9:50	1B	242	23.7	13.9	
	9:51	5C	375	23.8	9.5	
	9:52	10C	535	23.7	12.8	
	9:53	15C	715	24.1	7.6	
	9:54	19B	840	24.6	11.4	
	9:55	AG	900	24.7	12.4	
	9:56	FG	200	24.5	10.5	
	9:57	CP	144	24.4	1.6	
Cruise	10:02	1B	242	24.7	12	
	10:03	5C	375	24.8	7.2	
	10:04	10C	535	24.6	5.1	
	10:05	15C	715	24.8	4.2	
	10:06	19B	840	25	7.2	
	10:07	AG	900	25	5.6	
	10:08	FG	200	24.5	7	
	10:10	CP	144	24.5	1.5	
Cruise	10:15	1B	242	22.7	1	
	10:16	5C	375	22.6	1.5	
	10:17	10C	535	22.2	2.2	
	10:19	15C	715	22.2	0.4	
	10:20	19B	840	22.6	7	
	10:22	AG	900	23.2	6	
	10:23	FG	200	23	4.5	
	10:25	CP	144	23.4	0	
Cruise	10:52	1B	242	21.8	0	
	10:53	5C	375	21.8	0	
	10:54	10C	535	21.6	0	
	10:55	15C	715	21.8	0.5	
	10:56	19B	840	22.1	0.5	
	10:57	AG	900	22.6	0	
	10:58	FG	200	21.9	1.7	
	11:00	CP	144	21.7	0	
Descent	11:04	1B	242	23	1.4	Top of Descent
	11:05	5C	375	23.2	1.5	
	11:06	10C	535	23	0	
	11:07	15C	715	23	0	
	11:08	19B	840	23.5	1.7	
	11:09	AG	900	24	2.5	
	11:10	FG	200	23.4	2.5	
	11:12	CP	144	23.3	0	
Descent	11:17	4C	343	24.3	17.4	Landing
	11:18	4C	343	24.5	17.5	
	11:20	4C	343	24.4	17.2	

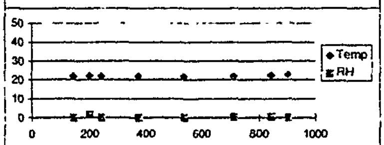


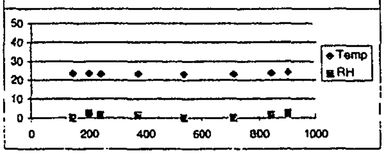






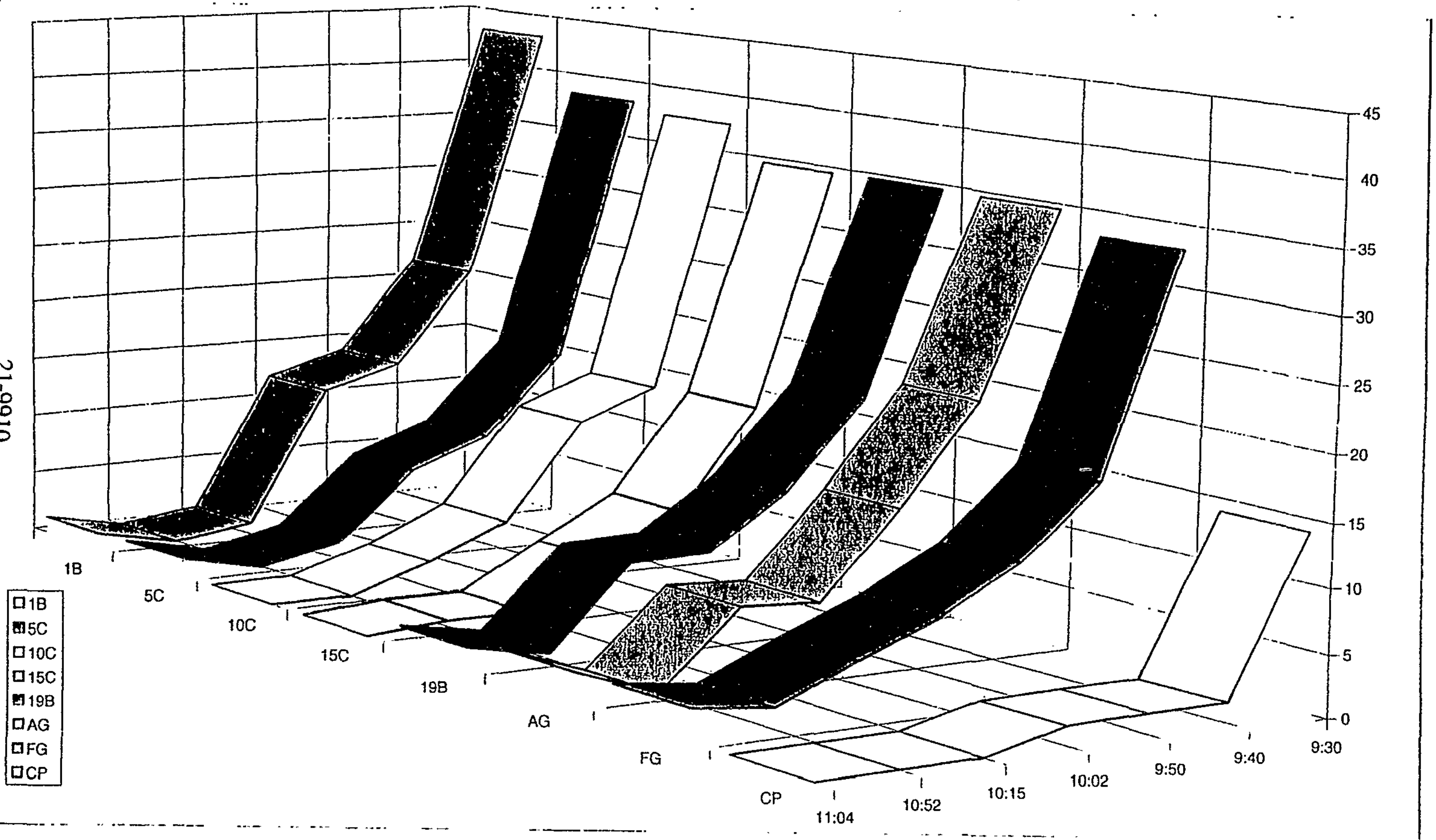






RH v Time NR Flight

Relative Humidity versus time for Non-Revenue Flight
at seats 1B,5C,10C,15C,19B, Aft Galley, Fwd Galley and Cockpit



Temperature and Humidity Measurements

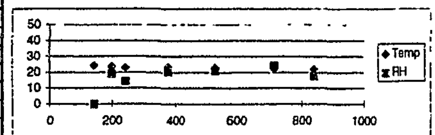
FRESH

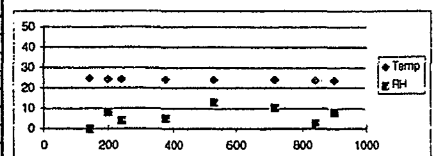
Min R.H

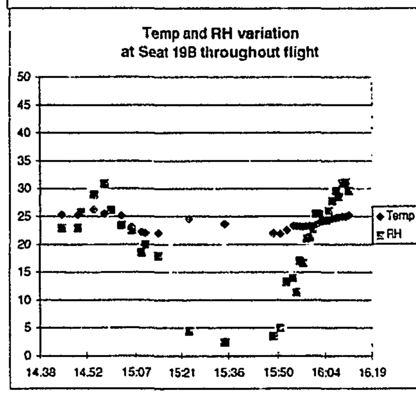
0 - 2.5%

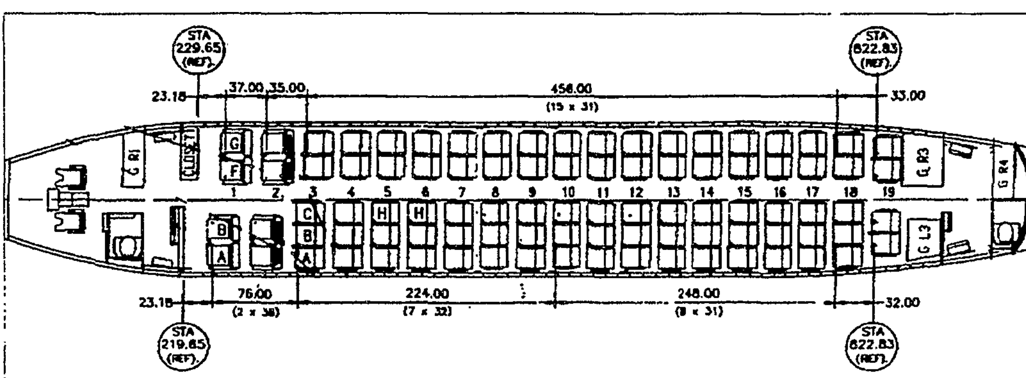
Revenue Test Flight 24 August 1997 AN 276 BNE-ROK

Phase	Time	Location	X (Approx)	Temp	RH	Comments
Gate	14:45	19B	840	25.3	22.9	
	14:50	19B	840	25.3	23	
Push Back	*14:51*	*19B*	*840*	*25.7*	*25.8*	
	14:55	19B	840	26.2	29	
	14:58	19B	840	25.5	30.9	
Takeoff	15:00	19B	840	26.1	26.2	
	15:03	19B	840	25.1	23.5	
	15:06	19B	840	23.1	22.5	
	15:09	19B	840	22.2	18.5	
	15:10	19B	840	22	20	
	15:14	19B	840	22	17.9	
	15:14	15C	715	22.2	24.3	
	15:15	10C	535	22.7	20.9	
	15:15	5C	375	23.1	20.5	
	15:16	1B	242	22.8	14.5	
	15:16	FG	200	23.3	19.2	
	15:17	CP	144	24.1	0	
	15:24	19B	840	24.5	4.5	
	15:35	19B	840	23.6	2.5	
	15:36	AG	900	23.6	8	
	15:37	15C	715	24	10.4	
	15:38	10C	535	24	13	
	15:39	5C	375	24.2	5.1	
	15:40	1B	242	24.1	4	
	15:41	FG	200	24.2	8.2	
	15:42	CP	144	24.8	0	
Descent	15:49	19B	840	22	3.6	
	15:51	19B	840	21.8	5	
	15:53	19B	840	22.5	13.3	
	15:55	19B	840	23.3	14	
	15:56	19B	840	23.2	11.4	
	15:57	19B	840	23.2	17.1	
	15:58	19B	840	23.1	16.7	
	15:59	19B	840	23.2	21	
	16:00	19B	840	23.2	21.3	
	16:01	19B	840	23.2	22.7	
	16:02	19B	840	23.4	25.5	
	16:03	19B	840	23.8	25.5	
Landing	16:04	19B	840	24.1	24.4	
	16:05	19B	840	24.2	24.4	
	16:06	19B	840	24.3	26	
	16:07	19B	840	24.6	27.8	
Shutdown	16:08	19B	840	24.7	29.6	
	16:09	19B	840	24.8	28.6	
	16:10	19B	840	24.9	31	
	16:11	19B	840	24.9	31.1	
	16:12	19B	840	25.2	29.6	







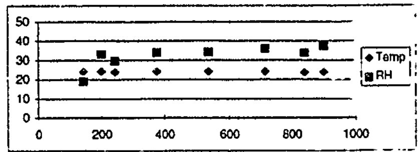


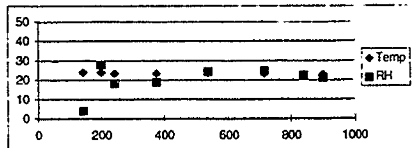
Temperature and Humidity Measurements

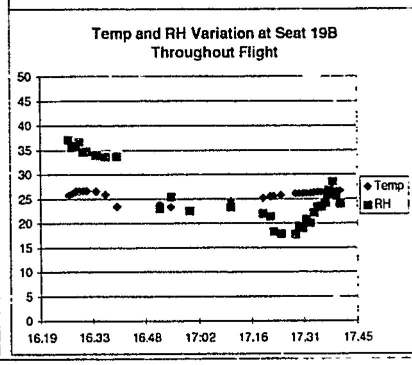
(RECIRC)

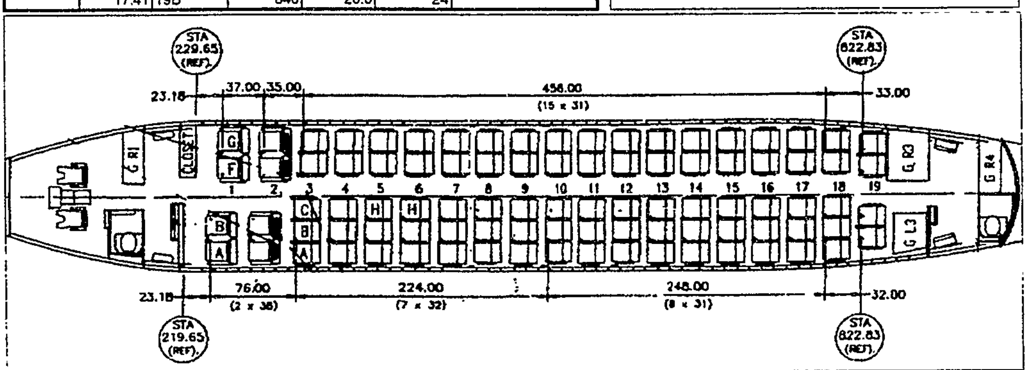
Revenue Test Flight 24 August 1997 AN ??? ROK-BNE

Phase	Time	Location	X (Approx)	Temp	RH	Comments
	16:27	19B	840	25.7	37.2	
Start	16:28	19B	840	26	35.7	
	16:29	19B	840	26.5	35.9	
	16:30	19B	840	26.5	36.7	
	16:31	19B	840	26.6	34.7	
	16:32	19B	840	26.6	34.8	
Takeoff	16:34	19B	840	26.5	34	
	16:37	19B	840	25.8	33.7	
	16:40	19B	840	23.4	33.8	
	16:42	AG	900	23.6	37.5	
	16:42	15C	715	23.8	36	
	16:42	10C	535	24	34.2	
	16:43	5C	375	24	34	
	16:43	1B	242	23.7	29.5	
	16:43	FG	200	24.1	33	
	16:44	CP	144	23.9	19	
	16:52	19B	840	23.9	23	
	16:55	19B	840	23.3	25.4	
	17:00	19B	840	22.6	22.5	
	17:01	AG	900	22.8	21.1	
	17:01	15C	715	23	24.6	
	17:02	10C	535	23.2	24.2	
	17:03	5C	375	23.3	18.8	
	17:03	1B	242	23.3	18.2	
	17:04	FG	200	23.8	27.7	
	17:05	CP	144	23.8	4	
	17:11	19B	840	24.5	23.3	
	17:20	19B	840	25.1	22	
	17:22	19B	840	25.4	21.3	
	17:23	19B	840	25.5	18.3	
	17:25	19B	840	25.7	17.8	
	17:29	19B	840	26	17.7	
	17:30	19B	840	26	19.4	
	17:31	19B	840	26	19	
	17:32	19B	840	26.1	20.8	
	17:33	19B	840	26.1	20.1	
	17:34	19B	840	26.2	22.1	
	17:35	19B	840	26.3	23.3	
	17:36	19B	840	26.4	23.5	
	17:37	19B	840	26.4	24.2	
	17:37:40	19B	840	26.6	26	
	17:38	19B	840	26.6	26.8	
	17:39	19B	840	26.6	28.5	
	17:40	19B	840	26.6	25.6	
	17:41	19B	840	26.6	24	









FRESH @ Row 19

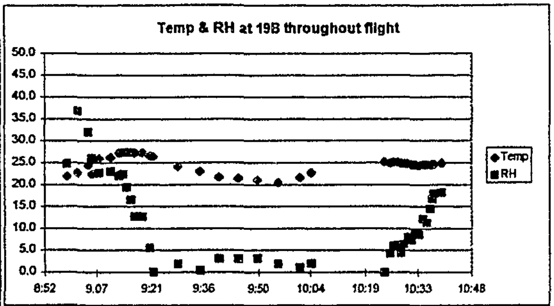
Min R.H 0%

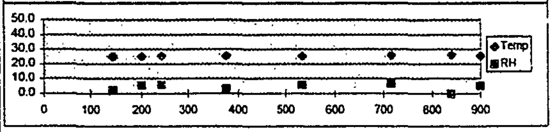
BNE-MKY

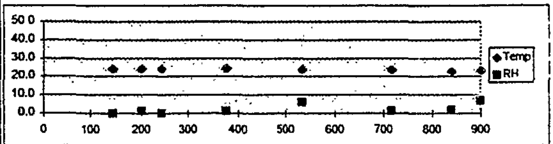
Temperature and Humidity Measurements

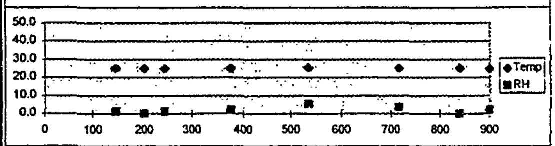
Revenue Test Flight 25 August 1997 AN 262 BNE-MKY

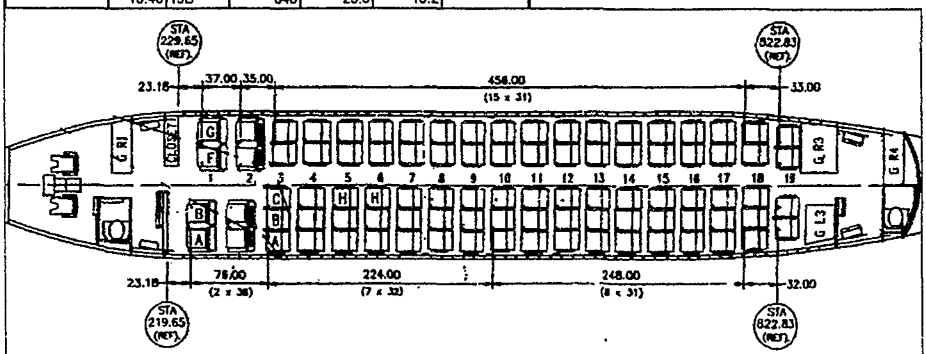
Phase	Time	Location	X (Approx)	Temp	RH	Comments
Push Back	8:59	19B	840	22.0	24.8	
	9:02	19B	840	22.8	36.9	
	9:05	19B	840	24.5	32.0	
	9:06	19B	840	22.5	26.0	
	9:08	19B	840	26.0	22.7	
	9:11	19B	840	26.3	23.0	
	9:13	19B	840	27.4	22.0	
Takeoff	9:14	19B	840	27.5	22.3	
	9:15	19B	840	27.5	19.4	
	9:16	19B	840	27.5	16.5	
	9:17	19B	840	27.3	12.7	
	9:19	19B	840	27.3	12.7	
	9:21	19B	840	26.6	5.5	
	9:22	19B	840	26.4	0.0	
	9:23	AG	900	26.0	5.1	
	9:23	15C	715	26.2	6.8	
	9:24	10C	535	26.0	6.1	
	9:24	5C	375	25.8	3.3	
	9:25	1B	242	25.8	6.1	
	9:25	FG	200	25.6	5.6	
	9:26	CP	144	25.1	2.1	
	9:29	19B	840	24.2	1.9	
Cruise	9:35	19B	840	23.0	0.4	
	9:40	19B	840	21.7	3.0	
	9:45	19B	840	21.5	3.0	
	9:50	19B	840	21.1	3.2	
	9:56	19B	840	20.5	1.9	
	10:02	19B	840	21.6	1.1	
	10:05	19B	840	22.8	2.0	
	10:07	AG	900	23.4	7.0	
	10:08	15C	715	23.8	1.4	
	10:09	10C	535	24.1	6.1	
	10:10	5C	375	24.4	1.1	
	10:11	1B	242	24.4	0.0	
	10:12	FG	200	24.3	1.5	
	10:13	CP	144	24.2	0.0	
Top of Descent	10:21	CP	144	25.2	1.1	
	10:22	FG	200	25.1	0.0	
	10:22	1B	242	25.1	1.0	
	10:23	5B	375	25.2	2.0	
	10:23	10C	535	25.7	5.4	
	10:24	15C	715	25.4	3.8	
	10:24	19B	840	25.4	0.0	
	10:25	AG	900	25.2	2.4	
	10:26	19B	840	25.0	4.3	
	10:27	19B	840	25.2	6.0	
	10:28	19B	840	25.2	6.2	
	10:29	19B	840	25.0	4.5	
	10:30	19B	840	24.9	6.3	
	10:31	19B	840	24.9	8.0	
	10:32	19B	840	24.8	7.4	
	10:33	19B	840	24.7	9.0	
	10:34	19B	840	24.4	8.7	
	10:35	19B	840	24.7	12.2	
	10:36	19B	840	24.6	11.3	
	10:37	19B	840	24.7	16.7	
Landing	10:37	19B	840	24.7	14.6	
	10:38	19B	840	24.8	18.0	
	10:40	19B	840	25.0	18.2	









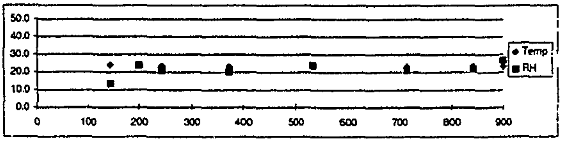


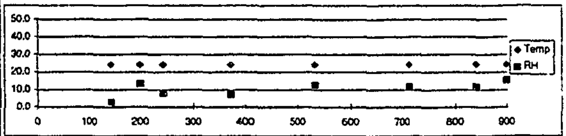
MKY-BNE

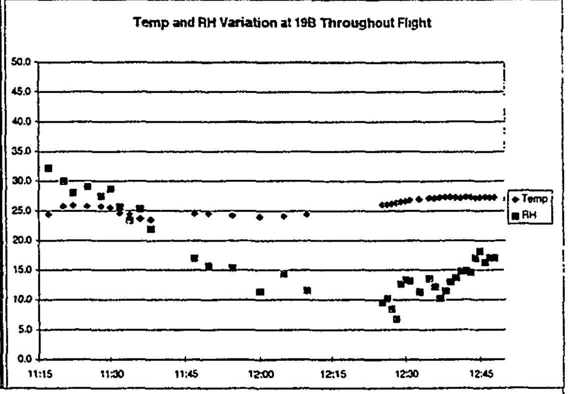
Temperature and Humidity Measurements

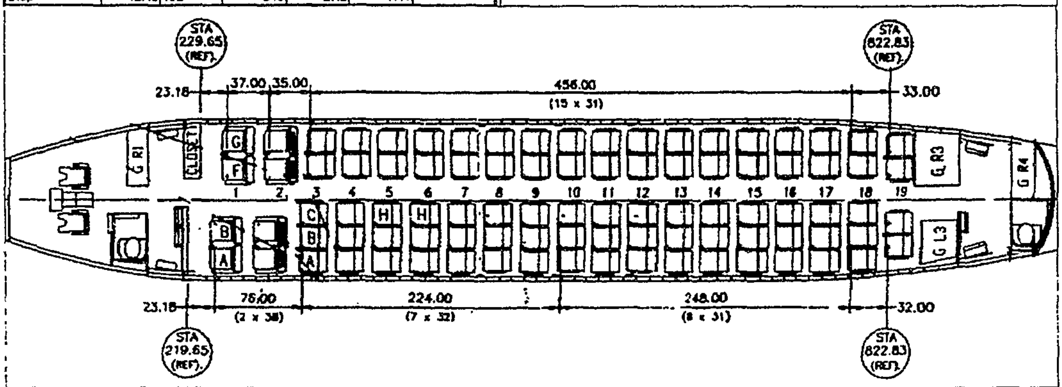
Revenue Test Flight 25 August 1997 AN 263 MKY-BNE

Phase	Time	Location	X (Approx)	Temp	RH	Comments
Push Back	11:17	19B	840	24.4	32.2	
Start	11:20	19B	840	25.7	30.0	
	11:22	19B	840	25.9	28.1	
	11:25	19B	840	25.7	29.1	
Takeoff	11:28	19B	840	25.7	27.5	
	11:30	19B	840	25.5	28.7	
	11:32	19B	840	24.6	25.7	
	11:34	19B	840	24.3	23.4	
	11:36	19B	840	23.6	25.3	
	11:38	19B	840	23.4	22.0	
	11:38	AG	900	23.3	26.8	
	11:39	15C	715	23.2	21.2	
	11:39	10C	535	23.1	23.7	
	11:40	5C	375	22.9	20.2	
	11:40	1B	242	23.3	21.2	
	11:41	FG	200	23.7	24.0	
	11:42	CP	144	23.9	13.5	
	11:47	19B	840	24.5	17.0	
	11:50	19B	840	24.5	15.7	
	11:55	19B	840	24.2	15.4	
	12:00	19B	840	24.0	11.4	
	12:05	19B	840	24.1	14.4	
	12:10	19B	840	24.4	11.6	
	12:13	AG	900	24.2	15.4	
	12:13	15C	715	24.2	11.7	
	12:14	10C	535	24.3	12.5	
	12:15	5C	375	24.0	7.2	
	12:16	1B	242	24.1	7.9	
	12:17	FG	200	24.1	13.2	
	12:18	CP	144	24.2	2.7	
Top of Descent	12:25	19B	840	26.0	9.6	
	12:26	19B	840	26.0	10.2	
	12:27	19B	840	26.1	8.5	
	12:28	19B	840	26.3	6.8	
	12:29	19B	840	26.5	12.7	
	12:30	19B	840	26.6	13.4	
	12:31	19B	840	26.8	13.2	
	13:32	19B	840	27.0	14.1	
	12:33	19B	840	26.9	11.3	
	13:34	19B	840	27.2	11.3	
	12:35	19B	840	27.1	13.6	
	12:36	19B	840	27.1	12.2	
	12:37	19B	840	27.2	10.3	
	12:38	19B	840	27.3	11.5	
	12:39	19B	840	27.3	13.0	
	12:40	19B	840	27.2	13.7	
	12:41	19B	840	27.1	14.8	
	12:42	19B	840	27.3	14.9	
	12:43	19B	840	27.2	14.6	
	12:44	19B	840	27.1	17.0	
Landing	12:45	19B	840	27.2	18.2	
	12:46	19B	840	27.3	16.3	
	12:47	19B	840	27.2	17.1	
Stop	12:48	19B	840	27.2	17.1	





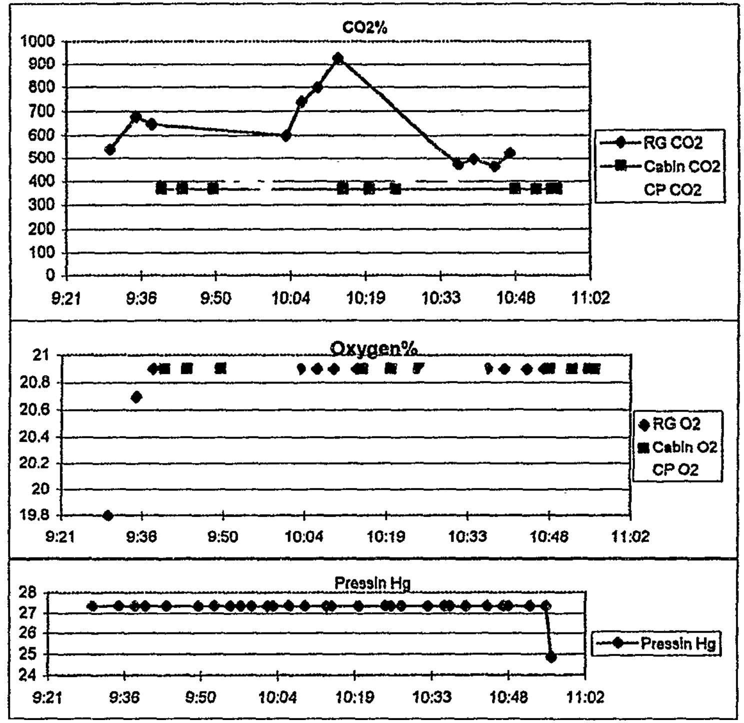




AIR QUALITY MEASUREMENTS

VH-EWI, NON REVENUE FLIGHT 24 AUG. 1997 - ECS FRESH

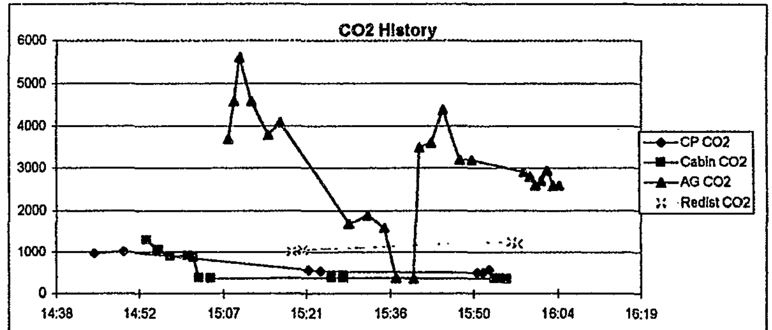
Area	Time	CO2-ppm	Oxy%	CMB%	TOXppm	Pressin Hg
Rear galley	9:30	540	19.8	0	0	27.35
	9:35	680	20.7	0	0	27.35
	9:38	650	20.9	0	0	27.35
Cabin	9:40	365	20.9	0	0	27.35
	9:44	365	20.9	0	0	27.35
	9:50	365	20.9	0	0	27.35
Cockpit	9:53	405	20.9	0	0	27.35
	9:56	420	20.9	0	0	27.35
	9:58	390	20.9	0	0	27.35
	10:00	385	20.9	0	0	27.35
	10:03	435	20.9	0	0	27.35
Rear galley	10:04	600	20.9	0	0	27.35
	10:07	740	20.9	0	0	27.35
	10:10	800	20.9	0	0	27.35
	10:14	930	20.9	0	0	27.35
Cabin	10:15	365	20.9	0	0	27.35
	10:20	365	20.9	0	0	27.35
	10:25	365	20.9	0	0	27.35
Cockpit	10:26	415	20.9	0	0	27.35
	10:28	410	20.9	0	0	27.35
	10:33	425	20.9	0	0	27.35
	10:36	420	20.9	0	0	27.35
Rear galley	10:37	475	20.9	0	0	27.35
	10:40	500	20.9	0	0	27.35
	10:44	465	20.9	0	0	27.35
	10:47	525	20.9	0	0	27.35
Cabin	10:48	365	20.9	0	0	27.35
	10:52	365	20.9	0	0	27.35
	10:55	365	20.9	0	0	27.35
	10:56	365	20.9	0	0	24.85

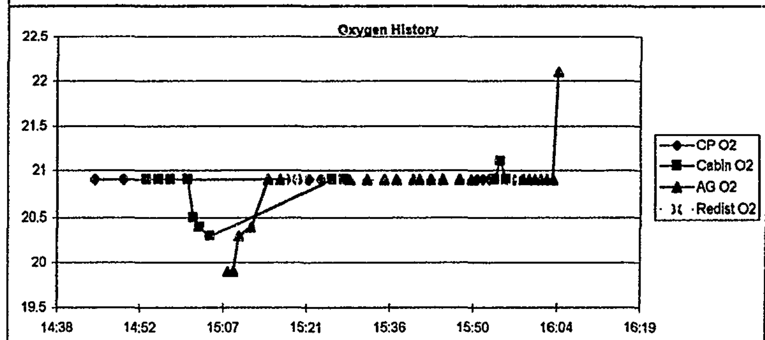


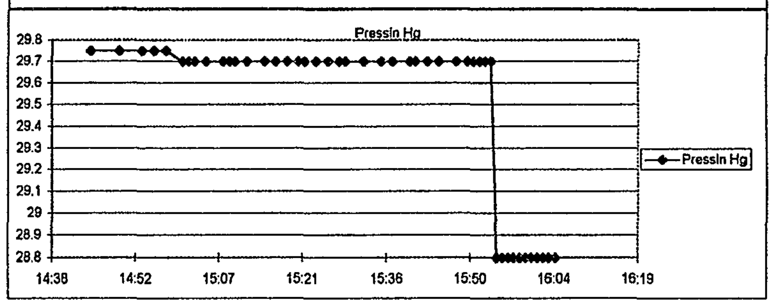
AN262 BNEROK 240897

VH-EWI, AN262 BNEROK 24 AUG. 1997 - ECS FRESH

Area	Time	CO2-ppm	Oxy%	CMB%	TOXppm	PressIn Hg	Phase
Cockpit	14:45	970	20.9	0	0	29.75	PARK
	14:50	1015	20.9	0	0	29.75	PARK
Cabin	14:54	1300	20.9	0	0	29.75	TAXI
	14:56	1070	20.9	0	0	29.75	TAXI
	14:58	900	20.9	0	0	29.75	TAXI
	15:01	910	20.9	0	0	29.7	T/O
	15:02	860	20.5	0	0	29.7	CLB
	15:03	370	20.4	0	0	29.7	CLB
	15:05	365	20.3	0	0	29.7	CLB
Rear galley	15:08	3700	19.9	0	0	29.7	CLB
	15:09	4600	19.9	0	0	29.7	CLB
	15:10	5600	20.3	0	0	29.7	CLB
	15:12	4600	20.4	0	0	29.7	CLB
	15:15	3800	20.9	0	0	29.7	CLB
	15:17	4100	20.9	0	0	29.7	CRZ
Punkalouvre	15:19	1020	20.9	0	0	29.7	CRZ
	15:21	1050	20.9	0	0	29.7	CRZ
Cockpit	15:22	550	20.9	0	0	29.7	CRZ
	15:24	530	20.9	0	0	29.7	CRZ
Cabin	15:26	370	20.9	0	0	29.7	CRZ
	15:28	370	20.9	0	0	29.7	CRZ
Rear galley	15:29	1700	20.9	0	0	29.7	CRZ
	15:32	1900	20.9	0	0	29.7	CRZ
	15:35	1600	20.9	0	0	29.7	CRZ
	15:37	370	20.9	0	0	29.7	CRZ
	15:40	365	20.9	0	0	29.7	CRZ
Rear galley	15:41	3500	20.9	0	0	29.7	CRZ
	15:43	3600	20.9	0	0	29.7	CRZ
	15:45	4400	20.9	0	0	29.7	CRZ
	15:48	3200	20.9	0	0	29.7	CRZ
	15:50	3200	20.9	0	0	29.7	DESC
Cockpit	15:51	490	20.9	0	0	29.7	DESC
	15:52	490	20.9	0	0	29.7	DESC
	15:53	560	20.9	0	0	29.7	DESC
Cabin	15:54	360	20.9	0	0	29.7	DESC
	15:55	355	21.1	0	0	28.8	DESC
	15:56	350	20.9	0	0	28.8	DESC
Punkalouvre	15:57	1270	20.9	0	0	28.8	DESC
	15:58	1220	20.9	0	0	28.8	DESC
Rear galley	15:59	2910	20.9	0	0	28.8	DESC
	16:00	2800	20.9	0	0	28.8	DESC
	16:01	2600	20.9	0	0	28.8	DESC
	16:02	2700	20.9	0	0	28.8	DESC
	16:03	2930	20.9	0	0	28.8	DESC
	16:04	2585	20.9	0	0	28.8	DESC
	16:05	2600	22.1	0	0	28.8	LAND



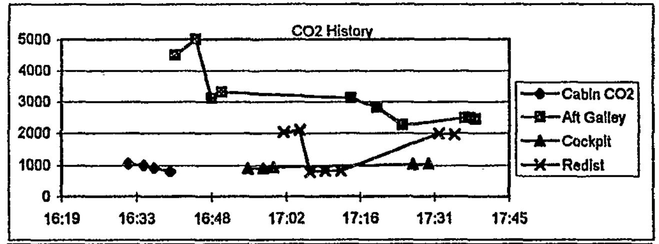


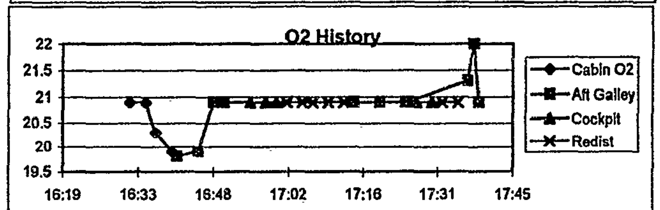


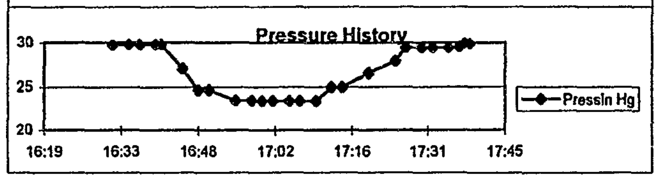
AN263 ROKBNE 240897

VH-EWI, AN263 ROKBNE 24 AUG. 1997 - ECS RECIRC

Area	Time	CO2-ppm	Oxy%	CMB%	TOXppm	Pressin H	Phase
Cabin	16:32	1050	20.9	0	0	29.7	TAXI
	16:35	1000	20.9	0	0	29.75	T/O
	16:37	915	20.3	0	0	29.75	CLB
	16:40	815	19.9	0	0	29.75	CLB
Rear galley	16:41	4500	19.8	0	0	29.75	CLB
	16:45	5000	19.9	0	0	27	CRZ
	16:48	3100	20.9	0	0	24.65	CRZ
	16:50	3300	20.9	0	0	24.65	CRZ
Cockpit	16:55	910	20.9	0	0	23.45	CRZ
	16:58	900	20.9	0	0	23.45	CRZ
	17:00	945	20.9	0	0	23.4	CRZ
Punkalouvre	17:02	2040	20.9	0	0	23.4	CRZ
	17:05	2100	20.9	0	0	23.4	CRZ
	17:07	800	20.9	0	0	23.4	CRZ
	17:10	825	20.9	0	0	23.4	CRZ
	17:13	830	20.9	0	0	24.95	CRZ
Rear galley	17:15	3100	20.9	0	0	24.95	CRZ
	17:20	2810	20.9	0	0	26.5	CRZ
	17:25	2250	20.9	0	0	27.85	DESC
Cockpit	17:27	1030	20.9	0	0	29.4	DESC
	17:30	1050	20.9	0	0	29.4	DESC
Punkalouvre	17:32	1990	20.9	0	0	29.4	DESC
	17:35	1960	20.9	0	0	29.4	DESC
Rear galley	17:37	2480	21.3	0	0	29.45	DESC
	17:38	2500	22	0	0	29.9	LAND
	17:39	2445	20.9	0	0	29.9	TAXI

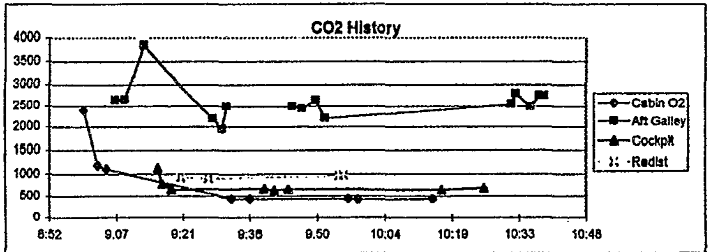


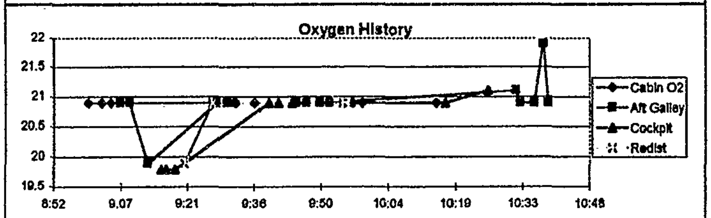


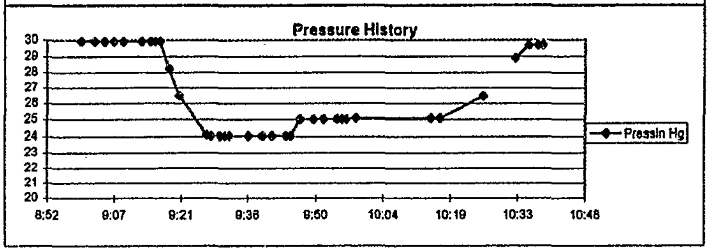


VH-EWI, AN262 BNEMKY 25 AUG. 1997 - ECS FRESH

Area	Time	CO2-ppm	Oxy%	CMB%	TOXppm	Pressin Hg	Phase	Comments
Cabin	9:00	2400	20.9	0	0	29.95	TAXI	Levels drop as a/c
	9:03	1190	20.9	0	0	29.95	TAXI	taxis from terminal
	9:05	1115	20.9	0	0	29.95	TAXI	area.
Rear galley	9:07	2650	20.9	0	0	29.95	TAXI	
	9:09	2660	20.9	0	0	29.95	TAXI	
	9:13	3850	19.9	0	0	29.95	T/O	Significant increase
	9:15 -		19.9	0	0	29.95	CLB	noticeable on take off
Cockpit	9:16	1130	19.8	0	0	29.95	CLB	roll.
	9:17	770	19.8	0	0	29.95	CLB	
	9:19	650	19.8	0	0	28.25	CLB	Oven ON
Punkalouvre	9:21	930	19.9	0	0	26.5	CLB	Food/oven odours.
	9:27	900	20.9	0	0	24.1	CLB	Carts moved forward.
Rear galley	9:28	2200	20.9	0	0	24.05	CRZ	
	9:30	1950	20.9	0	0	24.05	CRZ	
	9:31	2500	20.9	0	0	24.05	CRZ	
Cabin	9:32	440	20.9	0	0	24.05	CRZ	
	9:36	435	20.9	0	0	24.05	CRZ	
Cockpit	9:39	665	20.9	0	0	24.05	CRZ	
	9:41	640	20.9	0	0	24.05	CRZ	
	9:44	660	20.9	0	0	24.05	CRZ	
Rear galley	9:45	2500	20.9	0	0	24.05	CRZ	
	9:47	2450	20.9	0	0	25.05	CRZ	
	9:50	2650	20.9	0	0	25.05	CRZ	
	9:52	2210	20.9	0	0	25.05	CRZ	
Punkalouvre	9:55	970	20.9	0	0	25.05	CRZ	
	9:56	980	20.9	0	0	25.05	CRZ	
Cabin	9:57	440	20.9	0	0	25.05	CRZ	
	9:59	430	20.9	0	0	25.1	CRZ	
	10:15	440	20.9	0	0	25.1	CRZ	
Cockpit	10:17	650	20.8	0	0	25.1	CRZ	
	10:26	685	21.1	0	0	26.5	DESC	
Rear galley	10:32	2550	21.1	0	0		DESC	
	10:33	2800	20.9	0	0	28.95	DESC	
	10:36	2500	20.9	0	0	29.7	DESC	
	10:38	2750	21.9	0	0	29.7	LAND	
	10:39	2750	20.9	0	0	29.7	TAXI	



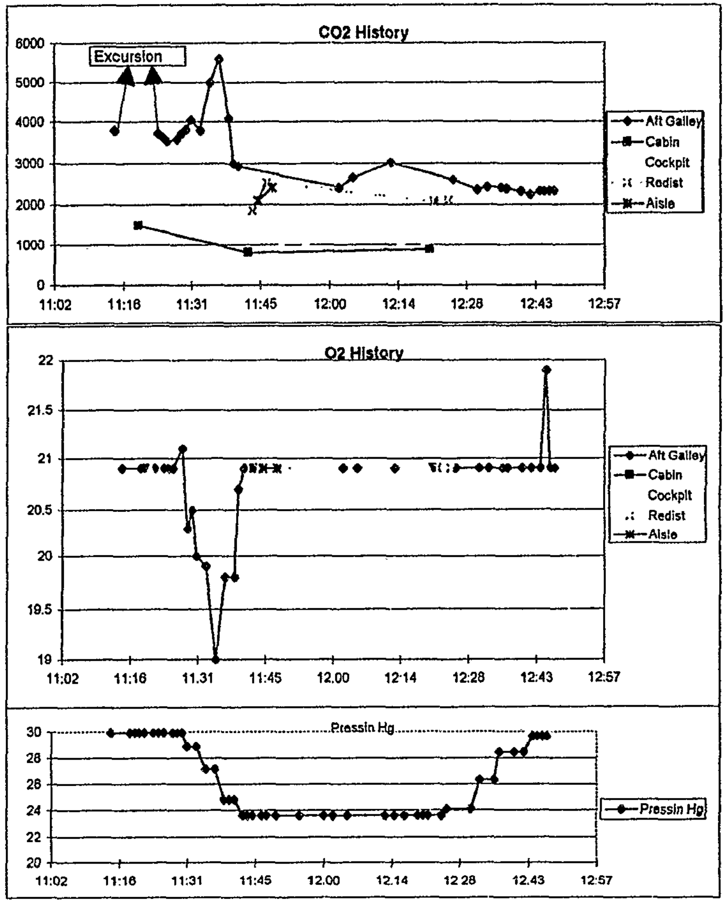




VH-EWI, AN263 MKYBNE 25 AUG. 1997 - ECS RECIRC

Area	Time	CO2-ppm	Oxy%	CMB%	TOXppm	Pressin Hg	Phase
Rear galley	11:15	3800	20.9	0	0	29.95	PARK
	11:19	Exceed	20.9	0	0	29.95	PARK
Cabin	11:20	1500	20.9	0	0	29.95	PARK
Cockpit	11:21	1800	20.9	0	0	29.95	TAXI
Rear galley	11:22	Exceed	20.9	0	0	29.95	TAXI
	11:24	3730	20.9	0	0	29.95	TAXI
	11:25	3650	20.9	0	0	29.95	TAXI
	11:26	3550	20.9	0	0	29.95	TAXI
	11:28	3600	21.1	0	0	29.95	TAXI
	11:29	3720	20.3	0	0	29.95	T/O
	11:30	3830	20.5	0	0	29.95	CLB
	11:31	4050	20	0	0	28.9	CLB
	11:33	3800	19.9	0	0	28.9	CLB
	11:35	5000	19	0	0	27.15	CLB
	11:37	5600	19.8	0	0	27.15	CLB
	11:39	4100	19.8	0	0	24.85	CLB
	11:40	3000	20.7	0	0	24.85	CLB
	11:41	2930	20.9	0	0	24.85	CRZ
Cabin	11:43	815	20.9	0	0	23.65	CRZ
Punkalouvre	11:44	1650	20.9	0	0	23.65	CRZ
Aisle	11:45	2100	20.9	0	0	23.65	CRZ
Punkalouvre	11:47	2525	20.9	0	0	23.65	CRZ
Aisle	11:48	2400	20.9	0	0	23.65	CRZ
Cockpit	11:50	1050	20.9	0	0	23.65	CRZ
	11:55	1065	20.9	0	0	23.65	CRZ
	12:00	1230	20.9	0	0	23.65	CRZ
Rear galley	12:02	2400	20.9	0	0	23.65	CRZ
	12:05	2650	20.9	0	0	23.65	CRZ
	12:13	3020	20.9	0	0	23.65	CRZ
Cockpit	12:15	1085	20.9	0	0	23.65	CRZ
	12:17	1240	20.9	0	0	23.65	CRZ
	12:20	1100	20.9	0	0	23.65	CRZ
Cabin	12:21	890	20.9	0	0	23.65	CRZ
Punkalouvre	12:22	2070	20.9	0	0	23.65	CRZ
	12:25	2100	20.9	0	0	23.65	CRZ
Rear galley	12:28	2800	20.9	0	0	24.15	DESC
	12:31	2360	20.9	0	0	24.15	DESC
	12:33	2420	20.9	0	0	26.35	DESC
	12:36	2400	20.9	0	0	26.35	DESC
	12:37	2380	20.9	0	0	28.45	DESC
	12:40	2310	20.9	0	0	28.45	DESC
	12:42	2235	20.9	0	0	28.45	DESC
	12:44	2310	20.9	0	0	29.7	DESC
	12:45	2310	21.9	0	0	29.7	LAND
	12:46	2320	20.9	0	0	29.7	TAXI
	12:47	2330	20.9	0	0	29.7	PARK

AN263 MKYBNE 250897



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APPENDIX II

AIR-QUALITY TESTING ABOARD ANSETT AIRLINES BAe146 AIRCRAFT

PRINCIPAL INVESTIGATOR BIOGRAPHICAL INFORMATION

(3 pages)

Biographical Information regarding Principal Investigator

Richard B. Fox
Senior Engineer
AlliedSignal Aerospace Company
AlliedSignal Engine Division
Materials Engineering Laboratory

1. Basic Data

Name:	Richard Fox
Employer :	AlliedSignal Aerospace
Business Address:	P.O. Box 52181 Phoenix, AZ 85072-2181 Mail Stop 46-00/302-101
Telephone:	(602) 231-2076 Desk (602) 980-1388 Cellular
Fax:	(602) 231-1142
E-Mail	richard.fox@alliedsignal.com
Date Bio Prepared:	October 28, 1997

2. Educational Record **(begin with High School)**

Institution	*Course*	*Years Completed*	*Date of Graduation*	*Degree*
Washington High	Sciences	4	May 1974	Diploma
Glendale Community College	Chemistry, Physics Biology, Mathematics	2	May 1997	AA Liberal Arts
Arizona State University	Zoology, Chemistry	2	May 1978	BS Zoology

3. Professional Experience

From	*to*	*Employer*	*Title*	*Duties*
12-96	Pres	AlliedSignal	Engineer III	Air quality and Emissions measurement team leader
5-90	12-96	AlliedSignal	Engineer II	Air quality and Emissions measurement team leader
7-88	5-90	AlliedSignal	Engineer I	Chemistry analysis, air quality and emissions measurement
4-86	7-88	AlliedSignal	Engineering Assoc.	Chemistry analysis, air quality and emissions measurement
4-85	4-86	Ross Laboratory Div of Abbott Pharmaceutical	Lab Technician	Assist in new plant startup and chemical analysis

3. Professional Experience, continued

From	*to*	*Employer*	*Title*	*Duties*
1-79 &8-84	10-83 4-85	Phelps Dodge Corp.	Senior Chemist	Analytical group leader Laboratory budgeting
10-83	8-84	Phelps Dodge Corp.	Assistant Shift Foreman	Coordinate smelter operations to maximize production without violating air quality standards

4. Memberships and activities in Societies

Society	*Grade*	*Committee*	*Year*	*Position*
American Society of Heating ,Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE)				
	Associate Member	ASHRAE Aviation Subcommittee	1997	Co- Chairman of Research Subcommittee
		SPC161	1996	Standard for air quality in commercial aircraft- represent aircraft engine manufacturers
Society of Automotive Engineers (SAE)				
	Member	E-31 Engine Emissions Measurement 1987-present	93-97	Main Committee Chairman
			91-97	Cabin air quality subcommittee chairman
	Consultant	AC-9 Aircraft Environmental Systems 1990- present		

5. Principal Technical Interest Areas

Aircraft cabin air quality, engine exhaust and smoke measurement, smoke plume visibility, engine lubricant and fuels certification.

6. Honors

Award	*Organization*	*Date*
Premier Achievement Award	AlliedSignal	1997
Alpha Epsilon Delta Premedical Honor Society	Arizona State University	1977-1978
Deans List	Glendale Community College	1976
National Honor Society	Washington High	1973-1974

7. Publications

Sponsor of the following Aerospace Standards

SAE ARP4418	Measurement of Air Quality in Aircraft Cabins	1995
SAE ARP1533C	Calculation of Emission Indices from Aircraft Emissions	1995
SAE ARP 1179C	Smoke Emission Measurement Procedures	1997

Documents in Process

SAE AIR 4476	Aircraft Cabin Air Quality	1990-1997
ASHRAE SPC161	Standard for Air Quality in Commercial Aircraft	1996-1997

8. Patents

U.S. and Foreign Patents pending on Bleed Air Contamination Monitor.

9. Projects

Technical Liaison and Project Monitoring subcommittee chairman for ASHRAE Research Project 959. Determine Aircraft Supply System Contaminants for Aircraft of Varying age and Types. Project goes out for bids on November 11, 1997. Research to be completed within one year.

AlliedSignal project to identify thermal decomposition products of fluids used on board aircraft when exposed to hot bleed air temperatures. Project completion , January 1998.

10. Certifications

EPA Sections 608 and 609 Universal ground equipment and transportation certification for freon recovery from air-conditioning systems.

ACKNOWLEDGMENTS

The following key people contributed many hours of their time and resources to allow this project to be performed in a time efficient and effective manner:

1. Don Love- Technical Director Australia **Aero International (Regional) AI(R)**
2. Peter Gibbs- Fleet Technical Officer **Ansett Australia**
3. Kevin Currie- Occupational Risk Manager **Ansett Australia**
4. Karen Skehan- Purser **Ansett Australia**
5. Judy Schache- Purser **Ansett Australia**
6. Dr. David Lewis- Medical Director **Ansett Australia**
7. Dr. Kevin Sleigh- Medical Doctor **Ansett Australia**
8. George Lee- Chemist, Occupational Hygiene **Queensland Health Scientific Services**

In addition, the following contributions were made:

Ansett Australia- provided flight crews and mechanics and aircraft to expedite setup and flight testing during both non revenue and revenue flights.

AlliedSignal Aerospace- provided air quality testing equipment and manpower as well as funding for laboratory analysis of samples.

AI(R)- provided manpower and funding for laboratory analyses

ASDOR FILTERS- provided a new set of cabin and cockpit filters to allow testing of both new and high time filters.

ATTACHMENT 1

MOBIL OIL AUSTRALIA LIMITED
TRICRESYLPHOSPHATE AND MOBIL JET OIL II

(1 page)

Mobil Oil Australia Limited (ACN 004 052 984)

Pegasus Centre, Cnr Millers & Kororoit Creek Rds, Altona Victoria 3018

FAX TRANSMISSION

MOA/MONZ SHARED SERVICES
ENVIRONMENT, HEALTH & SAFETY

To	Dr Dai Lewis - Medical Director Ansett Australia Fax: 9623 3093	No. Of Pages: 17 (including this page) If you do not receive all pages please call 61 3 9286 5405 or fax 61 3 9286 5461
cc		
From	Martin Webb - EH&S Manager	Date: 23/05/97

Dai,

Attached are MSDB's for Mobil Jet Oil II and Tricresylphosphate as requested.

These were taken from our latest cut of CD-MACSIN so they are the most up to date versions.

As you are aware, Tricresylphosphate is only present in Mobil Jet Oil II in low concentrations. As can be seen on the MSDS for Tricresylphosphate, the 'ortho' isomer (which is the form for which there are health issues) is present in at levels less than 0 5% in the Tricresylphosphate. The percentage of Tri-ortho-cresylphosphate in Mobil Jet Oil II is therefoevery low; most probably less than 0.02%.

I trust this helps.

Martin

AlliedSignal
AEROSPACE

ATTACHMENT 2

REPORTED CONCENTRATIONS AND CRITERIA VOLATILE ORGANIC COMPOUNDS: FOR HEALTH AND COMFORT

HOLCOMB ENVIRONMENTAL SERVICES

(17 pages)

Volatile Organic Compounds: Reported Concentrations and Criteria for Health and Comfort.

Larry C. Holcomb and Joe F. Pedelty, Holcomb Environmental Services, Olivet, MI.

Introduction

Indoor air quality (IAQ) and its potential effect on human health is a topic of continuing debate, often with divergent definitions of health (Cain et al, 1995; Lunau, 1993; Samet, 1993). Part of this debate includes questions concerning which parameters should be used to determine IAQ and at what concentrations they should be controlled. Along with carbon dioxide (CO_2) and respirable suspended particulates (RSP), volatile organic compounds (VOCs) are considered by some to be a primary indicator and surrogate for IAQ. The expected relationship between VOC concentrations and IAQ comes from the odor and/or irritancy of the compounds but there are also concerns for adverse health effects due to exposures to VOCs indoors (Meggs, 1993). A significant amount of effort is now being put forth to monitor VOC emissions from various products and to monitor VOCs in indoor air. Much of this effort appears to move forward without knowing at what concentrations one would expect to encounter adverse impacts.

Measurement of VOCs

There are currently several different sampling/analytical methods for measuring VOCs in indoor environments. Sampling can be active, mechanically collecting a known volume of air, or passive, allowing the sample to diffuse onto a collecting media. Samples can be taken via canister or various sampling media (e.g., charcoal, Tenax) (Wolkoff, 1995). Sampling strategies can include either area or personal samples. Personal samples generally produce higher reported concentrations (Wallace et al., 1991).

VOC concentrations can be reported individually for detected compounds or reported as total VOC (TVOC). TVOC can be calculated by adding the concentrations of individual VOC or simply calculated from the total detector response created by the sample. There are also continual sampling methods where air is pulled through a flame ionization detector (FID), photoionization detector (PID) or photoacoustic infrared (IR) detector and the results given as TVOC (Hodgson, 1995).

Each variable in the sampling and analysis protocol can result in differences in both the compounds which are detected and the concentration which is determined. TVOC results, in particular, can vary significantly depending on how they are sampled, analyzed and totaled (Hodgson, 1995). At present, there are no standardized methods for the determination of VOCs or TVOC in indoor air. The results reported will depend on, and vary with the methods chosen.

Concentrations of VOC in Indoor Environments

There have been three recent reviews of VOCs in indoor environments (Brown et al, 1994; Holcomb, 1993; Holcomb and Seabrook, 1995). Holcomb (1993) reported an average concentration of TVOC for North America in public places of 315.1 μg/m³ with a range of 17.85 - 1,627 μg/m³. Brown et al. (1994) reviewed VOC data worldwide and reported a geometric mean TVOC concentration of 180 μg/m³ and an arithmetic mean of 1,808 μg/m³ in established offices (no range reported). Brown et al. (1994) also report individual VOC concentrations for four VOC. These are summarized in Table 1. Holcomb and Seabrook (1995) report individual VOC concentration which are summarized in Table 2. In general, average concentrations of individual VOC tend to be below 50 μg/m³ and are generally ≤10 μg/m³.

VOC Exposure Standards

At present, the only exposure standards, or criteria, for VOC are occupational exposure standards such as the Threshold Limit Values (TLV) set by the American Conference of Governmental Industrial Hygienists (ACGIH) or the Permissible Exposure Limits (PEL) set by the Occupational Safety and Health Administration (OSHA). These exposure standards are designed to protect workers from adverse health effects for typical occupational exposure durations (e.g., 5 days/week and 8 hrs/day). The ACGIH TLVs and OSHA PELs for individual VOCs generally fall into the 1 - 100 ppm (3 - 3,000 mg/m³) range

(ACGIH, 1993; OSHA, 1993). These concentrations are approximately three to five orders of magnitude higher than those found in commercial and residential environments.

Some proposed criteria for VOC and TVOC in non-industrial environments are much lower than occupational exposure standards and tend to rely on TVOC as a surrogate for VOC exposures. This will lead to certain inherent inaccuracies. TVOC is a mixture of many individual VOCs, each with its own odor threshold, irritation threshold and toxicity. As sources vary, TVOCs can also vary widely in their constituents, both between buildings and within buildings over time. Using TVOC as a surrogate for IAQ may not adequately reflect the potential for adverse effects or SBS type symptoms.

Some of the proposed criteria include:

Molhave (1991a) - TVOC

< 200 μg/m³	Comfort Range
200 - 3,000	Irritation and discomfort if other factors exist
3,000 - 25,000	Discomfort Range
>25,000	Toxic Range (headaches, neurotoxic effects possible)

In another paper, Molhave (1991b) suggests a tentative guideline of 3,000 μg/m³ for TVOCs in indoor air

Seifert (1990) - TVOC 300 µg/m³

Guidelines for individual classes of compounds are as follows:

Alkanes -	100 µg/m³	Esters -	20
Aromatics -	50	Carbonyles -	20 (excluding formaldehyde)
Terpenes -	50	Other -	50
Halocarbons -	30		

No individual compound should exceed 50% of its class' guideline.

Gammage et al. (1989) - 5,000 µg/m³ TVOC

Holcomb (1993) - 3,000 µg/m³ TVOC.

ASHRAE Standard 62-1989 relies largely on recognized cognizant authorities for recommended indoor air quality levels. That standard does not have guideline levels for TVOC because there are no such standards in existence. However, the Std. 62-1989 draft revision has come out with guidelines for TVOC as follows:

< 300 µg/m³ - Complaints unlikely

300 - 3,000 µg/m³ - Complaints possible

> 3,000 µg/m³ - Complaints likely

Without recognition by a cognizant authority for a concentration level or a measurement method for TVOC, the Std. 62-1989 revision committee appears to no longer be following policy procedures of the past, but rather is adopting new policy without the rationale of a recognized cognizant authority that has gone through a rigorous rule making process.

VOC and SBS

Exposure to VOCs can cause a wide variety of adverse effects including neurotoxicity, hepatotoxicity, nephrotoxicity and carcinogenicity (Molhave and Nielsen, 1992; Feron et al, 1992). However, these effects occur at high exposure levels, generally several orders of magnitude above those found in indoor environments. Exposures to VOC at concentrations closer to those found in indoor environments involves stimulation of odor, taste and irritation perceptions (Molhave and Nielsen, 1992; WHO, 1989).

Odor thresholds for VOCs range over several orders of magnitude (e.g., approx. 0.1 - 1,000 mg/m^3). Reported odor thresholds for a single VOC can vary by over two orders of magnitude depending on the studies reviewed (AIHA, 1993; USEPA, 1992). It is not known how the presence of several VOC at relatively low concentrations (10 - 100 $\mu g/m^3$) may affect their odor thresholds.

[redacted]

Irritation is believed to be caused by stimulation of the trigeminal nerve. Experiments using rats have found thresholds of stimulation that range from 3 - 3,000 ppm for 31 different organic compounds (Silver, 1992). Irritation thresholds for various VOCs in humans, determined in anosmic (lacking a sense of smell) subjects, fall in the same general range (Cometto-Muniz and Cain, 1994).

The American Society for Testing and Materials (ASTM) has developed a test method which quantifies the irritant potency of an air sample using the depression of respiratory rates in mice (Anderson , 1992). Schaper (1993) has published the results of a series of tests which show a good correlation between the irritancy of a chemical as measured by mouse respiratory depression (RD50, 50% depression of respiratory rate) and the TLV for that chemical (TLV = 0.03 X RD50; r2 = 0.78). These are relatively high concentrations when compared to concentrations found indoors.

Trigeminal nerve stimulation can result in several different reflexes including decreased respiratory rate, increased nasal secretions, increased nasal airflow resistance and sneezing (Silver, 1992). Falk et al. (1993) have demonstrated increased nasal mucosa swelling in subjects with a history of nasal distress who were exposed to formaldehyde concentrations of 0.073 and 0.174 mg/m^3. While there can be measurable changes in response to exposures, it is important to differentiate between an adaptive response and an adverse effect. All organisms

have the ability to produce physiological responses to changes in their environments. It is often these responses which prevent the exposure from producing an adverse effect. They should not necessarily be considered an adverse effect in and of themselves.

Symptoms generally associated with poor IAQ or sick building syndrome (SBS) include eye, nose or throat irritation, headache and lethargy (Mendell, 1993; Sundell, 1994). These are symptoms that can be associated with exposure to VOCs. However, symptom prevalence is not consistently associated with TVOC concentrations across studies (Mendell, 1993; Sundell, 1994; Wolkoff, 1995), and thresholds for VOC effects are in the mg/m^3 range rather than the $\mu g/m^3$ concentrations found in indoor environments (Holcomb and Pedelty, 1995).

Problems with attempting to study a possible link between SBS symptoms and TVOC/VOC come from several sources. 1) TVOC is a mixture of many individual VOCs, each of which has its own odor and irritation threshold. 2) The effects of mixtures of VOC, or VOC and other substances (e.g., ozone) is not well understood. 3) SBS is a multifactoral syndrome of which VOCs may or may not play a part in any given instance. 4) VOC concentrations and SBS symptoms both vary with time. Study parameters may not accurately reflect this. 5) Since thresholds for VOC effects occur at concentrations higher than those generally

found in indoor environments, studies of problem buildings may not be of those with high enough VOC concentrations to be causing symptoms.

Conclusions

The relationship between VOC exposure in indoor environments and its relationship to adverse health effects or SBS type symptoms continues to be a matter of debate and study. Methods for sampling, analyzing and reporting VOC are not standardized and variations in these can lead to significant differences in reported values. This is especially true of TVOC since a potentially wide range of individual VOC and concentrations is boiled down to a single number.

In spite of the lack of standardization for measuring and reporting VOCs, the concentrations found in most environments are three or more orders of magnitude below exposure standards which are set on health based criteria and concentrations known to cause adverse health effects.

While a relationship between higher concentrations of VOC or TVOC indoors and comfort or SBS type symptoms (e.g., irritation) cannot be discounted, it has yet to be demonstrated in a rigorous manner. Indoor air criteria for VOCs or TVOC which are based on comfort run the risk of being overly restrictive.

In spite of the problems and uncertainties associated with VOCs and TVOC in indoor environments, their use as a surrogate for IAQ will likely continue. Standardizations for their measurement and reporting is needed. Research designed to determine if there is a threshold to VOC effects in real environments and what those thresholds may be will help in setting exposure criteria for IAQ purposes. If the symptoms of concern are acute, it may be better to correlate symptom prevalence with maximum concentrations rather than average concentrations.

Table 1 - Concentrations of TVOC and VOC in offices as reported by Brown et al. (1994).

Compound	Concentration (μg/m³) Arithmetic Mean	Geometric Mean
TVOC	1,080	180
m-methylethylbenzene	30	8
1,2,3-trimethylbenzene	70	9
chloroform	110	10
h-hexane	66	12

Table 2 - Concentrations of TVOC and VOC in public places as reported by Holcomb and Seabrook (1995).

		Concentration (μg/m³)		ACGIH	% of
Compound	Average	Smoking	Nonsmoking	TLV(μg/m³)	TLV
TVOC	315.1				
Benzene	7.4	7.9	6.5	32,000	0.023
Trichloroethylene*	25.8	31.9	18.7	269,000	0.010
1,1,1-trichloroethane*	38.4	27.3	60.4	1,910,000	0.002
Tetrachloroethylene*	55.8**	101.7	26.4	170,000	0.033
(Without Bayer data)	2.4	2.6	2.0		0.001
Toluene	40.2	50.5	29.2	180,000	0.022
O-Xylene	10.5	14.8	5.7	434,000	0.002
M, P-Xylene	32.7	38.0	36.8	434,000	0.007
Ethyl Benzene	7.9	11.3	4.5	434,000	0.002
P-Dichlorobenzene	1.1			60,000	0.002
Styrene	8.0			213,000	0.004
Undecane	16.2			No TLV	
Decane	23.9			No TLV	
Dodecane	8.3			No TLV	
Carbon Tetrachloride	3.2			31,000	0.010
Octane	18.2			1,400,000	0.001
α-Pinene	3.8			No TLV	

* - Compound not believed to be produced by tobacco smoke

** - Value included extremely high data reported by Bayer and Black (1986) that may not be representative.

References

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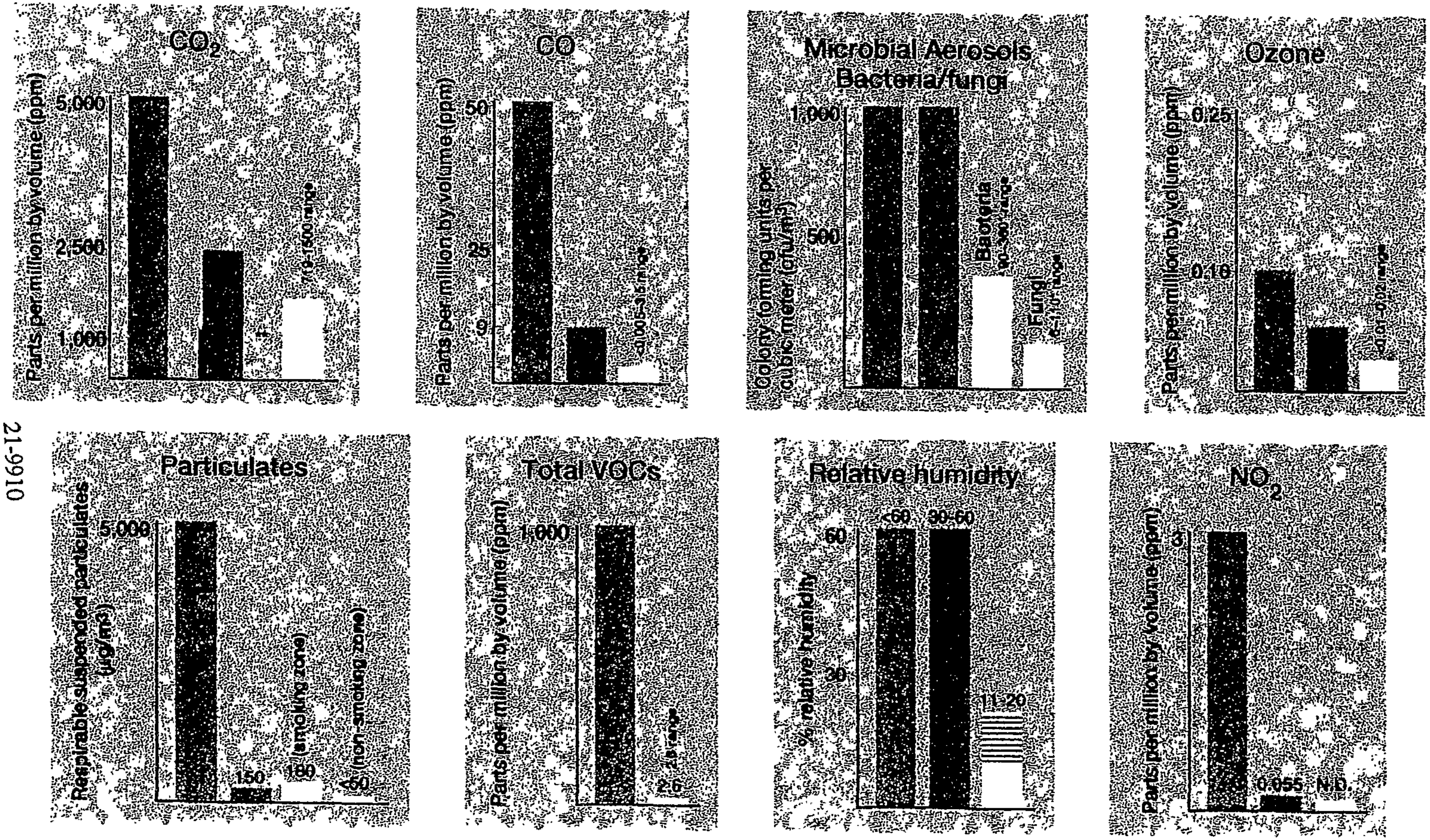
ATTACHMENT 3

COMPARISON OF AIRPLANE AIR-QUALITY TEST RESULTS TO EXISTING STANDARDS

BOEING

(2 pages)

Comparison of Airplane Air Quality Test Results to Existing Standards



*360 cfu/m3 was the upper limit of the range reported.

Note: Graphs represent the highest airplane cabin measurement values in flight from listed studies.

N.D.-Non detect

** Building Contaminant Indicator

Health (OSHA)

Comfort ASHRAE 62-1989, 62-1981(CO_2)

Airplane

131166.1/SB

AlliedSignal
AEROSPACE

ATTACHMENT 4

ACTIVATED CARBON ADSORBENCY OF SELECTED MATERIALS AND ORDORS

DUSTFREE, INC

(3 pages)

FEED DOCUMENT THIS DIRECTION
IMPORTANT
FAX MESSAGE
TO Chris Vanfleet
COMPANY [illegible]
FAX NO. 877-4904
FROM D. Rowsky
NO. OF PAGES 15

ACTIVATED CARBON ADSORBENCY OF SELECTED MATERIALS & ODORS (CONTINUED)

Some of the contaminants listed in the table are specific compounds, some represent classes of compounds, and others are mixtures and of variable composition. Activated charcoal's capacity for odors varies somewhat with the concentration in air, with humidity, and temperature, and with the actual velocity used through the filters. The numbers given represent typical or average conditions and might vary in specific instances. The values in the table have been assembled from many sources including laboratory tests and field experience. In cases where numerical values were not available, the author has listed his opinion of the probable capacity based on general experience. This table should be used as a general rule only.

The capacity index has the following meaning:

4 High capacity for all materials in this category. One pound takes up about 20% to 50% of its own weight-average about 1/3 (33-1/3%). This category includes most of the odor causing substances.

3 Satisfactory capacity for all items in this category. These constitute good applications but the capacity is not as high as for category 4. Adsorbs about 10 to 25% of its weight-average about 1/16 (16.7%).

2 Includes substances which are not highly adsorbed but which might be taken up sufficiently to give good service under the particular conditions of operation. These require individual checking.

1 Adsorption capacity is low for these materials. Activated charcoal cannot be satisfactorily used to remove them under ordinary circumstances.

* Straight activated charcoal does not have much capacity for such reactive gases, such as ammonia, formaldehyde, etc. In some cases where the gas is chemically reactive, appropriate impregnated activated charcoal can be recommended. Those odorants marked above with an asterisk fall into this category.

P.O. Box 519 • Royse City, Texas 75189-0519 • 214-635-9565 • FAX: 214-635-7972

DUST FREE INC

Technical Bulletin
DF-250

March 1993

Granulated Adsorbent-Activated Carbon

ACTIVATED CARBON ADSORBENCY OF SELECTED MATERIALS & ODORS

* Acetaldehyde	2
Acetic Acid	4
Acetic Anhydride	4
Acetone	3
* Acetylene	1
* Acrolein	3
Acrylic Acid	4
Acrylonitrile	4
Adhesives	4
Air-Wick	4
Alcoholic beverages	4
* Amines	2
* Ammonia	2
Amyl acetate	4
Amyl alcohol	4
Amyl ether	4
Animal odors	3
Anesthetics	3
Aniline	4
Asphalt fumes	4
Automobile exhaust	3
Bathroom smells	4
Benzene	4
* Bleaching solutions	3
Body odors	4
Borane	3
Bromine	4
Burned flesh	4
Burned food	4
Burning fat	4
Butadiene	3
Butane	2
Butanone	
Butyl acetate	4
Butyl alcohol	4
Butyl cellosolve	4
Butyl chloride	4
Butyl ether	4
* Butylene	2
* Butyne	2
* Butyraldehyde	3
Butyric acid	4
Camphor	4
Cancer odor	4
Caprylic acid	4
Carbolic acid	4
Carbon disulfide	4
* Carbon dioxide	1
Carbon monoxide	1
Carbon tetrachloride	4
Cellosolve	4
Cellosolve acetate	4
Charred materials	4
Cheese	4
* Chlorine	3
Chlorobenzene	4
Chlorobutadiene	4
Chloroform	4
Chloronitropropane	4
Chloropicrin	4
Cigarette smoke odor	4
Citrus and other fruits	4
Cleaning compounds	4
Coal smoke odor	3
Combustion odors	3
Cooking odors	4
* Corrosive gases	3
Creosote	4
Cresol	4
Crotonaldehyde	4
Cyclohexane	4
Cyclohexanol	4
Cyclohexene	4
Dead animals	4
Decane	4
Decaying substances	4
Deodorants	4
Detergents	4
Dibromoethane	4
Dichlorobenzene	4
Dichlorodifluoromethane	4
Dichloroethane	4
Dichloroethylene	4
Dichloroethylether	4
Dichloromonofluoromethane	3
Dichloronitroethane	4
Dichloropropane	4
Dichlorotetrafluoroethane	4
Diesel fumes	4
* Diethylamine	3
Diethyl ketone	4
Dimethylaniline	4
Dimethylsulfate	4
Dioxane	4
Dipropyl ketone	4
Disinfectants	4
Embalming odors	4
Ethane	1
Ether	3
Ethyl acetate	4
Ethyl acrylate	4
Ethyl alcohol	4
* Ethyl amine	3
Ethyl benzene	4
Ethyl bromide	4
Ethyl chloride	3
Ethyl ether	3
Ethyl formate	3
Ethyl mercaptan	3
Ethyl silicate	4
* Ethylene	1
Ethylene chlorohydrin	4
Ethylene dichloride	4
Ethylene oxide	3
Essential oils	4
Eucalyptole	4
Exhaust fumes	3
Fertilizer	4
Film processing odors	3
Fish odors	4
Floral scents	4
Fluorotrichloromethane	3
Food aromas	4
* Formaldehyde	2
* Formic acid	3
Fuel gases	2
Fumes	3
Gangrene	4
Garlic	4
Gasoline	4
Heptane	4
Heptylene	4
Hexane	3
* Hexylene	3
* Hexyne	3
Hospital odors	4
Household smells	4
Hydrogen	1

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ACTIVATED CARBON ADSORBENCY Continued

* Hydrogen bromide	3
* Hydrogen chloride	2
* Hydrogen cyanide	3
* Hydrogen fluoride	2
* Hydrogen iodide	3
* Hydrogen selenide	2
* Hydrogen sulfide	3
Incense	4
Indole	4
Inorganic chemicals	3
Incomplete combustion	3
Industrial wastes	3
Iodine	4
Iodoform	4
Irritants	4
Isophorone	4
* Isoprene	3
Isopropyl ether	4
Kerosene	4
Kitchen odors	4
Lactic acid	4
Lingering odors	4
Liquid fuels	4
Liquor odors	4
Lubricating oils and greases	4
Lysol	4
Masking agents	4
Medicinal odors	4
Melons	4
Menthol	4
Mercaptans	4
Mesityl oxide	4
Methane	1
Methyl acetate	3
Methyl acrylate	4
Methyl alcohol	3
Methyl bromide	1
Methyl butyl ketone	4
Methyl cellosolve	4
Methyl cellosolve acetate	4
Methyl chloride	3
Methyl chloroform	4
Methyl ether	3
Methyl ethyl ketone	4
Methyl formate	3
Methyl isobutyl ketone	4
Methyl mercaptan	4
Methylcyclohexane	4
Methylcyclohexanol	4
Methylcyclohexanone	4
Methylene chloride	4
Mildew	3
Mixed odors	4
Mold	3
Monochlorobenzene	4
Monofluorotrichloromethane	4
Moth balls	4
Naphtha (coal tar)	4
Naphtha (petroleum)	4
Naphthalene	4
Nicotine	4
* Nitric acid	3
Nitro benzenes	4
Nitroethane	4
* Nitrogen dioxide	2
Nitroglycerine	4
Nitromethane	4
Nitropropane	4
Nitrotoluene	4
Nonane	4
Noxious gases	3
Octalene	4
Octane	4
Odorants	4
Onions	4
Organic chemicals	4
Ozone	4
Packing house odors	4
Paint and redecorating odors	4
Palmitic acid	4
Paper deteriorations	4
Paradichlorobenzene	4
Paste and glue	4
Pentane	3
Pentanone	4
* Pentylene	3
* Pentyne	3
Perchloroethylene	4
Perfumes, cosmetics	4
Perspirations	4
Persistent odors	4
Pet odors	4
Phenol	4
Phosgene	3
Pitch	4
Plastics	4
Poison gases	3
Pollen	3
Popcorn and candy	4
Poultry odors	4
Propane	2
* Propionaldehyde	3
Propionic acid	4
Propyl acetate	4
Propyl alcohol	4
Propyl chloride	4
Propyl ether	4
Propyl mercaptan	4
* Propylene	2
* Propyne	2
Putrefying substance	3
Putrescine	4
Pyridine	4
Radiation products	2
Rancid oils	4
Resins	4
Reodorants	4
Ripening fruit	4
Rubber	4
Sauerkraut	4
Sewer odors	4
Skatole	4
Slaughtering odors	3
Smog	4
Smoke	4
Solvents	3
Sour milks	4
Spilled beverages	4
Spoiled food stuffs	4
Stale odors	4
Stoddard solvent	4
Stuffiness	4
Styrene monomer	4
Sulfuric acid	4
* Sulphur dioxide	2
* Sulphur trioxide	3
Tar	4
* Tarnishing gases	3
Tetrachloroethane	4
Tetrachloroethylene	4
Theatrical makeup odor	4
Tobacco smoke odor	4
Toilet odors	4
Toluene	4
Toluidine	4
Trichloroethylene	4
Trichloroethane	4
Turpentine	4
Urea	4
Uric acid	4
Valeric acid	4
Valericaldehyde	4
Vinegar	4
Vinyl chloride	3
Volatile materials	3
Waste products	4
Wood alcohol	3
Xylene	4

SUBMISSION TO THE SENATE REFERENCES COMMITTEE
RURAL AND REGIONAL AFFAIRS AND TRANSPORT

ON THE INQUIRY INTO

AIR SAFETY - BAE 146
CABIN AIR QUALITY

SUBMISSION NUMBER 11B

British Aerospace Australia Limited

Mr Bruce Jones
Senior Vice President Australasian Support
PO Box 312
BOTANY NSW 1455

Phone: «WorkPhone»
Fax: «Fax»
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26 October 1999

The Secretary
Rural and Regional Affairs and Transport References Committee
Parliament House
Canberra ACT 2600

Dear Sir,

In my letter of 3rd September1999, enclosing British Aerospace's submission to the Australian Government Senate Inquiry into Airspace 2000, I reserved British Aerospace's right to make further submissions on the BASI Occurrence Brief to an in-flight cabin air quality incident on an Australian registered BAe 146.

I now enclose British Aerospace's initial response to BASI Occurrence Brief 199702276 and would be grateful if you could distribute it to the Senate Committee Inquiry members. Please note that British Aerospace continues to reserve it's right to make further supplementary submissions to the Senate Committee Inquiry as appropriate on any of the issues the Committee is considering in relation to the BAe 146 aircraft.

British Aerospace looks forward to contributing to the Senate Committee Inquiry and assisting the Committee in addressing any issues relating to the BAe 146 aircraft.

Yours Sincerely,

Bruce Jones
Senior Vice President
Australasian Support

26th October 1999

British Aerospace Supplementary Submission To The Senate Rural and Regional Affairs and Transport References Committee

RESPONSE TO THE BASI OCCURRENCE BRIEF 199702276

BRITISH AEROSPACE Plc: BAe 146-300: 10 JULY 1997

Introduction

This submission is supplementary to the briefing paper lodged by British Aerospace on 3 September 1999 in connection with the Senate Committee Inquiry. That initial briefing paper referred to the BASI investigation into the above incident and explained that, until the BASI Occurrence Brief had been officially released, British Aerospace was unable to respond publicly. The Occurrence Brief was released on 6 September 1999 and British Aerospace now sets out below its preliminary comments on that document, pending the outcome of further enquires with NJS.

Summary

- British Aerospace disagrees with the conclusions of the Occurrence Brief. In particular, its Safety Recommendations fail to take account of the modifications introduced both by BAe and the engine and APU manufacturers since the early 1990's specifically designed to address the issue of possible contamination of the cabin air supply.
- On the basis of the circumstances described in the Occurrence Brief, this incident would not have occurred had the procedures set out in BAe's Master Minimum Equipment List ("MMEL") been applied to the known "defect" in the aircraft's bleed air system.
- The Occurrence Brief refers to anecdotal reports of "health problems" suffered by flight and cabin crew of various Australian operators. As indicated in its initial briefing paper, however, British Aerospace believes that recent complaints regarding cabin air quality on BAe 146 aircraft have largely no connection with the subject incident.
- British Aerospace has expressed its disappointment to BASI regarding the procedures followed in the preparation of the Occurrence Brief and in particular the level of consultation afforded to it.

The Incident

- According to the Occurrence Brief, the cause of the incident was oil contamination of the cabin air supply due to a leaking oil seal.
- The problem with the leaking oil seal was first noted by the operator on 17 June 1997, some 23 days before the incident.
- Had the corresponding engine bleed air system been treated as inoperative, the provision of the MMEL would have required it to be isolated and placarded (highlighted extracts from the MMEL are attached). Application of these procedures would have avoided any contamination of the air supply. The Occurrence Brief makes no reference to this.
- Once the contaminated air supply was isolated, the remaining sectors were flown without incident.
- British Aerospace is liaising with NJS to obtain further details of this incident not included in the BASI report in order to ascertain whether there are any maintenance or operational considerations arising out of this incident which need to be addressed.

General Cabin Air Issues

- British Aerospace accepts that from time to time oil may leak into the cabin air system. However, between 1991 and 1992, when it became evident that this was an issue, British Aerospace in conjunction with AlliedSignal developed modifications to reduce the frequency of such leaks (see section 5 of British Aerospace's initial briefing paper).
- As part of the modifications an air filtration system was offered to the operators as a customer option. The Occurrence Brief makes no mention of whether air filters or other modifications had been installed on the aircraft in question.
- The Occurrence Brief also refers to anecdotal reports of health problems alleged to have been suffered by flight and cabin crew of various Australian operators and suggests that there is a link between these and the incident under investigation. While the nature of the Occurrence Brief makes it impossible for British Aerospace to comment on or assess the details of any of these further incidents, it is British Aerospace's view that recent complaints regarding cabin air quality have largely arisen from circumstances unconnected to oil contamination and are therefore not relevant to the incident investigated by BASI. British Aerospace has in any event recently been working with Ansett to introduce a package of enhancements to improve the BAe 146 cabin environment (see section 6 of British Aerospace's initial briefing paper), none of which are mentioned in the Occurrence Brief.
- In 1998 CASA conducted a review of the BAe 146 air conditioning system's compliance with certification standards relating to cabin air quality and is understood to have been satisfied with the results. This also is not mentioned in the Occurrence Brief.

Conclusion

- For the reasons set out above, British Aerospace disagrees with the conclusions of the Occurrence Brief and the Safety recommendations made therein. It believes that the Occurrence Brief should in particular have addressed the issues of maintenance actions and operational procedures applicable to the incident.

BRITISH AEROSPACE
Australia

Facsimile

REGIONAL AIRCRAFT

PRIORITY

To	John O'Keefe	**From**	Bruce Jones
Department	Senior Research Officer	**Department**	Australasian Support
Company	Senate Committee Parliament House	**Tel.**	+61-2-9666 8200
Fax.	0262775811	**Fax.**	+61-2-9666 8065
Date	28 October, 1999	**Ref.**	bj/28-1091
No. of Pages	3	**Email**	bkjones@baea.com.au
Subject	**British Aerospace Supplementary Submission October 26th 1999**		

Dear John,

As discussed during our brief telephone conversation this morning I request that the attached 2-page document be included with our Supplementary Submission dated October 26th 1999.

Best regards,

Bruce Jones
Senior Vice President
Australasian Support

British Aerospace Australia
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28th October 1999

The Secretary
Rural and Regional Affairs and Transport Committee
Parliament House
Canberra ACT 2600

Dear Sir,

With my letter of October 26th 1999 I provided a supplementary submission containing the British Aerospace response to the BASI Occurrence Brief 199702276. Within the submission there is reference to the Master Minimum Equipment List (MMEL) and the statement that "highlighted extracts from the MMEL are attached". The referenced extracts were inadvertently omitted from the supplementary submission when it was sent to you. I have attached the document (2 pages) for submission to the Committee and ask that you attach them to our earlier supplementary submission dated October 26th 1999.

Thank you for your assistance in this matter.

Yours sincerely

B.K. Jones
Senior Vice President
Australasian Support

A British Aerospace Company
British Aerospace Australia Limited
ACN 008 423 005

DEFINITIONS

1. In this list, the items of equipment are classified in systems according to the ATA specification. Individual items within a given ATA classification are numbered sequentially.

2. "Item" (Column 1): The equipment, system, components or function as listed in Column 1.

   NOTE: Items annotated in UPPER CASE letters indicates the precise flight deck legend used.

3. "Number Installed" (Column 2): The number of the specified items normally installed in the aircraft. This number identifies the aircraft configuration considered in developing the MMEL.

   NOTE: The operator's MEL should list the number installed in a particular aircraft.

4. "Number Required for Despatch" (Column 3): The minimum number of the specified items required for operation provided the conditions defined in Column 4 are met.

5. "Remarks or Exceptions" (Column 4): This column includes a statement prohibiting operation or permitting operation with a specific number of items inoperative, provisos (conditions and limitations) for such operation and appropriate notes.

6. Dash (-): This symbol indicates a variable quantity when used in Columns 2 or 3.

   NOTE: The operator's MEL should list the numbers appropriate to his particular aircraft in Columns 2 and 3.

7. "Placarding"
   Each inoperative item must be placarded to inform and remind the crew members and maintenance personnel of the equipment condition. To the extent practicable, placards should be located adjacent to the control or indicator for the item affected such that it is clear to the operating crew that it or its associated system is inoperative.

   NOTE: The practice of specifying which items must be placarded, by means of an asterisk (*), has been discontinued.

8. "Inoperative": A system or item of equipment is deemed inoperative if it malfunctions such that it does not accomplish its intended purpose and/or is not consistently functioning within its designed operating limit(s) or tolerance(s).

9. "(O)": The use of this symbol in Column 4 indicates that an appropriate operating procedure (or change to an existing procedure) must be established, published and utilised to maintain the required level of safety while operating under the terms of the (M)MEL.

   Normally, these procedures are accomplished by the flight crew. However, other personnel may be qualified and authorised to perform certain functions.

1. SYSTEM & SEQUENCE NUMBERS ITEM	2. NUMBER INSTALLED	3. NUMBER REQUIRED FOR DESPATCH	4. REMARKS OR EXCEPTIONS
36 PNEUMATIC			
-00-1 Engine Bleed Air Systems	4	3	(O)One may be inoperative provided: a) Associated isolation valve is closed, and b) The aircraft is not despatched into known or forecast icing conditions.
-10-1 APU Air Valve (If Installed)	1	0	(M)(O)May be inoperative provided the valve is secured closed and the APU AIR switch remains OFF. The APU may be used for electrical power.
-20-1 ENG AIR FAULT Lights	4	3	(M)(O)One may be inoperative provided: a) The associated pressure reducing valve/isolation valve is in the closed position, b) The remaining three systems are fully operative, and c) The aircraft is not despatched into known or forecast icing conditions.
-20-2 ENG AIR VALVE Lights	4	3	(M)(O)One may be inoperative provided: a) The associated pressure reducing valve/isolation valve is in the closed position, b) The remaining three systems are fully operative, and c) The aircraft is not despatched into known or forecast icing conditions.

SUBMISSION TO THE SENATE REFERENCES COMMITTEE
RURAL AND REGIONAL AFFAIRS AND TRANSPORT

ON THE INQUIRY INTO

AIR SAFETY – BAE 146
CABIN AIR QUALITY

SUBMISSION NUMBER 11C

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RECEIVED
10 DEC 1999
Senate Rural and Regional Affairs and Transport Committee

9th December 1999

Mr Andrew Snedden
The Secretary
Rural and Regional Affairs and Transport References Committee
Parliament House
Canberra ACT 2600

Dear Mr Snedden,

I write to deal with two points outstanding from BAe's evidence to the Senate Committee on 2 November and a third issue of clarification which John O'Keefe raised with me when we spoke on 3 December.

1 We agreed at the hearing to provide copies of our correspondence with BASI concerning their report into the NJS incident in July 1997. Please find these attached.

2 We were asked in evidence whether we knew anything about an English parliamentary investigation into the issue of cabin air. We have since made enquiries and confirmed that, so far as we can ascertain, no such investigation is in progress nor are there any current plans for one.

3 When I spoke to John on 3 December, he asked me to clarify the "issue" to which Bill Black was referring in the third paragraph on page 90 of the transcript. I am sorry if there was any ambiguity. The point that Mr Black was seeking to make was simply that, given the evidence of symptoms said to have been suffered worldwide by crew of a range of aircraft types (not just the BAe 146), it is difficult to deny the existence worldwide of some form of general health issue. For completeness, however, I should also add the following.

- As BAe neither employs nor has been party to an examination of any of the persons concerned, we obviously cannot comment on the precise clinical nature or cause of any individual's symptoms.
- None of the test results or other data gathered to date has (to BAe's knowledge) produced any evidence of a connection between any such general health issue and the BAe 146 (or indeed the aircraft industry generally).
- We nevertheless acknowledge that the general health issue to which Mr Black referred would benefit from further research.

I hope that the above has clarified the position.

Yours sincerely

Bruce Jones
Senior Vice President
Australasian Support

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IN STRICT CONFIDENCE

22nd July 1999

Mr Barry Sargeant
Deputy Director
Bureau of Air Safety Investigation
PO Box 967
Civic Square
ACT 2608

Dear Mr Sargeant,

Subject: Occurrence Report 199702276 (Your Ref: BO/9702276)

I am in receipt of your letter dated July 2nd in which you seek comments on the content and findings of the draft Occurrence Report 199702276 concerning an incident involving BAe146-300 VH-NJF on 10 July 1997. British Aerospace Regional Aircraft have reviewed the Occurrence Report and consider that significant changes are necessary to ensure that it fully reflects actions taken before, during and following the incident to ensure that all aspects of the occurrence are fully addressed.

We note that very little information on the occurrence has been provided and the Report tends to digress into broader issues that are not related to this particular incident. British Aerospace believes the Report should focus on the incident to determine whether any particular corrective action is required pertinent to the particular circumstances of the event.

In addition to seeking amendments to the Report British Aerospace Regional Aircraft also request a meeting with BASI to establish what further assistance we can provide in preparation of the report and the investigation.

In response to the draft Occurrence Report I have detailed below British Aerospace Regional Aircraft comments and where appropriate, operational documents are attached for reference purposes.

1. Flight Crew procedures

1.1 The BAe Flight Manual Emergency Procedures provide instructions for oxygen masks to be donned and then the contaminated air supply to be identified and isolated. The specific extracts from the Flight Manual are attached for reference. The Occurrence Report makes no reference to the compliance or non-compliance to emergency procedures in this particular incident - we request clarification.

1.2 The Occurrence Report provides no reason or rationale as to why the crew elected to carry on flying following the incident and provides no indication of what medical attention was sought or received by the crew. We request clarification and consider that this information is a necessary inclusion to the Report.

2. Maintenance Practices

2.1 The Report does not address the maintenance actions undertaken prior to, or immediately following, the incident. We understand that a report was found indicating that there had been possible oil contamination three weeks earlier and that the aircraft was cleared for continued flight. We assume this was through implementing the MEL, which provides continued operation for a 10-day period. A copy of the MEL extract is attached for reference and the maintenance actions need to be included in the Report.

2.2 While operating with a MEL item the defective air supply should be correctly labelled so that it is not used and the operating crew made aware of the MEL item prior to the flight. The Report needs to make reference to these important procedures.

2.3 The Report makes no reference to the maintenance investigation and findings following the incident. If the oil contamination reported three weeks earlier was the cause of the odour then the resulting maintenance actions are pertinent to the Report. If maintenance actions identified a different source of contamination then this should be referenced in the Report.

2.4 British Aerospace Regional Aircraft believe that the existing recommended procedures to deal with such an incident are satisfactory.

3 The Design

3.1 While the Report infers that there is a "problem" with the BAe146 design there is no specific supporting information or evidence provided to allow us to respond. Type approval for the BAe146 was obtained from the UK Civil Aviation Authority in 1984 and in excess of 350 of the type are in service throughout the world. No fatalities have occurred due to any technical failure in more than 4.5 million hours of operation. Australian certification was granted following a detailed technical review of the Airworthiness Requirements and the design of the aircraft. There were no additional requirements or modifications required for the air conditioning system and both Ansett and the Australian Department of Aviation accepted compliance concurring with both the CAA and FAA. If BASI have concerns over the design then we require specific information to enable British Aerospace to respond and unless such information is available, we consider that the inferences are inappropriate and should be removed from the Report.

3.2 Certain failures within the engine bearings and the oil system can produce the contamination described in the Report. As you may be aware, British Aerospace Regional Aircraft and Allied Signal, under their own initiative, have developed modifications to reduce the frequency of those failures. The Report makes no reference to these modifications and whether the aircraft concerned in the incident had the modifications embodied. We suggest you investigate whether there is a modification available relevant to the part that failed and whether it has been introduced to this aircraft. Without this information we are unable to identify the failure or recommend rectification actions. Please note that no Airworthiness Authority has mandated these modifications.

4. General Issues

4.1 The Report makes several references to alleged medical conditions suffered by BAe146 crew. We strongly believe that the report should refer to investigations carried out to check the veracity of the information provided to BASI. We would be concerned if BASI is basing an important part of its report on the comments of crew who failed to follow correct reporting procedures. You will obviously appreciate that such failure denies all interested parties the opportunity to fully investigate these issues.

4.2 The Report also makes reference to possible causes of odours and, due to lack of supporting information, we cannot understand your basis for making these statements. Without the information such as maintenance actions/findings and the modification standard of the aircraft we consider it inappropriate to make assumptions on the cause of symptoms.

4.3 British Aerospace Regional Aircraft also has concerns over other statements within the report and requests responses to our questions below so that we can fully respond to the Report:

- The Report makes several references to the disproportionate number of complaints relating to the BAe146. Has there been a widespread survey in respect of many different types of aircraft to arrive at this conclusion? We would be grateful if you could provide us with details of this and explain the basis for this statement in the report.
- Is there any substantive evidence of the alleged link between the oil leak and the symptoms experienced by the pilot in command? (Loss of situation awareness compared to nausea experienced by the supernumerary crew member)
- In the last paragraph of the second page of the Report it is stated that " as a result of information received during the course of the investigation it is apparent that the effects of cabin air contamination of BAe 146 aircraft range well beyond in-flight incapacitation of operating crew". To arrive at such a conclusion we assume that you have carried out a substantial investigation that you can support with evidence. We suggest that this needs to be expanded on in the report and be made available to all interested parties.
- It is apparent from the Report that there are also a considerable number of industrial relations issues, which appear to be relevant, and we suggest this area also needs expanding. For example:
  - Why does the Report state that only a small number of cabin air reports are entered into the log book when this is the responsibility of the crew and the airline?
  - Why are reports made verbally to the Bureau rather than formally?
  - Why do employees fear reprisal from their employers for reporting what they consider flight safety issues?
  - Why are incidents that require maintenance action not being reported?
  - Why is pack "burn out" still being referred to as it is a practice which is not now undertaken nor ever recommended as routine maintenance for the control of cabin air contamination?
  - Why is the engine diffuser mod programme not referred to as a corrective action?
  - Why are APU seal modifications not referred to as a corrective action?

5. The Recommendations

Regarding the recommendations, British Aerospace Regional Aircraft remain satisfied that the aircraft complies with the Airworthiness Requirements based on the events that have been reported to us and the subsequent investigations made by our suppliers and us.

British Aerospace requests a meeting with BASI to discuss the Report and the points raised in this communication to enable us to respond thoroughly to the draft Report.

Yours faithfully
For and on behalf of
British Aerospace Regional Aircraft

Bruce Jones
Senior Vice President Australasian Support
British Aerospace Australia Regional Aircraft

SMOKE OR FIRE ON FLIGHT DECK OR IN CABIN – ANY SOURCE

3B

Oxygen masks, smoke goggles	Flight crew don, select mask regulator to EMERGENCY.
Crew communications	Establish.

ATC Transponder	A7700
Air Traffic Control	INFORM
PANEL FLOOD lights	Select STORM
Flight Deck Emerg Lts	ON
GALLEY SWITCH	SHED (if fitted)
FASTEN BELTS	ON
CABIN EMERG LTS	ON
NO SMKG	ON
Flight deck door	Close

NOTE:

1. *Land at nearest suitable airfield.*
2. *If source of fire can be identified, continue with appropriate procedure below or on Cards 4A/4B/5A.*

SMOKE FROM CABIN EQUIPMENT/FURNISHINGS

Isolate domestic equipment by selecting GALLEY switch to SHED or if not fitted by switching off or pulling CB in galley or on cabin attendants panel. Use portable fire extinguisher to fight fires in furnishings or cabin.

SMOKE FROM AIR CONDITIONING SYSTEM

If smoke occurs on change over between Engine Air and APU Air, revert to previous air source.

NOTE: All Engine Air should normally be OFF for take–off and landing.

If smoke is NOT dispersing:

PACK 2 . . . . OFF
CABIN AIR . . . . FRESH

After 1 minute is smoke dispersing ?

YES → Check ENG 3 & 4 & APU for abnormalities

NO ↓

PACK 2 . . . . ON
PACK 1 . . . . OFF

After 1 minute is smoke dispersing ?

YES → Check ENG 1 & 2 for abnormalities

NO ↓

PACK 2 . . . . OFF

NOTE: Control of pressurisation not available.

Descend as soon as possible to 10 000 ft or minimum safe altitude if higher.

PRESSURISATION . . . . MAN – OPEN
RAM AIR VALVE(if fitted) . . . . OPEN

NOTE:

1. *Do not open flight deck window.*
2. *Land as soon as possible.*

ATA 36 PNEUMATIC

36-00-1 Engine Bleed Air Systems

MAINTENANCE (M)

Nil.

OPERATIONS (O)

a) Ensure that the airplane is not operated in known or forecast icing conditions.

b) Ensure that the ENG AIR switch for the inoperative Bleed Air System remains at OFF throughout the flight.

c) After engine start and prior to take-off, in turn select the ENG AIR switch ON then OFF for each operational Bleed Air System. Between each selection of the switches confirm that the associated ENG AIR VALVE annunciator comes on then goes out, indicating that the isolation valve has opened then closed.

Note: An AIR LO TEMP warning will be given should any airframe De-icing System be selected ON with an Eng Air valve inoperative.

36-10-1 APU AIR Valve (If Installed)

MAINTENANCE (M)

a) Ensure valve is closed by selecting the APU AIR switch to OFF and viewing the 'VLV NOT SHUT' annunciator to ensure that it is extinguished. The valve is therefore closed.

b) Select the APU AIR switch to OFF and placard the switch 'DO NOT SELECT ON' (Location overhead panel 211-50-08).

NOTE : Loss of power supply to this valve ensures closure.

OPERATIONS (O)

Ensure the APU AIR switch is at OFF and remains at OFF throughout the flight.

26/8/99

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Mr Barry Sargeant
Deputy Director
Bureau of Air safety Investigation
24 Mort Street
Braddon
ACT 2612

Dear Mr Sargeant,

Re: Occurrence Report 199702276 involving BAe146 VH-NJF

I am in receipt of the second draft of the above report, made available to me on Wednesday 24 August. Whilst we are grateful for the opportunity to make verbal comments to you, we are dismayed at the time made available to us to do so, (i.e. by 9am Thursday August 25), especially given the time differences existing between me and my colleagues in the United Kingdom. Given the importance of the matter, I have set out below the substance of those comments, which in the time available, we have formulated:

1. BAe's previous comments

1.1 As you are aware, BAe submitted a detailed response to the first draft of the report on 22 July 1999. Despite various requests, we were not afforded the opportunity to discuss our submission or the Report with you or any members of your team in person. Given the nature of the Report and its recommendations, we were surprised at this lack of consultation.

1.2 Similarly, we are also disappointed to note that the second draft fails to take into account or address the majority of our comments. In particular, it fails to answer the majority of the points we raised in paragraphs 1, relating to flight crew procedure, and 2, maintenance procedures, and why those procedures were not followed.

1.3 According to the Report, the cause of the incident was oil contamination of the air supply, (although there is no evidence of the investigative basis for this finding). BAe accepts that from time to time oil may leak into the air system. However, as we have previously advised, when it became evident that this was occurring, BAe in conjunction with Allied Signal in between 1991 and 1992, developed modifications to reduce the frequency of such leaks. A customer option of an oil filtration system was also introduced. No mention is made of such modifications in your Report, or even whether the aircraft in question was fitted with them. Given such modifications, we consider that the safety recommendations in your Report have already been complied with.

1.4 In any event, on the basis of the circumstances described in the Report, the sole reason why this incident occurred is because maintenance and operating procedures set out in the relevant MEL, were not followed. Had the defective air supply been correctly labelled and isolated, the alleged oil contamination would not have occurred (as is demonstrated by the fact that when the flight continued the scheduled sectors with the number 4-engine bleed air system turned off, these were completed without incident). Further, the aircraft appears to have been operated for more than the ten-day period set out (recommended) in the MEL. Given these facts, we are surprised that these matters are not referred to in the Report.

1.5 Similarly, basic aircrewmanship dictates that in this type of situation oxygen masks should have been immediately donned. If this had been the case, the affected crewmembers would not have been prevented from properly carrying out their assigned duties, and hence there should have been no threat to air safety. We do not consider the comment "the crew did not consider the use of oxygen masks..... necessary in the situation", to be an adequate explanation of why this was not done.

2. Anecdotal Evidence

2.1 Much of the report relates to purely anecdotal evidence of other incidents. You seek to link these with the incident under investigation. While the nature of the Report makes it impossible for us to comment on or assess the further incidents referred to, it is our firm view that recent complaints regarding cabin air quality arise from circumstances largely unconnected to oil contamination and are not therefore relevant to the incident under investigation. Yet, not only does the Report refer extensively to this anecdotal evidence, it fails to mention the additional customer optional modifications that BAe has recently developed in conjunction with Ansett Australia to address cabin air quality issues and which are currently being embodied on Ansett's fleet.

3. Failure to ICAO Practices

We have expressed our disappointment at your refusal to have a meeting with us to discuss this Report. We also understand that you failed to follow ICAO guidelines as set out in Annex 13, in that you failed to follow standard reporting layout and that you made no formal notification to the UK Air Investigation Board. We understand that the AAIB have made separate representations to you to that effect. We also are led to believe that, at no stage, did you contact UK Civil Aviation Authority, the Design Authority for the aircraft.

4. Conclusion

In summary, our position remains that we continue to disagree with the substance or your Report. We again request the opportunity to meet with you and your team to go through the Report in detail.

Yours sincerely

B.K. Jones
Senior Vice President
Australasian Support

CC: Mr Rob Lee Director BASI

1. SYSTEM & SEQUENCE NUMBERS ITEM	2. NUMBER INSTALLED	3. NUMBER REQUIRED FOR DESPATCH	4. REMARKS OR EXCEPTIONS
36 PNEUMATIC			
-00-1 Engine Bleed Air Systems	4	3	(O)One may be inoperative provided: a) Associated isolation valve is closed, and b) The aircraft is not despatched into known or forecast icing conditions.
-10-1 APU Air Valve (If Installed)	1	0	(M)(O)May be inoperative provided the valve is secured closed and the APU AIR switch remains OFF. The APU may be used for electrical power.
-20-1 ENG AIR FAULT Lights	4	3	(M)(O)One may be inoperative provided: a) The associated pressure reducing valve/ isolation valve is in the closed position, b) The remaining three systems are fully operative, and c) The aircraft is not despatched into known or forecast icing conditions.
-20-2 ENG AIR VALVE Lights	4	3	(M)(O)One may be inoperative provided: a) The associated pressure reducing valve/ isolation valve is in the closed position, b) The remaining three systems are fully operative, and c) The aircraft is not despatched into known or forecast icing conditions.

SUBMISSION TO THE SENATE REFERENCES COMMITTEE
RURAL AND REGIONAL AFFAIRS AND TRANSPORT

ON THE INQUIRY INTO

AIR SAFETY – BAe 146
CABIN AIR QUALITY

SUBMISSION NUMBER 11D
Date Received: 10 April 00

British Aerospace Australia

Mr Bruce Jones
Senior Vice President Australasian Support
PO Box 312
BOTANY NSW 1455

Phone: 02 9666 8200
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Email:

BAE SYSTEMS

RECEIVED
10 APR 2000
Senate Rural and Regional Affairs and Transport Committee

SUPPLEMENTARY SUBMISSION INCORPORATING OPENING STATEMENT

BAE SYSTEMS

10 April 2000

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BAE SYSTEMS

SUPPLEMENTARY SUBMISSION INCORPORATING OPENING STATEMENT

10 April 2000

We would like to thank the Committee for the opportunity to appear before you again. We hope to be able to assist the Committee further in concluding this inquiry.

Since we last appeared before you on 2 November 1999, you have heard a significant amount of further evidence. We would like to take the opportunity in this opening statement to comment on a number of matters which have arisen.

Certification

First, we can confirm that the BAe 146 aircraft does comply with all applicable Australian airworthiness standards relevant to the cabin air issue. Although this has been questioned in the evidence of a number of the witnesses, we can assure you that the aircraft does fully comply and no dispensations or exemptions have been granted by the Australian authorities in this regard. It should not be overlooked that this aircraft is certificated not only in Australia but also in 36 other countries, including the UK and the US. Each of those countries applies exactly the same standards to matters relating to cabin air as does Australia. Over 50 different carriers operate approximately 350 aircraft of this family around the world.

Cabin Air Flow

A particular question has been raised concerning the rate of fresh air flow into the aircraft and whether the BAe 146 complies with the regulatory requirements covering this. We have tabled before the Committee an Appendix to this opening statement (**Appendix 1**), which explains both the relevant regulatory requirement and what the BAe 146 achieves. In our opening statement to the Committee on 2 November 1999, we referred to figures for the aircraft's performance, which were subsequently commented on in the evidence of both AFAP and the FAAA. In fact the figures quoted were the regulated flow rate for the cockpit (10 cubic feet per minute per person in normal operations) and the ASHRAE proposed level for the cabin (5 cubic feet per minute). As you can see from the Appendix, the aircraft actually does considerably better than those.

The fact is that the BAe 146 meets the regulatory requirement for fresh air flow in normal operations by a wide margin (between 7 and 10 times better). Based on the data contained within the ASHRAE submission to the Committee, the aircraft also compares well with the Boeing 777 in this regard. We will be happy to go into this issue in more detail in answer to questions if you wish.

Aircraft Age and Continuing Airworthiness

We would also like to comment on the impression given by some of the evidence that the BAe 146 is a relatively old aircraft and that this may have some relevance to the

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matter. Again this is not in fact the case. The aircraft was first certificated in 1984. Modern jet aircraft generally have an operating life of over 30 years, whereas the average age of the Australian BAe 146 fleet is 10 years, 7 months.

During the life of any aircraft, it is standard practice for the aircraft manufacturer to produce numerous modifications as part of their ongoing enhancement and improvement of the aircraft. These modifications can be categorised as optional, recommended or mandatory. Mandatory modifications are those which are agreed between the manufacturer and airworthiness authorities to be necessary to address significant safety issues and are made legally compulsory. Apart from mandatory modifications, the decision whether to implement a particular modification and the timing of so doing is a decision for each aircraft operator.

We have tabled before the Committee a Schedule of the various modifications and procedures relevant to cabin air quality which, in conjunction with the engine and APU manufacturers, we have introduced to the BAe 146 since 1990 (**Appendix 2**). All of the modifications in that Schedule are categorised as either recommended or optional and none have been made mandatory by the airworthiness authorities. They are made available as part of the ongoing product improvement programme we offer to all of our customers. Such modification programmes are standard practice among all aircraft manufacturers.

As I hope that Schedule demonstrates, we take our responsibilities as an airframe manufacturer very seriously and will continue to do so. We are proud of the fact that, after 5.2 million flight hours, the 146 fleet has never suffered a fatal accident due to technical failure, which makes it one of the safest aircraft in operation today.

Test Programmes

The BAe 146 cabin air supply has been the subject of detailed testing on a number of occasions. In addition to extensive initial certification testing carried out in 1982, we have participated in a number of outside test programmes: in particular those conducted by Dr Vasak in 1992, Domnick Hunter Limited also in 1992 and Allied Signal and Ansett in 1997. We were also informed and considered the results of Dr Van Netten's testing following its completion in 1996. You have heard a range of different opinions during the course of your inquiry regarding potential contaminants in the cabin air supply and their possible effects. However it must not be overlooked that none of the testing carried out to date has produced any evidence of any such contaminant exceeding or even approaching the currently recognised safety levels. This testing has been conducted both on the ground and in flight and has included complaint aircraft, one of which had a known seal failure.

Present BAE SYSTEMS Actions

None of this means that we are in any way complacent. Indeed, BAE SYSTEMS is currently progressing a number of matters which we hope will add to our knowledge in this area or otherwise move matters forward.

- We are conducting a survey of all BAe 146 operators seeking information on any cabin air quality incidents their fleets may have encountered. So far the

results of this survey are confirming the effectiveness of the modifications introduced in the past to address the issue.

- We are developing our own test programme to enable us to develop further data on any potential contaminants in the cabin air supply. The intention is to use a portable detector to carry out a series of controlled measurements of the cabin air environment, having introduced known quantities of specific contaminants into the air conditioning system of a non-service (test) aircraft. This will enable us to build up a profile of the signature of each potential contaminant at each stage of flight. The detector can then be used by individual operators to determine the precise profile of any contamination suspected on a particular aircraft This should enable more precise corrective maintenance action to be taken and may also identify any further design enhancements which can be introduced.

- You have heard evidence from Mobil about their work on Mobil 291. I am pleased to be able to tell you that that product has now been approved by both BAE SYSTEMS and Honeywell (formerly Allied Signal) for use in the BAe 146's engines.

The other development there has been since we last appeared before the Committee is that the UK House of Lords has recently announced a Select Committee enquiry into the aircraft cabin environment. The scope of the enquiry appears to be quite broad and general air safety is specifically excluded. We mention the enquiry simply because, when we last appeared, you asked us to check whether there was any current UK Parliamentary investigation into this area and we later confirmed that, so far as we could ascertain, there was none (as indeed was then the case). In the circumstances we think it right to update this information for you.

Swedish incident

The Committee has heard from some witnesses about a recent incident involving a Swedish operator and we would like to update you briefly on that.

On 12 November the flight crew of a Swedish operated BAe 146 reported experiencing symptoms of nausea and light headedness as they were descending to land following a domestic flight. They both donned oxygen masks and the aircraft landed without further incident. Immediately following the incident, BAE SYSTEMS issued an All Operator Message emphasising the need for flight crew to don oxygen masks in the event that they experience any fumes or unusual physical symptoms.

The incident is currently the subject of investigation by the Swedish Accident Investigation Board. Both BAE SYSTEMS and Honeywell are playing a full part in that investigation, the results of which will be published in due course by the Swedish authorities. However it is fair to say that during the course of the investigation to date, which has included full engine testing and strip down and in-flight testing of the aircraft, nothing has been encountered which has made either BAE SYSTEMS or the investigator in charge think it necessary to take further safety action at this time.

Short-term health risks

During the evidence of earlier witnesses to this inquiry, there were suggestions that BAE SYSTEMS accepts that there are short-term health risks associated with the aircraft. We have not in fact accepted this. The aircraft test data available does not support such a conclusion and indeed points the other way. We therefore cannot accept this proposition.

While we have no direct information on the clinical nature or cause of any individual's symptoms, we are very much alive to the fact that there are reports of symptoms being suffered worldwide by crew of a range of aircraft types (not just the BAe 146). We agree that there would be benefits in further research into this area. Indeed, as we have already said, BAE SYSTEMS is itself developing a test programme to help gather further data.

Future Action

Finally we would like to address an issue which the Committee has raised with a number of witnesses: namely to identify which is the correct body to take forward any ongoing investigation into the issues raised by this inquiry. We have carefully considered the various options which the Committee has canvassed with earlier witnesses, including the possibility of vesting the task in some form of independent panel or expert. In our view however the better option would be for any future investigation to be coordinated by and channelled through the appropriate aviation authorities. We say this not least because civil aviation is regulated on an international level and there is a need for national bodies to liaise with their counterparts in other countries.

As we have previously commented, cabin air quality is an international and industry wide issue. On 5 April 2000 a Federal Aviation Authorisation Act was signed into US law by President Clinton, which will instigate a year long study by the US National Academy of Sciences, in conjunction with the FAA, into the very issues being considered by this Committee as they affect the aviation industry as a whole. We attach an extract of the relevant section from that Act as a further Appendix to this opening statement (**Appendix 3**). The EU has also recently published a Green Paper into air passenger rights, which includes the issue of the aircraft cabin environment.

If the results of Australian experience and research are to be fed into this international process, the body best able to do this is CASA, being the body charged with the relevant regulatory responsibility under Australian law and with whom its overseas counterparts would expect to deal. If there is a need for further research and investigation within Australia which CASA feels is beyond its expertise or resources, this function could readily be passed to the ATSB (a body also known and respected internationally), on the basis that its findings would then be channelled back through CASA.

In conclusion we would say that the BAe146 is an aircraft in widespread use around the world (for instance it is the second largest user of European airspace after the Boeing 737). We are proud of its outstanding safety record. That is supported by the evidence you have heard from both the operators and the regulators during the course of your inquiry. We are nevertheless conscious of the concerns which have been raised during the course of this inquiry and we are keen to provide what further assistance we can to you. We are therefore happy now to answer any questions the Committee may have.

APPENDIX 1

FRESH AIR FLOW RATES IN NORMAL OPERATION

1 Requirement

The BAe 146 aircraft was certificated by the UK CAA to JAR.25 Change 5. The paragraph relating to airflow volume requirements is JAR.25.831(a), which requires for normal operation that:

'Each passenger and crew compartment must be ventilated, and each crew compartment must have enough fresh air (but not less than 10 cu.ft. per minute per crew member) to enable crew members to perform their duties without undue discomfort or fatigue.

No additional requirement nor any alleviation to this requirement was imposed by CASA or by any other authority when the BAe.146 was certificated in any other country.

2 Air Supply in Normal Operation

The aircraft is normally operated utilising two air conditioning packs. These can be set to either recirculation mode (60% fresh, 40% recirculated air) or 100% fresh air.

2.1 40% Recirc Mode

For the flight deck with two pilots over **six times** the regulated amount of fresh air is supplied. There are three seats are available on the flight deck, the third to accommodate a training captain or supernumary crew member With three pilots, over **four times** the regulated amount is supplied.

For the passenger cabin, the airworthiness requirements address the abnormal (ie, single air conditioning pack) situation rather than normal operation. However, with both packs operating, the airflow rate to the passenger cabin is in fact comparable to the level required for the flight deck.

2.2 100% Fresh Mode

For the flight deck with two pilots over **ten times** the regulated amount of fresh air is supplied. With three pilots, over **six times** the regulated amount is supplied.

For the passenger cabin, 50% more than the level required for the flight deck is provided.

		Fresh Air Requirement cfm per person	Fresh Air Delivered cfm per person	Factor	Total Air Delivered cfm per person
Flight Deck	Recirc Mode	10	60.9	6.9	101.4
	Fresh Mode	10	101.4	10.2	101.4
Passenger Cabin	Recirc Mode	N/A	9.0	N/A	15.0
	Fresh Mode	N/A	15.0	N/A	15.0

3. Assumptions

- Flight deck calculations in the above table assume two flight crew.
- Passenger cabin calculations in the above table assume three flight attendants and 90 passengers, which represents the five abreast cabin layout typical of Australian operators.
- Mass flow to volume flow conversion assumes air density equivalent to an 8000 ft. passenger cabin at 20 deg C
- Aircraft flow rates are applicable to a 30,000 ft. cruise condition.

APPENDIX 2

Chronology of BAe modifications and enhancements introduced since 1990 relevant to cabin air quality issues

Engines

Date	Type of Modification
January 1990	SIL 36/9 – Installation of catalytic converters
October 1990	EM SB.72 – 258 No 9 bearing seals
December 1990	SIL 36/11 – Bleed hogging trouble shooting procedures
April 1995	EM SB.72 –340 – Improved number 1 bearing assembly
June 1995	EM SB.72 – 340 – Improved air diffuser oil tubes
December 1995	EM SB.72-1009 – Improved number 2 seal assembly
March 1997	EM SB.72 – 1034 – Improved number 2 bearing
April 1997	EM SB.72 – 1035 – Air diffuser with new oil tubes
October 1998	EM SB.79-1010 – Improved number 1 seal

Auxiliary Power Unit

Date	Type of Modification
July 1991	APU 49-6573 – Stiffened exhaust flange to reduce leaks
October 1991	APU 49-6595 – Revised dipstick to avoid oil over-filling
February 1992	APU 49-6641 – Improved cooling fan seal to prevent leaks
March 1992	APU 36127A – New bleed air connector seal
April 1992	APU 36115A – Improved bleed air duct seal
May 1992	APU 36115B – Improved exhaust sealing
June 1993	APU 36115E – APU bay ventilation improvements
July 1993	APU 36019E – Improved inlet flexible duct seal
October 1993	APU 36153A – Introduction of oil ejector system
October 1995	APU 49-7158 – Oil level sight gauge to avoid oil overfilling

August 1996	APU 49-7285 – Improved cooling fan for compatibility with ejector mod
February 1998	APU 49-7346 – Improved compressor shaft seal

Environmental Control System

Date	Type of Modification
May 1990	ECS 01087A – Ram air duct improvements to prevent leakage
May 1990	ECS 50095A – Fume extraction for aft galley
May 1990	ECS 40002M – Introduction of air outlets forward toilet
September 1990	SIL 21/27 – "Oil contamination of air conditioning system"
September 1991	SIL 21/30 – Cabin and flight deck malodours trouble shooting procedures
October 1991	ECS 65188M – Introduction warm air outlets/aft vestibules
January 1993	HCMO 01316A – Introduction of filters in air conditioning ducts
January 1993	HCMO 01316B – Introduction of filters in air conditioning ducts
September 1994	ECS 01343A/B/C – Improved duct joints in bleed air supply
July 1998	ECS 01627A – Introduction of duct clamp assembly
July 1998	40424 A to G Cabin airflow enhancements
May 1999	ECS 40424 H to K – Cabin airflow enhancements
July 1999	ECS 40424 L – Cabin airflow enhancements

APPENDIX 3

WENDELL H. FORD AVIATION INVESTMENT AND REFORM ACT FOR THE 21ST CENTURY

TITLE VII--MISCELLANEOUS PROVISIONS

Sec. 725. Passenger cabin air quality.

SEC. 725. PASSENGER CABIN AIR QUALITY.

(a) STUDY OF AIR QUALITY IN PASSENGER CABINS IN COMMERCIAL AIRCRAFT-

(1) IN GENERAL- Not later than 60 days after the date of the enactment of this Act, the Administrator shall arrange for and provide necessary data to the National Academy of Sciences to conduct a 12-month, independent study of air quality in passenger cabins of aircraft used in air transportation and foreign air transportation, including the collection of new data, in coordination with the Federal Aviation Administration, to identify contaminants in the aircraft air and develop recommendations for means of reducing such contaminants.

(2) ALTERNATIVE AIR SUPPLY- The study should examine whether contaminants would be reduced by the replacement of engine and auxiliary power unit bleed air with an alternative supply of air for the aircraft passengers and crew.

(3) SCOPE- The study shall include an assessment and quantitative analysis of each of the following:

(A) Contaminants of concern, as determined by the National Academy of Sciences.

(B) The systems of air supply on aircraft, including the identification of means by which contaminants may enter such systems.

(C) The toxicological and health effects of the contaminants of concern, their byproducts, and the products of their degradation.

(D) Any contaminant used in the maintenance, operation, or treatment of aircraft, if a passenger or a member of the air crew may be directly exposed to the contaminant.

(E) Actual measurements of the contaminants of concern in the air of passenger cabins during actual flights in air transportation or foreign air transportation, along with comparisons of such measurements to actual measurements taken in public buildings.

(4) PROVISION OF CURRENT DATA- The Administrator shall collect all data of the Federal Aviation Administration that is relevant to the study and make the data available to the National Academy of Sciences in order to complete the study.

(b) COLLECTION OF AIRCRAFT AIR QUALITY DATA-

(1) IN GENERAL- The Administrator may consider the feasibility of using the flight data recording system on aircraft to monitor and record appropriate data related to air inflow quality, including measurements of the exposure of persons aboard the aircraft to contaminants during normal aircraft operation and during incidents involving air quality problems.

(2) PASSENGER CABINS- The Administrator may also consider the feasibility of using the flight data recording system to monitor and record data related to the air quality in passengers cabins of aircraft.