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Design and Experimental Analysis of Aircraft Air Distribution System

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Abstract: In this paper, the methodology of aircraft air distribution system has been analyzed theoretically and experimentally. To achieve that, ducting pressure loss and air flow throw gaspers calculation has been done for cabin ducts according to the exact location of individual air distribution system in the cabin. The length of gasper air flow was compared with the distance between gasper outlet and passenger seats and the velocity of the gaspers has been measured with velocity gage on the mockup. Finally design results show a good agreement between air flow throw gaspers and gasper to passenger distance that makes comfortable air feeling conditions. Also the experimental analysis on the mockup validates the results of outlet velocity of gaspers and perforations calculation. Therefore, the validity and feasibility of the design methodology of installation gasper system to a cabin air distribution system for least modifications, suitable location and efficient air flow throw gaspers is confirmed.

Keywords: Air Distribution System, Aircraft, Gasper, Environmental Control System, Pressure Loss

1. Introduction

An environmental control system (ECS) is used to protect passengers and crew members in aircraft from different pressure, moisture and temperature of ambient environment. The air distribution system is an important component of the environmental control system since it is used to distribute conditioned air properly to the cabin, providing a healthy and comfortable cabin environment. So it is very challenging to design or develop a comfortable and healthy cabin environment for aircraft with special missions.

Mo et al. used particle image velocity to measure air distribution in an aircraft cabin, [1]. In this study all seat backs except those next to windows were lowered so that the laser beam could penetrate the space. The different study of air distribution system was done at the practical situation. Dechow et al. studied cabin air quality by measuring VOC, particulate and ozone concentration, etc, [2].

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However, they did not study the component effects of air distribution system separately in detail. Zhang and Chen validated a CFD program with experimental data from an environmental chamber with displacement air distribution, [3]. Compared with the experimental study, numerical studies of air distributions in an aircraft cabin are less expensive.

In order to provide individual passenger air gasper system to cabin air distribution system of an aircraft with special mission, simple calculations and experimental validations will be help to achieve design criteria in order to convince certification authorities.

The passenger air gasper system is installed in addition to cabin main air supply. The gasper supplies the same conditioned air from the air conditioning pack. The air gaspers are supplied by existing cabin main duct having series of outlet holes/perforations for cabin cooling. Gasper system location at cabin is illustrated in Fig. 1.

The passenger service unit (PSU) including air gasper is located on cabin ceiling service panel. The air gasper is connected by flexible hose to the upper duct giving flexibility and allowing quick-disconnection to the service panel for opening or removal. Gasper attachment is designed in according to Fig**.** 2. There are two attachment consist of branch duct and a flexible hose.

2. Research method

2.1. Gasper air flow

The upper duct is only supplied by the existing air conditioning system with a lower air flow. The calculation of gasper air flow is based on this condition with all gaspers are in open position. The addition of gaspers does not decrease the amount of fresh air supply both in the cabin and flight deck compartment.

2.2.Ducting system

The air gasper ducting system consists of rigid and flexible duct. The rigid duct consists of an assembly of air gasper, upper duct including its popping out branches. The flexible duct (hose) connects both rigid ducts to accommodate part alignment and maintenance purpose.

The following assumptions are taken for the analysis and calculation: All gaspers, hoses and ducts have smooth inner wall, both gaspers in a PSU are assumed as one outlet duct, the upper duct outlet holes are sharp edge perforated grills/screens inside a duct and assumed as the upper duct branches and the upper duct obstructions are orifices.

2.3. Ducting system pressure loss

Two kind of flow rates are taken into pressure loss calculation, lower flow rate and higher flow rate. Each flow rates produces its respective pressure loss in the ducting system.

With points of zero (zero flow rate (W_0) - zero pressure loss (ΔP_0)), (lower flow rate (W_{lo}); lower pressure loss (ΔP_{lo})) and (higher flow rate (W_{hi}) – higher pressure loss (ΔP_{hi})), the pressure loss of ducting system is defined as, [4]:

$$\Delta P = Z * W^R \qquad (1)$$

The value of W is a variable of air flow rate, while Z and R are constants and are extracted as, [4]:

$$R = \log(\Delta P_{lo}/\Delta P_{hi}) / \log(W_{lo} / W_{hi}) \qquad (2)$$

$$Z = \Delta P_{lo}/W_{lo}^{R} = \Delta P_{hi} / W_{hi}^{R} \qquad (3)$$

The ducting system pressure loss analysis contains a performance calculation based on geometric construction of the upper duct and gasper configuration.

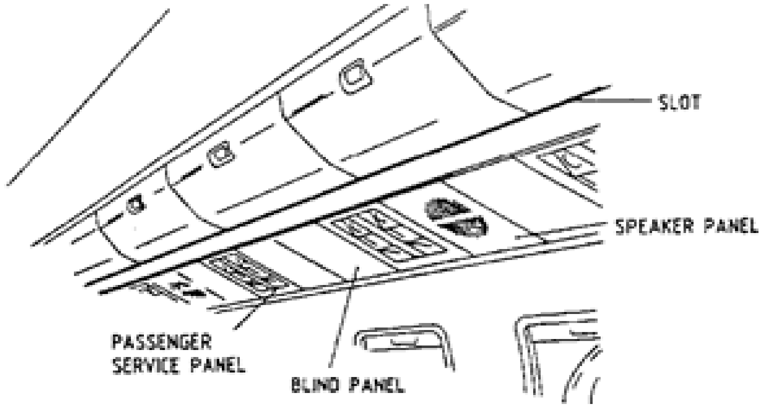

Fig. 1. Gasper system location at cabin.

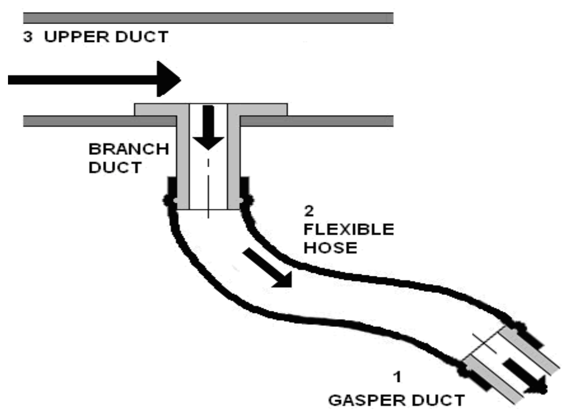

Fig. 2. Air Gasper System Schematic.

The ducting system is assumed to have two types of outlets, gasper outlet and upper duct slot outlet. The gasper outlets are represented as solid line with notation number of 11111112, 111112, 1112 for the front cabin and 1212, 121112, 12111112 for the aft cabin (Fig. 3). The upper duct outlets are represented as dotted line with notation number of 111111112, 1111112, 11112, 112 for the front cabin and 122, 12112, 1211112, 121111112 for the aft cabin. All lines are supplied by single line 1 from air conditioning, see Fig. 3.

The following calculations are based on International Standard Air (ISA+0) and shown in Table 1, [5].

Pressure loss coefficient of a duct system consists of several component loss coefficients such as straight duct ($K_{strduct}$), bend (K_{bend}), orifice ($K_{orifice}$), expansion (K_{expan}), contraction ($K_{contrac}$), perforated screen (K_{perfor}) and outlet loss coefficient (K_{outlet}).

Line loss coefficient as sum of pressure lost coefficients were calculated, [4].

$$K_{line}=K_{strduct} + K_{bend} + K_{orifice} + K_{perfor} + K_{contrac}+K_{expan} + K_{outlet} \quad (4)$$

Table 1. Air Properties

ISA	P	T		ρ	
Elevation	(Psia)	(ºC)	(ºR)	(slug/ft^3)	(kg/m^3)
S/L	14.7	15	519	0.002378	1.225

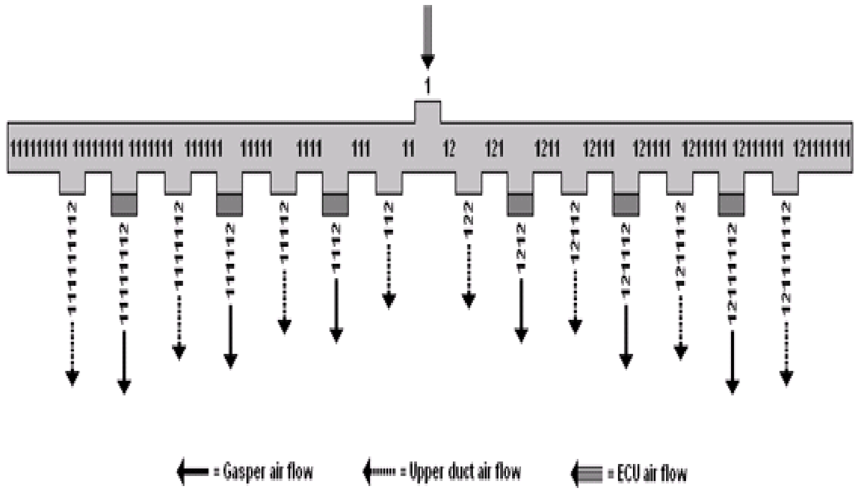

Fig. 3. Cabin air distribution system schematic.

The friction loss coefficient of each straight duct and hose ($K_{strduct}$) are calculated from a moody diagram for lower and higher flow rates, [5]. Some assumptions are taken for the pressure loss coefficient calculations.

a. The lines 111111111 and 121111111 are end ducts. End duct is an orifice with zero air flow rate. This condition is achieved by putting an infinite pressure loss. Due to the limitation of the calculation process, an assumption value of pressure loss coefficient of 10000000000 is taken for both lines.

b. The upper duct outlet holes are assumed as squared edge perforated grills/screens inside a duct and positioned as the upper duct branches, [4].

c. The gasper internal mechanism has an obstruction behaving as a round wire screen.

d. An outlet is similar to a sudden expansion with an inlet infinite area.

Two kinds of air flow rates are taken into pressure loss calculation: assumed, lower flow rate of 202.95 cfm and higher flow rate of 367.75 cfm, [6]. These values are for standard condition of ISA+0 (Table 1), [5]. The lower flow rate represents the air conditioning supply air and the higher flow rate for air conditioning plus recirculation fan supply at cabin ventilation system, [6].

Iteration with a constraint of equal pressure loss between legs is taken to define the percentage of air flow between lines.

In manifold, from line E to any outlet with any path, the pressure losses are equal shown at Fig. 4.

Pressure loss of path A to a1 is equal to that from A to a.

$$\Delta P_{A\ to\ a1} = \Delta P_{A\ to\ a} \tag{5}$$

$$\Delta P_{A\ to\ a1} = (K_{A\text{-}a1} * q_{A\text{-}a1}) + ({}_{B\text{-}A}K_{tA\text{-}a1} * q_{B\text{-}A}) \tag{6}$$

$$\Delta P_{A\ to\ a} = (K_{A\text{-}a} * q_{A\text{-}a}) + ({}_{B\text{-}A}K_{tA\text{-}a} * q_{B\text{-}A}) \tag{7}$$

The ΔP above consists of leg pressure loss, total leg pressure loss and the differential pressure loss between the legs.

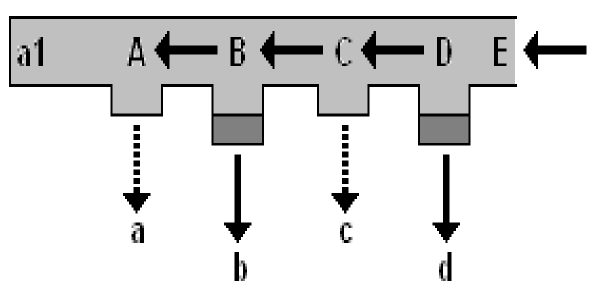

Fig. 4. Manifold schematic.

The total pressure loss is the sum of the leg pressure loss and its main line pressure loss. The differential pressure loss between legs must be zero due to same outlet at cabin pressure or cabin altitude.

The air throw of gasper is a distance of the air exits from a gasper and can be determined from, [4]:

$$Throw = 0.8 * C' * Q / [50 \sqrt{(A_t * C_d * R_{fa})}] \quad (8)$$

Q is air flow, A_t is total area of exit, V_x is velocity at x distance from outlet face, R_{fa} is dimensionless ratio of free area to total area of exit, dimensionless C' is constant from Table 2 and dimensionless C_d is coefficient of discharge of the exit, [4].

3. Results and discussion

The pressure loss characteristic of the air gasper system ducting for upper duct will be:

$$\Delta P_{psi} = 0.000000538 * W_{cfm}^{1.994430} \quad (9)$$

The air gasper system ducting pressure loss characteristic for upper duct has been shown at Fig. 5 based on Eq. 9.

According to duct air flow rate from the air conditioning (202.95 cfm), the pressure loss of the air gasper system is 0.022 psi.

With a given total duct air flow rate, the air flow distribution of each line, air velocity in the grill area and the cabin main supply exhaust (slot) are shown in the Fig. 6.

The minimum velocity of the air at duct perforation holes of 1.87 m/s decreases to 0.98 m/s in the outlet (slot) and the maximum velocity of the air at perforation holes of 12.68 m/s decreases to 3.8 m/s. With all in open position the air flow extracted by gaspers from the duct is 2.29% (4.67 cfm from total ECS supply of 202.95 cfm).

The air flow rate minimum for a gasper is 0.36 cfm. With a minimum air velocity of gasper 3.41 m/s, for a free opening the value of C' will be 5.7 [4]. Throw distance for each duct is calculated about 17 inches from Eq. 8. Fig. 7 shows gasper to passenger distance is about 14 inches.

3.1. Experimental work

Aircraft air distribution design method must be validated by experimental results. To achieve this purpose, aircraft air distribution mockup was made in the life support laboratory. Mockup consists of ECS, cabin model, ducting and gaspers. Fig. 8 shows aircraft air distribution mockup.

Table 2. Values of C' [4]

Type of Outlet	V_0=500-1000	V_0=2000-10000
Free Opening		
Round or Square	5.7	7.0
Rectangular, Large aspect Ratio < 40	4.9	6.0
Annular Slots, Axial or Radial	3.9	4.8
Grills & Grids		
Free Area %40 or more	4.7	5.7
Perforated Panels		
Free Area 3-5%	3.0	3.7
Free Area 10-20%	4.0	4.9

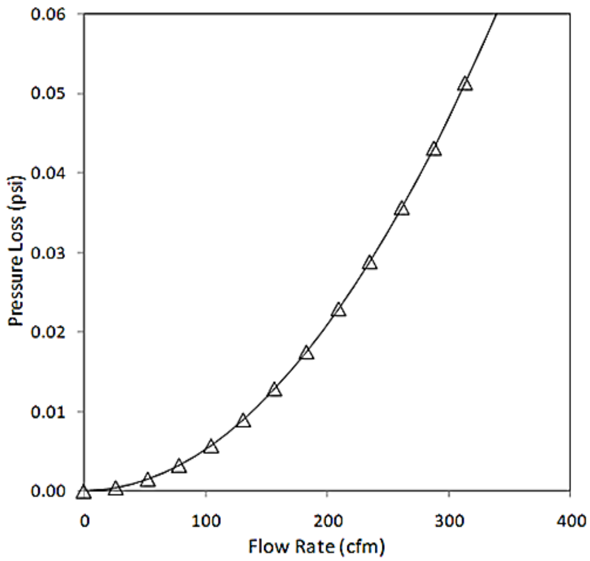

Fig. 5. Air gasper system operating diagram.

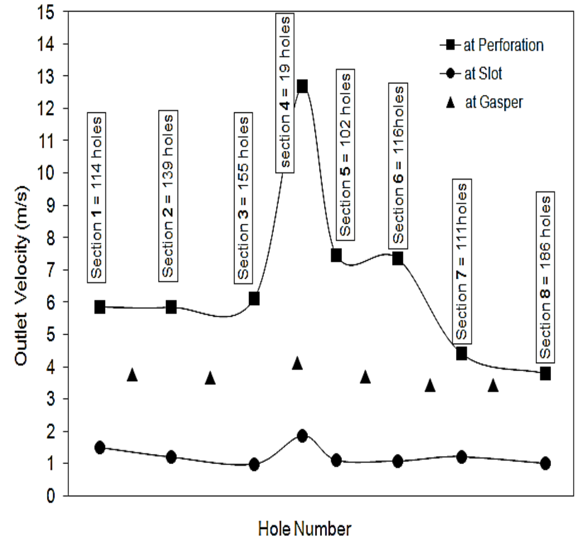

Fig. 6. Duct Air Outlet Velocity.

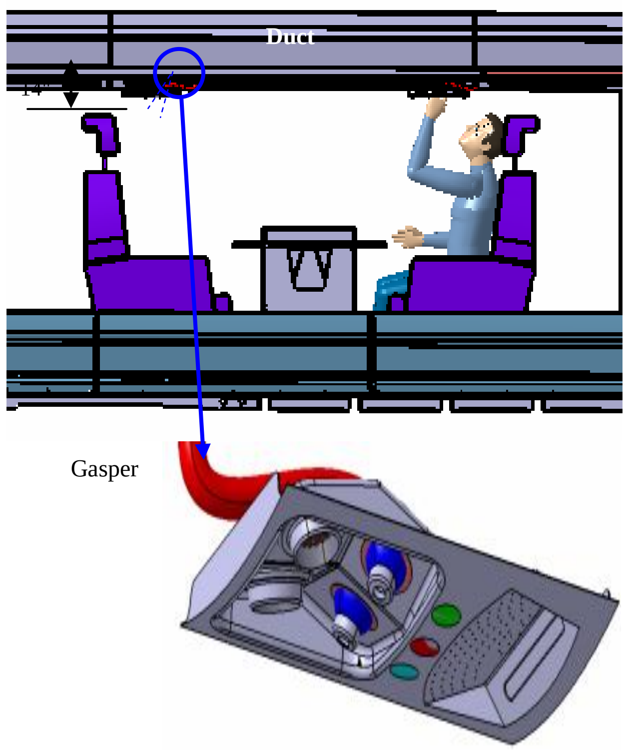

Fig. 7. Gasper to Passenger Distance.

Fig. 8. Aircraft Air Distribution mockup.

According to the ECS supply [6], the air outlet velocity of perforations was measured by velocity gage and is shown in Fig. 9. The calibration of the gauge is confirmed by calibration certificate [6,10].

The average of measurement is compared with theoretical results in Fig. 10.

The measurement difference is about 28% and occurred at third section of perforation holes because of flow turbulence intensity and reality condition of air flow throw the duct. Also air outlet velocity of 6 gaspers was measured by velocity gage and has been compared with calculations in Fig. 11.

The upper duct air distribution among gaspers is from 3.1 m/s to 4.1 m/s, with maximum 24% difference that are relatively uniform.

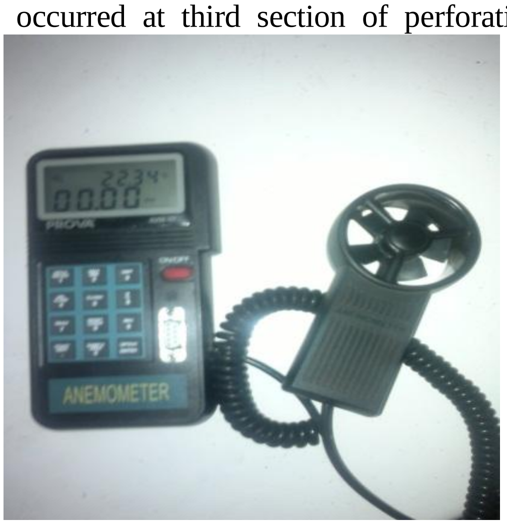

Fig. 9. Velocity Gage Equipment.

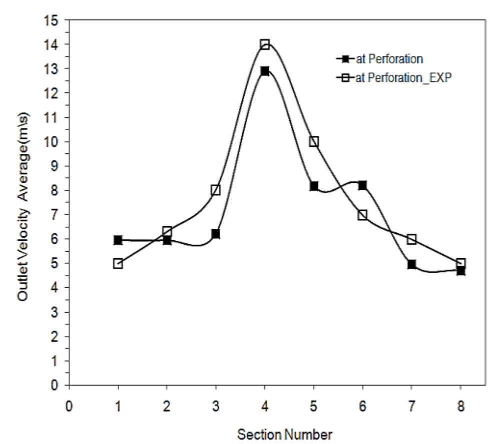

Fig. 10. Theoretical and Experimental data Comparison of Perforations Outlet Velocity.

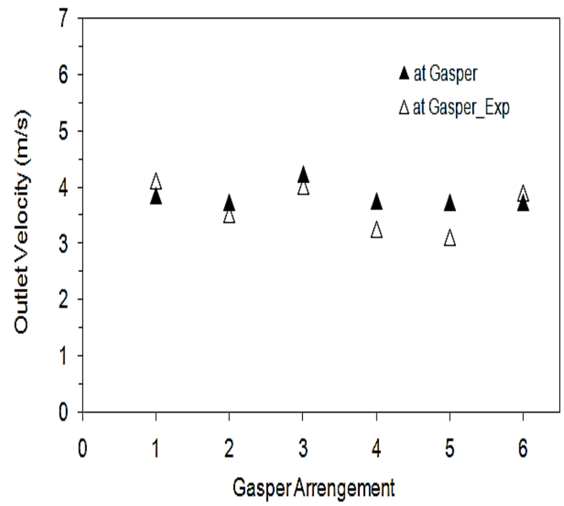

Fig. 11. Theoretical and Experimental data Comparison of Gasper Outlet Velocity.

4. Conclusions

Ducting pressure loss and air flow throw gaspers calculations were done for cabin ducts according to the exact location of individual air distribution system in the cabin of a modified aircraft.

This paper showed new individual air distribution system in the cabin of a modified aircraft with the duct gaspers minimum velocity, its throw length is sufficient to gasper and passenger distance theoretically and experimentally.

It was found that the upper duct air distribution among gaspers is relatively uniform. In addition, the agreement between the air velocity calculations results and the experimental data are reasonably good.

5. Nomenclature

A	Area (m^2)
C_d	Coefficient of discharge of the exit
C_p	Specific heat ($kJ/Kg^0 K$)
D	Diameter of duct / hose (m)
ECS	Environmental Control System
K	Pressure lost coefficient
P	Pressure (psi)
PCU	Passenger Service Unit
q	Dynamic pressure (psi)
Q	Volume Flow Rate (CFM)
R_{fa}	Dimensionless ratio of free area to total area of exit
T	Temperature (^oC)
V	Velocity (m/s)
W	flow rate (CFM)
x	Distance from outlet face (m)
ρ	Density (kg/m^3)
ΔP	Pressure loss (psi)
C'	Constant coefficient

Subscripts

hi	Higher
lo	Lower
t	Total

Superscript

+0	Reference Condition

References

[1] Mo, H.; Hosni, M.; Jones, B., "Application of particle image velocimetry for the measurement of the airflow characteristics in an aircraft cabin ", ASHRAE Transactions, 2003.

[2] Dechow M., "Concentrations of selected contaminants in cabin air of airbus aircrafts ",

Chemosphere, 1997.

[3] Zhang, T.; Chen, Q., "Novel air distribution systems for commercial aircraft cabins", Building and Environment, 2007.

[4] John, C.,"Aero thermodynamic Systems Engineering and Design", SAE AIR, New York, 1990.

[5] Fax, R. W.; Mc. Donald, A.T., "Introduction to Fluid Mechanics", John Wiley & Sons, New York, 1985.

[6] Techreport, A., "Aircraft Maintenance manual & Flight Manual", Iran Aircraft Manufacturing Industries, 2010.

[7] Wei. L., Sagnik. M.;"State-of-the-Art Methods for Studying Air Distributions in CommercialAirlinerCabins", Building and Environment, 2012.

[8] Richard. B.,William W.,Ghyrn W. ;"ADS-B Withina Multi-aircraft Simulationfor Distributed Air-ground Traffic Management", 23rd Digital Avionics Systems Conference, 2004.

[9] J. Fiser., M. Jicha1.;"The influence of air duct geometry on air jet direction in aircraft cabin ventilated by mixing ventilation", EPJ Web of Conferences, 2013.

[10] G.Cai. ;"Modeling and Optimization of Air Distribution Systems for Commercial Aircraft Cabins Using CFD Techniques", eResearch SA Summer Scholarship, 2011.