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APPLICATION OF FINITE ELEMENT ANALYSIS IN EFFECTIVE DESIGN OF FLIGHT CONTROL CIRCUITS IN A TYPICAL LIGHT TRANSPORT AIRCRAFT

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ABSTRACT

In small commuter category aircraft, the control surfaces viz., Aileron, Elevator and Rudder are operated using mechanical flight control system consisting of elements like push-pull rods, cables, pulleys, quadrants, etc. There is a considerable reduction in stiffness of the flight control circuit due to the stretch in these elements, resulting in control surface deflections lesser than desirable values. This paper focuses on the application of Finite Element Analysis (FEA) in design, analysis and optimization of flight control circuits of a typical Light Transport Aircraft (LTA) using FEA software Altair Hypermesh and MSC Nastran. Various Finite Element Modelling techniques have been extensively used in this study to simulate the control circuit mechanisms that exist on the aircraft. The stiffness and stretch values obtained from the analysis are in good agreement with the experimental results obtained from ground tests conducted on the LTA. The methodology proposed in this paper minimizes the time and effort in designing and implementing an optimum control circuit, and also eliminates the need for extensive ground testing.

Keywords: aircraft, flight controls, finite element, stiffness, control Stretch.

INTRODUCTION

Flight Control System (FCS) is a device that pilots use to control the aircraft's direction and attitude. It is broadly classified as primary and secondary systems. The aileron, elevator and rudder constitute the primary control system and are required for controlling an aircraft during flight as shown in Figure-1 [1].

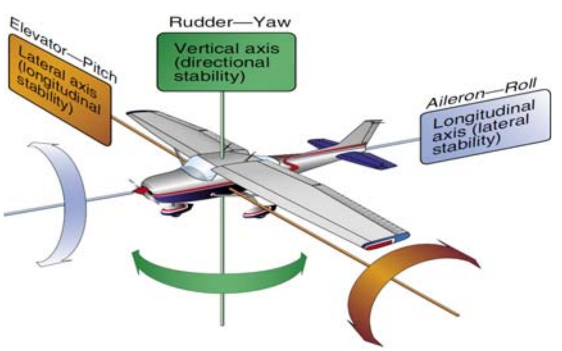

Figure-1. Airplane controls, movement, axes of rotation and type of stability [1].

Flaps, leading edge devices, spoilers, and trim systems constitute the secondary control system and improve the performance characteristics of the airplane or relieve the pilot of excessive control forces. The architecture of the flight control system, essential for all flight operations, has significantly changed over the years. In small aircraft, the force required to operate the control surfaces is small enough, allowing the use of simple mechanism consisting of push pull rods and cables. In large aircraft, the forces required to operate the control surfaces are large enough to warrant introduction of powered controls, thus relieving the pilot efforts. Based on this, the operating mechanism of flight control systems can be broadly categorized into the following:

i. Fully mechanical control comprising of push-pull rods, cables, pulleys, quadrants, etc on small commuter airplanes as shown in Figure-2 [2].
ii. Powered or servo-assisted control on large commuter airplanes as shown in Figure-3 [2].

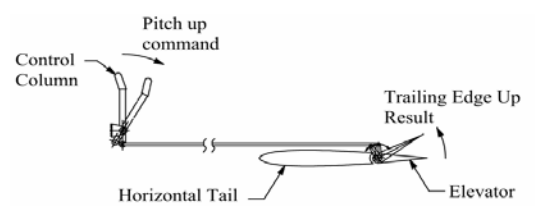

Figure-2. Schematic of a fully mechanical control [2].

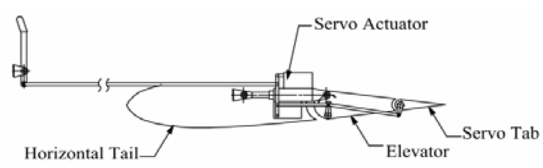

Figure-3. Schematic of a powered or servo-assisted control [2].

In general, the flight control circuits are designed to have minimal stretch in the circuit, not exceeding 20%, as per aircraft standards [3]. Ground tests are carried out to confirm the stretch and stiffness values in the control circuit. Redesign of circuit is carried out, if necessary, to obtain acceptable results. The process is generally iterative in nature, and has both cost and time implications.

In this paper, a methodology demonstrating effective utilization of FEA is proposed to minimize the

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time and effort in design and implementation of an optimum control circuit in the early design stage, eliminating the need for extensive ground testing. Elevator Control circuit of a typical LTA has been chosen for the case study. Modeling and simulating the control circuit mechanisms on the aircraft is a challenging task. To begin with, a simple 1D Finite Element (FE) model is developed to optimize the control circuit leverages and to improve the stiffness of the control circuit without changing the overall gearing. This is followed by a detailed FE model to predict the stretch and stiffness values more accurately.

ELEVATOR FCS IN A TYPICAL LTA

In the LTA under consideration, the elevator control circuit mechanism is fully mechanical, consisting of combination of push pull rods and cables as shown in Figure-4. Cables are used mainly to have weight and space advantage, which are running from cockpit to rear fuselage. Pulleys/Quadrants are used to convert rotary motion to linear motion or vice versa. Series of push pull rods are used between the cable controls and the control surface. Bell-crank levers are used at regular intervals to reduce the length of push-pull rods for improving its buckling margins. These are also used to change the direction and leverage of the control circuit.

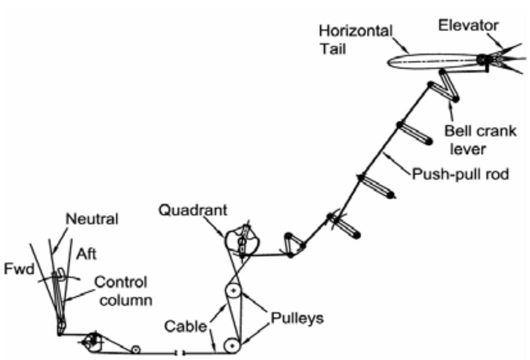


Figure-4. Schematic of LTA's Elevator FCS.

FINITE ELEMENT MODELLING

FEA software Altair Hypermesh [4] is used as pre and post processor, and MSC NASTRAN [5] is used as a solver. Basically two types of FE models have been used for simulating the elevator FCS of the LTA:

a) Simple 1D FE model
b) Detailed FE model

The simple 1D FE model shown in Figure-5 consists of CROD and RBE2 elements. CROD elements with appropriate cross section and material properties represent the cables, push-pull rods; and RBE2 elements represent the control mechanism of pulleys, quadrants, levers, etc. This FE model with appropriate boundary conditions has been used to obtain the optimum lever ratios and load distributions such that the stretch values are within acceptable limit.

With the lever ratios obtained from the 1D model, a detailed FE model has been developed using the 1D elements (CROD, CBAR) to represent the push-pull rods, cables, bolts, etc.; 2D elements (CQUAD4) to represent the levers, supporting brackets, control column, etc.; and 3D elements (CHEXA) to represent the quadrants, pulleys, levers, etc., with appropriate cross section and material as shown in Figure-6. To maintain the connectivity and to capture the geometry, CTRIA3 and CPENTA elements are used. In addition to this, rigid (REB2) and interpolation (RBE3) elements are used at appropriate locations.

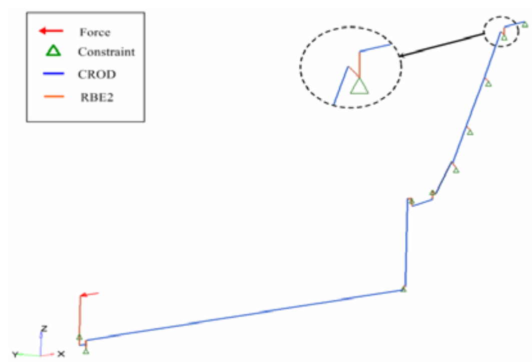
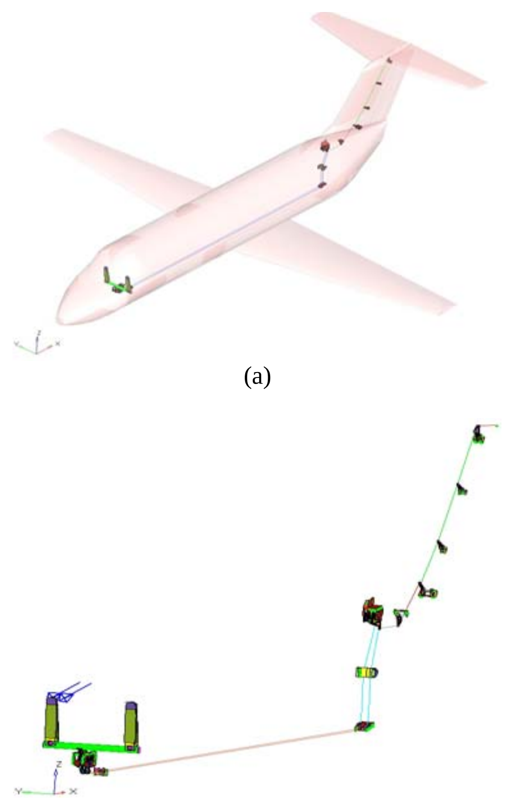


Figure-5. Simple 1D FE model created using CROD and RBE2 elements.



(a)

(b)

Figure-6. Detailed FE model of Elevator FCS- (a) FE model superimposed on LTA geometry, (b) FE model shown in isolation.

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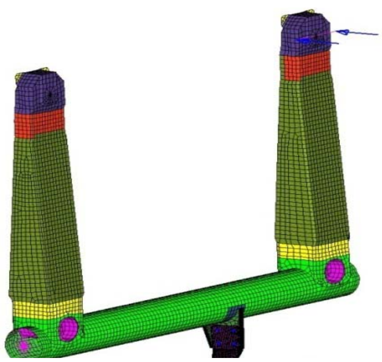
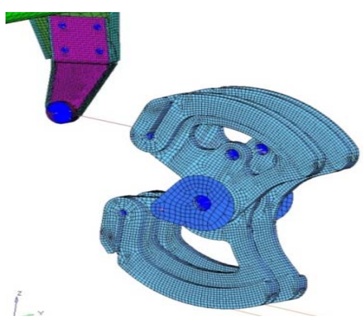
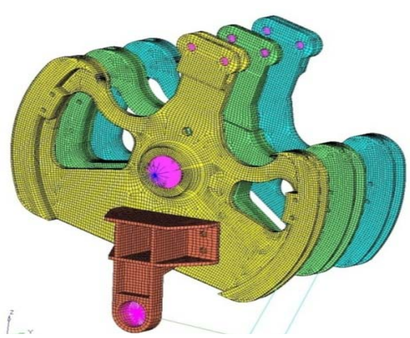
This FE model consists of all the components in the control circuit along with supporting structure that attaches these FCS components to the Fuselage and Empennage structure. Details of the FE model of various components are shown in Figure-7. Simulating boundary conditions to represent the control circuit mechanism as in the aircraft is quite a challenging task. The results are highly dependent on these boundary conditions; hence extensive care has been taken during the FE modelling to obtain the simulation as close to the realistic one. This was achieved by controlling the degrees of freedom (DOF) in CBAR and RBE3 elements.



(a)



(b)



(c)

Figure-7. Components in detail FE model- (a) Control column, (b) Front quadrant assembly, (c) Rear quadrant assembly.

ANALYSIS AND RESULTS

Linear static analysis was carried out for the pilot loads mentioned in FAR [6] using MSC Nastran SOL-101 [5]. Using 1D FE model, the leverages have been modified to improve the control circuit stiffness and to achieve optimum load distribution without altering the overall Gearing Ratio. By obtaining optimum load distribution on individual components, there is a good scope for optimizing the weight of the control circuit. The displacement plot of the simple 1D FE model of the elevator control circuit is shown in Figure-8.

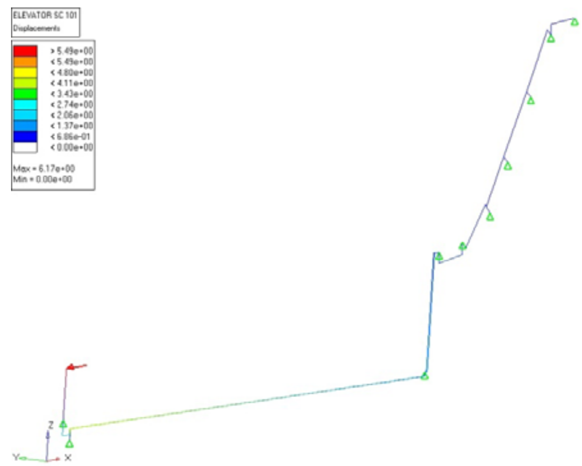


Figure-8. Displacement plot of FCS obtained using Simple 1D FE model.

The detailed FE model with the optimum leverages obtained from 1D FE model has been analyzed for loads mentioned earlier. The displacements plots for the same are shown in Figure-9 and Figure-10 which clearly indicates that the displacement values are higher compared to 1D FE model. This is mainly due to the detailed modelling of the control circuit elements and inclusion of the supporting structure.

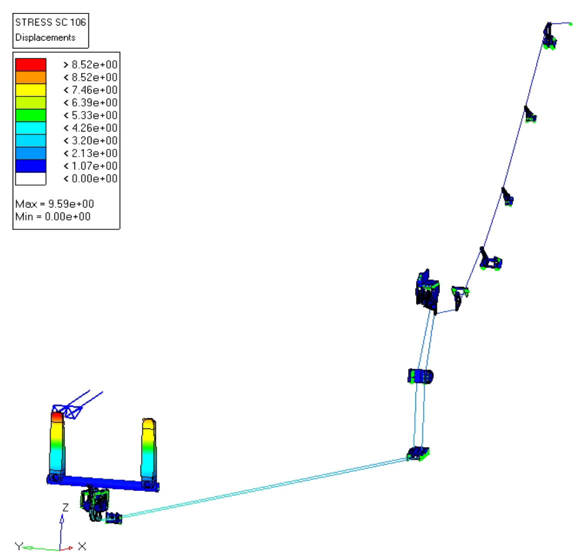


Figure-9. Displacement plot of FCS obtained using detailed FE model.

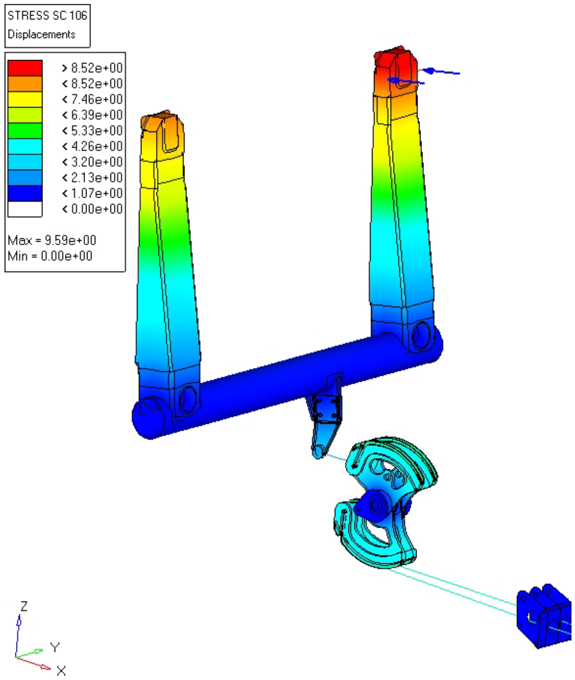


Figure-10. Displacement at control column obtained using detailed FE model.

Table-1 shows the displacement and stretch values obtained from Finite element analysis and the ground test conducted on the LTA. It shows that the values obtained from the detailed FE model is in good agreement with the ground test results. The small difference noticed may be due to airframe structural flexibility, which is not modelled in the present study.

Table-1. Displacement and Stretch values obtained from FEA and Ground Test.

	Displacement at control column (mm)	**Stretch in the circuit**
Simple 1D FE model	6.17	4.79%
Detailed FE model	9.59	7.45%
Ground test	10.2	7.92%

CONCLUSIONS

The present study demonstrates the application of FEA in design, analysis and optimization of flight control circuits of a typical LTA. To begin with, a simple 1D FE model is developed to optimize the control circuit leverages and to improve the stiffness of the control circuit without changing its overall gearing. Then, a detailed FE model with the optimum leverages obtained from the 1D FE model has been created and analyzed to predict the stretch and stiffness values more accurately. The displacement and stretch values obtained from this is in good agreement with the ground test results. The methodology proposed in this paper minimizes the time and effort required to design an optimum control circuit which eliminates the need for extensive ground testing.

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