PEG Modifications & Enhancements for SLS Block-1 and Block-1B Vehicles

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**Introduction**

- Marshall Space Flight Center (MSFC) Guidance, Navigation, & Control (GN&C) Team has an expanded responsibility going from Space Launch System (SLS) Block-1 to Block-1B vehicles
  - Characteristics of Block-1 ascent burn allow for use of a modified version of Space Shuttle’s Powered Explicit Guidance (PEG) algorithm
  - Long-arc burns and the need to carry out Lunar Vicinity and Earth Escape missions require enhancements to PEG for Block-1B

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Block-1 Modifications to PEG Since Shuttle

**Block-1’s ascent burn arc (~13°) similar size as Space Shuttle**
- Allows for straight adaptation of Shuttle’s PEG with the ascent desired velocity mode

**Modifications:**
- Multi-phase PEG and PEG Phase Manager
  - Replaces Shuttle’s algorithmic approach to switch between 3 phases for a data-driven approach
  - Moves calculation of most burn times and all mass-flowrate-to-initial-mass time constants out of time-to-go computation algorithm into an outer loop wrapper
- Lofting parameter for Launch Abort System Jettison
  - Induces additional lofting by applying an altitude bias to the desired radius magnitude
- Engine-Out Logic
  - Uses inertial velocity to decide if an alternate mission target is needed in response to a CS engine-out
- Thrust Factor
  - Similar to Shuttle’s FT_FACTOR
  - Provides updated propulsion knowledge to PEG

*Modifications allow an outer loop to drive PEG for Block-1*
Block-1B 1-target VS 2-target Ascent Guidance

**Block-1B Ascent Profile**
- Boost stage: Two Solid Rocket Boosters and CS engines burn to booster separation
- CS burn: CS engines burn to intermediate point in ascent trajectory
- EUS Ascent: EUS engines burn to LEO insertion

**Two flight techniques studied early in Block-1B design:**

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<td>Separate targeted burns for CS and EUS Ascent (i.e. PEG reset for EUS Ascent burn)</td>
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- **2-target baselined for Block-1B**
- **1-target presented several convergence issues that led to several bullet-proof enhancements to PEG kept for Block-1B**

**Challenging 1-target guidance problem led to several bullet-proofing enhancements for PEG**
**Block-1-to-Block-1B Enhancements**

- **Safeguards for Constructing Turn Rate Vector**
  - Limiting Tangent of Thrust Angle
    - Useful initial strategy to limit turn rate magnitude
    - Bullet-proof enhancement from 1-target problem
  - Elevation-limit
    - Shuttle heritage
    - Ensures thrust direction from PEG’s steering law does not have a component retrograde compared to cutoff radial direction
    - Required to close engine-out 2-target scenarios
  - Sign Reversal of Thrust Turning Rate Vector
    - Constructs augmented coordinate frame to protect orthogonality constraint from yielding a thrust turning rate sign reversal
    - Bullet-proof enhancement from 1-target problem

*Safeguards developed for Turn Rate Vector to address stress situations due to long-arc burns*
Block-1-to-Block-1B Enhancements

- **Scaling Identity Jacobian in PEG Corrector**
  - Applies a contraction factor to PEG’s traditional Identity matrix Jacobian as a simplified scheme to improve PEG’s convergence for long-arc burns
  - Bullet-proof enhancement from 1-target problem

- **Plane Constraint Strategy**
  - Strategy to unify plane constraint for both ascent and in-space burns
  - PLANE_OFF, RV_NULL, V_NULL, INTERCEPT

- **New Desired Velocity Routines**
  - Linear Terminal Velocity Constraint
    - Shuttle heritage
    - Used for ARB and TLI burns
  - Hyperbolic Target

Additional enhancements bullet proof PEG and make PEG capable of carrying out Block-1B missions
Conclusion

- Space Shuttle PEG modified to accommodate initial evolution of SLS, Block-1
- Several enhancements to PEG required going from Block-1 to Block-1B to carry out demanding Block-1B missions
- Improvements make PEG capable for use on the SLS Block-1B vehicle as part of the GN&C System
Thank you!

Any questions?
PEG Linear Tangent Guidance Geometry

Current LVLH ($X_L; Z_L$)

Trajectory, or burn arc

$\vec{\lambda}(t_o)$

$\vec{\lambda}(t_{ref}) = \vec{\lambda}_c$

$\vec{\lambda}(t_o + t_b)$

Thrust angle ($\phi$)

Thrust vector rotation direction (inertial thrust arc)

$Z_L$

$Z_G$ Cutoff LVLH ($X_G; Z_G$) or Guidance Frame