TAIL STRIKE AVOIDANCE SYSTEM (TSAS)

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ABSTRACT

A tail strike is a common incident where the empennage of the aircraft collides with the ground while either during a takeoff or landing. In this advanced era there are different systems for different aircrafts to prevent it but none of them is a definitive one which could actually prevent this to a great extent assuredly. This paper highlights the paramount importance of this new concept referred to as Tail Strike Avoidance System (TSAS) which is a smartly engineered mechanical system that almost eliminates the friction due to a tail scrape as opposed to the tail skid device employed under the empennage of the aircraft. The net retardation imposed on the aircraft during the takeoff roll for a Boeing 737-800 was found to be 0.1 m/s² under typical takeoff settings whereas the acceleration due to the maximum thrust force is 3 m/s² [1] for the maximum takeoff weight.

Nomenclature

AOA	Angle Of Attack
VMU	Velocity Minimum Unstick
Ff	Friction force
g	Gravity (9.81 m/s²)
a	acceleration
d	Deceleration
s	Displacement
ρ	Density
µ	Coefficient of friction
v	Velocity

α Final velocity

β Initial velocity

m Aircraft mass

R Reaction force

A Area

T Thrust force

F.S Factor of safety

Cl Coefficient of lift

C.g Center of gravity

C.p Center of pressure

MAC Mean Aerodynamic chord

MTOW Maximum Takeoff Weight

APU Auxiliary power unit

3.3 Introduction

Under serious circumstances like wind shear and heavy turbulence via crosswinds or pilot error, a tail strike is likely to occur. For the ill-fated Japan Airlines Flight 123 and China Airlines Flight 611 it was a disaster resulting in the death of 505 and 255 people onboard respectively. These few cases of severe tail strikes occurred majorly based on the pilot error, Boeing 747-200 at Brussels airport on 27th Oct 2008, Aero Mexico at Madrid airport Boeing 767-200 16th April 2013, Emirates Flight EK 407, A340-400, 20th March 2009, Qantas Airways, flight QF8421, Boeing 737-838, 1 August 2014, Qatar Airways Flight 778, Boeing 777, 15th September 2015, Sunwings Boeing 737, 21st July 2017. Aircraft manufacturers like Boeing and Airbus have installed tail skids under the empennage of their aircrafts that contains a crushable cartridge which shows the magnitude of tail strike by the depth to which it's compressed. After being compressed it exposes the tail skid assembly to the ground. . Hence the need to tackle this physical threat of a tail strike, a sturdy device below the empennage of the aircraft is suggested that neither imposes any friction that will delay in the takeoff nor will it expose the tail surface directly to the ground. The paper compares the friction of a TSAS and a tail skid device and the retardation imposed on the aircraft through the ground contact of a tail skid device. Few case scenarios are considered to show the effect of deceleration by the transition of center of gravity and velocity near to VMU.

2.0 Dynamics

2.1 Forces during the take-off run

Approaching VMU (The airspeed at which the aircraft can lift off at a high angle of attack) for the case when C.g is at C.p or at 25% of MAC [2] the net pitching moment about the main landing gear will be largely due to the Elevator as the weight of the aircraft will be supported by the lift force. The downward lift force generated by the elevator close to VMU for the elevator deflection of 20 degrees which is maximum limit for 737 [3]. For the typical flaps & slats settings with MTOW [1] of a 737-800 the VMU attained is around 82.3 m/s for an area of 124.5 m² [2] for both wings from the equation of lift for a typical lift coefficient at 11 degrees of AOA when tail skid contacts the ground [4]. The maximum elevator downwards force obtained at a 20 degree deflection at 97.2 % VMU obtained is 2.62 Tons for net elevator area about 6.55 m².

$$L = 1/2\ Cl\ \rho\ A\ v^2 \quad \cdots (1)$$

2.2 Moments analysis

After constructing a scaled model of 737-800 [5] the exact distances were determined for the analysis of moments. In order to find the force at the tail skid the pitching moment about the main landing gear is calculated as 0.235 Tons. To determine the net reaction imposed on the tail skid the analysis about the main landing gear through the difference of weight and lift yields 2.385 Tons at the elevator by taking out 0.235 Tons from 2.62. Finally the reaction force determined at the tail skid by the analysis of moments is 1.24 times the elevator force which comes out to be 2.957 Tons.

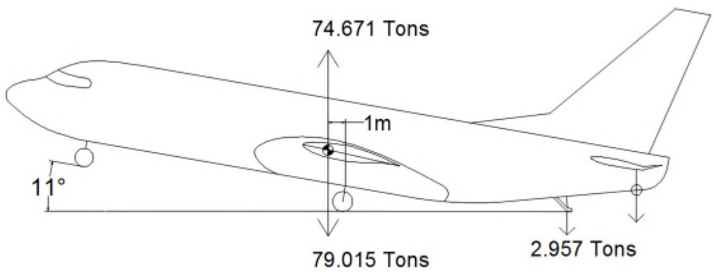

Fig 1. Lift force and tail skid force reaction due to elevator in terms of tons

2.3 C.g limits effect

Forward limit for a 737-800 is 12% of MAC and aft limit is 31% [6] hence for MTOW, C.g at 12% of MAC will yield 9.615 Tons of upwards force at the elevator hence taking out 2.62 Tons of downwards force developed by the elevator hence still in order to rotate the aircraft a net 7.015 Tons will be required to overcome by increasing the airspeed beyond 82.3 m/s to begin lift off. For the case when C.g is at 31% of MAC it will result in a force of 3.3 Tons downwards at the elevator and hence in order to tackle this a negative pitching moment or rotation input will be required to control the AOA as otherwise it will yield a net of 5.92 Tons of force below the elevator which when magnified yields a net of 7.34 Tons at the tail skid.

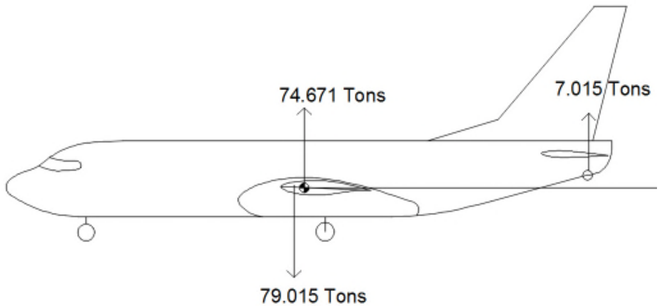

Fig 2. C.g at 12 % of MAC, 7.015 Tons required by the elevator to rotate the aircraft at 97.2 % VMU

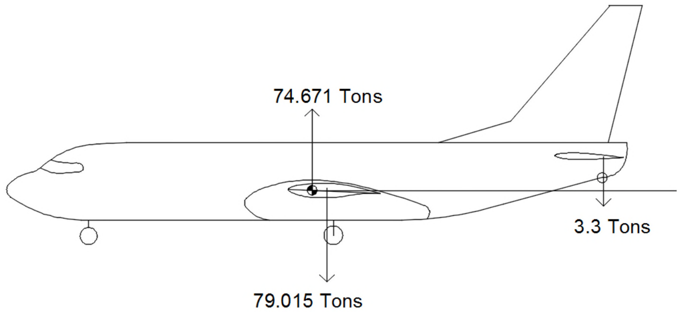

Fig 3. C.g at 31 % of MAC 3.3 Tons required by the elevator to prevent the self-rotation of the aircraft at 97.2 % VMU

3.0 Friction

3.1 Material analysis

Friction coefficient between a steel tail skid and tarmac goes up to a maximum of 0.5 [7, 8] under normal temperature conditions, however rolling friction coefficient between a typical aircraft tire and tarmac ranges from 0.001-0.04 [9, 10, 11]

3.2 Retardation

The deceleration imposed on the aircraft by the tail skid for an intense rotation can be estimated via the following equations.

$$Ff = \mu R \cdots (2)$$

$$d = \frac{(T - Ff)}{m} \cdots (3)$$

Net force of friction comes out to be 1.48 Tons from 2.95 Tons downwards reaction whereas the net thrust force is a maximum of 24.8 Tons [1]. The resultant deceleration is around 0.1 m/s^2 for MTOW with C.g at 25% of MAC. However for flex temp of even 98% thrust for MTOW the deceleration is 0.17 m/s^2. The deceleration by C.g situated at 31% of MAC which is the maximum aft limit results in 0.38 m/s^2 with an intense rotation input of pull up.

3.3 Prolonged takeoff run

In order to achieve a difference 1 m/s to attain VMU, from 81.3 m/s to 82.3 m/s it requires around 1 meters of runaway length with full thrust while tail skid contacts the ground and net acceleration is 2.9 m/s^2.

$$S = (\alpha^2 - \beta^2)/2a \cdots (4)$$

With the acceleration of 2.62 m/s^2 and C.g situated at 31% of MAC under intense rotation input around 2 meters of runaway length is required to achieve a difference 1 m/s to attain VMU.

4.0 Potential threats by a tail strike

4.1 Flex Temp

It is a technique employed to reduce the wear & tear imparted on the engines at full thrust hence to prolong the life of engines pilots are instructed to take the advantage of the distance by a longer runway length for takeoff at lower engine thrust. Due to this any mistake in data entry may result in a catastrophe as this may result in an intense rotation performed by the pilot that could cause retardation due to tail scrape. Emirates Flight EK 407 was a miracle where if the pilots hadn’t pushed the throttle a second earlier to maximum thrust which is TOGA detent it would have rather been a disaster. Hence with flex temp applied acceleration of aircraft is already low and a tail scrape can cause a considerable retardation in this case.

4.2 One engine out

For the situation when one engine dies either due to a bird strike or due to any other cause the deceleration imposed on the aircraft through the tail skid will remain the same yet the thrust will be halved hence more runway length and time will be required to attain VMU to liftoff. The distance required for takeoff becomes 4 meters of runaway length to achieve a difference 1 m/s to attain with full thrust of the remaining engine for a deceleration of 0.1 m/s^2

4.3 Latching effect

The cracks that form on runways over the period of time can prove to be an instigating factor for the case when even a momentary tail strike occurs but right in or near the crack. This can result in the tail skid shoe especially of a Boeing 777 latching in the crack and resulting in the rapture of the runaway portion surrounding the crack and inflicting a damage to the tail skid assembly.

5.0 TSAS

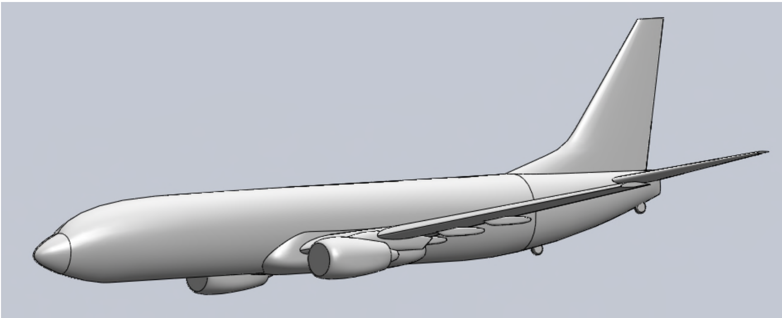

Fig 4. 3D model constructed with a TSAS device that incorporates two wheels shown below the tail of a 737-800.

5.1 Structural strength

TSAS is a simple device to be installed under the tail of the aircraft where a tail skid lies however it also has a second wheel to prevent the further damage to the tail right after liftoff for a low ascent rate and higher AOA that still causes a tail scrape that can be harmful to the APU which is crucial for inflight engine startup and backup power. Hence applying a factor of safety of 1.5 and 4g [12] dynamic factor for the case of sudden fall or abnormal decent due to weather or incorrect approach in the flare phase while landing the compressive strength of the TSAS needs to be a minimum of 18 Tons for a net elevator down force of 2.385 Tons.

6.0 Psychological perspective

EICAS warns the pilots of a tail strike but when the situation is intensely pressurizing by any error which is likely to be a pilot error which can be incorrect approximation of any of the factors taken into account prior to takeoff in order to ensure proper flex temp namely wind speed, ambient temperature, aircraft weight and the runway length. The matter of so many lives should not be left on the part of training & heuristics when it can be controlled assuredly, as safety comes by eliminating the potential causes, hence a TSAS device can offer no friction or any damage to the tail.

7.0 Conclusion

As the tail skid device causes considerable amount of retardation, needs a cartridge replacement and sometimes does not even warns the pilots [13], it also wears the runway and inflicts damage to the aircraft which can in some cases result in aircraft being written off as the damage goes beyond economic repair. For Boeing 747-200 at Brussels airport on 27th Oct 2008 or Aero Mexico at Madrid airport Boeing 767-200 16th April 2013 a tail scrape made both the aircrafts to be written off. Hence a TSAS device eliminates any such cause and can easily tackle a tail strike by either due to pilot error or due to weather conditions. The maximum retardation an aircraft can encounter by a tail skid can go up to 0.38 m/s^2 without flex temp applied hence with flex temp it can go even higher than 0.38 m/s^2 and for the common case with flex temp applied it can go up to 0.17 m/s^2. Since there are many case scenarios that can drastically increase the magnitude of deceleration for instance when a pilot underestimates the takeoff weight for flex temp or miss calculates the center of gravity that results in over rotation, hence a TSAS device with wheels in it offers negligible friction while rolling and its necessity is eminent.

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