DESIGN, DEVELOPMENT, SIMULATION AND REALIZATION OF EXPANSION JOINTS IN ECS ENGINE BLEED SYSTEM FOR A TYPICAL LIGHT TRANSPORT AIRCRAFT

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ABSTRACT

In a commercial aircraft, ventilation to the cabin is normally through environmental control system normal bleed air system, ECS emergency back-up pressurization system and ram air. Bleed air is primarily used to provide pressurization by supplying air to the environmental control system. Additionally, bleed air is used for de-icing of aircraft leading edges. The bleed air needs to be tapped from engine and conveyed to the ECS pack through pipe routings. The bleed air pipes that tap the air from engine would experience a varying pressure load (as high as 140psi) and varying temperature (as high as 340°C) at different segments. This would obviously produce the expansion/ contraction of pipes which will result in axial moment and swaying of pipelines from their nominal configuration. These movements should be compensated by means of providing suitable expansion joints/thermal compensators to avoid undesirable loads at the support points which may affect the overall functioning of the system. The real challenge lies in designing such a complex system where suitable expansion joints need to be provided within stipulated airframe configuration satisfying the installation requirements, yet cost and weight effective. In the present work, a methodology has been developed for design of ECS pipe routings, using flexible hose- metallic bellows as a thermal compensator, with the aid of finite element analysis. This paper also talks about the qualification of the bellows through acceptance tests and implementation on a typical light transport aircraft.

Keywords: aircraft, ECS, engine bleed, braided bellows, thermal load, bellow qualification, EJMA.

INTRODUCTION

In the LTA, the air conditioning system operates using engine bleed air and supplies controlled conditioned air to the passenger and the crew compartments. Refrigeration is produced by a single bootstrap air cycle system. The schematic arrangement of the air conditioning system is shown in Figure-1. The temperature control functions are accomplished automatically by an electronic controller in conjunction with an electro-pneumatic Temperature Control Valve. Scheduled maintenance has been minimized by the use of air bearings in the Cold Air Unit (CAU) and high-pressure water separation. Re-circulated cabin air is mixed with sub-zero air conditioning pack outlet air to achieve the required cabin conditioning airflow with minimum engine bleed airflow. The conveyance of air is through pipe routings.

These pipe routings are hot lines that tap the bleed air from the engine and pass through the ejector system. The hot air passing through these lines would be cooled and subsequently used for ECS of the aircraft. ECS pipe routing design for a typical LTA is shown in Figure-2.

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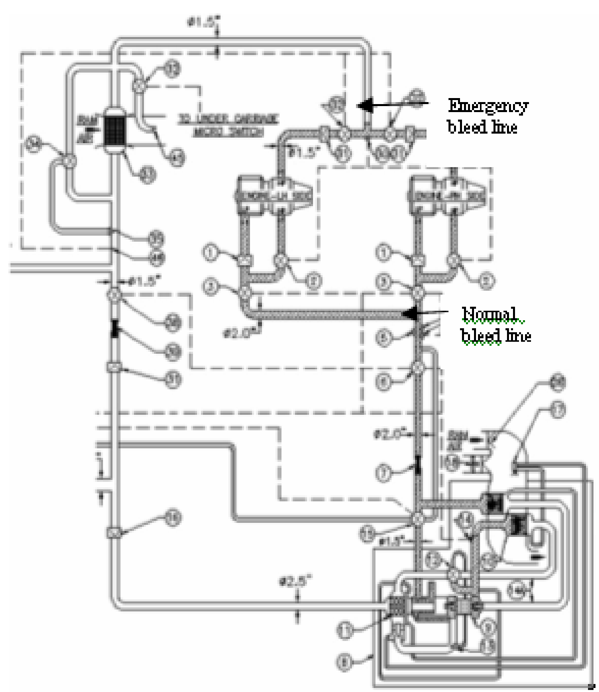

Figure-1. ECS bootstrap schematic.

points available in the aircraft structure and also fixed ECS configuration, the routing of pipes (skewness, length) to suitably accommodate the joints becomes an arduous task. The skewness of pipe in both planes adds to the complexity of the design. Hence the simulation of the

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joints in Finite element analysis to decide these parameters is an absolute necessity.

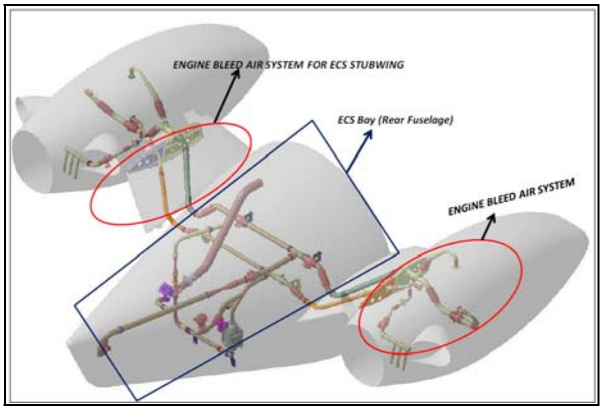

Figure-2. ECS routing in rear fuselage and engine nacelle of LTA.

METALLIC BRAIDED BELLOWS

With a number of expansion joints/flexible hoses available, the selection of a suitable thermal compensatory element for the LTA, purely depended on design constraint posed by the engine manufacturer. i.e., the moment at engine tapping point not to exceed 1730kg-mm (150 lb-in). A feasibility study was carried out step by step exploring the usage of metallic bellows, gimbals, braided bellows etc. With the limited anchoring points available due to pre-defined airframe and fixed nacelle contour, various configurations of pipe routings- altering flexible hose locations was studied using FE analysis. Eventually, the braided bellow was found to suffice the design requirement. The braided bellow has a property to give angular and lateral deflection as shown in Figure-3 and Figure-4, thus compensating the deflection in pipes- basically due to thermal loads, which are cyclic in nature.

The thermal compensation by providing expansion joints at crucial bends would minimize the loads that is experienced at the supporting points which is a one of the main requirement of the aircraft ECS design. Figure-5 shows a typical braided metallic bellow that has been developed and used in the aircraft. The braided bellow is a metal hose with convolutions, over which steel braids are wound to give a tie-rod effect. The hose along with braids are welded to steel flanges to restrict the axial elongation. Collars are provided on both ends to give additional support to the braid ends. Flexible hose of various sizes have been used in the entire aircraft on need basis.

The stiffness of bellow plays an important role in counteracting the pipe deflection. Here, the stiffness of the bellow was guided by the maximum length that can be accommodated within the limits of configuration. The estimation of bellow stiffness was based on iterative FE analysis which is explained in subsequent chapter. The stiffness parameters for bellows at various locations were supplied and these custom made bellows (Figure-6) were manufactured by Metallic Bellows (India) Pvt. Ltd. Chennai. Industry standard design data handbook EJMA [1] was used as reference in design.

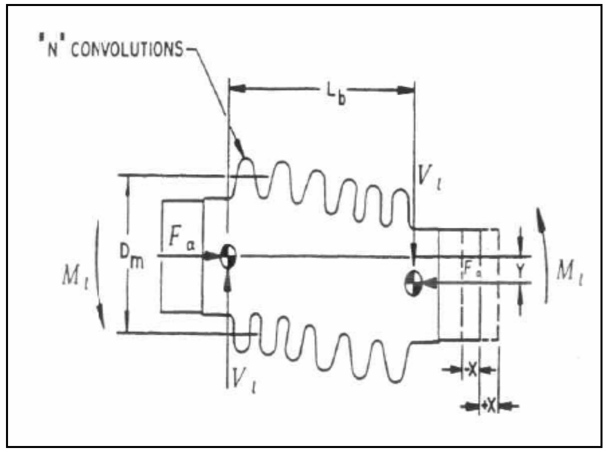

Figure-3. Lateral deflection (Single expansion joint) [2].

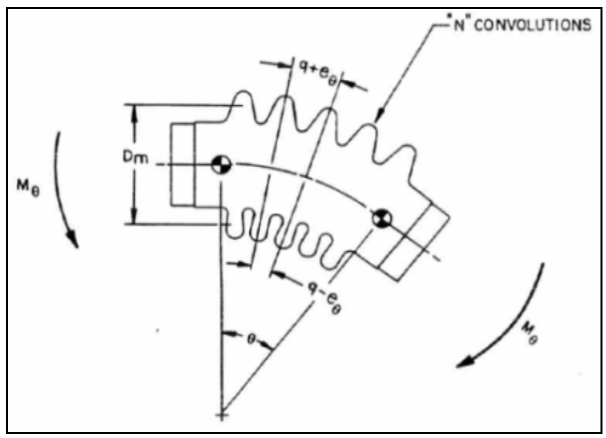

Figure-4. Angular rotation (Single expansion joint) [2].

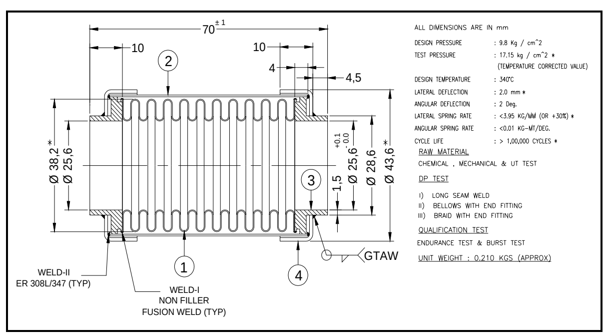

Figure-5. Typical bellow with stiffness details.

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Figure-6. Flexible hoses (Braided bellows).

DESIGN CYCLE WITH FE SIMULATION

In any mechanical system, simulation of the LRU's which are subjected to variable loads such as temperature; pressure etc is a challenging task. At this stage, assistance in the form of effective FE software to simulate these systems in reality would be a boon. Reliability of such an analysis becomes crucial, as engineering decisions would be based on these results. Hence the simulation of such complex system in reality at their conceptual stage becomes an important task for the design/analysis engineer- since it would have an impact on cost and time in proving the system.

Commercial FE pre processor Altair Hypermesh has been used to model the pipe routings as well as bellows and MSC Nastran has been used for the analysis. The Pipes and anchoring brackets were simulated using CQUAD and CTRIA elements. Most importantly, the expansion joints viz, metallic bellows were modelled using CBUSH and RBE2 elements (Figure-7). The CBUSH elements have provision for simulating both lateral and angular direction stiffness parameters to precisely simulate bellow behaviour.

The loads considered for the analyses were the maximum temperature and pressure expected in the pipes as mentioned earlier. Final configuration was arrived based on the iterative studies carried out by simulating different modelling techniques, with different types of compensatory elements and by varying its number and the locations. Different compensatory elements like gimbals, bellows and braided bellows were explored. Based on the manufacturing, design and implementation constraints, cost and weight aspects the braided bellows with appropriate stiffness was selected.

Detail analysis was carried out on each pipe segment by varying the location of braided bellows with different stiffness values. The location and stiffness of bellows being sensitive with respect to the loads and moments experienced at the tapping points, a rigorous and iterative analysis was required to decide the final configuration of normal engine bleed line, emergency engine bleed line, and ejector lines.

The final configuration with braided bellows for normal and emergency bleed line inside the nacelle along with a dummy engine representation is shown in Figure-8.

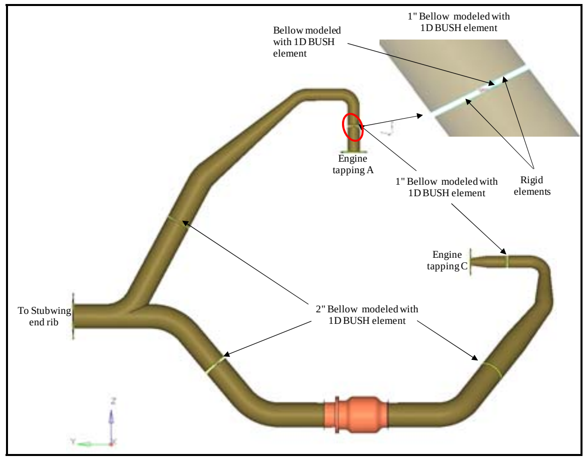

Figure-7. FE model of normal bleed line along with bellows.

The analysis showed that the moment at tapping ports with this configuration was within the acceptable limits satisfying the installation requirements. The FE contour of the normal and emergency bleed lines integrated with stubwing and nacelle structure is shown in Figure-9.

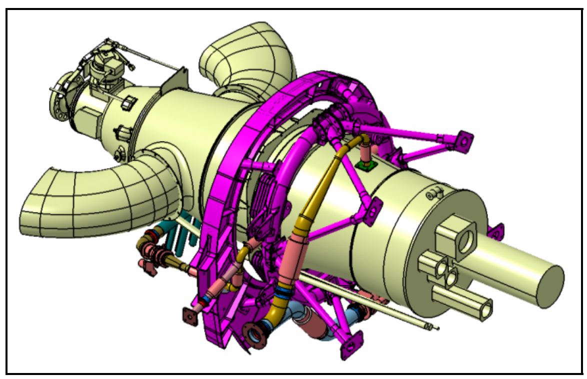

Figure-8. Normal and emergency bleed lines.

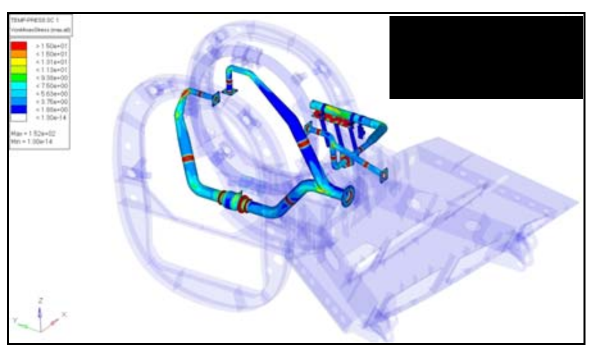

Figure-9. FE contour (stubwing, nacelle and engine mount structure are masked for clarity).

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INTEGRATED FE ANALYSIS WITH AIRCRAFT

Each ECS system pipe routing models were integrated to the main aircraft structure and an integrated FE analysis considering structural and engine loads along with thermal and pressure loads inside the pipe was carried out. From analysis, it was evident that, the present design with optimal bellow locations, engine tapping loads were within acceptable limits meeting the installation requirement. Figure-10 shows the FE von-mises stress contour for the ECS of LTA. For clarity, rear fuselage, stubwing and nacelle structural mesh are masked in the picture.

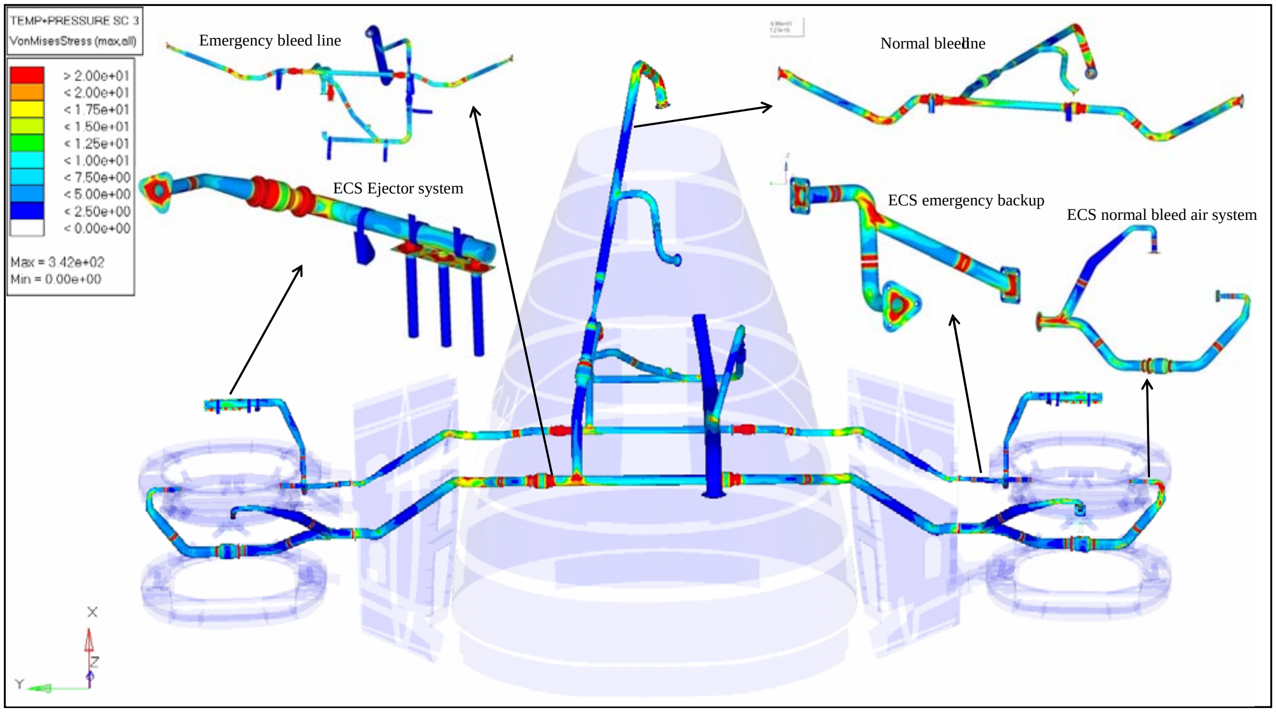

Figure-10. FE von-Mises stress contour of ECS system integrated with stubwing, nacelle and rear fuselage.

BELLOW QUALIFICATION

Since the bellows were tailor made to fulfill the installation requirement of the particular aircraft, the qualification tests were conducted to prove the functional and behavioural aspects. To prove the functionality of bellows, they were successfully subjected to essential qualification tests like endurance test (Figure-11), burst pressure test (Figure-12), proof pressure test, Vibration test (Figure-13), post vibration leakage test as per regulatory requirements before clearing for implementation on the aircraft. Based on results of the tests, the bellows were cleared for development flight trails by certification agency with operating life equal to aircraft life.

*Courtesy Metallic Bellows (India) Pvt. Ltd. Chennai

Figure-11. Endurance test.

*Courtesy Metallic Bellows (INDIA) Pvt. Ltd. Chennai
Figure-12. Burst pressure test items.

Figure-13. Vibration test (Longitudinal and transverse direction).

RESULTS AND DISCUSSIONS

The analysis simulating the bellows demonstrated the effectiveness of these expansion joints in hot lines of ECS. The isolated as well as integrated analysis clearly indicated that the maximum moment at tapping point was well within the allowable movement of 1730kg-mm as per engine installation requirement. The acceptable pipe routing with appropriate bends and skewness were based on integrated FE analysis to arrive at an optimal configuration for the entire ECS of LTA fulfilling the installation requirement. The detail analysis showed the margins well within the acceptable range, thus ensuring the structural integrity. The qualification tests which were conducted as per design regulations also showed that these indigenously developed bellows fulfill the qualification and acceptance functional requirement.

CONCLUSIONS

The metallic braided bellows were designed, developed based on FE simulation. An optimal configuration for the entire ECS of LTA fulfilling the installation requirement was arrived with the aid of FE analysis. With the successful demonstration of functionality and reliability of metallic bellows by acceptance qualification tests and clearance from certification authority, the indigenously developed bellows were installed and are satisfactorily working on the aircraft, thus demonstrating the product design, development and realization cycle. Through this exercise, a proven methodology for simulation of bellows for finalization of appropriate pipe routing, based on FE was developed which would help future projects.

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[2] 2008. Standards of Expansions Joint Manufacturers Association, Inc (EJMA), Ninth Edition, Byrne.