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A Review on Fluid Structure Interaction in Farings Design

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--Abstract-----
Structural loads are critical for aircraft design, especially joining members of the system. Wings, they are joining with fuselage through a structural member called fairings, these fairings plays major role in aerodynamic and structural factors of the wing and fuselage system. To design these fairings, there are standards followed by the industry worldwide, but it is vital to understand the behaviours of the fairings under flying condition, the aerodynamic load in the form of pressure will test the strength of the any structural members, especially joints like fairings in the aircraft, so it is important to understand and integrate design of the same through computational techniques like computational fluid dynamics (CFD) and structural analysis. With the focus on this, the work reviews and presents studies related for fairing design and behaviours under subsonic flying condition with different angle of attach. This work provides comprehensive guide design and implementing FSI in fairing design.

Keywords: *FSI, fairings, wings, CFD*

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I. INTRODUCTION

A fairing is a structure whose primary function is toproduce a smooth outline and reduces drag. These structures are covers for gaps and spaces between parts of an aircraft to reduce form drag and interference drag, and to improve appearance. Also called a "cockpit pod", it protects the crew on ultra lightning strikes. Commonly made from fibre, it may also incorporate a windshield. Elevator and stabilizer tips fairings smooth out airflow at the tips. Fluid-Structure Interaction analysis is a multi-physics problem where the interaction between two different analyses is taken into account. The FSI analysis in structural application involves performing a structural analysis in aero domain taking into account the interaction with the corresponding fluid analysis. The interaction between the two analyses typically takes place at the boundary of the aero application model - the fluid-structure interface, where the results of fluid analysis is passed to the aero structural analysis as a load. The FSI technique is used here to perform the analysis of the fairings behaviours under flying condition.

II. LITERATURE REVIEW

Marco Aurelio Rossi, etc. presents [1] a new methodology developed for an analytical model of a composite fuselage. It also presents finite element analyses of a simplified model and comparisons with more complete models. These comparisons show that there is a very good correlation between both models for the cases studied. Therefore, the applicability of the proposed procedure was demonstrated. Based on finite element analyses, the present paper also presents a weight comparison between a composite fuselage and an aluminium alloy one. This comparison assesses the weight reduction obtained with the use of composite materials for designing the fuselage. Dr.R.Rajappan, etc.,[2]thesis deals with bending Finite Element Analysis of monocoque laminated composite aircraft (subsonic and supersonic) wing using commercial software ANSYS. Theoretical background, mathematical formulation and finite element solution for a laminated composite shell structure are presented in this study. A monocoque aircraft wing is made of laminated composite with fibre angles in each ply aligned in different direction. Various airfoil thickness and ply angles were considered to study the effect of bending-torsion decoupling. R.Sivaji,[3] etc. carried out are search to simulate the complex, three-dimensional flow past the joined wing of a HALE aircraft, and to predict its structural behaviour based on three different structural models. J.Kennedy, [4], presented the design of metallic and composite aircraft wings in order to assess how the use of composites modifies the trade-off between structural weight and drag. In order to perform this the work used a gradient-based aero structural design optimization framework that combines a high-fidelity finite-element structural model that includes panel-level design variables with a medium fidelity aerodynamic panel method with profile and compressibility drag corrections. Dr.IngWilhelmRust,[5] etc. presented solutions include standard perturbation by single force imperfections, empirically proved displacement difference method and the Eigen value tracking method. A material model for mesomarco coupling of nonlinear panel and barrel analysis is presented which introduces nonlinear effects into a coarse meshed FE barrel model for preliminary design purposes. The literature reviews encourages the implementations and importance of fluid structure interaction in fairings design and structural design of aircraft.

III. FAIRINGS DESIGN

For any designer the need for a wing root fairing depends on what type of aerodynamic advantage is needed and depends on the type of components to be placed inside the fairings. The fairing design also changes according to the configuration of the wing (Low, mid or high). In-order to achieve the initial reduction in time for the creation of fairings automating the work is a very feasible solution as discussed earlier. For automation of a component in software it is convenient to create a template which can take the required shapes according to the input. The main reason for generating an automated design for the fairings is to ensure the time spent on initial design is reduced and the desired results are obtained with lesser effort. The design process of fairing design through CAD software took lot of initial considerations to keep the design as simple as possible. The very important aspect of this work was to keep the design datum components as basic as possible. By achieving this, flexibility of the design has increased a lot. Basic components like points, line, spline and conics where used in most cases to form the basic geometry of the fairings. Later simple and stable surface generation elements like multi-sections are used for surface generation. Initially for the process of automation, it is important that a stable and flexible template of the Component is designed parametrically. The more and detailed design made in the template helps to find different ways to implement in the script. It is also important that the number of inputs used for a particular template must be as low as possible. The input for the instantiation also needs to be the very basic components like planes, points, lines, surfaces and curves.

3.1 Design Template

The fairing templates are designed in a certain fashion and the inputs used for the instantiation is also required that the orientation is same. If the user has inverted orientation it is suggested that the inputs are refined first and then instantiate.

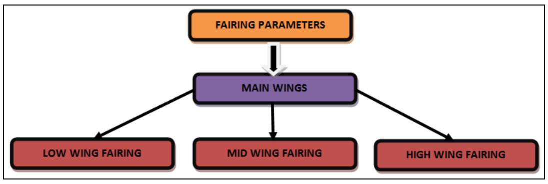

Figure 1 – Fairing Models

3.2 Low Fairing Template

The fairing for the low wing (Figure 2) configurations mostly has the necessity for placing any component under it. The component can be anything from the main landing gear or an environmental control system etc. The low fairing had to provide more space under the wing for placing ground accessible components also.

3.3 Mid Fairing Template

The mid wing is one of the configurations (Figure 3) which are not being used most commonly. But the work also provides a method to create a fillet or a fairing for some of the mid wing configuration. There is very little necessity for a wing pod and hence a controllable and parametric fillet is given for the mid fairing. The mid fairing essentially takes the shape of the wing section and creates a smooth connection between the fuselage and wing.

3.4 High Fairing Template

The high wing fairing (Figure 4) needs to provide some kind of covering and smoothness between the wing and fuselage. This template is designed in as much flexibility as possible to fulfill the requirement. The design also contains sketches similar to the low fairing template. Three sketches define the shape and size of the high fairing template.

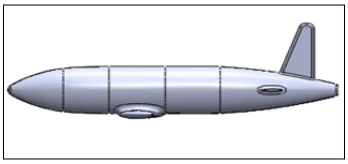

Figure 2 –Low Wing Fairing

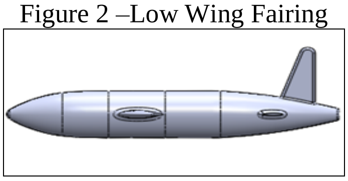

Figure 3 – Mid Wing Fairing

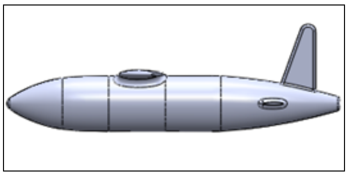

Figure 4 – High Wing Fairing

3.5 Functions of Fuselage

It is a provision of volume for payload (passengers & cargo). Provide overall structural integrity. It is the possible mounting of landing gear and power plant and antennas. The Primary considerations in Fuselage design are low aerodynamic drag, minimum aerodynamic instability, comfort and attractiveness in terms of seat design, placement, and storage space, safety during emergencies such as fires, cabin depressurization, ditching, and proper placement of emergency exits, oxygen systems, etc., ease of cargo handling in loading and unloading, safe and robust cargo hatches and doors. The layout procedures are follows pressurization requirements which affects fuselage section, location of power plant system, if internally mounted it will play a dominant effect, if payload occupy most of the fuselage volume then it will be the starting point for fuselage layout. Location of wing, horizontal tail surface location and landing gear mounting requirement. A sample model configuration (Figure 5) of the fuselage is given in the following table.

Table 1 - Fuselage Dimension Details

S.no	Description	Dimension Details(m) (Length x Dia.)
1	Cockpit Section	2 x 1.95
2	Centre Fuselage 1	1.75 x 2.1
3	Centre Fuselage 2	2.15 x 2.1
4	Centre Fuselage 3	2.1 x 2.1
5	Rear fuselage	2.2
6	Tail Cone	2.1

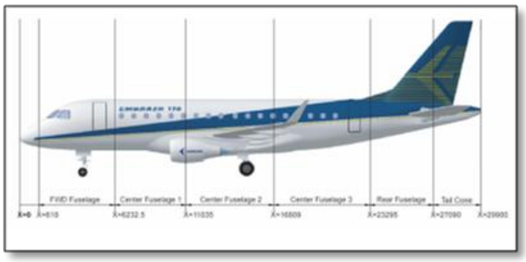

Figure 5 - Fuselage Section

IV. SIMULATION FUNDAMENTALS

4.1 Computation Fluid Dynamics

Computational fluid dynamics, usually abbreviated as CFD, is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. Computers are used to perform the calculations required to simulate the interaction of liquids and gases with surfaces defined by boundary conditions. Initial experimental validation of such software is performed using a wind tunnel with the final validation coming in full-scale testing, e.g. flight tests.

4.2 Structural Analysis

Structural analysis is the determination of the effects of loads on physical structures and their components. Structures subject to this type of analysis include all that must withstand loads, such as buildings, bridges, vehicles, machinery, furniture, attire, soil strata, prostheses and biological tissue. Structural analysis incorporates the fields of applied mechanics, materials science and applied mathematics to compute a structure's deformations, internal forces, stresses, support reactions, accelerations, and stability. The results of the analysis are used to verify a structure's fitness for use, often saving physical tests. Structural analysis is thus a key part of the engineering design of structures.

V. METHOD AND MATERIAL DETAILS

The following figure shows the analysis methodology of FSI based fairing analysis.

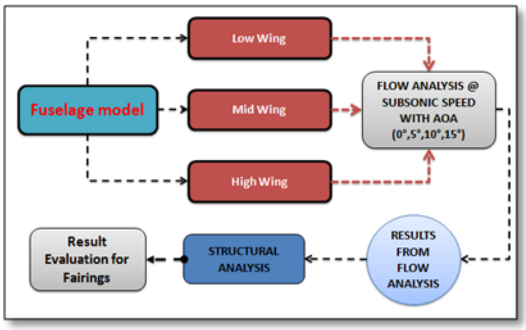

Figure 6- Analysis Method

The above model shows the clear picture of the analysis; the fuselage is modelled with structural members and connected to wings through fairings, the outer models are skinned with surface. The wings are designed with NACA 4 series airfoil. The fuselage is modelled with cross members made of high strength aluminium.

5.1 Materials

Material selection is quite frequently a compromise involving various considerations and the more important considerations have historically been those associated with mechanical properties. A list of selection criteria for materials is, static strength, fatigue, fracture toughness, crack growth, corrosion embrittlement and environment stability. Other criteria equally important are the criteria associated with producing the basic material in the forms required and fabricating the end product at a reasonable cost. The following table shows the comparison of material properties and theirs efficiencies. Metals and composites are used for construction of flights. Based on the design requirement materials are selected. The selection of materials includes many factors from strength to cost effectiveness. But there is no compromise in safety, so best in class materials will be used for manufacturing.

5.2 Static Strength Efficiency

For structural applications, the initial evaluation of various materials is a comparison of static strength efficiency that is a satisfactory means of measuring the material relative strength. For certain applications the effect of temperature should he considered, i.e. the lower strength of aluminum alloy 2024-Thi has better strength retention at elevated temperature than *7075-T6* alloy, and for this reason has been considered in supersonic high speed military aircraft applications. For example, that in a strength-limited aluminum design application, a titanium alloy with improved strength efficiency is substituted, with a resultant weight savings.

5.3 Fatigue

The behavior of materials under conditions of cyclic load can be evaluated as, the conditions required to initiate a crack and the conditions required to propagate a crack. Fatigue crack initiation is normally associated with the endurance limit of a material, and is undoubtedly familiar to most in the form of S-N curves.

5.4 Fracture

Fracture toughness may be defined as the ability of a part with a crack or defect to sustain a load without catastrophic failure. The Griffith fracture theory involves the use of the stress intensity approach, although it is based on a potential energy concept. In the “through cracked skin”, the stress intensity at the tip of the crack will increase as the crack propagates slowly under a static or cyclic applied stress, or as the applied stress increases at a constant crack length at some combination of crack length and stress, a critical stress intensity level is produced arid rapid crack propagation occurs. The critical stress intensity factor for a given material is itself a material property since it is dependent on other physical and mechanical properties of the material. It is a measure of how well a material is able to transfer load in the region of a crack tip, and is related to stress and crack length.

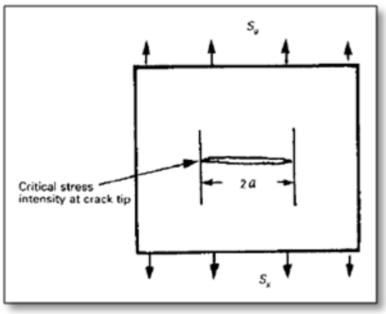

Fig. 6 - Stress Intensity and cracked skin

5.5 Aluminum Alloys

In commercial aviation and military transport aircraft where aluminum material counts for about 80% of the structural materials used, that material and its cost become major economic problems. Aluminum 2014 (aluminum-copper-magnesium alloy) has been used since 1920 on aircraft structures. In the 1940the demand for more tensile strength led to the introduction of the 7000 series alloys (Al-Zn-Mg-Cu), but the problems of stress corrosion cracking and soon become apparent. Stress corrosion remained a problem until 1960 when the introduction of the T73 double aging treatment produced a dramatic improvement. But the treatment reduced the tensile strength by about 10% and the additional development work was on to regain strength while retaining satisfactory stress corrosion resistance. In the early 1970s, it resulted in the appearance of 7050 and 7010 with an improved balance of properties.The problems of fatigue became prominent since the 1950'sand metallurgists have been less successful in developing fatigue resistant alloys. One of them is 2024-T3 and it still remains the yardstick for good fatigue resistance. The fatigue failure of aircraft wing spars caused several accidents in the early 1950s and the 7000 series alloys were in part to blame in that it had offered the designer higher tensile strength but no commensurate improvement in fatigue strength. By the late 1950s the safe-life design philosophy was giving way to fail-safe design since material growing cracks could be more safely monitored in service, following a much improved understanding of crack behavior. Crack stoppers could he designed in but usually with weight penalties so the demand was increasing for 7000 series strength with T2024, 3 levels of fatigue crack growth resistance and toughness. The demand for improved toughness reflects another deficiency in the 7000 series alloys. By using higher purity alloys much has been achieved and the 7075 and 7010 alloys have appreciably better strength in the presence of cracks than its predecessors. Recently, the premier new alloys, perhaps the most important aluminum material development are aluminum-lithium alloys which are about 10% lighter than conventional aluminum alloys, and about 10% stiffer. Substitution of aluminum-lithium for conventional alloys in an existing aircraft design would reduce weight by 8 to I 0%, and about 1 5% weight reduction could be achieved for new design. Primarily because of its superior fatigue performance, the high cost of lithium material, safety precautions in casting, the need for scrap segregation and handling, and closer control of processing parameters all continue to increase product costs more than three times above those of conventional aluminum alloys. But the advantage of using this material is that the manufacturers can use existing machinery and equipment to work and workers do not need special training. Other recently developed aluminum alloys can provide outstanding combination of strength, fracture toughness, fatigue resistance, and corrosion resistance for aircraft components. The basis for these alloy systems, called wrought PM alloys, is the rapid-solidification process. The commercially available wrought PM aluminum alloys are 7090 and 7091.

Table 2 - Aluminum Alloy for Applications

Material	Recommended Application
2024-T3, T42	Use for high strength tension application; has best fracture toughness and slow crack growth rate and good fatigue life. -T42 has lower strength than -T3. Thick plate has low short transverse properties and low stress corrosion resistance. Use T81 *for* high temperature applications.
2224-T3 2324-T3	8% improvement strength over 2024-T3; fatigue and toughness better than 2024-T3.
7075-T6, *T651, T7351*	Similar to 7075 but has better thick section (>3 in) properties than 7075. Fracture toughness. Between 7075 and 2024. Thick plate has low stress corrosion resistance.
7079-T6	Have higher strength than 2024, lower fracture toughness, and use for tension applications where fatigue is not critical. Thick plate has low short transverse properties and low stress corrosion resistance (T6) - T7351 has excellent stress corrosion resistance and better fracture toughness.
7150-T6	11% improvement strength over 7075-T6. Fatigue and toughness better than 7075-T6.
7178-T6,T651	Use for compression application has higher strength than 7075, lower Fracture toughness and fatigue life.
Aluminum-Lithium	Compared to conventional aluminum alloys: 10% lighter, 10% stiffer, and superior fatigue performance.
PM Aluminum	Compared to conventional aluminum alloys: Higher strength, good fatigue life, good toughness, higher temperature capability and superior corrosion resistance.

VI. CONCLUSION

The present work provides details on fuselage, fairings, fairings models and configuration, basic details through CAD, foundation work on computational fluid dynamics, structural analysis and the frame work for fluid structural analysis that will be the extension of the present work. The literature review shows sound details of the past woks of wings and fuselage design and analysis; this includes material details of the same. By exploring theses details it is evident that fluid structure interaction based analyze of fairings is vital for their designs. In the extension work of the present will be the simulation of fluid flow analysis of fairings at different angle of attack and structural performance of the same for a detailed design.

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