ENAE 791 Course Overview

- Challenges of launch and entry
- Course goals
- Web-based Content
- Syllabus
- Policies
- Project Content
Space Launch System – NASA
Antares Launch Vehicle – Orbital ATK
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Falcon 9 v1.1 – SpaceX
Falcon Heavy – SpaceX (2016)
New Shepard (Blue Origin)
New Shepard Landing (Blue Origin)
Stratolaunch Concept (Paul Allen)
Shuttle in Gliding Landing
SpaceX Propulsive Landing Tests
Dragon Cargo Spacecraft – SpaceX
Orion Spacecraft – NASA
Dragon 2 Spacecraft – SpaceX
Dream Chaser – Sierra Nevada Corp.
Dream Chaser Cargo Version
CST-100 – Boeing
Commercial Crew Size Comparison

Orion

CST-100

Apollo

Dragon

5.029m (198")

4.56m

3.912m (154")

3.7m

G. De Chiara © 2014
Blue Origins Biconic Spacecraft
Grasshopper – SpaceX
Spaceship One – Rutan Aircraft Factory
Spaceship Two - Virgin Galactic

Photo by MarsScientific.com and Clay Center Observatory
Lynx Suborbital Vehicle – XCOR
Low-Density Supersonic Decelerator
Mars Pathfinder/MER Landing Bags
MSL Skycrane Mars Landing System
Mars Colonial Transport – SpaceX
Space Launch - The Physics

- Minimum orbital altitude is \( \sim 200 \text{ km} \)

\[
\frac{\text{Potential Energy}}{\text{kg in orbit}} = -\frac{\mu}{r_{\text{orbit}}} + \frac{\mu}{r_E} = 1.9 \times 10^6 \frac{\text{J}}{\text{kg}}
\]

- Circular orbital velocity there is \( 7784 \text{ m/sec} \)

\[
\frac{\text{Kinetic Energy}}{\text{kg in orbit}} = \frac{1}{2} \frac{\mu}{r_{\text{orbit}}^2} = 30 \times 10^6 \frac{\text{J}}{\text{kg}}
\]

- Total energy per kg in orbit

\[
\frac{\text{Total Energy}}{\text{kg in orbit}} = KE + PE = 32 \times 10^6 \frac{\text{J}}{\text{kg}}
\]
Theoretical Cost to Orbit

- Convert to usual energy units

\[
\frac{Total \ Energy}{kg \ in \ orbit} = 32 \times 10^6 \frac{J}{kg} = 8.9 \frac{kW \ hrs}{kg}
\]

- Domestic energy costs are \(~\$0.09/kWhr\)

\[\begin{align*}
&\text{Theoretical cost to orbit} \quad \$0.99/kg
\end{align*}\]
Actual Cost to Orbit

- SpaceX Falcon 9
  - 13,150 kg to LEO
  - $65 M per flight
  - Lowest cost system currently flying
- $4940/kg of payload
- Factor of 5000x higher than theoretical energy costs!
What About Airplanes?

- For an aircraft in level flight,

\[
\frac{\text{Weight}}{\text{Thrust}} = \frac{\text{Lift}}{\text{Drag}}, \quad \text{or} \quad \frac{mg}{T} = \frac{L}{D}
\]

- Energy = force x distance, so

\[
\frac{\text{Total Energy}}{\text{kg}} = \frac{\text{thrust} \times \text{distance}}{\text{mass}} = \frac{Td}{m} = \frac{gd}{L/D}
\]

- For an airliner (L/D=25) to equal orbital energy, d=81,000 km (2 roundtrips NY-Sydney)
Equivalent Airline Costs?

- Average economy ticket NY-Sydney round-round-trip (Travelocity 1/27/14) ~$1500
- Average passenger (+ luggage) ~100 kg
- Two round trips = $30/kg
  - Factor of 30x more than electrical energy costs
  - Factor of 165x less than current launch costs
- But...
  you get to refuel at each stop!
Equivalence to Air Transport

- 81,000 km ~ twice around the world
- Voyager - one of two aircraft to ever circle the world non-stop, non-refueled - once!
Orbital Entry - The Physics

- 32 MJ/kg dissipated by friction with atmosphere over ~8 min = 66kW/kg
- Pure graphite (carbon) high-temperature material: $c_p = 709 \text{ J/kg}^\circ\text{K}$
- Orbital energy would cause temperature gain of 45,000$^\circ$K!
- Thus proving the comment about space travel, “It’s utter bilge!” (Sir Richard Wooley, Astronomer Royal of Great Britain, 1956)
"Once you make it to low Earth orbit, you’re halfway to anywhere!"

- Robert A. Heinlein
Goals of ENAE 791

- Learn the underlying physics (orbital mechanics, flight mechanics, aerothermodynamics) which constrain and define launch and entry vehicles
- Develop the tools for preliminary design synthesis, including the fundamentals of systems analysis
- Provide an introduction to engineering economics, with a focus on the parameters affecting cost of launch and entry vehicles, such as reusability
- Examine specific challenges in the underlying design disciplines, such as thermal protection and structural dynamics
Contact Information

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Web-based Course Content

- Data web site at http://spacecraft.ssl.umd.edu
  - Course information
  - Syllabus
  - Lecture notes
  - Problems and solutions

- Interactive web site at http://elms.umd.edu
  - Communications for team projects (forums, wiki, blogs)
  - Surveys for course feedback
  - Videos of lectures
Syllabus Overview (1)

- Fundamentals of Launch and Entry Design
  - Orbital mechanics
  - Basic rocket performance
- Entry flight mechanics
  - Ballistic entry
  - Lifting entry
- Aerothermodynamics
- Thermal Protection System (TPS) analysis
- Entry, Descent, and Landing (EDL) systems
Syllabus Overview (2)

• Launch flight mechanics
  - Gravity turn
  - Targeted trajectories
  - Optimal trajectories
  - Airbreathing trajectories

• Launch vehicle systems
  - Propulsion systems
  - Structures and structural dynamics analysis
  - Avionics
  - Payload accommodations
  - Ground launch processing
Syllabus Overview (3)

- Systems Analysis
  - Cost estimation
  - Engineering economics
  - Reliability issues
  - Safety design concerns
  - Fleet resiliency
  - Multidisciplinary optimization

- Case studies

- Design project
Grading Policies

- Grade Distribution
  - 15% Problems
  - 20% Midterm Exam
  - 35% Term Project
  - 30% Final Exam

- Late Policy
  - On time: Full credit
  - Before solutions: 70% credit
  - After solutions: 20% credit
A Word on Homework Submissions...

- Good methods of handing in homework
  - Hard copy in class (best!)
  - Electronic or scanned copies via e-mail
    (please put “ENAE791” in the subject line!!)

- Methods that don’t work so well
  - Leaving it in my mailbox (particularly in EGR)
  - Leaving it in my office
  - Uncommented spreadsheets or .m files
  - Handing it to me in random locations
  - Handing it to Dr. Bowden
A Word about Homework Grading

- Homework is graded via a discrete filter
  - ✓ for homework problems which are essentially correct (10 pts)
  - ✓- for homework with significant problems (7 pts)
  - ✓-- for homework with major problems (4 pts)
  - ✓+ for homework demonstrating extra effort (12 pts)
  - 0 for missing homework

- A detailed solution document is posted for each problem after the due date, which you should review to ensure you understand the techniques used
Term Project - Space Tourism Transport
Term Project - Top Level Requirements

- Design a system to allow the transport of tourists to low Earth orbit for an economically viable cost
  - Launch vehicle
  - Launch and entry vehicle
  - Parametric payload models (mass/volume) to be provided

- Mission models
  - Market a function of transportation cost
  - Cost-optimized design process
  - Goal is “breakthrough” level of $300/kg
Term Project

- Work as individuals or two-person teams (your choice)
- Design an architecture to support tourist flight operations in the most cost effective manner possible
- All vehicles will be conceptually designed from scratch (no “catalog engineering”!)
- Parametric design parameters will be provided for human spacecraft systems not ENAE791-relevant
- Design process should proceed throughout the term
- Formal design presentations at end of term