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AIRCRAFT CABIN AIR QUALITY

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SUMMARY

This document is primarily intended to address industry and government questions regarding the impacts of recent Congressional activity on the subject of air quality. Air conditioning system performance levels on currently operational aircraft are documented. The effects upon aircraft design and operation are addressed, along with rough estimates of the economic consequences of proposed requirements.

In addition, a brief overview of the factors affecting the comfort of aircraft occupants is provided, along with some suggestions regarding steps which the industry might consider as a means of minimizing any discomfort encountered by the flying public.

DISCUSSION

In recent months some reports have appeared in the news media that have alleged problems with aircraft cabin air quality. These reports have discussed discomfort and illnesses experienced by the public and flight crew members during and after flights, as well as concerns about the transmission of contagious diseases on aircraft. The perception created in the mind of the public is that aircraft cabin air quality is responsible for these complaints, even though studies by agencies such as the *Center for Disease Control* (CDC) and the *National Institute for Occupational Safety and Health* (NIOSH) have not supported these statements.

On 29 July 1993 a hearing was conducted by the House *Subcommittee on Technology, Environment, and Aviation* (23 OSHR 249) which highlighted the subject of cabin air quality. Subsequently, Rep. Jerrold Nadler (D-NY) authored a House Resolution requesting a bill that requires minimum airflows and other changes in the area of cabin environmental control. On 20 August 1993, the FAA requested support from *Douglas Aircraft* in answering questions arising from the proposed legislation. Among the questions from the FAA were the impacts upon the flying public of three specific changes in requirements:

- A minimum supply of 20 cubic feet per minute per person of "fresh" air.
- Operation at a maximum cabin altitude of either 5000 feet or 2500 feet, in place of the current requirement of 8000 feet maximum.
- Control of cabin humidity to a level of 40 percent relative humidity (RH).

Although the primary focus of the questions was the economic impact in the area of resulting fare increases, other concerns were also addressed. This paper provides information in Tables 1-4 regarding the estimated economic impacts, and Tables 5-11 provide information about the cabin airflow provided on DC-9, DC-10, MD-80, and MD-11 aircraft. The following discussion will address some of the technical issues, and will also provide some background about the validity of the concerns which have been expressed. In addition, proposed changes intended to improve the "quality" of the air in the aircraft cabin will be included.

BACKGROUND

Prior to addressing the economic and operational consequences of these proposals, it may be useful to provide a brief discussion of the health issues involved as well as some background information regarding environmental systems design on modern aircraft.

First, it is important to understand the distinction between comfort and health. Aircraft manufacturers and airline operators have a need to provide a healthy cabin environment, and a goal of providing a comfortable one. With any large group of people such as the occupants of a commercial aircraft, what is considered comfort is often subject to conflicting opinions. Once a healthy environment is provided, decisions must be made about how to maximize the numbers of comfortable people. Decisions must also be made regarding the point at which the incremental improvement in the percentage of satisfied people is not justified by the cost involved, since these costs will have to ultimately be reflected in an increase in the price of tickets.

It is important to note that, given the numbers of people gathered in the relatively small space of an aircraft cabin, even an aircraft designed and operated without regard to cost would still be unable to guarantee that a passenger with a contagious disease would not transmit it to those in the near vicinity. The same statement is true of similar situations such as school classrooms, sporting events, theaters, and other forms of public transportation. The environment provided on an aircraft does a comparatively good job of minimizing health problems for the occupants when the system hardware is maintained and used.

The one clearly documented case in which health problems for a number of people could be traced to an aircraft involved a situation which could have been avoided. Due to a dispatch delay, a loaded aircraft was kept at the terminal for over three hours without operating the aircraft's environmental control system (ECS). Without the benefits which would have been provided by the ECS, the spread of a contagious disease within the closed environment of the cabin was almost inevitable.

The potential health effects of the aircraft cabin air can be divided into two categories: chemical effects, and biological effects. Chemical effects would involve the need to provide adequate oxygen and prevent the introduction of undesirable contaminants. Also needed is the removal of many of the byproducts of human occupancy, such as carbon dioxide, carbon monoxide, and tobacco smoke. Biological effects would involve efforts to prevent the accumulation of bacteria and viruses harmful to humans.

Chemical Effects

The oxygen levels provided on equipment built by *Douglas Aircraft* significantly exceed the needs established by studies going back many years, conducted in a number of government and private scientific research projects. In addition, during the process of obtaining FAA certification of our aircraft it is necessary to demonstrate that the aircraft's environmental control system will not introduce contaminants into the air supply, and will keep potential outside agents, such as ozone, below acceptable levels.

Similarly, the carbon dioxide and carbon monoxide levels in the cabin are kept far below those at which medical studies have shown effects upon health might begin to appear. Some people have expressed concern about the occasional measurement of carbon dioxide levels above some published guideline values. It should be understood that these guideline values do not represent health hazards in themselves, but are intended as a convenient means of spotting poor air change rates in buildings. As can be seen in the attached tables, the rate of air change in the cabin can hardly be termed poor. The published levels of carbon dioxide required to adversely affect human health are more than 10 times greater than the highest levels recorded on in-service commercial aircraft in any study .

Some recent comments have compared aircraft to buildings and some have referred to the guidelines published by the *American Society of Heating, Refrigeration, and Air-Conditioning Engineers* (ASHRAE). Although the current ASHRAE guidelines call for an airflow of 15 cubic feet per minute (cfm) per person, until 1989 the guideline was 5 cfm, less than half that provided by aircraft at the same time. The change to a 15 cfm guideline by ASHRAE was not done for health reasons but "*to satisfy the odor perceptions of 80 % or more of visitors.*" In a typical building, the amount of free volume per person is much greater than on an aircraft, and a greater flow per person is needed to change the air rapidly enough to remove odors.

Questions have also been raised about the much higher airflow per person provided in the aircraft cockpit, when compared to the cabin. This flow rate is not driven by health requirements for the crew, but by the need to provide sufficient airflow to maintain thermal control. On a relative scale the cooling loads in the cockpit are much greater than in the cabin, due to the presence of electronic equipment and to the large solar loads resulting from the much higher ratio of window area to volume.

Biological Effects

The ECS design on *Douglas Aircraft* products is intended to minimize the spread of diseases between occupants and to avoid providing a breeding ground for organisms such as those responsible for *Legionnaires' Disease*, etc. Although no system can guarantee an occupant with a communicable disease will not transmit it, particularly to someone in close proximity, the rate of air change in the cabin helps to reduce the probability of this occurring.

The *MD-11* ECS air recirculation filters will catch most of the bacteria and viruses that might be present in the air passing through them, since they are designed for filtration at a nominal size of 1 micron. The *MD-11* filters are rated at over 99.9 % efficiency for a particle size of 0.3 micron. At the larger size of bacteria, the filtration efficiency will be even better. This is in sharp contrast to the performance of filters used in systems in public buildings and in home systems. These units typically filter at about the 400 micron level.

The basic design of our ECS equipment helps to preclude water collecting in persistently moist areas which might provide a breeding ground for disease-causing organisms that have historically caused problems in buildings and homes.

Proposed Requirements

Using the background information above as a starting point, comments will be offered on each of the proposed requirements.

A Minimum Fresh Air Supply of 20 cfm per Person

As discussed above, this proposed requirement has no basis in scientifically recognized health needs. Its imposition on existing aircraft would result in either reduction in allowable passenger loads, or major redesign and replacement of the aircraft ECS equipment. Each "solution" would create major increases in costs that would have to be passed along to the public in the price of the passenger tickets. Table 1 and Table 2 present some quick approximations of the costs involved.

It appears that the impetus for the proposal to require all "fresh" air has arisen from a belief that any recirculated air is automatically of poor quality, even though the typical home and office building has a much higher percentage of recirculated air than is found on an aircraft. As a point of reference, about half of the *DC-10* fleet has no recirculation installed and the other half use recirculation. Surveys of *DC-10* users do not show any correlation between the use of recirculation and the frequency of complaints about air quality. The surveys indicated that complaints varied from flight to flight and aircraft to aircraft, with no clear link to the use of recirculation. In some cases a fuselage rated as providing excellent air quality on one flight has been rated as having poor air on the next flight and good air on the flight following that one.

It should be recognized that increasing the airflow into the cabin from outside the aircraft will increase the probability of problems with the cabin humidity level and make control of cabin ozone levels more difficult. An increased inflow of the extremely dry air found at high altitude will result in a decrease in the relative humidity in the cabin, which will cause a greater number of the passengers to experience dehydration and discomfort. An increase in the inflow of outside air will require that the catalytic converters used to convert ozone to oxygen be redesigned and enlarged. If this is not done there would be an increase in the cabin air ozone concentration, with the attendant health hazards.

Another concern about this proposal arises from the lack of definition of the term "fresh air." Although many people interpret this to mean air from outside the aircraft, others consider that air that has been through a filter system can also be termed "fresh."

Reduction of the Maximum Cabin Altitude to 5000 feet or 2500 feet

This proposal requires that the maximum altitude of the aircraft cabin be limited to a lower value (either 5000 feet or 2500 feet) than the current altitude requirement of 8000 feet. This would have many impacts, both from a safety aspect and from a cost viewpoint. It would be impractical to rework existing aircraft to permit compliance while continuing to fly at the same aircraft altitudes as are currently used, so operating altitudes would have to be reduced. Table 3 presents some quick approximations of the increased costs associated with reducing the aircraft operational altitudes. Table 4 presents estimated costs associated with redesign of aircraft to permit future production to comply with the proposed cabin altitude requirements.

Some potential safety questions are also associated with this proposal. Literal compliance with the proposal would require that the aircraft be pre-pressurized before take-off from a high altitude airport such as Denver or Mexico City. It would also mean landing in a pressurized condition at high altitude airports. In such circumstances, opening the cabin doors in an emergency would not be possible until the aircraft was depressurized. There would also be concerns about passenger discomfort due to the rapid pressure changes associated with short flights between high altitude airports.

The proposal to require a much lower maximum cabin altitude has its origins in an assumed cause for discomfort experienced occasionally by some people. The current standards for a maximum cabin altitude of 8000 feet are supported by a number of physiological studies such as those reported in the NASA *Bioastronautics Data Book* (NASA SP-3006). These studies show that, although the maximum workload capability is reduced somewhat at this altitude, unimpaired normal activity is not a problem for individuals in normal physical condition and seated individuals should not expect to experience problems. Naturally, individuals with significant health problems may be an exception, but these people should not be traveling without special precautions under any circumstances.

Control of Cabin Air to a Relative Humidity of 40 %

At cruise altitudes, aircraft cabin air is very dry, particularly on long flights. On an aircraft with recirculation the relative humidity will typically be in the range of 10-20 %, and on aircraft without recirculation it will be about 5-10 %. Similar conditions can occur in heated buildings in winter, in dry climates, etc. The dry air can cause dehydration, with effects which are similar to those stated in many illness complaints. However, the proposed aircraft change is not considered an attractive solution to this problem.

Humidification has many negative consequences. It will result in substantial increases in condensation on any cold surface inside the aircraft. Any areas where water collects will serve to promote mold and bacteria growth, with potential health hazards. The condensation may also drip on the passengers and crew and may damage or discolor the aircraft interior. The potential increase in corrosion problems associated with condensation will represent an indirect cost increase, while the humidification system itself will be a direct cost increase.

Although the requirements will depend upon the specific aircraft and the route structure, general studies have shown that the necessary water and the system to dispense it may run about 10 % of the weight of the passengers. Non-recurring cost for procurement, installation design, and certification of a humidification system is estimated at 4 million dollars. An existing aircraft would have both a reduction in passenger capacity and a required increase in the ticket price to cover the costs.

An additional consequence is that - if this proposal were to be implemented as law - the aircraft could not be dispatched with the system inoperative. This would result in either the installation of redundant systems or the acceptance of increased numbers of dispatch delays. These impacts are probably unacceptable due to both the costs and to the public demand for dependable transportation.

It appears that a better solution would be to attack the basic problem of passenger and crew dehydration. Most people are unaware of the low humidity in the cabin in flight. Even if aware of it, few recognize the large amounts of water they are losing through their skin and breath in a dry environment, or of the degree to which their own actions can reduce or aggravate the situation. Most passengers consume alcohol and caffeinated drinks such as coffee before and during flights. These will escalate the dehydration rate since they act as diuretics. It would be preferable for both the passengers and crew to consume significant quantities of water, juices, and caffeine-free drinks prior to and during flights.

SUGGESTED INDUSTRY ACTIONS

The following general guidelines are suggested as a means of maximizing passenger and crew comfort and minimizing any health problems.

- Operate the air conditioning system whenever the cabin is occupied, to help minimize the transmission of disease.
- Attempt to determine which passengers have colds or flu, and seat these people as far from the healthy passengers as the circumstances permit.
- Encourage flight crew and passengers to consume water, juices and caffeine-free drinks before and during flight. Use pre-flight videos and in-flight magazines to educate the public.

TABLE 1

APPROXIMATE INCREASE IN TICKET PRICE

RESULTING FROM PASSENGER OFF-LOADING TO MEET 20 CFM/OCCUPANT ON CURRENT AIRCRAFT

Aircraft Model	Ticket Percentage Increase
DC-9-30	7.5 %
DC-9-40	11.3 %
DC-9-50	22.0 %
MD-80	48.1 %
DC-10	5.5 %
MD-11	30.0 %

TABLE 2

ESTIMATED INCREASE IN AIRCRAFT COSTS

ASSOCIATED WITH MAINTAINING CABIN CAPACITY CAPABILITY WHILE PROVIDING 20 CFM/OCCUPANT

Aircraft Model	Non-Recurring Costs	Recurring Costs
DC-9-30	TBD	TBD
DC-9-40	TBD	TBD
DC-9-50	TBD	TBD
MD-80	$6 Million ECS Development	$30,000 per aircraft/year
DC-10	TBD	TBD
MD-11	TBD	TBD

TABLE 3

APPROXIMATE INCREASE IN OPERATING COSTS

RESULTING FROM CRUISE ALTITUDE LIMITATION TO MEET SPECIFIED CABIN ALTITUDE ON CURRENT AIRCRAFT

Cabin Altitude	Aircraft Model	Cruise Altitude Limit (feet)	Additional Cost per Year/Aircraft
5000 feet	MD-80	29,600	$200,000
5000 feet	DC-10	34,000	$262,500
5000 feet	MD-11	34,000	$262,500
2500 feet	MD-80	24,200	$300,000
2500 feet	DC-10	28,000	$1,062,000
2500 feet	MD-11	28,000	$1,062,000

TABLE 4

ESTIMATED INCREASE IN AIRCRAFT COSTS AND WEIGHTS

ASSOCIATED WITH MAINTAINING SPECIFIED CABIN ALTITUDE AT CURRENT CRUISE ALTITUDES

NON-RECURRING COSTS

TASKS	ESTIMATED COSTS
Installation Design Work	$1,000,000 PER MODEL
Full Scale Fatigue Test	$10,000,000 PER MODEL

RECURRING COSTS

Cabin Altitude	Aircraft Model	Increase in Aircraft Empty Weight (lbs)	Additional Fuel Burn per Year/Aircraft
5000 feet	MD-80	900	1.2 percent
5000 feet	MD-11	4,500	1.3 percent
2500 feet	MD-80	1,600	2 percent
2500 feet	MD-11	6,200	1.3 percent

TABLE 5

DC-9 CABIN AIRFLOWS

Aircraft Series	Total Air Flow (cfm) per Occupant	Outside Air Flow (cfm) per Occupant	Air Changes per Hour (Total flow)	Air Changes per Hour (Outside flow)	Total Air Flow (cfm)	Outside Air Flow (cfm)	Number of Occupants Assumed
DC-9-10	21.0	21.0	29.2	29.2	1680	1680	80
DC-9-20	21.0	21.0	29.2	29.2	1680	1680	80
DC-9-30	18.6	18.6	28.0	28.0	2051	2051	110
DC-9-40	17.9	17.9	26.9	26.9	2050	2050	120
DC-9-50	16.4	16.4	24.5	24.5	2134	2134	130

TABLE 6

MD-80 CABIN AIRFLOWS

Aircraft Series	Total Air Flow (cfm) per Occupant	Outside Air Flow (cfm) per Occupant	Air Changes per Hour (Total flow)	Air Changes per Hour (Outside flow)	Total Air Flow (cfm)	Outside Air Flow (cfm)	Number of Occupants Assumed
MD-80	17.5	13.4	25.8	19.8	2625	2016	150
MD-87	19.9	15.2	31.1	23.8	2641	2021	133

TABLE 7

MD-11 CABIN AIRFLOWS

ECON ON - 250 Occupants Selected

Condition	Total Air Flow (cfm) per Occupant	Outside Air Flow (cfm) per Occupant	Air Changes per Hour (Total flow)	Air Changes per Hour (Outside flow)	Total Air Flow (cfm)	Outside Air Flow (cfm)	Number of Occupants Assumed
All Packs On	24.4	10.0	19.7	8.1	6100	2500	250
2 Packs On	24.4	10.0	19.7	8.1	6100	2500	250

TABLE 8

ECON ON - 400 Occupants Selected

Condition	Total Air Flow (cfm) per Occupant	Outside Air Flow (cfm) per Occupant	Air Changes per Hour (Total flow)	Air Changes per Hour (Outside flow)	Total Air Flow (cfm)	Outside Air Flow (cfm)	Number of Occupants Assumed
All Packs On	30.4	16.0	24.6	12.9	7600	4000	250
2 Packs On	28.8	14.4	23.3	11.7	7200	3600	250

TABLE 9

MD-11 CABIN AIRFLOWS

ECON OFF - Any Passenger Load Selected

Condition	Total Air Flow (cfm) per Occupant	Outside Air Flow (cfm) per Occupant	Air Changes per Hour (Total flow)	Air Changes per Hour (Outside flow)	Total Air Flow (cfm)	Outside Air Flow (cfm)	Number of Occupants Assumed
All Packs On	22.0	22.0	17.8	17.8	5500	5500	250
2 Packs On	14.4	14.4	11.7	11.7	3600	3600	250

TABLE 10

DC-10 CABIN AIRFLOWS (ALL SERIES)

(*ECON* MODE AVAILABLE)

Condition	Total Air Flow (cfm) per Occupant	Outside Air Flow (cfm) per Occupant	Air Changes per Hour (Total flow)	Air Changes per Hour (Outside flow)	Total Air Flow (cfm)	Outside Air Flow (cfm)	Number of Occupants Assumed
All Packs on HI, no Fans	26.2	26.2	20.0	20.0	5500	5500	210
2 Packs on HI, 1 Pack on LO, 2 fans	30.6	23.0	23.4	17.6	6433	4833	210
1 Pack on HI, 2 Packs on LO, 3 fans	31.3	19.8	23.9	15.1	6566	4166	210
3 Packs on LO, 4 fans	31.9	16.7	24.4	12.7	6700	3500	210
2 Packs on HI, 4 fans	31.9	16.7	24.4	12.7	6700	3500	210
2 Packs on HI, 3 fans	28.1	16.7	21.5	12.7	5900	3500	210
2 Packs on LO, 4 fans	25.4	10.2	19.4	7.8	5333	2133	210

TABLE 11

DC-10 CABIN AIRFLOWS (ALL SERIES)

(*ECON* MODE NOT AVAILABLE)

Condition	Total Air Flow (cfm) per Occupant	Outside Air Flow (cfm) per Occupant	Air Changes per Hour (Total flow)	Air Changes per Hour (Outside flow)	Total Air Flow (cfm)	Outside Air Flow (cfm)	Number of Occupants Assumed
All Packs On	26.2	26.2	20.0	20.0	5500	5500	210
2 Packs On	17.1	17.1	13.1	13.1	3600	3600	210
1 Pack On	8.1	8.1	6.2	6.2	1700	1700	210