DEVELOPMENT AND WIND TUNNEL EVALUATION OF AN SMA BASED TRIM TAB ACTUATOR FOR A CIVIL AIRCRAFT

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ABSTRACT

This paper presents about the development and wind tunnel evaluation of an SMA based smart trim tab for a typical 2 seater civil aircraft. SMA actuator was housed in the port side of the elevator for actuating the trim tab. Wind tunnel tests were conducted on a full scale Horizontal Tail model with Elevator and Trim Tab at free stream speeds of 25, 35 & 45 m/sec and also for a number of deflections of the elevator (30° up, 0° neutral & 25° down) and trim-tab 11° & 21° up and 15° & 31° down). To measure the hinge moment experienced by the trim-tab at various test conditions, two miniaturized balances were designed and fabricated. Gain scheduled proportional integral controller was developed to control the SMA actuated smart trim tab. It was confirmed during the tests that the trim-tab could be controlled at the desired position against the aerodynamic loads acting on it for the various test conditions.

Key Words: SMA actuator, PI controller, Trim-tab, Hinge moment, Wind tunnel test

1. INTRODUCTION

Trim tabs are small surfaces connected to the trailing edge of a larger control surface on a aircraft, used to control the trim of the controls, i.e. to counteract aero-dynamic forces and stabilize aircraft in a particular desired attitude without the need for the operator to constantly apply a control force. This is done by adjusting the angle of the tab relative to the larger surface. Changing the setting of a trim tab adjusts the neutral or resting position of a control surface (such as an elevator or rudder). As the desired position of a control surface changes (corresponding mainly to different speeds), an adjustable trim tab will allow the operator to reduce the manual force required to maintain that position to zero, if used correctly.

Trim tabs are used for small lifting up or bringing down the nose of the aircraft in cruise flight. It is also deployed in the direction opposite to the deployment of the larger control surface to which it is

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attached. Currently there are various types of trim tab actuation mechanisms available. They are usually hydraulically, pneumatically, electro-mechanically actuated. The most important problems associated with the various types of actuation systems are as follows

In hydraulic actuators the biggest disadvantage of the system is the problem of contamination of the entire system. Besides this it has problems associated with leakage, complexity and flammability of the hydraulic fluid. It has high maintenance cost and large pressure drops in the transmission line and in valves. In the case of pneumatic actuators, leakage poses a major problem. Here the system has to be large enough to develop the pressure compared to hydraulic actuator. Presently, the trend is towards electromechanical systems and the term "all electric" aircraft is commonly heard. But there is a serious disadvantage even with electromechanical system. During power failure the electromechanical systems gets jammed. It is very difficult to control an aircraft by the pilot with a jammed control surface since he has to apply a stick force opposing this.

One of the solutions to avoid mechanical jamming of control surface is by using active elements like SMAs as actuators. It completely eliminates the problem of jamming and is very clean, silent and has minimum number of moving parts. SMA based actuators not only possess high force to weight ratio, but also have other advantages such as

long fatigue life and high corrosion resistance. Therefore, these actuators are employed in numerous applications such as active helicopter rotor blade, adaptive airfoils, deployment of control surfaces and flap [1-10]. In the literature, different controllers have been developed to control the SMA actuators. This includes PD, PI, VSC, fuzzy logic, sliding mode [11-14], etc.

This paper presents the research work carried out to develop SMA based actuator mechanism to control the trim tab movement of a typical small size aircraft. In this particular case we have developed an actuator mechanism consisting of two antagonistically acting SMA wires for producing upward and downward deflection of the trim-tab. The necessary electronics and control software with gain scheduled proportional integral (GSPI) controller has been developed as a part of this exercise. The complete system has been tested against the aerodynamic load in the wind tunnel and the results have been presented here.

2. SMA MECHANISM

At Present the system existing on the aircraft in trim-tab consists of a linear servomotor and the associated electronics. The servomotor is housed inside the elevator and can be operated by electrically powering it. Once the trim-tab reaches the required angle the power to the servomotor is removed and the trim-tab gets held in that particular position. The current study aims to explore the possibility of replacing the servomotor based mechanism by an efficient SMA based mechanism. The Layout for placing SMA mechanism is shown in Figure 1.

SMA mechanism consists of two antagonistically acting SMA wires connected to a linear slider through a timer belt as shown in Figure 2. The slider is connected to one end of a connecting rod. The other end of the connecting rod is connected to the horn of the trim-tab. These antagonistically acting SMA wires deflect the trim-tab in upward or downward direction. SMA wires are connected to timer belt and pulleys so that no slippage occurs and even the slightest contraction of SMA wires produce corresponding deflection of trim-tab. Linear motion (LM) guide is incorporated so as to ensure perfectly linear movement of the slider moving on it. Connecting rod transfers the load and the movement generated by SMA to the trim tab. The two timer belt pulleys are anchored on to a C-shaped steel strip which is embedded in to the elevator so that the pulleys can rotate about their anchoring bolts.

3. INSTRUMENTATION AND CONTROL

In order to implement the closed loop system to control the trim tab actuation the required hardware and software are developed. The hardware used in this system are data acquisition module (USB 6009), DC-DC converters and linear potentiometer along with note book computer. Data acquisition (DAQ) module is used to interface the field signals with the computer to implement the closed loop control system. The programming signals are given through DAQ to the DC-DC converter which delivers the power to the SMA wires. The DC-DC converter accepts the programming voltage between 0-5V and delivers 0-6A. Here two DC-DC converters were used to energize the antagonistic pair of the SMA wires. The position sensor (linear potentiometer) was used to measure the movement of the trim-tab. The measured values were acquired through DAQ and fed to the computer for continuous control action. Rotary potentiometer was used to set the reference for Hansa Trim tab. The operating voltage is 5V. When voltage between 2V to 3V is supplied Trim tab stays in neutral position, when voltage is supplied between 3V to 5V Trim tab gets deflected upward which corresponds to 0° to 21° also linear potentiometer shows a displacement of 0mm to 12mm, and when voltage is supplied between 2V to 0V the Trim tab gets deflected downward which corresponds to 0° to -31° and linear potentiometer will show a displacement of 0mm to -14mm. The displacement is converted into angle using the calibration factor. The block diagram for trim tab actuation and control is as shown in Figure 3. Experimental open loop tests were conducted for obtaining the transfer function model. In the open loop testing the response was acquired for the step input. Transfer function for top and bottom actuation are 0.1218/(s+0.23) and 0.105/(s+0.13) respectively. Since it is a first order transfer function and to avoid overshoot and steady state error the Gain scheduled proportional integral (GSPI) controller is used to control the actuation of Trim tab. GSPI controller is a type of classical PI controller where the controller gains and parameters are varied depending on the system (Trim tab) response. The controller parameters viz; proportional and integral gains Kp and Ki are found for the obtained transfer functions. The closed loop controller based on Gain scheduled PI controller decides the current flow in SMA wires and enables the accurate positioning of the Trim tab.

4. WIND TUNNEL TESTING

The wind tunnel test was carried out on the assembly of full scale horizontal tail-elevator-trim tab

in the open circuit wind tunnel as shown in Figure 4. The tests were carried out at three free-stream speeds i.e. at 25m /s, 35m /s and 45m /s. Apart from its neutral position, tests were also carried out maintaining the upward deflection of elevator at 30° and the downward deflection at 25°; and the trim tab deflection set at 21° (up deflection) and 31° (down deflection).

4.1 Hinge Moments

Hinge moments were measured to estimate the moment generated by the trim-tab about its piano-hinge attached to the elevator. For this purpose an additional trim tab was fabricated and the cut out for housing this was made on the star board side of the elevator. This trim tab was fixed to the elevator by means of the two miniaturized balances designed for measuring the hinge moment. These balances were strain gauged with full bridge configuration and used to measure the trim-tab hinge moment on the star board trim-tab.

4.1.1 Design of Hinge Moment Balance

The balance acts as a link between the trim-tab and elevator for transferring the load/moment from trim-tab to the elevator as shown in Figure 5. Assuming the maximum wind load on the tab as 2kg as indicated in Figure 6, the balance element is sized. Average chord length of trim-tab= 80mm. Assuming a triangular distribution for the aerodynamic load on the trim-tab with a magnitude of 2kg, the hinge moment generated is 80*(2/3)*2=110kg-mm.

4.1.2 Calibration of Balance

The two hinge moment balances were strain gauged individually with full bridge configuration as shown in Figure 7. These were then calibrated for measuring hinge moments. The calibration was done by adding dead weights at a known distance of 100mm from the centre of the strain gauges for both forward and reverse directions. The moment induced was then plotted against the output voltage of the balance circuit. Typical calibration graph of balance 1 in forward direction is as shown in Figure 8. The calibration factor was obtained from the slope of the graph.

The trim-tabs on the port and starboard side were of same size and fixed symmetrically with respect to aircraft center line. Hence, the loads and moments seen by both the trim-tabs for independent

and identical deflection settings are same for zero degree yaw setting of the model. Maximum hinge moment (166.725 Kg-mm) is measured for neutral elevator with star board trim tab at 21° up and (port side SMA trim tab is kept neutral) at free-stream speed of 45m/s. The minimum hinge moment (-0.8753 Kg-mm) is generated for up-elevator with star board trim tab at 15° down (port side SMA trim tab neutral) at free-stream speed of 35m/s. The variation of hinge moment v/s trim tab deflection for different elevator deflections are shown in Figures 9-11.

5. RESULTS AND DISCUSSION

The wind tunnel tests were carried out on a full scale model of Horizontal tail, elevator and Trim-tab combination at test section speeds of 25m/s, 35m/s and 45m/s. Tests were done for three deflections (up, neutral and down) of elevator also the starboard side trim-tab was always kept in neutral position and port side trim-tab was actuated using SMA for different angles. The results for different configurations are given below:

Configuration-1: During this test the elevator was kept in neutral position and port side trim-tab was actuated for different angles like 12°up, 20°up, 15°down & 30°down for a wind speed of 25m/s. The result obtained is shown in Figure 12.

Configuration-2: During this test the elevator was kept in top position and port side trim-tab was actuated for different angles like 15°, 30° for wind speeds of 25m/s and 35m/s. The result obtained is shown in Figure 13.

Configuration-3: During the test the elevator was kept in bottom position and port side trim-tab was actuated for different angles like -12°,-21° for a wind speed of 45m/s. The result obtained is shown in Figure 14.

It can be seen from the Figure 12-14; the required angles are achieved using the SMA and the control accuracy was obtained at all angles.

6. CONCLUSION

This paper presents about the development and wind tunnel evaluation of an SMA based smart trim tab. The SMA based mechanism is designed to obtained the required angle of actuation. A GSPI controller was developed for controlling the SMA, with this input the Wind tunnel test was carried out to test whether the system is able to withstand the wind load. . The controller which was developed was able

to give the satisfactory performance in terms of angle and rate of deployment of trim tab as well as accurate positioning of the trim tab.

ACKNOWLEDGEMENT

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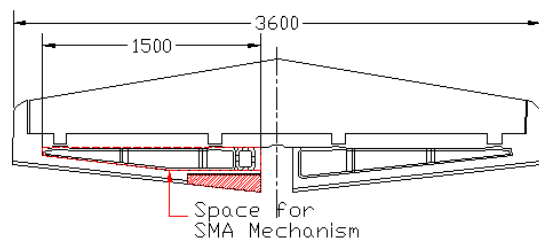
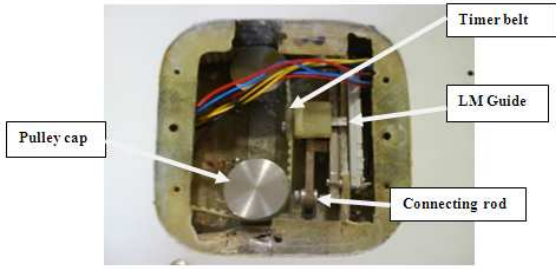**Figure 1. Layout for placing SMA mechanism**
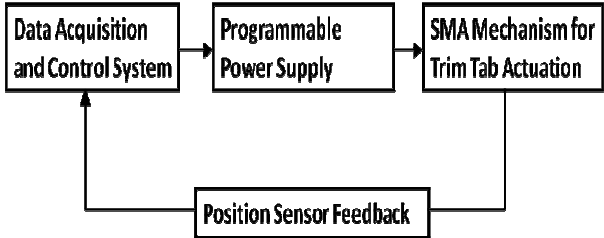
Figure 2. Pictorial view of the mechanism

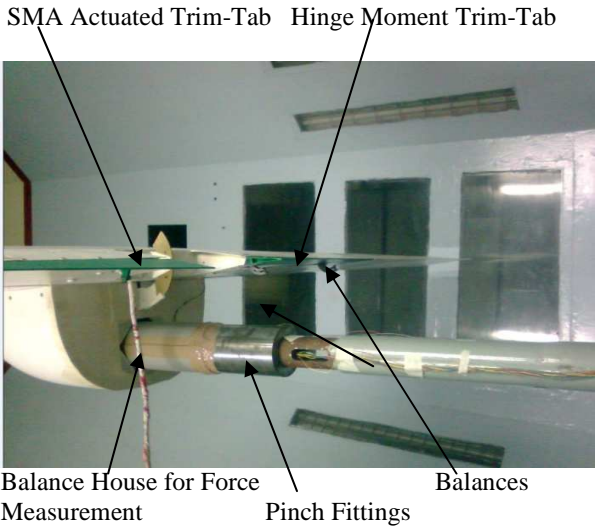**Figure 3. Block diagram for the trim tab actuation and control**

SMA Actuated Trim-Tab   Hinge Moment Trim-Tab

Balance House for Force   Balances
Measurement   Pinch Fittings

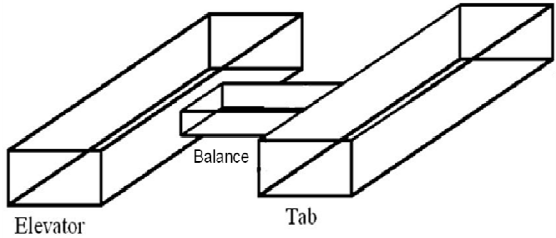**Figure 4. Pictorial view of wind tunnel test setup**
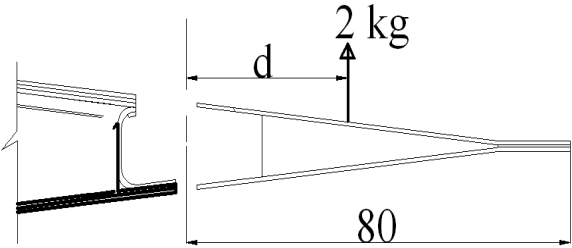

Figure 5. Schematic of positioning of balance

Figure 6. Design loads of balance
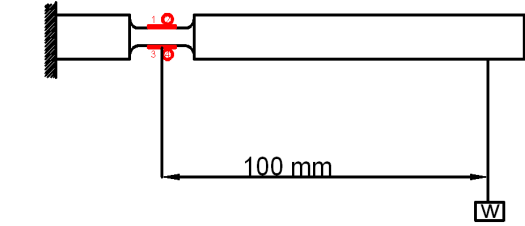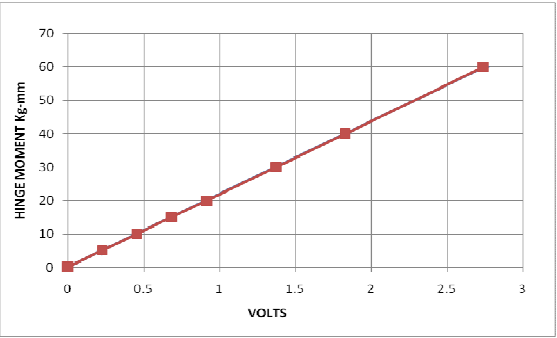

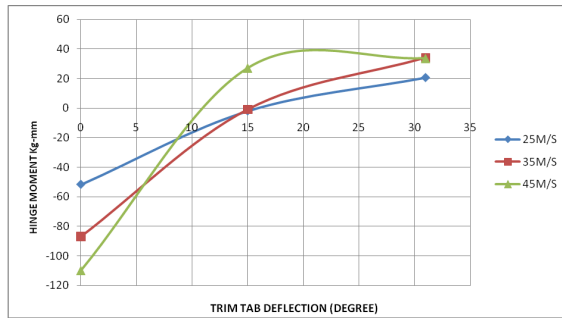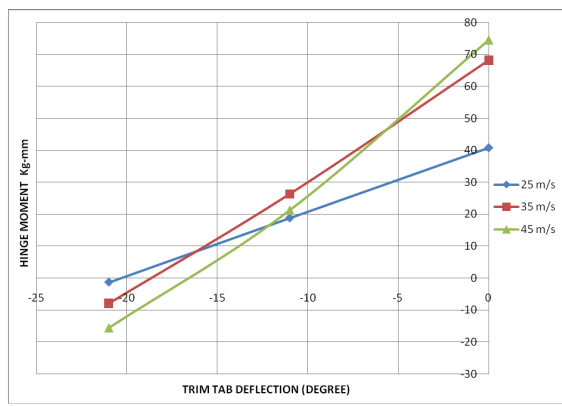**Figure 7. Schematic representation of calibration**

Figure 8. Calibration plot of balance
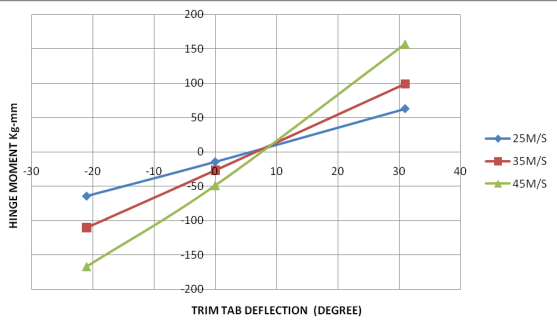
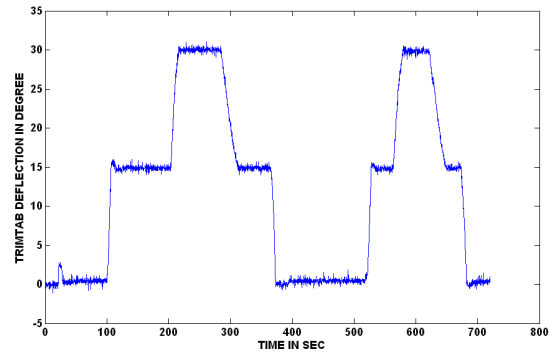**Figure 9. Hinge moments for elevator neutral**

Figure 10. Hinge moments for elevator up

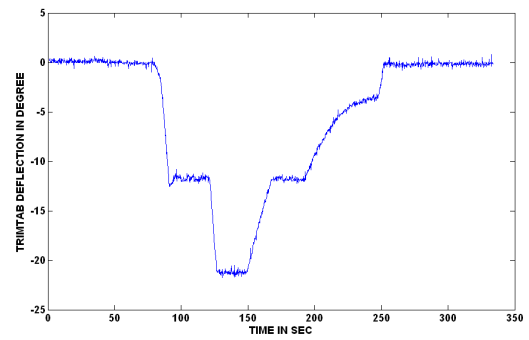**Figure 13. Deflection profile of SMA actuated trim tab for elevator top position at 25m/s & 35m/s**

Figure 11. Hinge moments for elevator down

Figure 14. Deflection profile of SMA actuated trim tab for elevator bottom position at 45m/s

Figure 12. Deflection profile of SMA actuated trim tab for elevator neutral position at 25m/s