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Mathematical Modelling of a Technique to Shorten of Landing Distance of Aircraft

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***Abstract*:There are multiple aircrafts which are unable to land in naval carriers or on geographical disadvantageous terrains due to high landing distance and unable to control the aircrafts speed. Till date only, disc brakes, certain aerodynamic braking systems like elevators, spoilers and rudders are employed by certain aircrafts to overcome the problem. In this paper, a new technology has been crafted for aircraft braking system in order to shorten landing distance for naval carriers and geographically disadvantageous terrains. Upon introducing this method, maintenance cost will reduce drastically as because wearing of the landing gear and tyre s will reduce as of before. Further the high energy required to deflect a rudder in case of ice landing will reduce as split rudders can be entwined for this purpose.**

I. INTRODUCTION

A brake is a device for slowing or stopping the motion of a machine or any moving vehicle. Aircraft brakes are usually hydraulically or pneumatically operated. A typical aircraft braking system uses links and cables that port some of the aircraft hydraulic pressure to the brakes after going through a valve that meters the amount of pressure. Aircraft disc brakes present in the landing gear are used for the purpose of braking during touchdown. Aerodynamic control surfaces also work as aircraft brakes by increasing drag; The naval-version aircraft requires very short length runways. And for this purpose various mechanical devices such as arrestor wires are being used which causes wear and tear of the landing gear mechanisms. Also for ice landing runways, usually rudder deflections are used which are mainly used by heavy weight aircrafts. But light weight and fighter aircrafts, cannot land on those surfaces.

In this technique, we will be involving the use of spoilers, drogue parachutes and rudder for the purpose of generating higher amount of drag. Drogue parachute is a mechanical system used to slow down a very fast moving vehicle from a very high speed to a relatively lower speed, It is used with some other modes of braking for greater stability & control and smaller landing distance. It is also referred to as Drag parachutes or brake parachutes as it is used to reduced the landing/braking distance by increasing the drag forces an an aerospace vehicle.

Spoilers are flat sheets or plates located on the top of the wing in order to reduce lift which are also termed as lift damper. They have precisely 3 main functions:

- Provide extra braking force during landing
- Ascending at lower altitudes without attaining any extra speed.
- Provide a medium of auxiliary device for roll control.
- These surfaces can never be used at high subsonic speeds as because they reduce lift generation. The rudder operates on the principle of changing the effective shape of the airfoil of the vertical stabilizer. When the deflection is in the rear direction then lift is created in the opposite direction creating higher amount of drag. 2-sectioned symmetrical split rudder is considered as a high lift device when it is deflected at an angle ranging from 0-45 degrees which is used for producing higher drag.
- Thrust reversers are mechanical devices used for the purpose of aircraft braking in which the direction of thrust produced is simply directed in the forward direction instead of backward. For jet aircrafts, thrust reversal is done by jet blast to fluid flow forward. Reverse thrust is put to action only after touchdown for higher deceleration rate in the landing roll due to residual aerodynamic lift present in the landing gear.

II. RELATED WORK

Many researchers are researching in this topic and have worked on different techniques to obtain various results like Bazuhair M. [3] had developed a technique on reducing landing run distance by using split elevator and 2 sectioned symmetrical rudder. [12] had developed a method of calculating landing distance upon addition of different thrust reversing systems taking in consideration of fail-safe technology. [13] had developed a complete design methodology for designing a spoiler taking the wing as it's reference.

III. PROBLEM FORMULATION AND GENERAL SOLUTION

The initial landing distance calculations are taken into consideration. The runway taken into consideration is the standard ICAO convention i.e. Asphalt runways, which are mainly used in aircraft carriers. Firstly, the existing spoiler design is re-calculated for increasing drag.

A. SPOILER CALCULATION METHODOLOGY:

Size- 10-15% chord length
Position- ahead of flaps
Purpose- (of landing) close to fuselage central line

$$\sum F = \frac{md}{dt(v)} = T - D - Fo - Fa - Ff = ma \quad (1)$$

$$W = WL = mg \quad (2)$$

$$L + N = W \quad (3)$$

$-D - Ff - FB = ma$ (4)
$Ff = \mu GN = \mu G(W - L)$ (5)
$LL = Lwf$ (6)
$D = ½ \text{ x } \rho \text{ x } v2 \text{ x } Sref \text{ x } CDL$ (7)
$CDoL = CDo + CDoLG + CDoHLD\_L$ (8)
$CDS = 1.9\sin(\delta s)Ss/Sref(2)$ (9)
$Ss = bscs(3)$ (10)
$\Delta CLs = Clc(bs/b)$ (11)
$FB = k1\mu BwL$ (12)
$SG = \int mvdv/(D + \mu(W - L) + FB)$ (13)
$VL = k2VS$ (14)
$SG = m/(\rho S(CDLG - CLL))\ln(1 + \rho S(CDL\mu GCDL)VL2/(2mg(\mu G + k1\mu G))$ (15)

B. REVERSED THRUST CALCULATION METHODOLOGY:

Now in case of reversed thrust, the following methodology has been chosen:

$Mtrue = (5\rho 0/\rho(1 + 0.2(VL/661.5)2)3.5 - 1) + 1)0.286) - 1)0.5$

$T0, M = T0 - \lambda Mtrue$

$Th, M = T0, M(\rho o/\rho)m$

$Trev' = 0.1 \text{ x } Th, m$

Total Reversed Thrust $=$ nx Trev' (16)

(n=no. of engines present)

C. SPLIT RUDDER CALCUALTION METHODOLOGY:

Only after calculating reversed thrust, we could calculate the split rudder drag value. And for that the following methodology was used:

We know that for an unsteady aircraft has the following equations of motion based on the 3-dimensional axis:

$mV^{\cdot} = \sum Fx.b$

$\sum Fy, b = \sum Fz, b = \sum MRx = \sum MRy = \sum MRz = 0$

$LLR = \int \int_0^{Vl} vdv/(mg(P/mlan \text{ x } g - fred - \rho Av2(Cx\alpha - fred \text{ x } Cy\alpha)$ (17)

$CD = Cx0 + KCy\alpha 2$ (18)

D. DROGUE PARACHUTE CALCULAION METHODOLOGY:

In case of drogue parachute, an existing parachute was considered and the details of the same was chosen from their technical specifications. After that, the following methodology was used for the purpose for calculating the net drag coefficient.

$Wd = 0.12(CDA)drogue + (0.28 \text{ x } 10 - 3)drogue \text{ x } q\infty(CDA)3/2$ (19)

Finally all the drag coefficients were summed up and the resultant drag was formulated.

Now, we know that more the coefficient of drag lesser will be the landing distance. Adopting this formula, the net landing distance was calculated.

IV. CASE STUDY BASED SOLUTION

The aircraft considered is F/A-18 E/F (Naval Version) for the purpose of validating the above equations. For spoiler, considered area, span and chord length followed by the spoiler drag coefficient were calculated from the equations (8),(9),(10),(11) which values stand out to be:

S_S=8.810m^2

b_S=6.81 m

C_S=1.2936 m

C_{DS}=0.1523

And the landing distance turned out to be:896.848 m.

Table 1 and figure 1 shows the analysis and the net landing distance upon addition of spoilers:

TABLE 1:Spoiler Vs Conventional Braking Procedures.

Brake Type	Drag Coefficient	Landing Velocity	Stopping Distance
Aircraft brake	0.087	91.892 m/sec	1570 m
Spoiler+ Brake	0.1523	91.892 m/sec	896.848 m

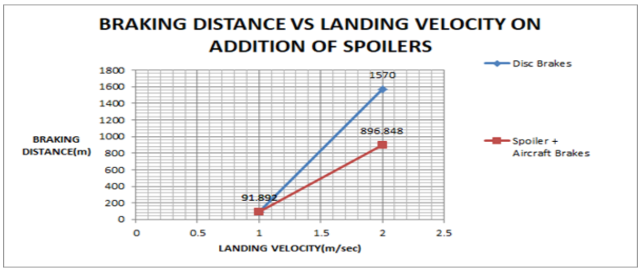

FIGURE 1:Braking Distance Vs Landing Velocity on Addition of Spoilers

In case of thrust reversers, only the net reversed thrust was calculated by the equation (16) ,which turned out to be: T_{rev}=14096.27 N

After calculating the net reversed thrust, the split rudder airfoil was chosen which is NACA 66-206ii and then the value of drag coefficient of rudder was formulated using the formula (17) :

C_D=0.068578. Upon addition of the split rudder the landing distance shortened which was calculated by the formula :L_R=661.3297 m.

Table 2 and figure 2 shows the analysis and the net landing distance upon addition of 2 sectioned rudder:

TABLE 2:Symmetrical rudder deflection Vs conventional braking procedure

Brake type	Drag coefficient	Landing velocity(m/sec)	Braking distance(m)
Aircraft disc Brakes	0.087	91.892	1570
Aircraft Brakes + 2 sectioned Rudder	0.155578	91.892	661.3297

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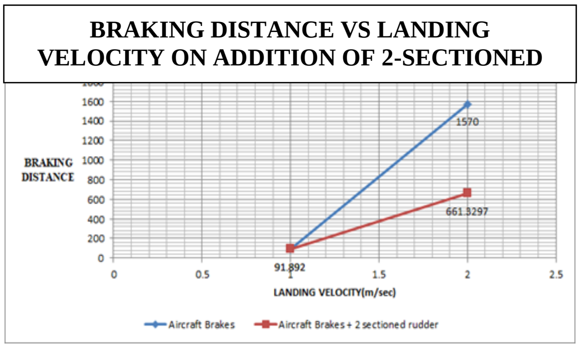

FIGURE 2: Braking Distance Vs Landing Velocity on addition of 2-sectioned rudder

Finally in case of drogue parachute, the parachute chosen had the following technical specifications:

- Shape: Ring Slot
- Radius:4.8 m
- No. of Gores: 20
- Panel Materials: Nylon Cloth PlA-C-7350, Type 1 2.25oz and Type II 3.5 oz
- No. of suspension lines:20
- Suspension line material: Nylon webbing, PlA- W- 5625, 102 kg
- Diameter: 36"
- Shape:Cone/Vane
- Pilot Chute
- Canopy Material:Nylon cloth , MIL-C-8021,Type I 4.75oz
- Vane Material: Nylon cloth, PIA-C-7350, Type I 2.25oz

Considering this specifications the drag coefficient was calculated by equation (19) along with the the landing distance was calculated.

Table 3 and figure 3 shows the analysis and the net landing distance upon addition of drogue parachutes:

TABLE 3:Drogue Parachute Vs Conventional Braking procedure.

Brake type	Drag coefficient	Landing velocity(m/sec)	Braking distance
Aircraft disc Brakes	0.087	91.892	1570 m
Brakes + Parachutes	0.42926	108.5994	318.19876 m

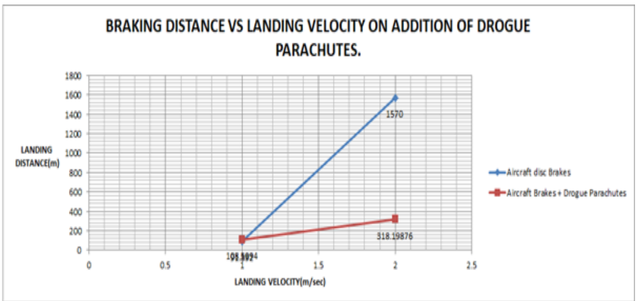

FIGURE 3: Braking Distance Vs Landing velocity on addition of drogue parachute

V. FINAL RESULT ANALYSIS

Table 4 and figure 4 shows the analysis and the net landing distance upon addition of spoilers, drogue parachutes, 2 sectioned rudder on the conventional aircraft brakes

Brake type	Drag coefficient	Landing velocity(m/s)	Braking distance(m)
Aircraft disc Brakes+spoiler+2 sectioned rudder + Drogue parachutes	0.56334	91.892	242.46458

TABLE 4: Final Result

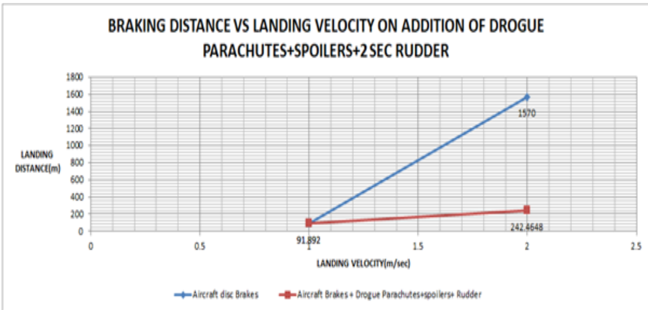

FIGURE 4: Braking Distance Vs Landing Velocity on addition of Drogue Parachutes+ Spoilers+ 2 sectioned rudder

VI. CONCLUSION

Hence, we summarize the various results obtained by us.

- We incorporated various techniques of braking and combined them on a particular aircraft (Case Considered F/A-18 E/F) in order to decrease its landing distance and by doing so we found out that the overall landing distance of an aircraft was reduced to just 242.46 meters which is ideal for carrier operation as most of the carriers have runway length of about 300 meters and use arresting gears to reduce the landing distance of the aircraft.
- The whole design process was based on asphalt runway due to its wide of usage in carrier operations. In this paper, the prerequisite landing distance for carrier operation was achieved without using the arresting gears and thereby increasing the life and durability of the landing gears and wheels of an aircraft.

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