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ESTIMATION OF RUNWAY LENGTH FOR THE TWO STAGES TO ORBIT VEHICLE

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Abstract

The Reusable Launch Vehicle (RLV) continues to be the unaccomplished dream of the world space community with the tremendous potential, it offers in bringing down the cost of accessing space. Single Stage to Orbit (SSTO) space plane is the ultimate goal, it is now reconciled that a Two Stage to orbit (TSTO) RLV is the one that is viable with the current state of art in materials technology. In India, ISRO is also in the process of developing similar technologies required for the Two Stage to orbit (TSTO) RLV and has carried out design studies in this frontier area and has taken initiatives by developing advance launch vehicles like RLV-Technology Demonstrator (RLV-TD) to validate hypersonic re-entry & landing characteristics of a Reusable Vehicle. These advance launch vehicle missions display wide variation in take-off and landing modes, staging, piloting, propulsion scheme and other key parameters. An attempt is made to conceptualize the landing site and estimate the runway length for the recovery of both stages of TSTO namely booster and orbiter. To meet the landing requirements for the recovery of booster and orbiter as winged body aircraft, there is need to have the landing site at Sriharikota as prime airstrip. This paper highlights the requirements for sizing of the airstrip, landing aids & instrumentation, real-time requirements, refurbishment facilities, meteorological & associated instruments required for the realisation of "Runway length analysis and the facilities for the future missions".

Keywords: *RLV, SSTO, TSTO, Re-entry, runway length*

Introduction

The concept of reusable launch vehicle is emerging as an accepted route for low cost, reliable and on – demand access to space. ISRO has conceptualised and tentatively frozen the dimensions of a two stage recoverable launch vehicle, called TSTO (Two Stage to Orbit). The reusable launch vehicle TSTO (Two Stage to Orbit) is the most cost effective configuration. An attempt is made to conceptualize the landing site for the recovery of both stages of TSTO namely booster and orbiter at SRIHARIKOTA. To meet the requirements for the recovery of stage as winged body aircraft, there is need to have the landing site at Sriharikota as Prime airstrip and standby at any other location. This paper highlights the layout of facilities that are necessary to be realised at SDSC SHAR. The following are discussed in detail:

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Airstrip specification

TSTO mission demands highly sophisticated landing facility for booster and orbiter. The corrections for runway length due to atmospheric parameters like elevation and temperature effects are taken into account in finalizing its dimensions.

Runway length due to atmospheric parameters

Correction for Elevation

Any increase in the altitude of the runway means a decrease in the wing body's optimum performance. Air density decreases with altitude. For elevated airports, an airplane requires lengthy runway to take off. Its rate of climb will be less, it approach will be faster, because True Air Speed (TAS) [TAS, the speed of the aircraft relative to the air mass in which it is flying] is more than the Indicated Air Speed (IAS) [IAS, is the air speed read directly from the air speed indicator on a aircraft] and the landing roll will be longer. Since, SDSC SHAR Mean Sea Level (MSL) height is 4m; the correction of elevation is negligible for SHAR.

Correction for temperature

Air density decreases with temperature. Warm air isless dense than cold air because there are fewer air molecules in a given volume of warm air than in the same volume of cooler air. As a result, on a hot day, an airplane will require extra length to take off; will have a poor rate of climb. So, the length corrected for elevation shall be further increased at the rate of 1% for each degree of centigrade the aerodrome temperature exceeds the standard sea level temperature. This correction is required for takeoff length determination. This correction may not be applicable for SDSC SHAR.

Sizing of the Airstrip

The following assumptions are made in sizing of the airstrip. The Dimension of the Booster is taken as reference value for the present calculation (reference 1). The coefficient of Lift (C_L) value at the time of landing is taken as 0.8 (based on the shuttle data reference 4). The value of parachute and thrust reversal is not taken into account for the present calculation. The coefficient of friction between the tyre and the runway strip is taken as 0.03 (reference 9). The Lift to Drag ratio (C_L /C_D) is taken as 4.5 at subsonic M=0.8 to M=0.2 at landing.

Airstrip length computations

Following values are taken into consideration for the present calculation to determine length of the airstrip.

Number of Seconds Free roll (N) = 3sec.
Weight of the Booster at Landing (W) = 765180N,

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Basic Wing area (S) = 175 sq m.

Wing Loading (W/S) = 4372.45 N/m^2

Standard Atmospheric density (ρ_∞)= 1.2 kg/m^3

Nominal touchdown Velocity (V_{TD}) = 75 m/s

Coefficient of Drag (C_D) = C_L / (L/D) = 0.1777

The following assumptions are used in calculation C_L, C_D and L/D values are constant throughout Ground Roll S_g . The Friction Coefficient is constant throughout the Ground Roll S_g. The formula used for calculating the length of the runway is given below, as per references 9 and 10

$$S_g = NV_{TD} + \frac{1}{2gJ_A} \ell n \left(1 + \frac{J_A}{J_T} V_{TD}^2\right) \quad (1)$$

Where S_g is the total ground roll. N is the time increment for the free roll. V_{TD} is the touchdown velocity.

$$J_T = \frac{T_{rev}}{W} + \mu_r \quad (2)$$

Where T_{rev} is the Thrust reversal. W is the weight of the booster at landing. μ_r is the coefficient of friction.

$$J_A = \frac{\rho_\infty}{2\left(\frac{W}{S}\right)} (C_D - \mu_r C_L) \quad (3)$$

Where, C_D is the drag coefficient. W/S is the wing loading. The length of the airstrip is computed by using the above formulae, considering an extra margin of 300m on both the ends of the runway and all other uncertainties excluding the correction for elevation and temperature, the total required length of the runway is presented after the dispersion analysis. The length of the airstrip for the RLV booster and orbiter is 4.6632 km.

Airstrip width computations

There is no standard formula for calculating the width of the airstrip. As per references 11, 12, 13, 14 the width of the airstrip is calculated based on the following points.

The distance between the outside edges of the main gear wheels.

The distance between wings mounted engines and the longitudinal axis of the booster.

The wing span (wing tip to wing tip) is 19.44 m.

The prevailing meteorological conditions.

The Turn radius of the Booster including the tractor.

The cross wind effects and its effect on Booster and Orbiter.

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The width of the airstrip proposed is 60m.

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Dispersion analysis of the airstrip length

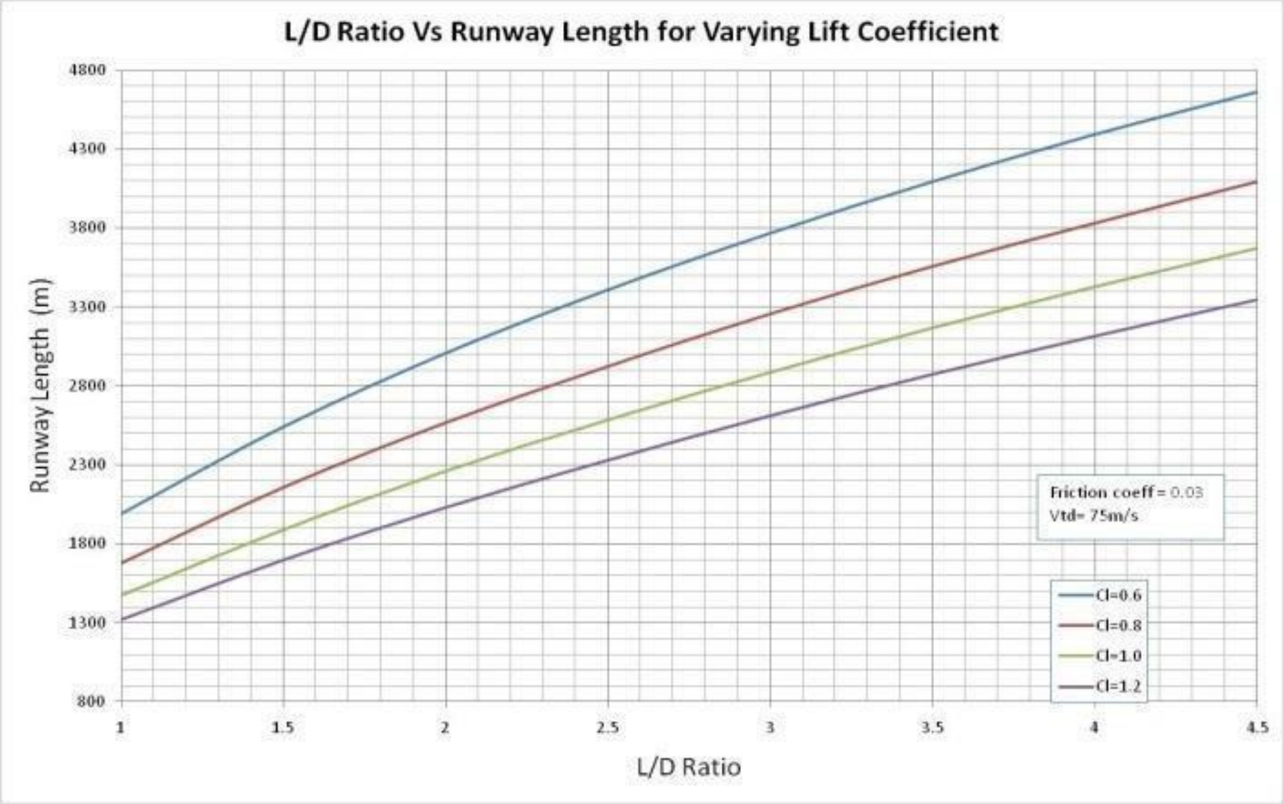
The dispersion analysis study is also carried out for length variation of runway. The major factor that dictates the length of the airstrip is Coefficient of lift and drag, friction factor, lift to drag ratio, touchdown velocity.

There are two cases studied to understand the dispersion of the runway length. The following cases are presented below to understand the variations of airstrip length.

1. Variation of lift to drag ratio (L/D) and lift coefficient (C_L).
2. Variation of friction coefficient (μ_r), lift coefficient C_L and lift to drag ratio (L/D).

Variation of lift to drag ratio (L/D) and lift coefficient (C_L)

The friction factor μ_r and touchdown velocity V_{TD} is taken as 0.03 and 75 m/s. The result obtained by varying L/D and C_L is given in Graph 1.



Graph 1: Variation of L/D ratio vs Runway length for varying Lift coefficient (C_L).

From the above Graph 1, the following inferences are arrived, The maximum length of the runway is 4.6632, for L/D value 4.5 and C_L =0.6. As coefficient of lift increases, the length of the runway decreases. The decrease in L/D ratio decreases the length of the runway. So, coefficient of lift (C_L) plays a major role in deciding the length of the runway.

Variation of friction coefficient (μ_r), lift coefficient C_L and lift to drag ratio (L/D)

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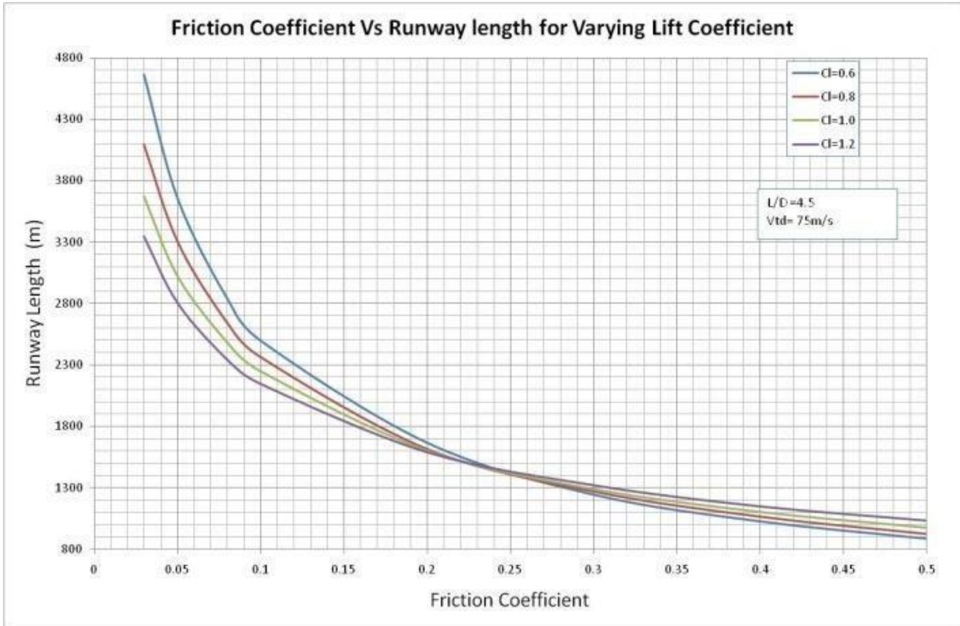
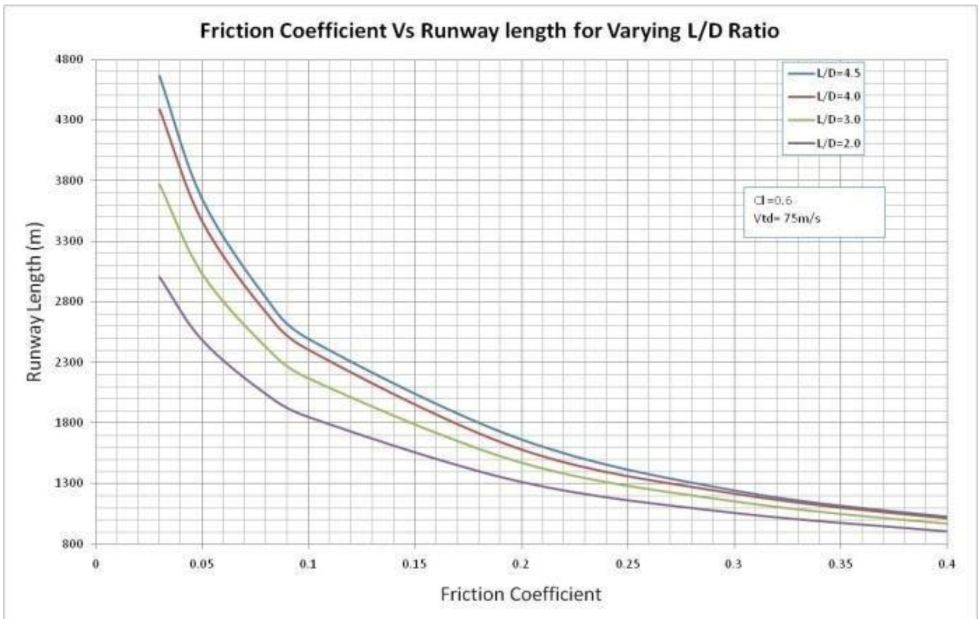
The friction factor μ_r and lift coefficient C_L is varied for constant lift to drag ratio L/D=4.5 and touchdown velocity V_{TD} =75m/s. The lift coefficient is varied between 0.6 and 1.2. The results obtained from the variation of friction coefficient (μ_r), lift coefficient C_L and lift to drag ratio (L/D) is given in Graph 2 and 3. From the graph 2 & 3, the following inferences are arrived, as lift coefficient decreases, the length of runway increases. The more the friction coefficient the lesser the runway length.



Graph 2: Variation of friction coefficient vs runway length for varying lift coefficient (C_L)



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Graph 3: Variation of friction coefficient vs runway length for varying lift coefficient (C_L)

Inferences of the dispersion analysis on runway length

The primary factors deciding the length of the airstrip are

- Touchdown velocity
- Friction factor.
- Lift to drag Ratio.
- Lift coefficient.

The following inferences are obtained from the dispersion analysis.

- Ground Roll (Sg) increases with decrease in lift coefficient.
- Ground Roll (Sg) decreases with decrease in the L/D ratio.
- Ground Roll (Sg) decreases with increase in the friction coefficient.
- Ground Roll (Sg) increases with increase in the touchdown velocity.

This is based on our assumption that friction, Lift and Drag coefficient are constant throughout ground roll. In actual case drag and friction coefficient increases due to deployment of Flaps, Parachutes, applications of brakes. Increase in drag coefficient value will further reduce L/D ratio which will reduce the ground roll. So, from the above analysis, all calculations are carried out at touchdown velocity of 75m/s.The Dispersion analysis indicates the maximum value of the runway is around to be 4.6632 km for all possible dispersions. The length of the air strip is 4.6632km and width of the airstrip is 60m.

Conclusion

In depth dispersion analysis of the parameters governing the airstrip calculations is done and the results are described. The important parameters that are governing the airstrip calculations are Touchdown velocity, Friction factor, Glide angle, lift and drag coefficients. The length of the airstrip for RLV TSTO is worked out to be 4.6632km length and width is 60m.

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