CABIN AIR IMPROVEMENT SYSTEM - BETTER CABIN AIR QUALITY AT LOWER FUEL CONSUMPTION

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Abstract

Current air conditioning systems of civil aircraft supply a constant fresh air flow to the cabin zones to maintain a sufficient air quality. With the new system approach the fresh air flow will be reduced to a level only to compensate the fuselage leakages during flight. The cabin air quality shall be maintained by a filter system, consisting of particle filtration, odour and vapour removal, carbon dioxide adsorption and humidity control.

The aims are: Improving cabin air quality, specially increasing cabin humidity and banning tobacco smoke odourants from supplied air and reducing the aircraft fuel consumption and cost of ownership with a minimum impact on aircraft operation. These aims can be met with the proposed CAROLA system (cabin air refreshing and olfactory abolishing system), provided that the technological challenge for the gas filtration will be solved. For the carbon dioxide adsorption experiences of spacecraft and submarine applications are available and can be exploited.

The feasibility of certification must be proven. Therefore, an agreement with the authorities must be found. They should specify a necessary air quality instead of the current required minimum fresh air flow.

The proposed CAROLA system offers advantages for both, airlines and passengers: The airlines profiting from a reduction in fuel consumption, better aircraft performance and lower cost of ownership and the cabin occupants enjoying a higher air humidity and cleaner air.

1. Current Air Conditioning

The aircraft operates in an environment where human beings are not able to survive. Therefore, an air conditioning system is indispensible for aircraft operation in order to maintain the cabin air at the necessary levels to meet temperature, air quality and pressure requirements and to prevent discomfort and health risks for passengers and crew.

With current air conditioning systems sufficient air quality is maintained with a high fresh air flow from the engine compressor during flight. Between 2.5 and 3 percent of the overall aircraft fuel consumption is caused by the bleed air (fresh air) demand.

This fresh air flow is conditioned in air conditioning packs and mixed with particle filtered recirculated air taken from the cabin. The mixed air is distributed to all cabin zones. Fresh air and recirculated flows are kept constant and secure a pleasant air exchange rate. A symmetrical distribution prevents longitudinal air flow within the cabin, i.e. from smoking to non-smoking areas. Due to the very dry ambient air at high altitudes the cabin air humidity is very low.

The cabin pressure is reduced to an equivalent cabin altitude of up to 8000 ft and controlled by the outflow valves. The current air system with a constant fresh air flow to maintain the air quality is called an 'open' system in contrast to closed systems with total recycling of the air in spacecraft and submarines.

2. Objectives for a new system concept

Every air conditioning system has to maintain a sufficient **air quality** for the occupants. With a questionnaire survey of 1,961 cabin attendants Scandinavian Airlines System (SAS) ascertains the subjects of complaints caused by the cabin climate (1). Especially two of them have been found to show the greatest extent: Smoky air with 69 percent of great inconvenience and dry air with 59 percent (table 1).

Subject of Complaint	not at all	to a certain extent	to a great extent
Noise	13	53	34
Cold	29	56	15
Cabin Temperature Variation	32	55	13
Heat	43	49	8
Variation in cabin pressure	36	51	13
Drafts	27	47	26
Static electricity	44	45	11
Dry air	10	31	59
Turbulence	22	60	17
Dust	62	31	7
Smoky air	4	26	69
Odours	26	61	13
Pungent smells	59	34	7

Table 1 Results of SAS survey of cabin attendants

Environmental tobacco smoke (ETS) consists of a complex mixture of gases and particles. While the particles are filtered within the recirculation system, the gas phase of ETS can not be removed with current filters. The first aim for the new system must be the reduction of ETS vapours in the recirculation air.

A relative humidity between five and 25 percent in the cabin is measured during cruise within the cabin (1). Values between 30 and 70 percent are felt to be pleasant (2). Humidifiers are complex, less reliable, produce costs and maintenance expense and need a high quantity of potable or destillated water. Therefore, the second aim for the new system is an increased cabin air humidity without the use of humidifiers.

Low **operating cost** for the airline is a major driver for every aircraft system design. An analysis of the direct operating cost (DOC) share of the air conditioning system is shown in figure 1 for the Airbus A340. The highest portion is the fuel consumption due to the secondary power demand. Almost half of the DOC share of the air conditioning system is caused by taking bleed air from the engine compressor. The third aim for the new system is to reduce bleed air demand and keep the impacts to the aircraft operation as small as possible.

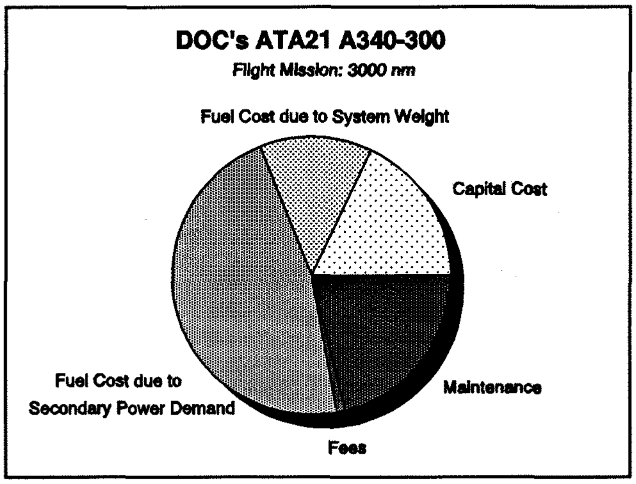

Figure 1 DOC shares of the air conditioning system A340

3. Cabin Air Quality

The new approach for the air conditioning system with reduced fresh air supply will influence the cabin air quality. In a first step the air quality within current aircraft cabins is analysed to judge the changes with reduced fresh air supply and the new system approach.

3.1 Particulate Contamination

Three aspects have to be considered to judge the particulate matter of cabin air quality: the total particle concentration (Total Suspended Particles, TSP and Respirable Suspended Particles, RSP), the contamination with ETS particles and the number of germs (bacteria, viruses, spores).

A high total particulate contamination may lead to irritations in the respiratory system, especially within the very dry environment of an aircraft cabin. Particles smaller than 2.5 microns (Respirable Suspended Particles, RSP) are able to get into the lungs.

Measurements of RSP in DC9/MD80 cabins showed mean values of about 130 $\mu g/m^3$, within the economy class/ smoking area it rises up to 220 $\mu g/m^3$ (3). Other measurements give results between 20 and 500 $\mu g/m^3$ (1). The American Society of Heating, Refrigerating and Air-Conditioning Engineers set a limit for a 24-hour exposition of 260 $\mu g/m^3$ (4). However, the SAS survey shows, that only a small minority of 7 percent of the attendants regards dust as a major problem.

Smoky air is one of the greatest subjects of complaint for the attendants. ETS has a particulate and gaseous phase. Most of the particles are smaller than one micron and belong to the respirable suspended particles. The mean component to judge the particulate phase of ETS is the nicotine, a colourless oil, which is found as an aerosol or connected to other particles. Measured concentrations of nicotine showed mean values of about 5 $\mu g/m^3$ (one value 21 $\mu g/m^3$) in non-smoking areas and between 10 and 40 $\mu g/m^3$ in smoking sections.

There is no substantial difference to other indoor concentration, like in trains, busses, waiting rooms, restaurants or lounges (5). The results are between 1 and 32 $\mu g/m^3$. The difference between smoking and non-smoking sections in aircraft cabins shows the effectiveness of zone separation and the filtration of the recirculation air. However, all measured values are well below the threshold limit value of 500 $\mu g/m^3$. Therefore, problems with smoky air are mainly caused by the gaseous phase of ETS.

Biologically derived particles that are known to become airborn include for instance viruses, bacteria, spores and fungi. Potential sources include outside air, contents of the cargo compartment, passengers and crew. At cruising altitude, outside air contains very few biological particles of any kind. The main sources are the cabin occupants. A sneeze produces approximately two million viable particles. Lots of biogenic particles, such as skin bacteria, result from human activity.

Very few information about the biological contamination in aircraft cabin air is available. During cruise there should be a very low concentration within the air, because the outside air is less contaminated. During passenger boarding and crew activity the number of biological particles increases, which no air conditioning system is able to prevent that, but it must prevent the spread of the germs and to keep the number of biological particles within the supplied air at a low level.

Reduction of fresh air supply will increase the recirculation flow in order to keep the total flow constant. The change of particulate contamination with decreased fresh air depends on filter efficiency. With the current used HEPA-filters (high efficiency particulate air filters) there will be no substantial differences with less fresh air flow.

3.2 Oxygen/Carbon Dioxide Concentration

The metabolic process of the cabin occupants requires oxygen and produces carbon dioxide (CO_2). That has to be considered by the assessment of the cabin air quality. Normal sitting persons have an oxygen consumption of about 18 liters per hour on ground pressure, that corresponds with 25 liters per hour at the reduced minimum cabin pressure. With a minimum fresh air rate of 10 CFM in current aircraft cabins this consumption reduces the partial oxygen pressure of fresh air by four millibars.

Decreased fresh air supply will reduce the available oxygen. With for instance 3 CFM fresh air per person the partial oxygen pressure will be reduced by six instead of four millibars with 10 CFM per person.

A minimum oxygen partial pressure is needed to secure a sufficient arterial oxygen saturation. 150 mbar are said to be a limit for older or ill people. With a maximum cabin altitude of 8000 ft and a share of 20.9 percent oxygen within the ambient air the fresh air oxygen partial pressure will be 158 mbar. It will be reduced between four and six millibars (dependent on fresh air flow) caused by respiration of the occupants. With usual cabin altitudes between 6000 and 7000 ft the partial pressure is well beyond the limit.

Carbon Dioxide (CO_2) is often used as an indicator for air quality at all. Due to the special environment, the CO_2 concentration is not sufficient as the only criterion to judge the aircraft cabin air quality, however.

The CO_2 concentrations in aircraft cabins have to be found to cover the range between 300 and 1500 ppm (0.03 to 0.15 percent). The ambient air has a CO_2 concentration of 300 ppm, 0.03 percent. In the galley area could higher values could be encountered, if dry ice for galley cooling is used.

Different threshold limits for CO_2 are known. All limits below 0.35 percent use the CO_2 concentration as an indicator for odour molestation caused by present persons, well known from Pettenkofer. At the low concentrations typically occuring indoors, CO_2 is harmless and not perceived by humans. To avoid adverse health effects, an acceptable long-term exposure range for CO_2 of 0.35 percent has been recommended (2). Under normal conditions, CO_2 concentrations up to 0.6 percent have only little effect on lung function (1).

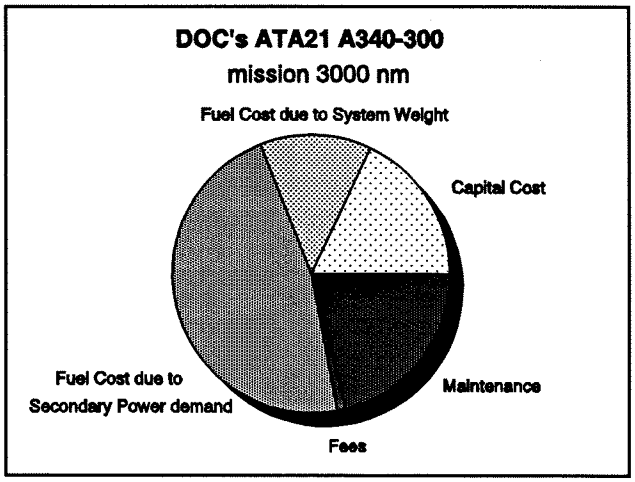

Figure 2 CO_2-concentrations as function of fresh air flow

Therefore, the measured and calculated (figure 2) CO_2 concentrations within aircraft cabins represent not a potential health risk for the occupants with the current fresh air flow. With substantial less fresh air a CO_2 adsorber within the recirculation cycle is required. The envisaged threshold limit has to consider a safety factor for irregular flow and is set to 0.25%.

3.3 Odours, Gases and Vapours

As contrast to the particles, gaseous contaminations are not removed by the recirculation filters. They are kept in acceptable concentrations by dilution with fresh air. Some essential components are analysed to judge risks and restrictions of comfort due to the gaseous contamination.

3.3.1 Odours. The olfactory sense is situated in the nasal cavity and is sensitive to several hundred thousends odourants in the air. Odours arise from gases, often gas mixtures. There are individual and cultural influences to the perception of odourants. In normal concentrations, odourants will not result in health risks. But they are a serious factor for the perceived air quality and the percentage of dissatisfied persons.

No validated measurement method for odour molestation is available. Therefore, no threshold limits are known. The relation between the CO_2 concentration and the perceived air quality (2) is only valid for persons just entering a room. The human nose detects not only the concentration of odourants, but also its gradient. There is a dynamic adaption of the olfactory sense to odourants. The SAS survey shows, that only a minority of 13 percent of the attendants perceive odours as a great complaint. But the impression of smoky air is caused by the gaseous phase of ETS. Besides that, many of the chemical components of ETS are known to be toxic or carcinogenic. A ban of cigarette smoking from aircraft cabins, which would solve the problem, is not to enforce for all long-range flights.

Decreased fresh air flow will reduce the dilution of gaseous contaminants and increase their contamination without the use of efficient filters. Means shall be provided to remove these components within the recirculation cycle.

3.3.2 Carbon Monoxide. Carbon Monoxide (CO) is an odourless gas, produced by incomplete combustion, i.e. as contents of tobacco smoke. But cigarettes are not the only producers of CO. Therefore, it is not siutable as indicator for the gaseous phase of ETS (5). The toxic impact is based up on the high affinity to the hemoglobine of the blood. CO is bound to hemoglobine with more than 200 times the affinity of oxygen. Very low concentrations of CO in the air can result in substantial carboxyhemoglobine (COHb) concentration in the blood. An excessive COHb concentration may cause an internal suffocation.

Measurements within aircraft cabins show maximum concentrations of 5 ppm CO, with mean values of about 1 ppm (1). The 8-hour threshold limit is set to 9 ppm, for one hour 35 ppm are permitted (4). No health risks will cause from the CO concentration in aircraft cabins with current air conditioning system.

The reduction of fresh air will increase the CO contamination within cabin air. The removal device required for odour components should also be able to adsorb CO.

3.3.3 Ozone. Ozone (O_3) is present in the stratosphere as a consequence of the photochemical conversion of normal oxygen (O_2) by solar ultraviolet radiation. Therefore, it occurs within the flight altitude of commercial aircraft. Toxic effects on the respiratory system are well known. Symptoms of an excessive ozone concentration are for instance cough, upper airway irritation, headage, fatigue or eye irritation.

The threshold limit for ozone is set by the FAR to 0.1 ppm (sea level equivalent) for any 3-hour period with a absolute limit of 0.25 ppm (FAR 25.832). In aircraft without ozon filters these limits can be exceeded. For most of the modern long-rage aircraft ozone converters are available. They prevent an excessive concentration.

Reduced fresh air flow will reduce ozone concentration in cabin air. It has to be clarified, whether the ozone converter can be neglected by introducing a CAROLA system.

3.4 Humidity

The presence of water vapour within the air is necessary to keep moist the mucous membranes within the nose, eyes and throat. Relative humidity means the ratio of the quantity of vater vapour present in the cabin air to the quantity which would saturate at the existing temperature. Values between 30 and 70 percent are felt to be comfortable (2,6).

During cruise, the conditioned fresh air from outside has a relative humidity less than one percent. The most significant producers of moisture are the cabin occupants. The average production rate is 0.018 g/s per person with low activity (6). Dependent on fresh air flow per occupant, the relative humidity in the cabin reaches 5 to 25 percent - with a temperature of 24 °C - with current air conditioning systems.

Lower fresh air flow will cause a higher relative humidity (figure 3). With 2.2 CFM per person the saturation of the air is met. It has to be considered that problems with condensation at the fuselage skins will arise with increased humidity.

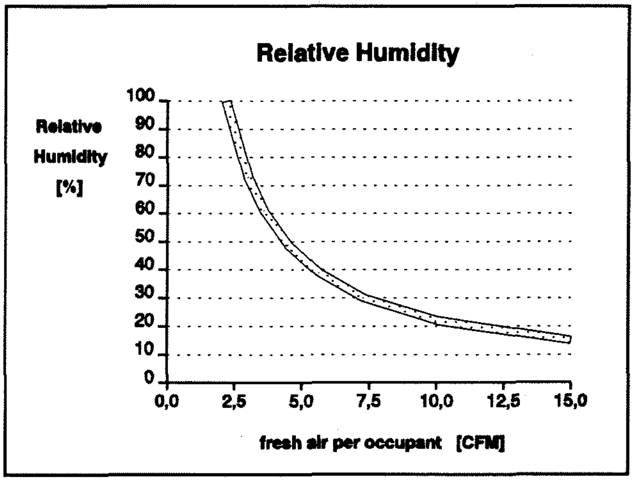

Figure 3 Relative humidity as function of fresh air flow

Low humidity is one of the most important impairments of cabin air quality. A lot of passengers and crew members complain of dry eyes and throats. Drinking a lot of liquid during flight is the only chance of alleviation within the current dry air. An increase of humidity will be a substantial improvement of comfort. However, health risks caused by low humidity are not expected.

3.5 Air Quality Threshold Limits within FAR/JAR

The requirements of FAR/JAR are based on the approach to maintain the cabin air quality by supplying a sufficient quantity of fresh air. Not less than 10 cubic feet per minute (CFM) have to be delivered to each passenger and crew member (FAR/ JAR 25.831).

The requirements (FAR 25.831 and 832) define the following limits for contaminations within the cabin air:

- Carbon monoxide: 50 ppm
- Carbon dioxide: 30000 ppm (planned 5000 ppm)
- Ozone: 0.1 ppm for any 3h period
  0.25 ppm as absolute threshold

The limits for CO and CO_2 are far beyond current values and can be met with less fresh air supply as well.

No further standards for air quality are given within FAR and JAR. The mentioned contaminants, however, are not sufficient to judge the air quality.

3.6 Assessment of the Cabin Air Quality

Two methods are used to judge the cabin air quality and the impacts of reduced fresh air flow:

- Where possible, an assessment of the absolute contamination level must have priority. Measured or calculated levels for aircraft cabins must be compared with threshold limits and levels within other indoor spaces.

- Where no measurements or calculations are feasible, for odour contamination e.g., means shall be provided to keep the concentrations at current levels or to reduce them, where necessary. A deterioration can't be accepted.

The analysis within the previous chapters showed that the current cabin air quality is not hazardous for the occupants. No contamination exceeds the threshold limits set by the FAR/JAR or other authorities. Where a comparison with other indoor spaces is possible, no unusual figures for cabin air contaminations are to be seen. The only exception is the ozone concentration, which occurs without the use of an ozone converter. However, too less results from measurements are available to judge the overall cabin air quality, especially measurements of biological contamination and concentrations of odourants are required.

A special fact within an aircraft cabin is the combination of dry and smoky air with the low pressure and possible stress of passengers and crew members. Such a combination could restrict the comfort more intense than the exceeding of a single threshold limit. Therefore, the concentration of every contaminant should be well below the threshold limits. The aim must be: Increasing air humidity, reducing odourants from cigarette smoke and keeping the other contaminants at least constant, better reducing them as well.

4. Technical Conception

4.1 Configuration

With the new approach the fresh air flow will be reduced to compensate only the fuselage leakages during cruise. The recirculation rate will increase up to 85% dependent on flight condition. The total cabin flow shall be kept constant. The cabin air quality will be maintained by means of a filter system within the recirculation cycle.

With this 'half-open' or 'half-closed' system approach a variable fresh air flow will be introduced. With the system called CAROLA (cabin air refreshing and olfactory abolishing system), the minimum fresh air flow will be about 3 CFM per person in high density cabin lay out.

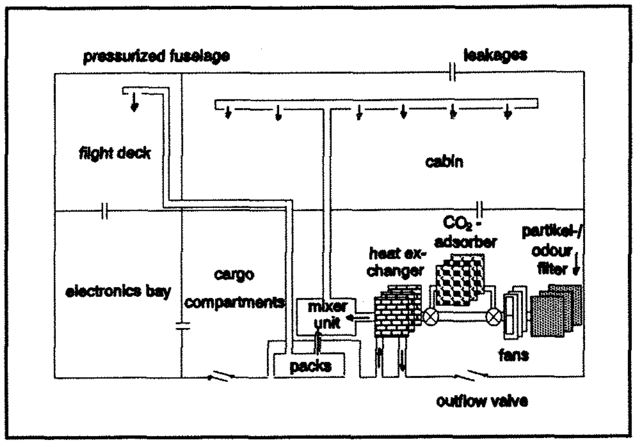

Figure 4 Possible configuration CAROLA system

Figure 4 shows one of the possible system configurations. Its definitive selection depends on technical realisation, certification aspects and market requests, if for example the flight deck will be supplied with fresh air only, additional heat exchangers will be necessary or the CO_2 adsorber will be partially by-passed. For the near future the CAROLA system shall be an on-top system, in the long-term the pack size shall be reduced.

4.2 Air Quality Control

4.2.1 Particle Filtration: The recirculation filters in new types of aircraft reach removal rates of more than 99%. These high efficiency particultate filters (HEPA filters) reduce the particle load within the cabin as much as feasible and prevent the spread of biological particles. Table 2 shows that an increased recirculation rate of 85% will not cause a noticeable increase of particulate contamination.

A relative contamination of 1 represents the pure fresh air flow or a filter efficiency of 100%. The basis for these figures are particle-free ambient air in high altitudes and a steady state, single zone cabin.

Filter efficiency	rel. concentration with 50% recirculation rate	rel. concentration with 85% recirculation rate
0	2	6.7
50	1.33	1.74
75	1.14	1.27
90	1.05	1.093
95	1.03	1.044
99	1.005	1.0086
99.99	1.00005	1.000086

Table 2 relative particulate contamination

The figures within table 2 are not exactly transferable to a current cabin. A multiple zone layout and an unsteady exposition rate will cause a time and position dependent concentration. Nevertheless, these figures show the neglectible change of the concentration with increased recirculation rate. The high filter efficiency will prevent the spread of germs with higher recirculation rates as well.

No health risk or loss of comfort will occur from the particulate matter. Therefore, the current HEPA filters are also sufficient for application into the CAROLA system.

4.2.2 Odour Removal: Sufficient removal of odourants is one of the greatest challenges for the realisation of the CAROLA system. No validated procedures for measuring the efficiency of odour filters are available. The human nose could not be simulated and copied till now, an electronic nose is not available. From the current point of view, only a panel of trained members is able to prove the effectiveness of odour filters.

The most important gaseous contaminants of ETS are well known. Cigarettes produce most of the odourants and dangerous gaseous contaminants. They preferably have to be removed by an odour filter. Odourants from human digestion, parfumes and outgasing from the furnishing have to be considered as well. The effectiveness for dangerous contaminants without odour effect has to be proven by measurements.

Odour and trace gas removal technology is known from spacecraft application. Three methods are applied (7,8,9):

- Physical adsorption
- Chemical adsorption
- Catalytic oxydation

The catalytic oxydation uses high temperatures and is not suitable therefore for an application in aircraft. Molecular sieves use physical adsorption. For odour removal the active charcoal is well known as an adsorber material for this method. Chemical adsorption uses the reaction of gas components with the adsorber material.

Only few approaches for odour removal within aircraft cabins are known. The usage of activated charcoals is not suitable due to the flammability of the material. Other materials were found for aircraft application, activated alumina e.g.(10). For additional removal effectiveness it can be impregnated with other substances, for example with potassium permanganate. A combination of physical and chemical adsorption can be introduced.

The odour removal will be done by non-regenerative means in a similar manner as the particle filtration. Therefore it is suitable to incorporate both filters into one housing as shown in figure 4.

However, the judgement of the olfactory effectiveness of the filters is the most difficult task.

4.2.3 CO_2 Adsorption: Fresh air flow of less than 6 CFM per occupant will cause a CO_2 level exceeding the threshold limit of 0.25% (see figure 2) and require a CO_2 removal within the recirculation cycle. Such type of filter technology is not used in current aircraft types. Experiences are available from spacecraft and submarine applications.

Prnicipally there are two approaches are feasible: Non-regenerative adsorber, which have to be removed after some flights on the one hand or regenerative adsorption processes on the other hand. The latter types of removal devices have got an adsorption part, which adsorbs CO_2 with physical or chemical procedures and a desorption part, which cleans the material for further adsorption.

All known non-regenerative devices will either show not sufficient useful life - only one or a few flights - or are too heavy with extended life. The logistic to change the cartriges is not available at the airports. Therefore, non-regenerative devices are not suitable for an aircraft application.

Regenerative adsorbers theoretically possess an unlimited life. An on-board desorption regenerates the material and keeps it useful. The desorption may occur with hot or low pressure air. Physical adsorption can be realised with molecular sieves, zeolites e.g., chemical adsorption with amines e.g. Both procedures are viable. In case of solid amines, means shall be provided to prevent an entering of caustic fluids into the recirculation air.

To minimize component weight and maintenance expense, a currently running system using rotating drum adsorbers seems to be the best solution.

The CO_2 adsorber finally to be selected should show low development risk, safe operation and lowest cost of ownership, which includes weight, space, purchase cost, reliability and maintenance cost. Because of their attainable efficiencies, only a share of the recirculation flow needs to be ducted through the adsorber.

For the long-term the application of dedicated semipermeable membrans seems to be feasible. They show much less complexity. With current available membrans, such devices would be too heavy and need too much space. Selectivity and permeability have to be increased. Research of new material is under progress, but its availability is not ensured yet.

4.2.4 Humidity Control: The current cabin air is too dry, but with substantial reduction of fresh air flow the water vapour increases. Due to the methabolic moisture produced by the occupants (see figure 3) it could exceeds the limit, where condensation at the fuselage skin comes to be a serious problem. A control of the water vapour becomes necessary. This necessity occurs in parallel to the necessity of a CO_2 adsorption. It is suitable to combine both tasks within one device, therefore.

Fortunately, both envisaged CO_2 adsorber materials - zeolites and amines - remove also water vapour. Therefore, the design of the CO_2 adsorber should consider the duty of humidity control as well. The upper design limit for relative humidity within the cabin air depends up on the insulation concept and will be at the lower end of the comfortable range, between 30 and 40% (about 5 to 7 g/kg).

4.3 Secondary Effects

Changes of the air conditioning system cause impacts on other systems and the stucture. Four essential secondary effects have to be considered:

- Heat balance with reduced cold air flow:

The heat balance must be met with a lower fresh air flow. Possibly an additional heat exchanger could be necessary to meet the temperature requirements within all environmental conditions.

- New insulation concept under request:

If the humidity increases, the condensation of water at the fuselage skin will become a serious problem. A new insulation concept with foams instead of fibre material shall prevent the condensation.

- Need for different types of outflow valves:

The thrust recovery valves currently in use show a high leakage rate. They need a high flow for controlling the cabin pressure not acceptable for the envisaged flow rates of the CAROLA system. Other valves, for example butterfly valves, keep the the necessary bleed air flow at a low level.

- New controlling concept required:

Current ECS controllers keep the fresh air flow constant. The new controlling concept has to ensure a variable fresh air flow depending on fuselage leaksges. A closed link to the cabin pressure control system is required in order to minimize the required flow.

4.4 Valuation of the new Approach

The new approach will be successful, if the **cabin air quality** could be improved and the **operating cost** could be reduced simultaneously. Therefore, the aims described in chapter 2 has to be met.

The first objective is the reduction of ETS vapour in the cabin air. The easiest way to achieve this is increasing of fresh air flow. With increased recirculation rate, however, a removal device for gaseous contaminants is required. To keep the air quality acceptable, the odour/gas filter must be high efficient with respect to ETS vapours. Thus, a validated test method to prove the effectiveness of the filters must be found.

The second aim is a higher air humidity without the use of humidifiers. This aim can be met with the proposed approach. For high density cabin layouts even a reduction of the water vapour within the recirculation air is required.

The third aim is the reduction of bleed air demand with a minimum of negative impact for aircraft operation. With introduction of the CAROLA system a reduction of the overall fuel consumption of the aircraft by one percent - net, including the negative secondary effects - is realistic. This reduction is not only cost effective, but an increased aircraft performance could be realized as well.

Every increase of complexity results in additional maintenance expense and higher purchase price. Increased weight reduces the reduction in fuel consumption. These disadvantages have to be balanced, better exceeded by the fuel savings. First rough estimations show a feasible substantial reduction in cost of ownership for long-range aircraft.

In the first step the CAROLA shall be an on-top system. A failure of this system has no impact on the aircraft operation and will not cause a reduction of the aircraft dispatch reliability. If the challenge of the removal of gaseous contamination from the air can be solved, CAROLA will be an economical system which leads to better cabin air quality and reduced cost of ownership simultaneously.

5. Certification Aspects

A new system approach can only be sucessful, if its certification is feasible. The basic approach within the FAR and JAR 25 is the requirement of a minimum fresh air flow to the cabin. 10 CFM must be at each crew member's disposal (JAR 25.831). *'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'*, as required in JAR ACJ 25.831(a). Unfortunately, no procedure is given to prove that expected air quality is not hazardous to the occupants. The required threshold limits for CO and CO_2 can be met with less fresh air than required, even with the envisaged flow demand of the CAROLA system, without the introduction of new filters. But these values mean a substantial restriction of cabin comfort and a rised health risk for elderly or sick occupants.

The task of the certification authorities is to set up a safety level for passengers and crew. Normally the requirements should define, **what** to fulfil and not **how** to achieve. The request to the authorities is to establish an arrangement, which level of cabin air quality must be met with an air conditioning system. Every aircraft manufacturer should be free in the way to meet the requirements.

6. Conclusion

The challenge for a new approach of an air conditioning system for commercial aircraft is an improvement of the cabin air quality **and** nevertheless a reduction in fuel consumption and cost of ownership simultaneously. An analysis of the air quality and the survey of SAS show the dry and smoky air as the two greatest subjects of complaints.

With the proposed 'semi-open' or 'semi-closed' system the main aims can be met. From the filter point of view the removal of odours and other gaseous contaminants is the most difficult problem, because no validated test method is available. For the adsorption of CO_2 experiences from applications in spacecraft and submarines can be used. The high efficiency particulate air filters (HEPA filters), known from application in current aircraft, are sufficient to prevent a noticeable increase of the particulate contamination and the spread of germs. The moisture will increase without the use of humidifiers to comfortable relative humidities. To prevent condensation at the fuselage skin, a new insulation concept is requested and the control of humidity within the CO_2 adsorber is envisaged.

An application within the next generation of long-range aircraft is obvious, because fuel consumption is as more important as longer the flight mission is. Also the cabin air quality, especially dry and smoky air, becomes more important with increasing flight time. An introduction of the CAROLA system will have advantages for both airline and passengers, not at least the crew. If the technical challenges were solved and a certification is feasible, better cabin air quality at lower fuel consumption and reduced cost of ownership could be assumed to be realistic with the proposed system approach.

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/10/ **William M. Needelman, PALL Corp.:**
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