DESIGN, SIMULATIONS AND ANALYSIS OF AN AIR LAUNCH ROCKET FOR HUNTING LOW EARTH ORBIT'S SPACE DEBRIS

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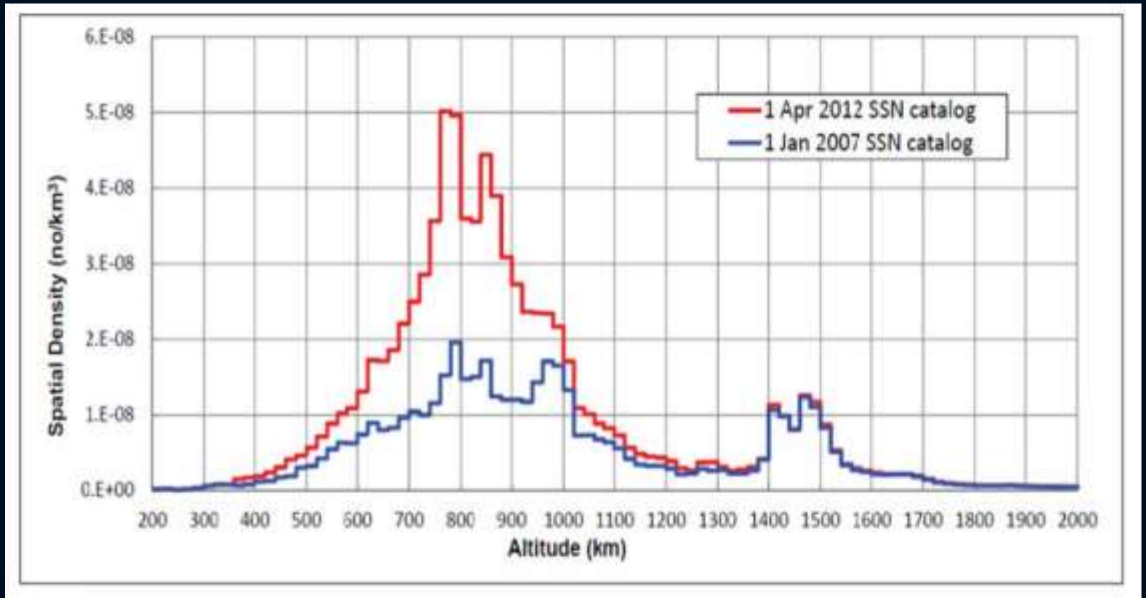
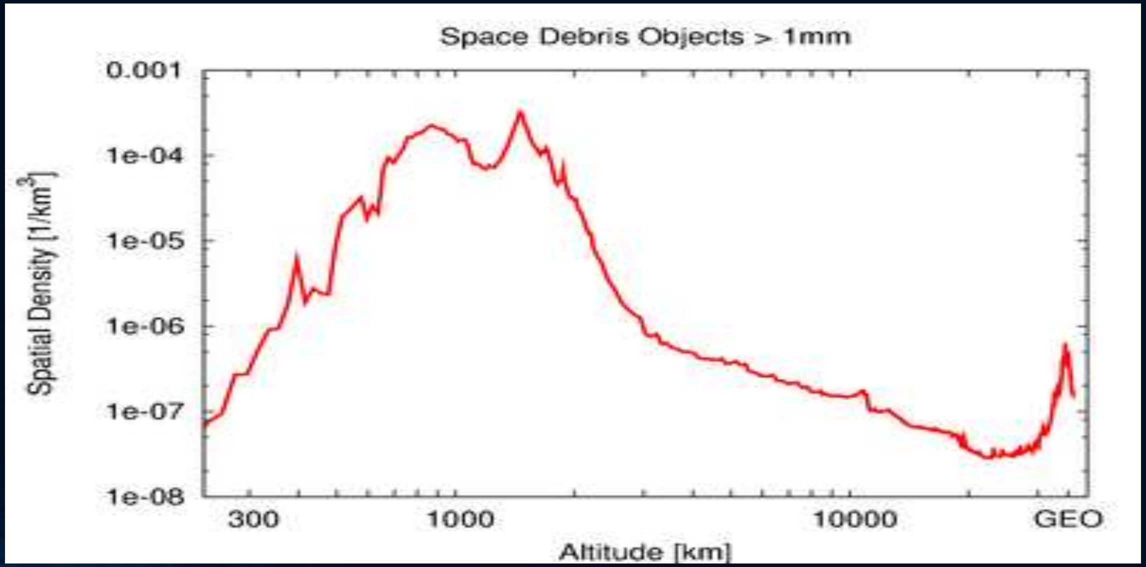
Contents

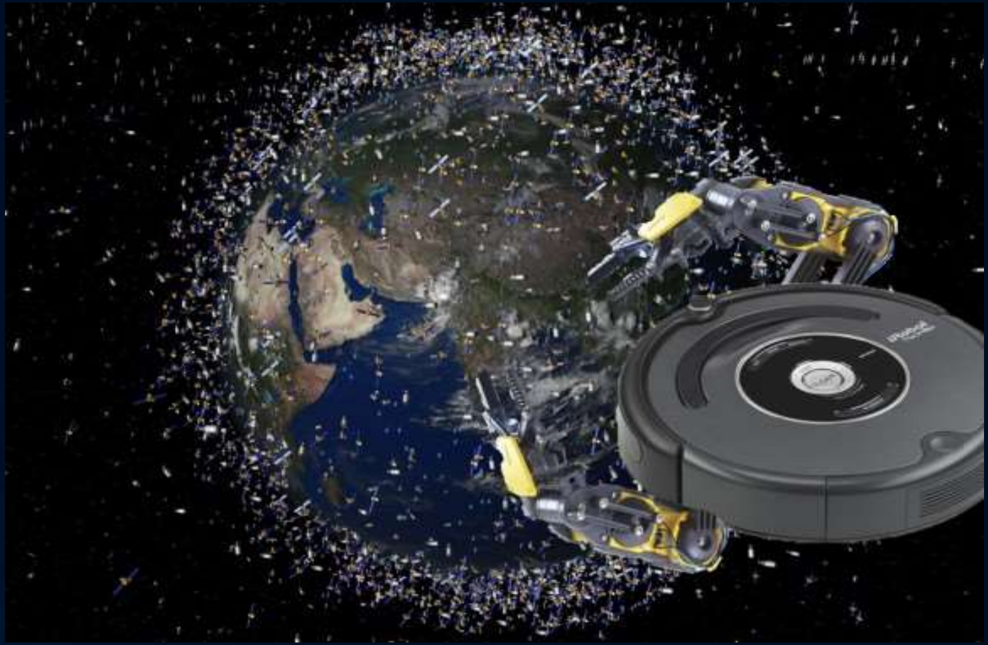
Space debris' threat to space projects

•As of 2009 about 19,000 debris over 5 cm are tracked while ~300,000 pieces over 1 cm exist below 2,000 kilometres (1,200 mi).

•They cause damage akin to sandblasting, especially to solar panels and optics like telescopes or star trackers that can't be covered with a ballistic Whipple shield.








esa


ESA

The Threat of Unburnt Space Debris

•In 1969 five sailors on a Japanese ship were injured by space debris

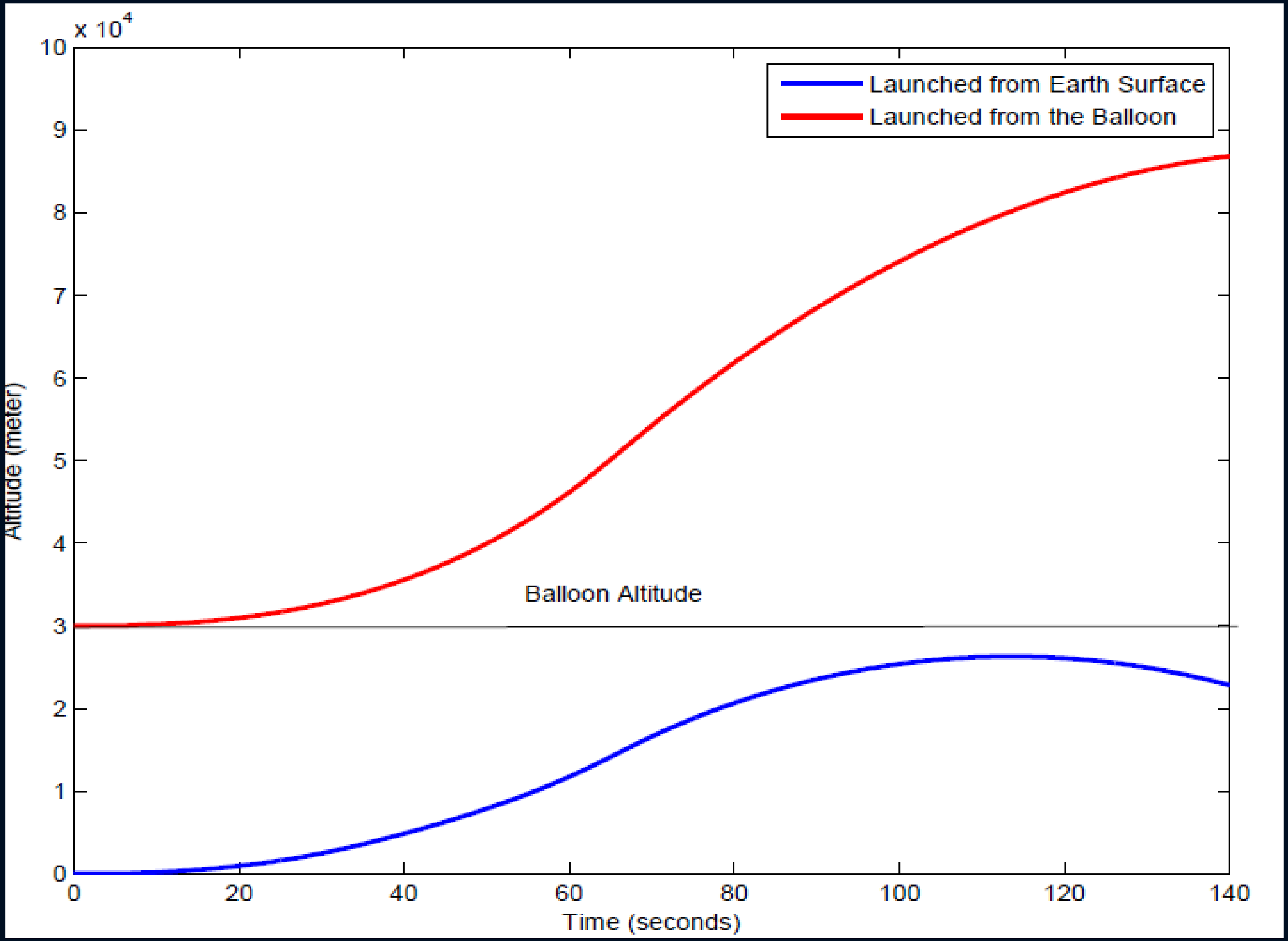
•In 1997 a woman from Oklahoma, was hit in the shoulder by a 10 cm × 13 cm piece of debris

•In the 2003 Columbia disaster, large parts of the spacecraft reached the ground and entire equipment systems remained intact.

•On 27 March 2007, airborne debris from a Russian spy satellite was seen by the pilot of a LAN Airlines Airbus A340 carrying 270 passengers whilst flying over the Pacific Ocean between Santiago and Auckland.

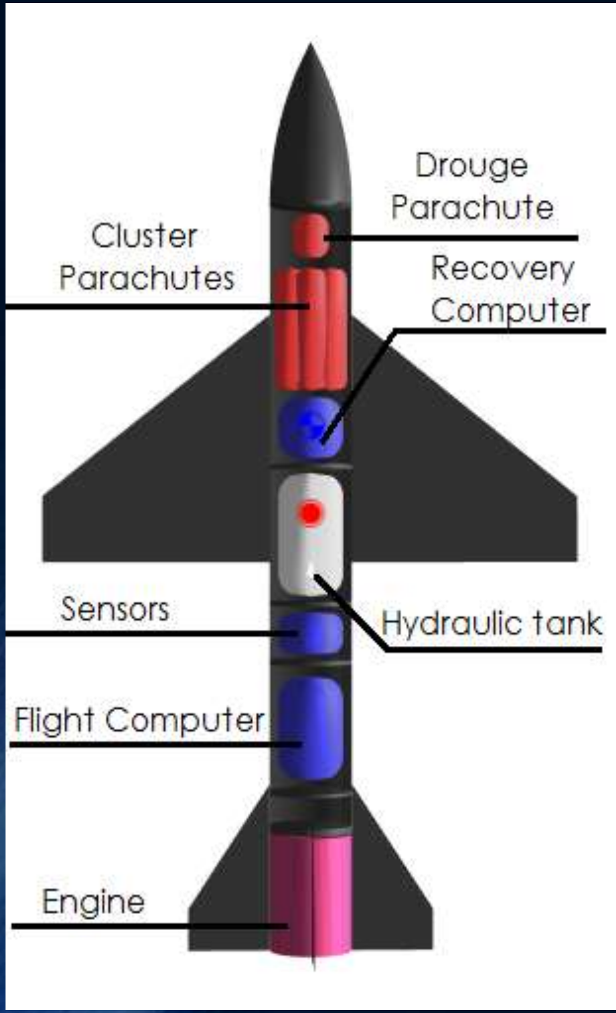
Concept illustration

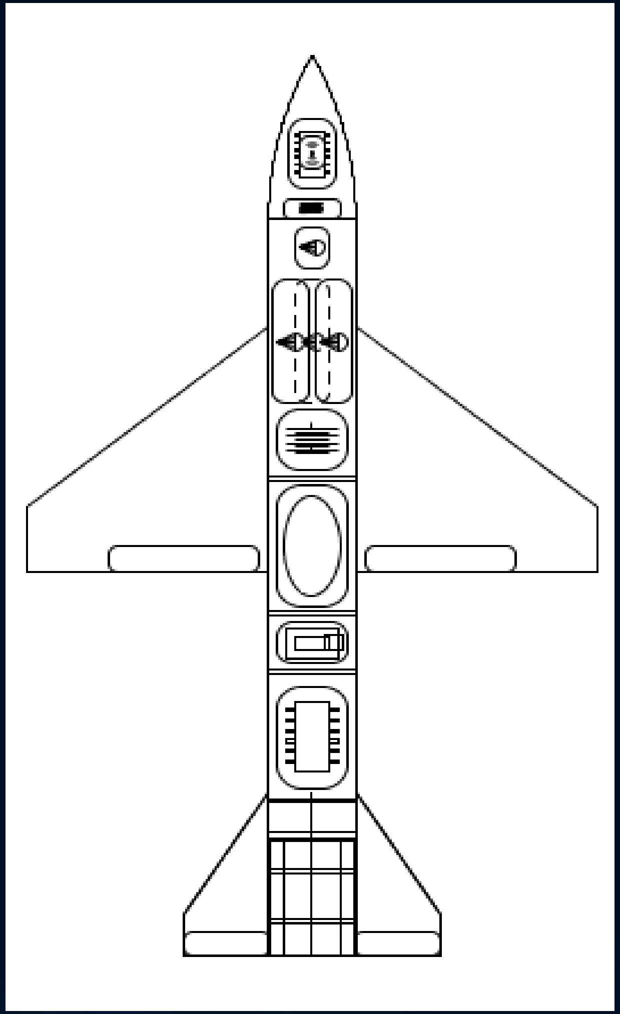
- the high altitude with less dense atmosphere would decrease drag dramatically as most of the fuel burnt is already burnt to overcome the high sea level – or near sea level – aerodynamic forces due to high air density.



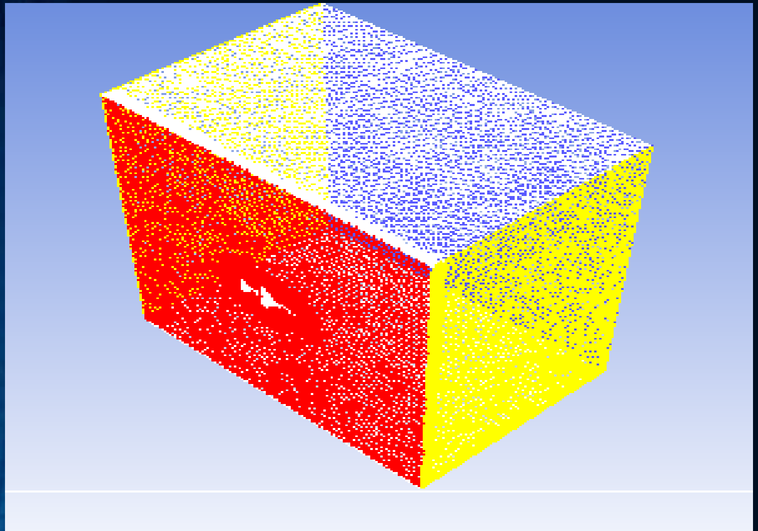
Altitude (Km)	Density	Temp. (K)	Pressure (Pa)	Viscosity
25	3.94658E-2	221	2.51102E+3	1.46044E-5
30	1.80119E-2	226	1.17187E+3	1.48835E-5

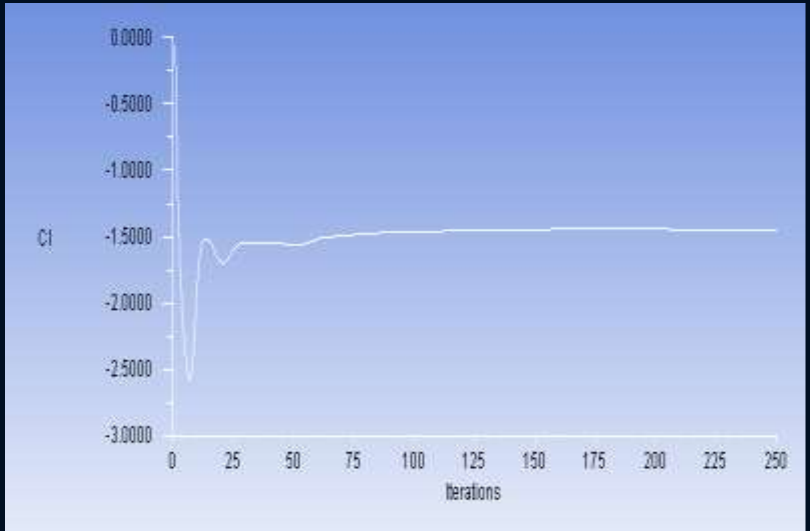
Air-Space Launch methods

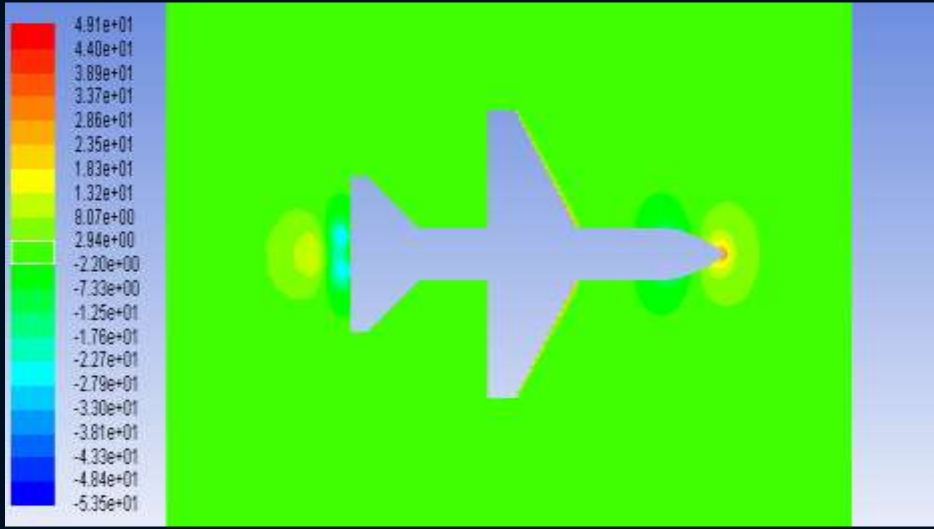


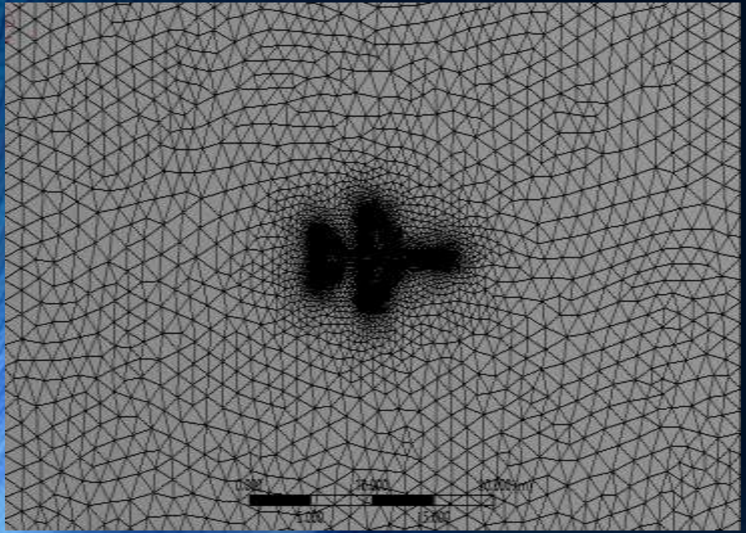


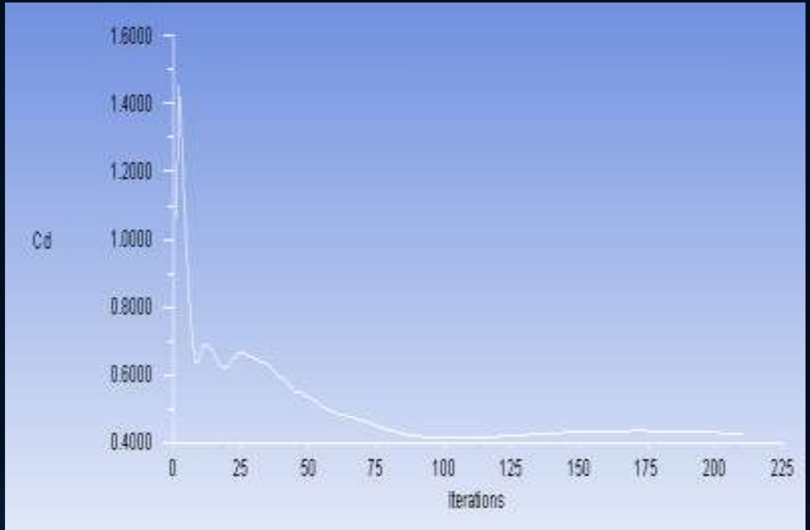
Aerodynamics

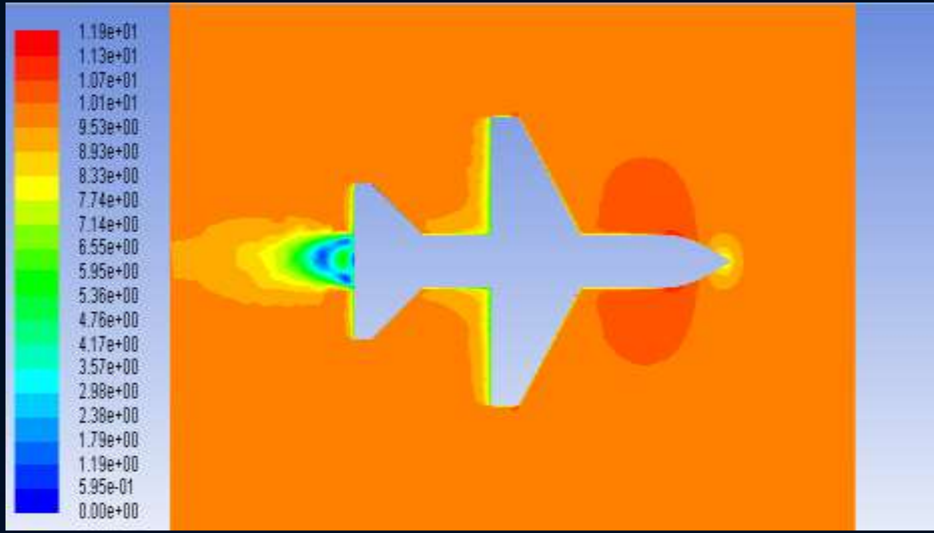




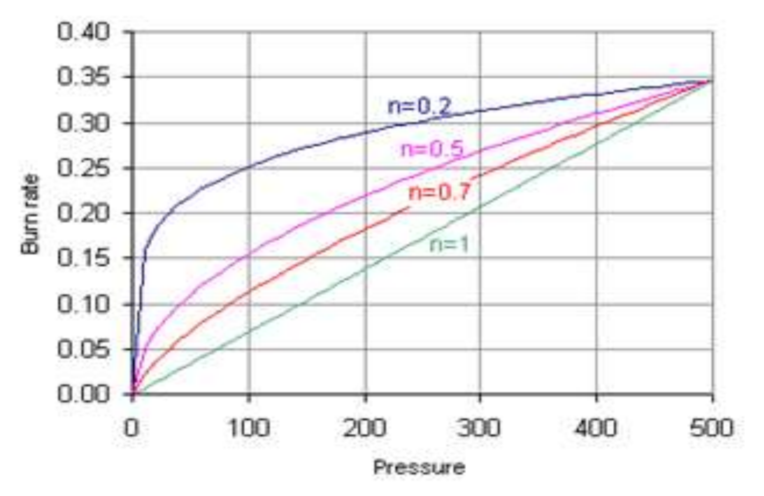


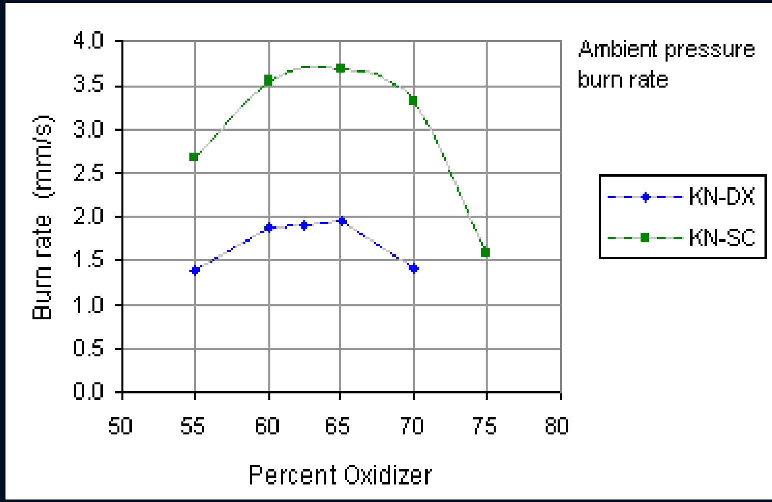






Propulsion system

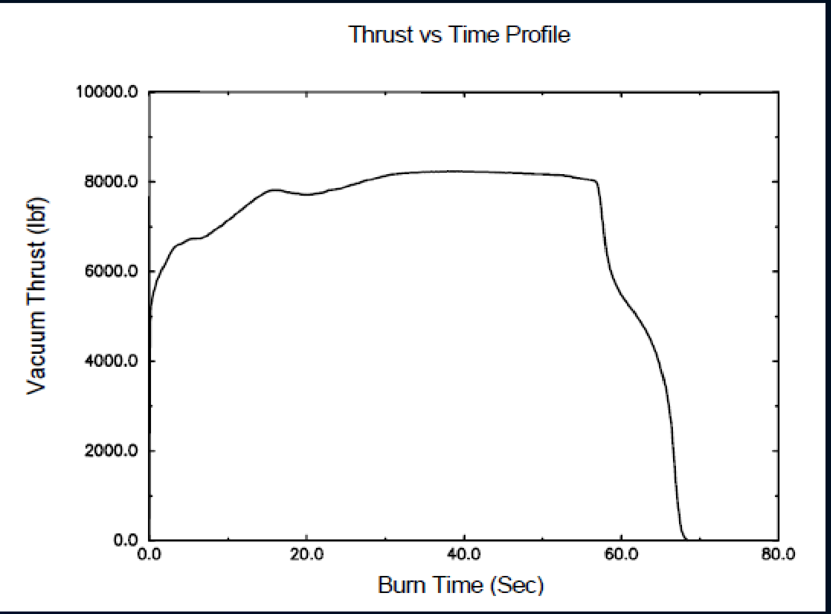




Propulsive unit choice

- MOTOR PERFORMANCE (70°F NOMINAL)
- Burn time, sec 67.7
- Average chamber pressure, psia 572
- Total impulse, lbf-sec 491,000
- Burn time average thrust, lbf. 7,246

ATK Orion 38

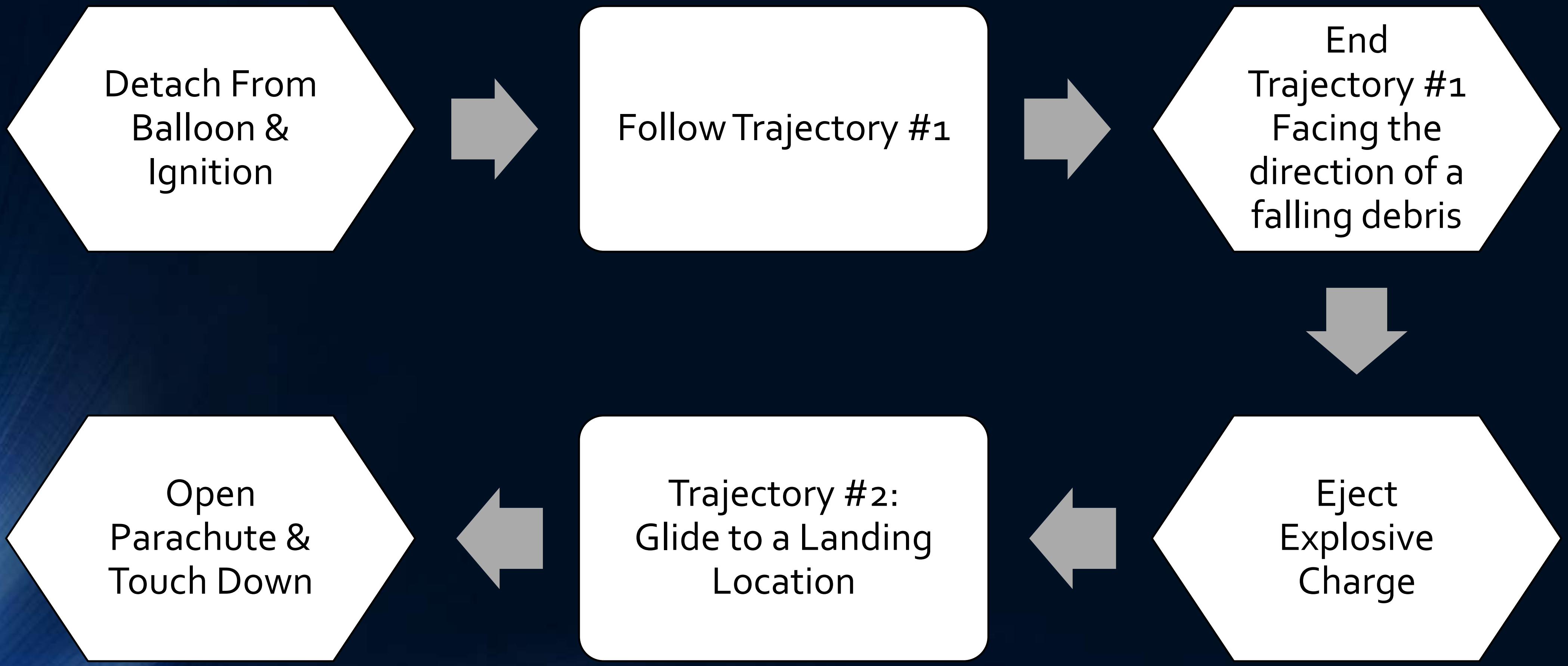


Recovery system




Recovery tests done at Green River Launch complex, Utah - USA

Rocket Trajectory Control Mission

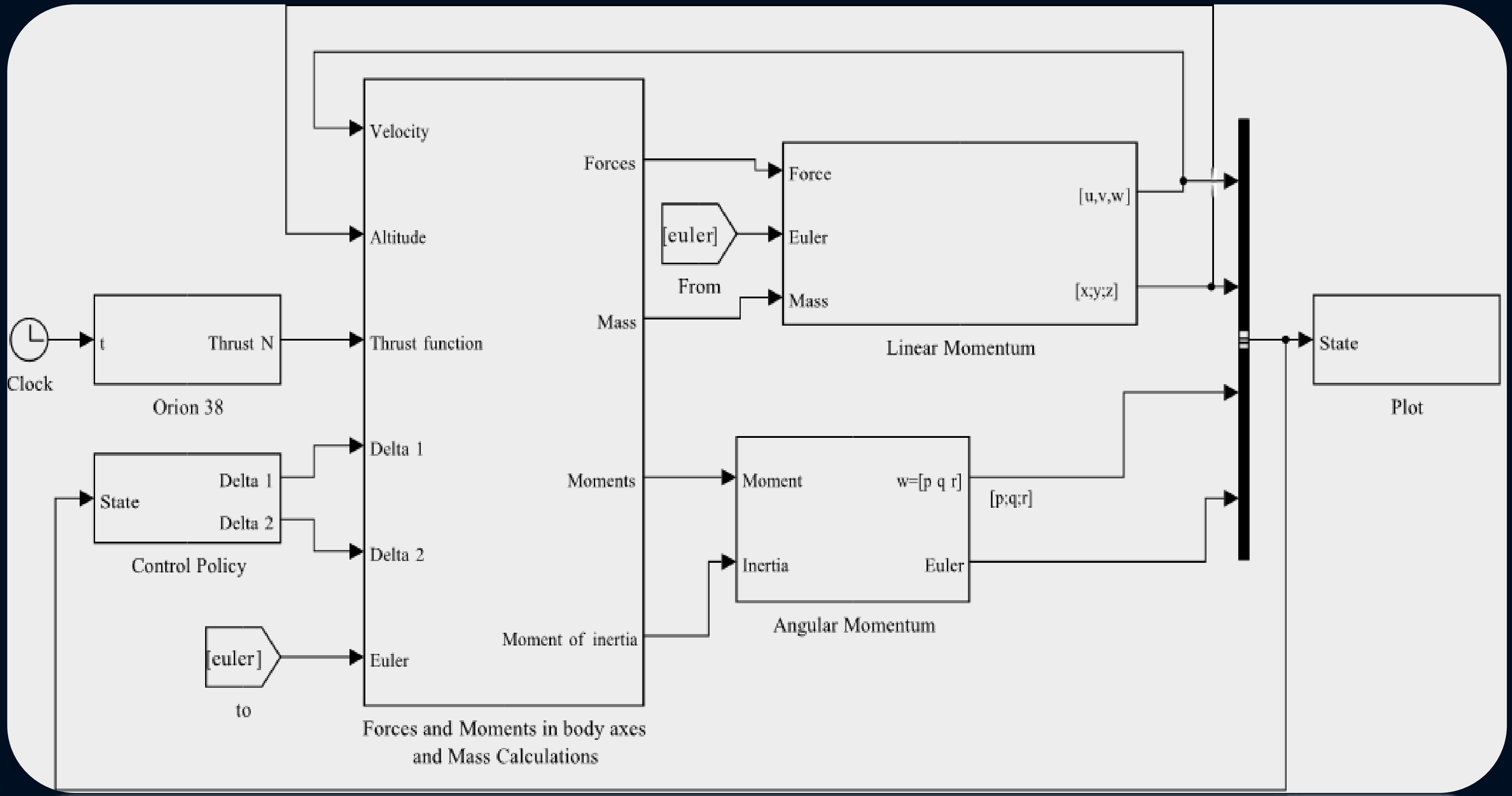


Rocket Trajectory Control Approach

- Build and Simulate the Mathematical Model.
- Trajectory Optimization: Open loop control policy.
  (Direct Trajectory Opt. by collocation and nonlinear programming)
- Trajectory Stabilization: Feedback along trajectory.
  (Time-Varying LQR)

Mathematical Model

- Equations of motion of a varying mass body.
- Forces : Gravity, Thrust and Aerodynamics.
- Control inputs: Rates of two angles of thrust vectoring.



Mathematical Model building blocks using SIMULINK software

Kinematics & Mass Calculations

State Vector:

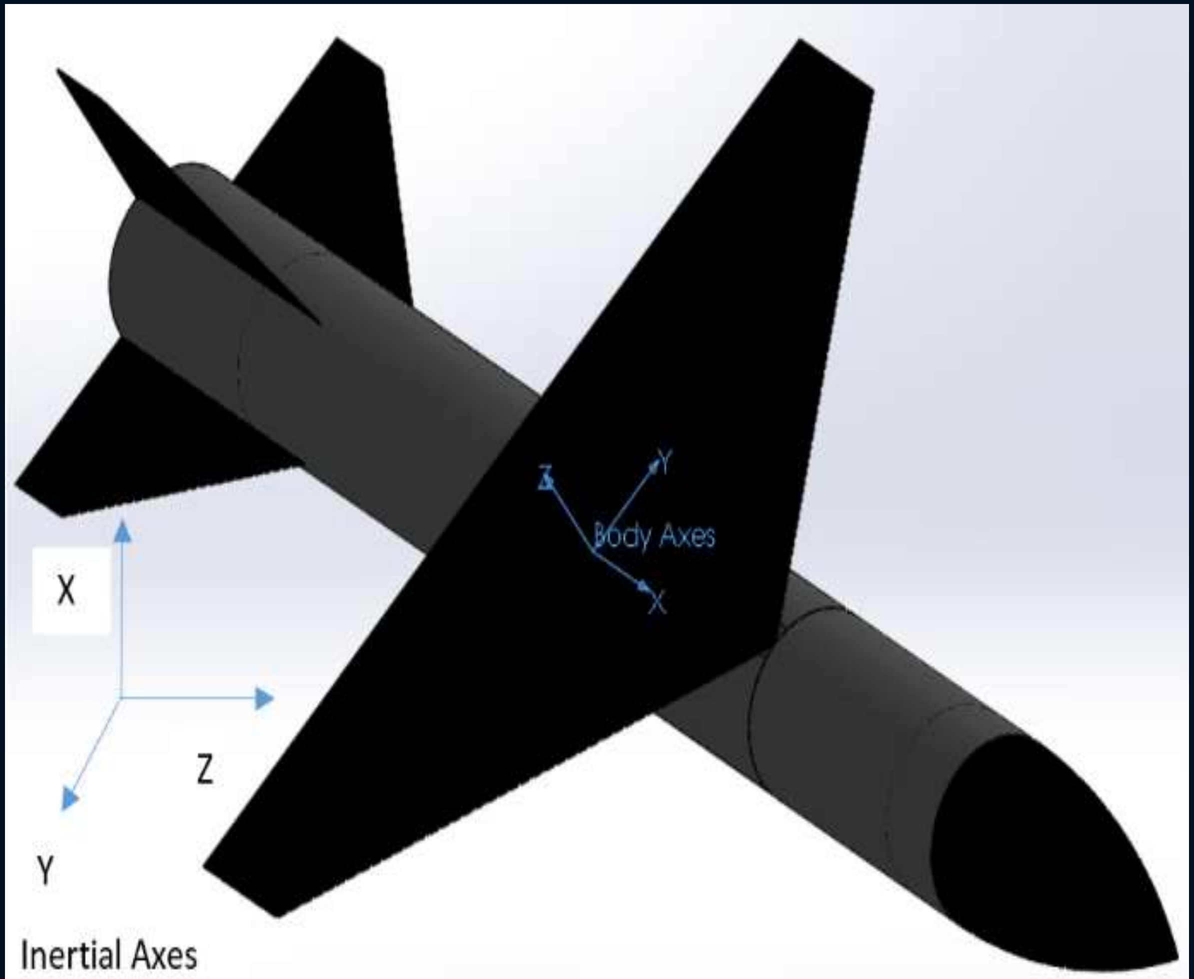
- $S = \left[\underline{X}^i\ \underline{V}^B\ \underline{\Theta}\ \underline{\omega}^B\ \ \underline{\delta}\right]$

Mass Varying:

- $m(t) = m_s + m_f\left(1 - r(t)\right)$

$$r(t) = \frac{\int_0^t thrust\ dt}{Total\ Impulse}$$

- $X_{cg}(t) = \dfrac{X_{cg_s} m_s + X_{cg_f} m_f\left(1 - r(t)\right)}{m(t)}$
- $I_{xx} = I_{xx_s} + I_f(t)$



Trajectory Optimization: Algorithm

Algorithm elements:

- Decision parameters for N discrete nodes:

$$\underline{D} = [S_1\ S_2 \ldots S_N\ U_0\ U_1 \ldots U_N]$$

As:

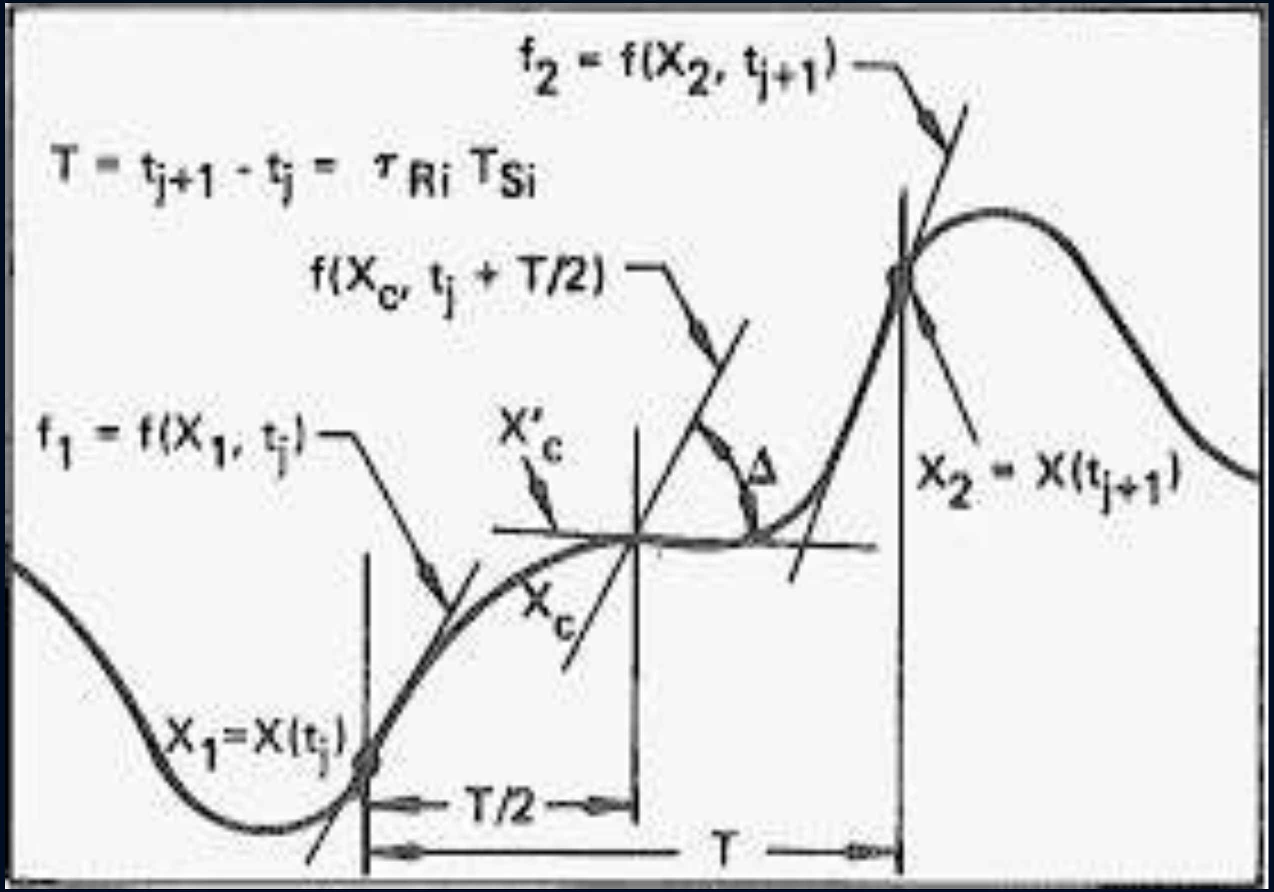
S: Piecewise cubic polynomials.

U: Piecewise linear interpolation.

- $\min\limits_{\underline{D}} \sum_{i=0}^{N-1} g(S_i\,, U_i)$

Such that $\forall i$

$$S_i' = f(S_i, U_i)$$
$$S_c' = f(S_c, U_c)$$
$$D_l \leq D \leq D_u$$



Ref. Hargraves, C., and S. Paris. "Direct trajectory optimization using nonlinear programming and collocation." Journal of Guidance, Control, and Dynamics 4 (1986): 121

Trajectory Optimization: Hunting Example

Trajectory Optimization: Hunting Example

- Optimize trajectory for Dynamics with non variant mass and thrust.

- This simplification reduces trajectory optimization time on a personal computer to about 30 seconds.

- However, the trajectory of the variant mass and thrust model diverges from the nominal trajectory.

- But, the resulting nominal trajectory of states and inputs: $[S_{nom}\ ,\mathrm{U_{nom}}]$ is useful to design a feedback policy.

Trajectory Stabilization: time-varying LQR

- Linearize the nonlinear dynamics $S' = f(S, U)$ along the nominal trajectory

$$S' = f(S_{nom}, U_{nom}) + \frac{\partial f(S_{nom}, U_{nom})}{\partial S}(S - S_{nom}) + \frac{\partial f(S_{nom}, U_{nom})}{\partial U}(U - U_{nom})$$

Or,

$$\bar{S}' = A(t)\,\bar{S} + B(t)\,\bar{u}$$

- The objective of TV-LQR is to minimize cost function:

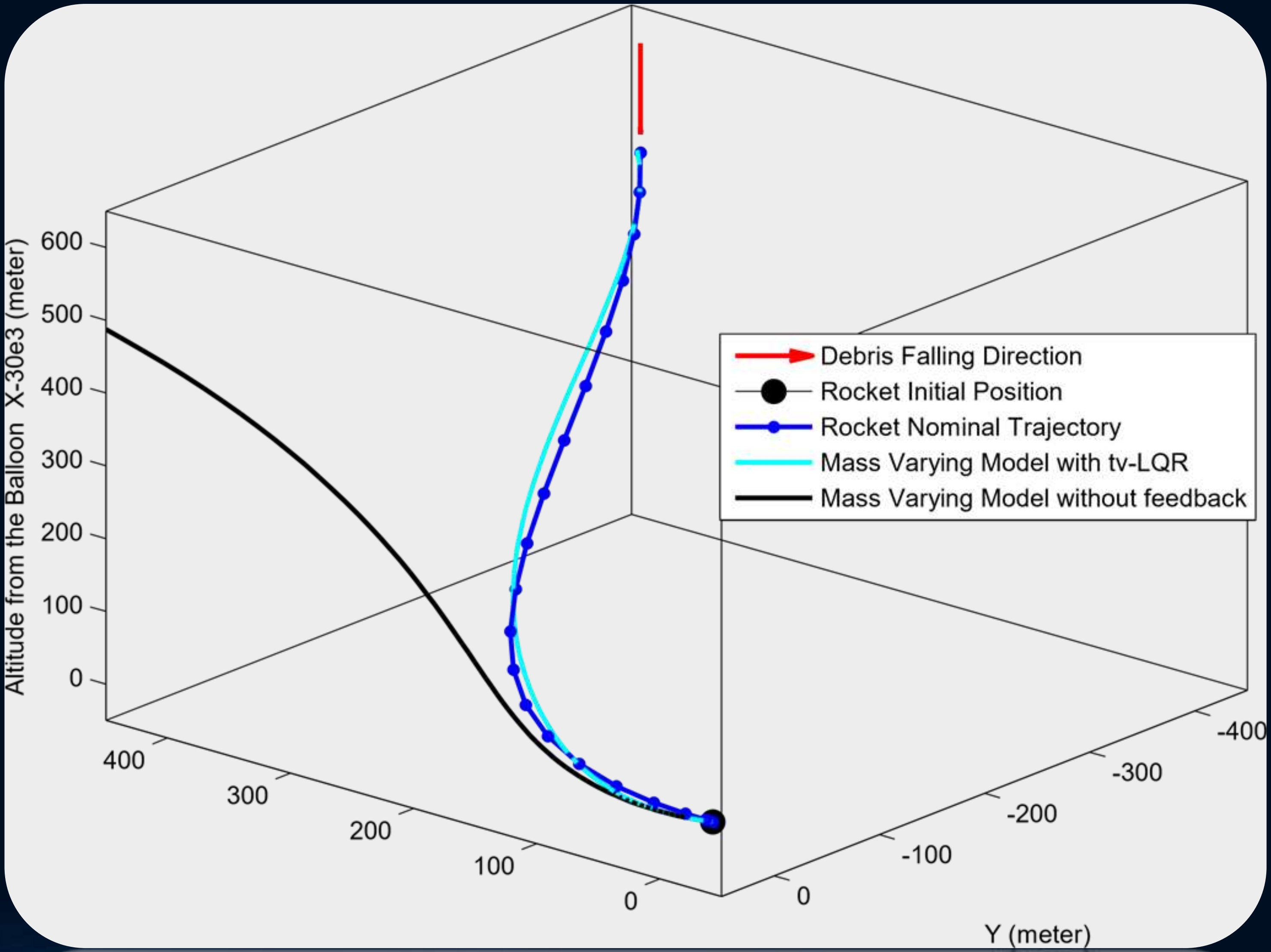
$$\min_{\bar{u}} \int_0^{tf} (\bar{S}^T\, Q(t)\, \bar{S} + \bar{u}^T\, R(t)\, \bar{u})\, dt + \bar{S}^T\, Q_f(t)\, \bar{S}$$

- From Riccati differential equation:

$$U = U_{nom} - k(t)\,(S - S_{nom})$$

Trajectory Stabilization: Hunting Example

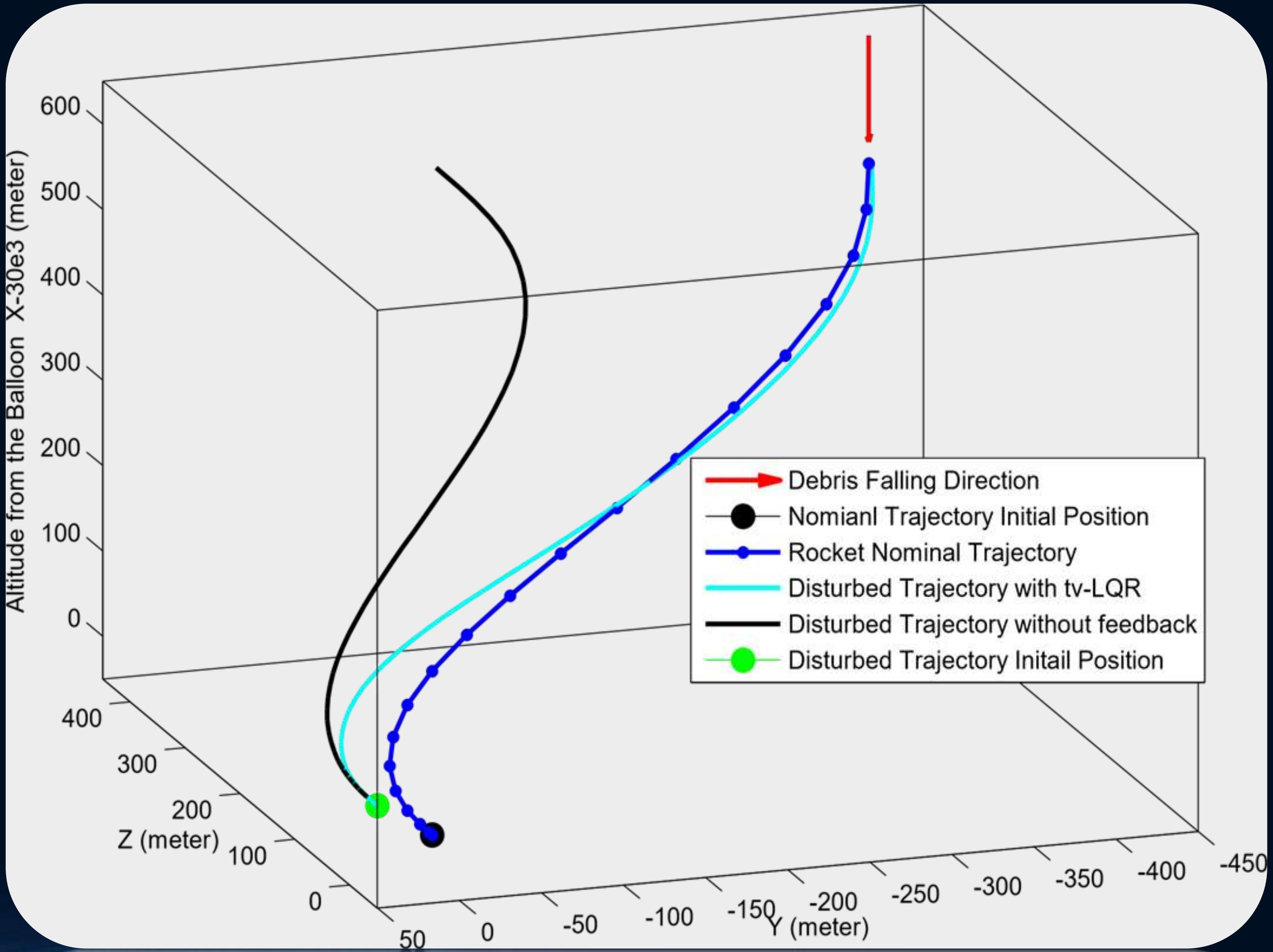
Designing linear feedback policy (TV-LQR) along the trajectory can deal with perturbations from mass and thrust varying.



Trajectory Stabilization: Robustness

- Moreover, the trajectory is robust even for different starting points.

- All trajectories start from certain space of initial conditions can be proved to converge to the nominal trajectory. (Future Work)



Space Education in Egypt (since 2013)

Target:-

- Initiating students of various departments with a passion to space that their dreams and hopes are POSSIBLE!
- Introducing the very first working prototypes in for space related projects to give an

Projects:-

- Sounding Rockets
- Space Rover prototypes
- Multi-copter UAVs

Sounding Rockets

- Succeeded in designing, building and launching the first sounding rocket ever in Egypt

- Three launched followed the first launch to gain the level 1,2 and 3 rocket flight certifications

The Experimental Sounding Rocket Association
is honored to present this award for

Team Sportsmanship

Cairo University - Egypt

June 27th, 2015

The Experimental Sounding Rocket Association
is honored to present the

MacGyver Award

for

Finding all the parts to build and successfully fly a rocket in base camp

Cairo University - Egypt

June 27th, 2015

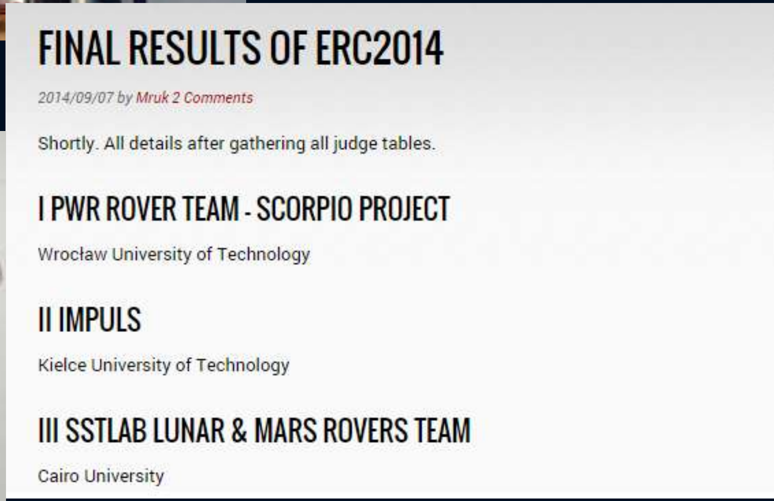
Space Rover prototypes

- Three successful prototypes

- More than 50 students participated in the projects

- 9^{th} place in the URC 2014 - USA
- 3^{rd} place in the ERC 2014 - POLAND

- 4 teams are participating from Egypt nowadays in international competitions


FINAL RESULTS OF ERC2014

2014/09/07 by Mruk 2 Comments

Shortly. All details after gathering all judge tables.

I PWR ROVER TEAM - SCORPIO PROJECT

Wrocław University of Technology

II IMPULS

Kielce University of Technology

III SSTLAB LUNAR & MARS ROVERS TEAM

Cairo University

Space Rover prototypes





Multi-copter UAVs

- Two successful flying models as the first in Aerospace Department, Cairo University.

- Several publications for different types of control.

- More than three graduations projects are inspired and following the steps of those models.

- Start collaboration with other researcher in other Egyptian universities.

Thank you!

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