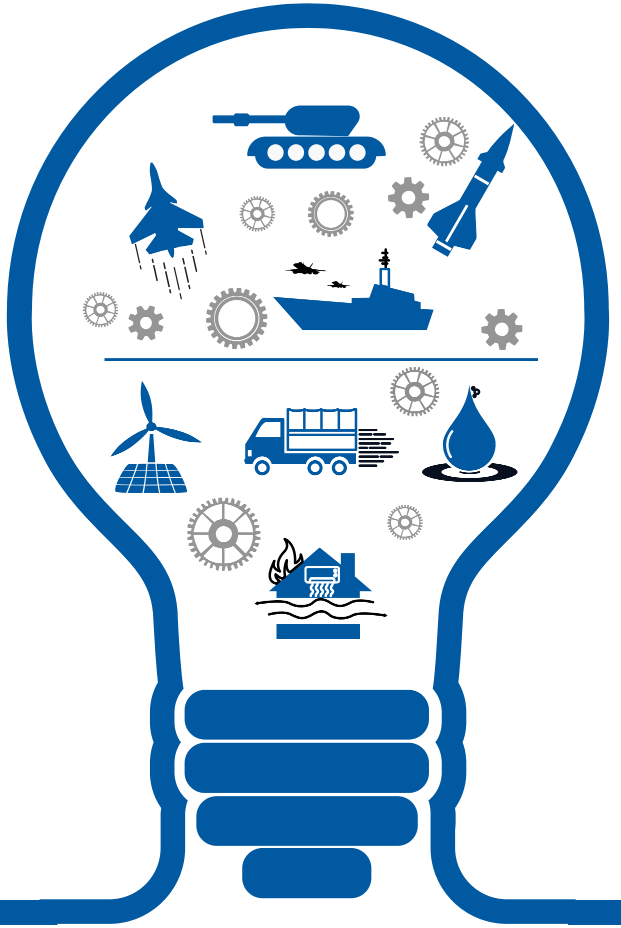
ZEUS NUMERIX

Projectile Aero Elasticity

REFERENCE MANUAL

http://labs.zeusnumerix.com/projectile-aero-elasticity/

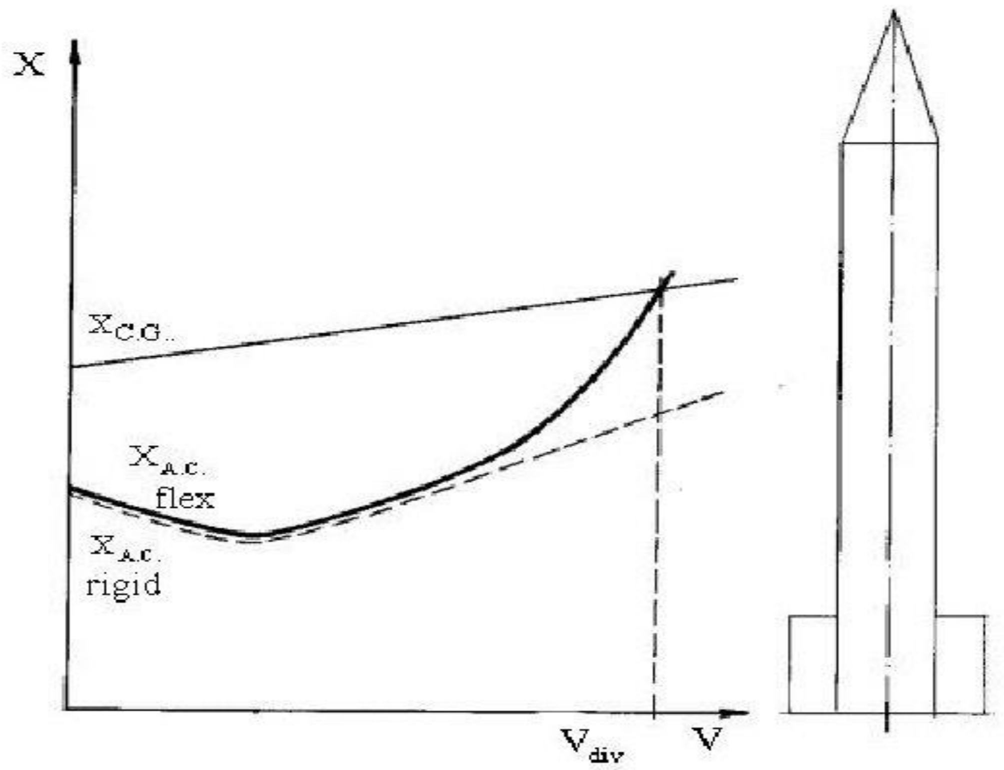


Build-to-Specifications | Product Approval | Engineering Services | Software Development

Contents

Introduction

- Aero-elastic effects have significant influence during the design and flight performance of slender projectile. Static instability or Divergence occurs when the aerodynamic load on the projectile equals the structural restoring moment.
- The aerodynamic lift of the projectile, especially on the nose and the tail, contribute to the its bending, causing additional forward shift of the aerodynamic centre Xcp.
- At certain velocity called the divergence velocity, the shift in Xcp coincide with the location of the CG, making the projectile, aerodynamically unstable. This velocity is called divergence velocity



Governing Equations

- Aero-elastic equation of motion

  $M\ddot{u} + C\dot{u} + Ku = F_1(u,\dot{u},\ddot{u}) + F_2(t)$ where, F represent Aerodynamic Loads

- F_1 which depends on the motion variables and F_2 which explicitly depends on time, t.
- The functions G_1, G_2 and G_3 are known linear functions of motion variable, its derivative and second derivative. Thus aero-elastic equation becomes

  $$M\ddot{u} + C\dot{u} + Ku = G_1(u) + G_2(\dot{u}) + G_3(\ddot{u}) + F_2(t)$$

- Since Divergence is a static phenomenon, all the derivative terms vanished, Hence the equation reduced to:

  $(K - G_1)u = F_2(t)$ => Condition for divergence => $(K\text{-}G_1)u = 0$

  $G_{1\ \text{aerodynamic}} = QS\,[CN_\alpha][u] = QS\,[CN_\alpha]\Phi\, q \longrightarrow [\emptyset]^T([K] - (QS)[C_{N\alpha}])[\emptyset]q = 0$

- This is non standard eigenvalue problem. Above equation is solved for unknown Q.

Web App - Usage

- User needs to upload input file containing details of projectile & flight condition
- Next upload contains length wise distribution of aerodynamic normal forces
- Final upload contains longitudinal variation of stiffness & mass of projectile

- Upon execution, following output is generated:

1. Plot showing natural mode shapes of the projectile
2. Deflection & slope for projectile at given flight condition
3. Summary presenting the divergence ratio indicating the margin available

- User can download the raw output data (textual format) for future reference

Input File Description

Parameter	Default Value	Unit	Description
Rocket_Length	1.0	m	Length of the projectile – From nose to tail end
Rocket_Diameter	0.05	m	Diameter of the projectile cylinder
Fin_Cant_Angle	40	Minutes	Cant angle of the tail fins
Pressure	85000	Pa	Static pressure at flight condition of maximum dynamic pressure
Temperature	280	K	Temperature at flight condition of maximum dynamic pressure
Mach	3.5	-	Mach number at flight condition of maximum dynamic pressure
AoA	5	Degrees	Maximum angle of attack possible during projectile flight
Fin_Ycp	0.1	m	Radial distance of center pressure for tail fins
No_of_modes_superposed	6	-	Number of modes to be used for eigen value solution
Number_of_element	70	-	Number of descretized one dimensional element for projectile
Rocket_Spin	1	-	1 – To account centrifugal force; 0 – To ignore centrifugal force

Input Force & Stiffness File Description

- Default force file name: CN_alf.txt
- There exists two columns of the data
- First column is axial location on the projectile. Unit is (m)
- 2nd column is corresponding CN_{α} i.e. normal force coefficient derivative. Unitless.

- Default stiffness file name: EI_MPUL.txt
- There exists three columns of the data
- First column is axial location on the projectile. Unit is (m)
- Second column is E.I i.e. multiplication of modulus of elasticity multiplied by moment inertia. The unit is (mm^4).
- Third column is mass per unit length corresponding to axial location. Unit is (Kg/m).

Summary File Description (Divergence_output.txt)

Parameter	Default Output	Unit	Description
Rocket Mass	3.4	Kg	Aggregate mass of projectile
CG from Nose	0.399	m	Distance of center of gravity from projectile nose
Peak Velocity	1174.0	m/s	Projectile velocity at maximum dynamic pressure
Peak Mach	3.5	-	Projectile Mach number at maximum dynamic pressure
Dynamic Pressure	728875.0	Pa	Maximum dynamic pressure against which projectile divergence is calculated
Divergence DP	1739727.2	Pa	Dynamic pressure at which projectile shall be unstable
Divergence Ratio	2.39	-	Ratio of dynamic pressure at divergence vs. maximum flight dynamic pressure
Divergence Velocity	1813.7	m/s	Projectile velocity at divergence condition
Mach Div	5.4	-	Projectile Mach number at divergence condition
Omega Div	2015.3	RPM	Projectile RPM at divergence condition
Lift Force Rigid	261.2	N	Net normal force on the projectile assuming it to have rigid shape
Zeta Factor	1.006	-	Ratio of normal force on flexible projectile vs. on rigid projectile
CP Shift	0.103	m	Shift in center of pressure due to projectile flexibility

Output File Description

- Mode_shape.txt presents the mode shapes of the projectile
- First column is axial location on projectile (m)
- Each of the next column show the mode shape of the projectile

- Nodal_deflection_slope.txt presents the shape of flexible projectile at the flight conditions of maximum dynamic pressure
- First column is axial location on projectile (m)
- 2nd column indicates the projectile deformation in term of lateral deflection (m)
- 3rd column indicates the deformation in term of slope (degrees)

References

- "Coupled aeroelastic analysis of a free flight rocket", D.S. Livshits, S. Yaniv, M. Karpel

WebApp is restricted for use with projectile diameters less 60 mm

Thank You !

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