Agenda

• Advanced Concepts Office (ACO) overview
• Earth-To-Orbit Team / Design Flow
• Modeling concepts in INTegrated ROcket Sizing (INTROS)
• Analyzing trajectory and performance
• Structural analysis
• Model wrap-up
• Typical sensitivities
We Are An Office Specializing In Pre-Phase A & Phase A Concept Definition

- RAVEN
- LTAS
- Habitat / Crew Systems
- CRYOSTAT
- CLARREO
- AXTAR

In-Space

Earth-to-Orbit
ACO Earth-to-Orbit Team

- High level concept performance
- Quick turnaround with high relative degree of accuracy
- Extremely useful for decision makers
  - Identify potential
  - Eliminate poor performers
  - Data input to cost and risk evaluations
  - Sensitivities to mitigate poor concepts and enhance others

- Recent activity
  - Highly integrated in Agency/MSFC Heavy Lift Vehicle evaluations
    - Exploration Systems Architecture Study (ESAS)
    - Constellation
    - Review of U.S. Human Spaceflight Plans (Augustine Commission)
    - Heavy Lift Launch Vehicle Study (HLLV)
    - Heavy Lift Propulsion Technology (HLPT)
    - Human Exploration Framework Team (HEFT)
    - Space Launch System (SLS)
Earth To Orbit Design Flow

Processes can be adjusted if necessary
Integrated Rocket Sizing (INTROS)

- Developed at MSFC
- Written in Visual Basic for Applications
- Approx. 600 subroutines and user defined functions
- Robust Mass Estimating Relationship (MER) database
- Utilizes basic spreadsheet inputs
- Establishes
  - Launch vehicle concept design
  - Stage sizing
- Facilitates
  - Integration of exterior analytical efforts
    - Structures, trajectories, element engineering
  - Vehicle architecture studies
  - Technology and system trades
  - Parameter sensitivities
Building INTROS Model

- Typically begin with established vehicle file(s)
- Top-level vehicle layout
  - Inline, number of stages, crew or cargo, boosters
- Body Geometry
  - Identify primary (load bearing) structures
  - Initially size propellant tanks
- Propulsion System
  - Engine type and arrangement
  - Define: mixture ratio, ullage, propellant properties
  - Evaluate fit and clearances
- Equipment selections and routine
  - Select items to be included in stage design
  - Routine is run that populates a mass accounting sheet
INTROS Mass Accounting

- **Primary Structures**
  - Interstage, intertank, skirts, tanks
  - Thrust/attach structure

- **Secondary Structures**
  - Closeout, fairings
  - Baffles (anti slosh/vortex)
  - Access tunnels

- **Separation Systems**
  - Stage-to-stage, fairing

- **Thermal Systems**
  - Closeout, thermal curtains, cork
  - Tank insulation
  - Equipment cooling
• **Main Propulsion System**
  - Engines
  - Engine installation
  - Feed Systems
  - Pressurization Systems
  - Pneumatic Systems
  - Thrust Vector Control
  - Upperstage Considerations
    - Repressurization
      - He bottles/lines
      - Restart equipment

Shuttle MPS
INTROS Mass Accounting

- **Power – Electrical**
  - Battery system
    - Cells
    - Conversion & distribution
    - Circuitry

- **Power – Hydraulic**
  - Hydraulic Auxiliary Power Units
  - Fuel storage & plumbing
  - Cooling system

- **Avionics**
  - Data mgmt/handling
  - Thrust Vector Control electronics
  - Instrumentation
  - Range safety
  - Guidance Navigation & Control
**Mass Accounting Wrap-Ups**

- **Stage Dry Mass with Growth**
- **Stage Burnout Mass**
  - Residuals
  - Reserves
  - In-flight losses
- **Stage GLOM**
  - Propellant
  - Purge helium
- **Vehicle GLOM**
  - Payload
  - Shroud
  - Provisions
  - Launch Abort System
  - Boosters

### Mass Accounting Table

<table>
<thead>
<tr>
<th>Mass Category</th>
<th>Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>STAGE DRY MASS W/O GROWTH</td>
<td>Dry mass growth allowance</td>
</tr>
<tr>
<td>STAGE DRY MASS W/GROWTH (mdry)</td>
<td>Residuals: Main propellant (liquid residual)</td>
</tr>
<tr>
<td></td>
<td>Prop Tank Pressurization Gases: Liquid Oxygen tank</td>
</tr>
<tr>
<td></td>
<td>Liquid Hydrogen tank</td>
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<tr>
<td></td>
<td>Subsystems                    Reserves: Main propellant (FPR)</td>
</tr>
<tr>
<td></td>
<td>Fuel bias</td>
</tr>
<tr>
<td></td>
<td>APU reactants</td>
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<tr>
<td></td>
<td>In-flight Fluid Losses: APU reactants</td>
</tr>
<tr>
<td>STAGE BURNOUT MASS (mbo)</td>
<td>Main Ascent Propellant: Liquid Oxygen</td>
</tr>
<tr>
<td></td>
<td>Main Oxidizer Tank            Main Fuel Tank</td>
</tr>
<tr>
<td></td>
<td>Oxidizer Feedlines            Fuel Feedlines</td>
</tr>
<tr>
<td></td>
<td>Liquid Hydrogen                Engine purge helium</td>
</tr>
<tr>
<td>STAGE GROSS LIFTOFF MASS (mgross)</td>
<td>Stage start propellant               Stage start propellant</td>
</tr>
<tr>
<td>STAGE PRELAUNCH GROSS MASS (mplgross)</td>
<td>Vehicle Stackup: Payload              Payload shroud</td>
</tr>
<tr>
<td></td>
<td>Payload shroud provisions (external PL.)</td>
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<tr>
<td></td>
<td>Launch escape system (LES)</td>
</tr>
<tr>
<td></td>
<td>Upper stage(s), gross</td>
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<tr>
<td></td>
<td>Strap-on(s), gross liftoff</td>
</tr>
<tr>
<td></td>
<td>Prelaunch gross</td>
</tr>
<tr>
<td></td>
<td>Less strap-on start consumption</td>
</tr>
<tr>
<td>VEHICLE GROSS LIFTOFF MASS (mgross_veh)</td>
<td>Stage start propellant              Stage start propellant</td>
</tr>
<tr>
<td></td>
<td>Strap-on start consumption</td>
</tr>
<tr>
<td>VEHICLE PRELAUNCH GROSS MASS (mplgross_veh)</td>
<td>Vehicle Stackup: Payload              Payload shroud</td>
</tr>
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<td></td>
<td>Payload shroud provisions (external PL.)</td>
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<td>Launch escape system (LES)</td>
</tr>
</tbody>
</table>
Transfer to Trajectory

• **Program to Optimize Simulated Trajectories**
  - POST 3D
  - FORTRAN 77 based developed at Langley
  - Targets and optimizes point mass trajectories for powered/unpowered vehicle near arbitrary rotating, oblate planet
  - Offers discrete parameter optimization capability

• **POST inputs from INTROS**
  - Target payload
  - Gross Liftoff Mass/Stage dry masses
  - Propellant load
  - Reference areas
  - Booster data
  - Engine data
  - Shroud/LAS mass
  - Injected weight estimate

• **Additional inputs**
  - Initial position and orientation
  - Wind profile
  - Atmosphere model
  - Gravity model
Trajectory Analysis

- **Constraints**
  - Determined by ground rules
  - Acceleration
  - Dynamic pressure
  - Final orbit
  - Free molecular heating rate: determines shroud drop

- **Outputs**
  - Optimized injected mass/payload
  - Flight profile to reach desired orbit
  - Vehicle orientation in orbit
  - Final state vector of vehicle
INTROS Model Revision

• Data from performance run is fed into vehicle model
  – Event timing with velocity
    ▪ Booster burn/jettison
      - SRB overboard mass
    ▪ Shroud jettison
    ▪ Main Engine Cutoff and staging
    ▪ Sub-orbital events
  – Injected mass
  – Total velocity change

• Data used to resize stages
  – Plus/minus propellant
  – Plus/minus payload
  – Propellant offload if stage fixed

• Redundant calculations are performed
  – Verifications
    ▪ Engine power levels and throttle settings
    ▪ Propellant flow rates and transient mass
    ▪ Stage impulse

• Eliminates a lot of common errors and adds scrutiny
Specific information is passed to the structural analyst.
Structural Analysis - LVA

- Standalone application for quick turnaround launch vehicle structural design and analysis
  - Provides itemized masses for primary structural elements
- Written at MSFC in Visual Basic
- Uses time proven engineering analysis methods
  - Material properties, load factors, aerodynamic loads, stress, elastic stability
  - Loads are run as single combined worst case
  - Also capable of analyzing event-specific loads
- Program designed to operate with minimum input
- LVA and predecessors serving NASA for over 26 years
• **Itemized primary structure mass**  
  – Tanks, skirts, shroud, intertank, interstage, thrust structure

• **Shear/bending moment/compression diagram**

![Graph of LVA Output](image)
• **Scale depiction of concept**
  – Station numbering
  – CG, CP, and concentrated masses
  – Identifies interferences and illustrates margins

• **LVA-determined masses are incorporated in INTROS**
• **For resizing purposes, new unit mass ratios are integrated**
Closing the Loop

- Iterative trajectory runs are made until injected mass predictions and actuals close within 300 lbm
- If loads break boundaries another LVA iteration is required
- Final report is generated (baseball card)
Sensitivities Short List

• Engine performance
  – Power level, thrust, impulse, mass
• Cargo or crew
• Shroud variables
  – Geometry, material, jettison time, payload density
• Boosters
  – Propellant, trace, case material, size, thrust, attach point
• Structural materials & design
  – Composites integration, battleship construction, tank location, hammerhead
• Mass Growth Allowance
• Ullage
• Flight Propellant Reserve
• Trajectory
  – Insertions orbit/inclination
  – Aerodynamic load constraints
  – Throttle profiles/engine out
• ACO ETO Team provides unique capability for NASA and MSFC
• Supported every agency / center level vehicle study from ESAS (2005) forward
• Jacobs ESTS employees are integral to this team
• The covered process is very streamlined & efficient
• Continued value through exterior input

• Thanks!

• Questions?