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Forum 116

Interplanetary Terminal Procedure Design Applied to Lunar Landing

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Interplanetary Terminal Procedure Design Applied to Lunar Landing

iTERPS

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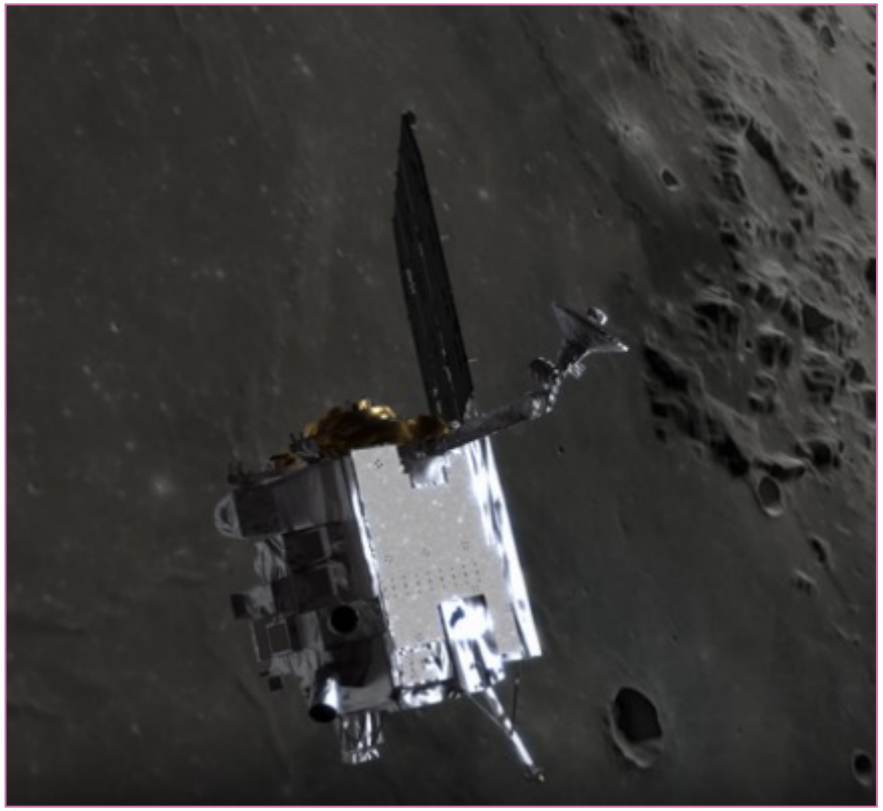
Background and Purpose

- Sea of Tranquility landing under Visual Flight Rules (VFR)
- Lunar south pole necessity for Instrument Flight Procedures (IFR)

iTERPS

A working theory to leverage current terminal procedure design (TERPS) criteria augmented with lunar physics in support of the exploration of the Moon, Mars and beyond



iTERPS Overview

- Lunar Procedure Innovation
- Entry Descent Approach and Landing
- Procedure Construction and Evaluation

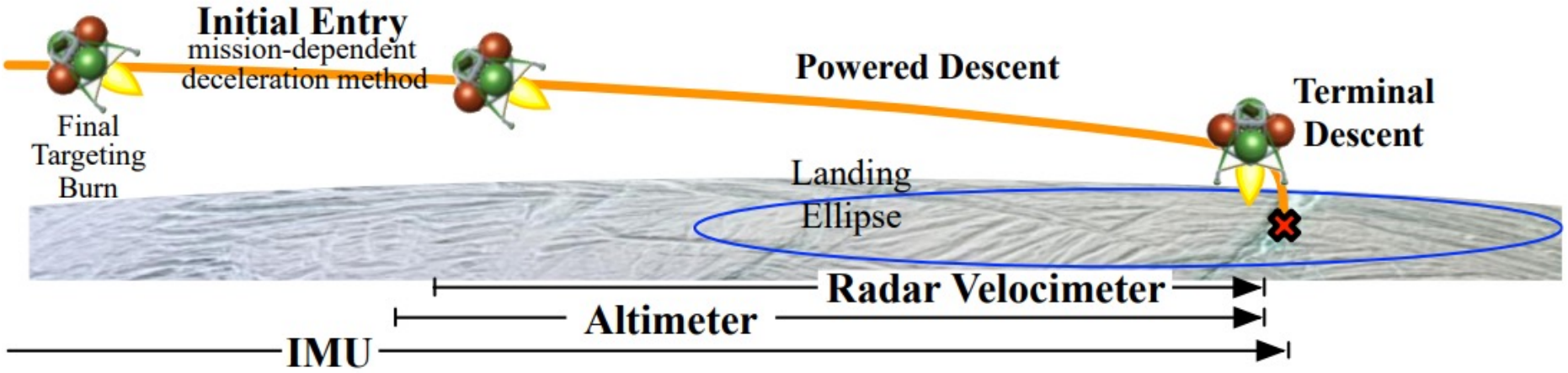
Lunar Procedure Innovation

- Human factors-vetted approach / missed approach procedures
- Scalability of Point-in-Space (PinS) safety calculations
- Applicability to Advanced Air Mobility procedure development & training
- Innovative fixed altitude-variable entry PinS approach
- Dynamic approach plate with vehicle interoperability

Entry Descent Approach Landing (EDAL)

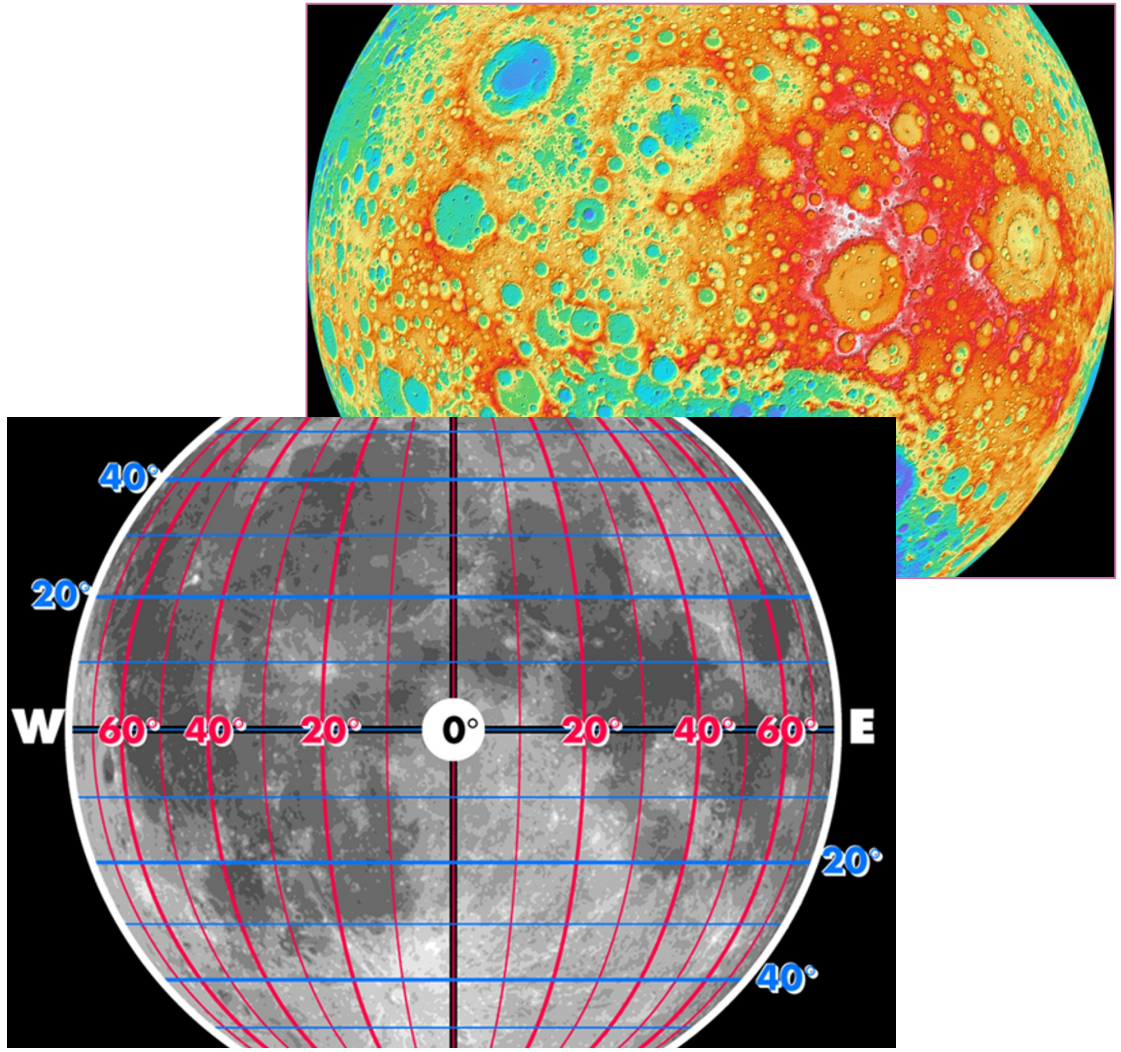
Entry Descent Landing (EDL) becomes Entry Descent *Approach* Landing (EDAL). Inclusion of approach procedures will provide innovative solutions to enable the safe execution of lunar landings:

- Construction
- Evaluation
- Validation
- Execution



EDAL Evaluation

- Lunar coordinates for waypoints via Selenographic coordinate system
- Satellite mapping
- Controlling obstacle identification and hazard mitigations



EDAL Construction

Landing Considerations

- **Obstructions-** Obstruction evaluation airspace analysis
- **Terrain-** Digital terrain elevation data
- **LiDAR-** Precision survey spatial data
- **Hazardous Conditions**

Vehicle Considerations

- **Flight Characteristics-** Flight controls with lunar physics
- **Energetics-** Dissipation of energy to arrest entry velocity & deceleration to zero-zero landing
- **Slope / Tilt Limitations**

iTERPS Design

- Lunar Unit Conversion
- Fixed Altitude Variable Entry Approach
- Dynamic PinS Approach Evaluation

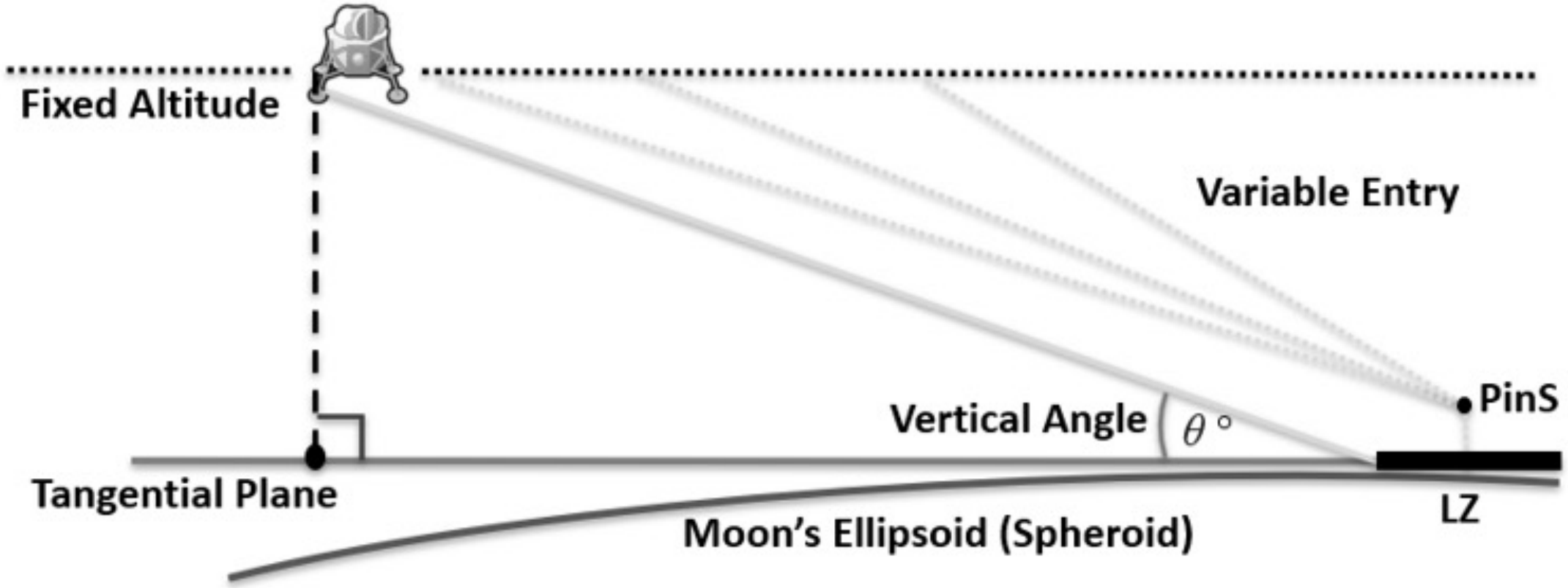
iTERPS Lunar Unit Conversion

Apply existing PinS precision approach criteria with augmented lunar physics, radius and vehicle handling qualities/characteristics to generate a lunar approach plate and coding.

Formula	Earth	Moon
Distance Glidepath	▪ Barometric distance ▪ Earth radius	▪ Vertical distance (ft or m) ▪ Moon radius
Turn Anticipation	▪ Heading change (degree)	▪ Vehicle limitation
Reaction and Roll	▪ Human + avionics (GNC)	▪ Autopilot + avionics + pilot monitor
Deceleration	▪ Earth gravity	▪ Moon gravity

EDAL Fixed Altitude - Variable Entry Approach Concept

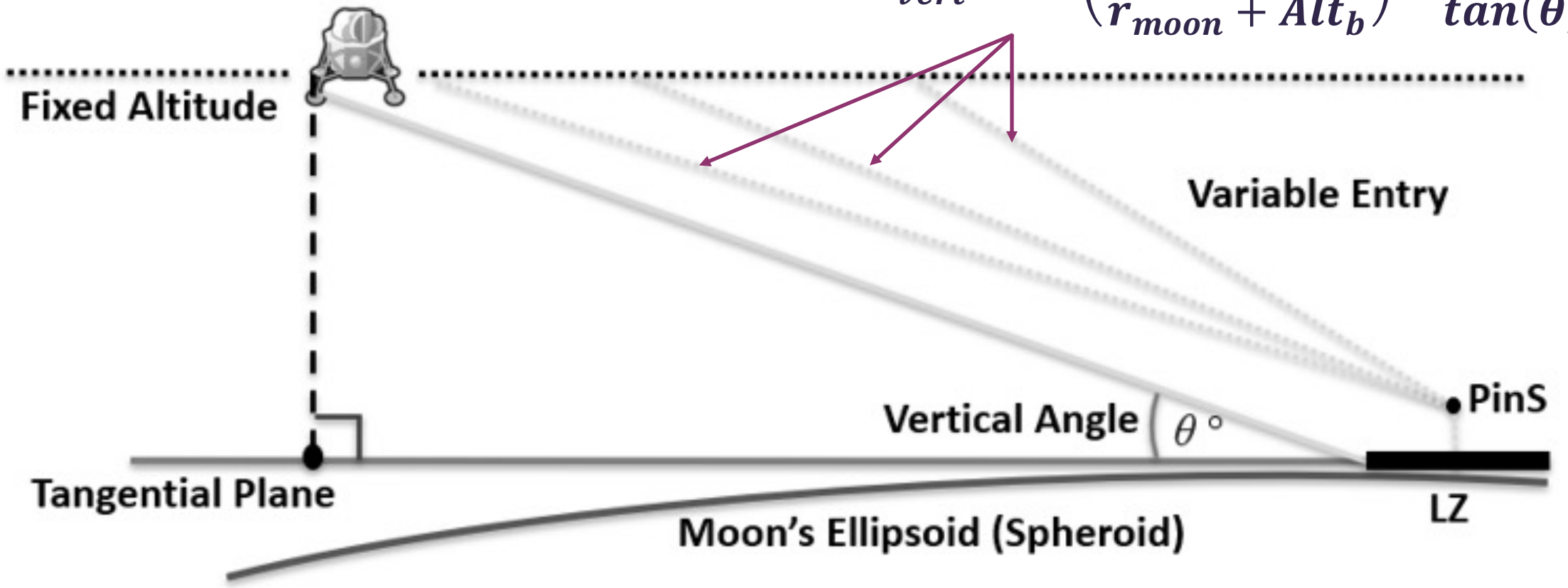
Tailor **glideslope intercept** to any PinS zero-zero landing.



EDAL Fixed Altitude - Variable Entry Approach Concept

Vertical distance between two points on glidepath

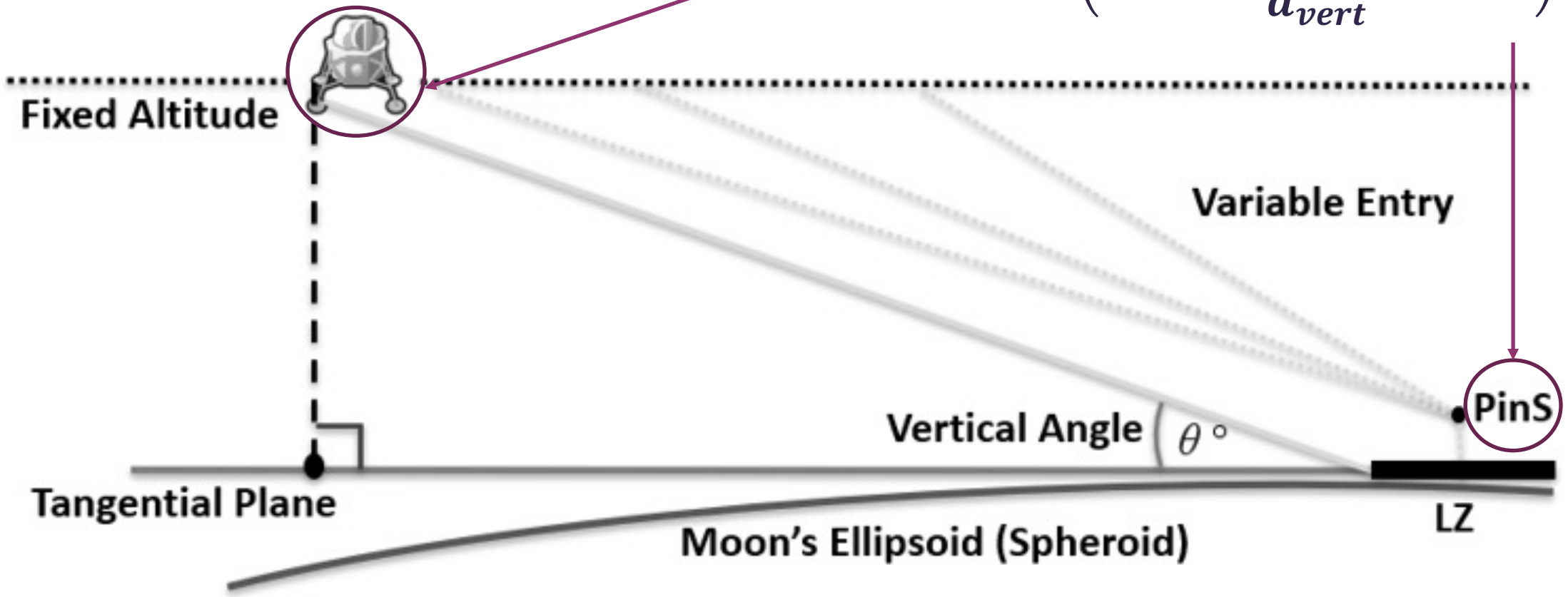
$$d_{vert} = ln\left(\frac{r_{moon} + Alt_e}{r_{moon} + Alt_b}\right) \text{x} \frac{r_{moon}}{tan(\theta)}$$



EDAL Fixed Altitude - Variable Entry Approach Concept

Descent angle capture

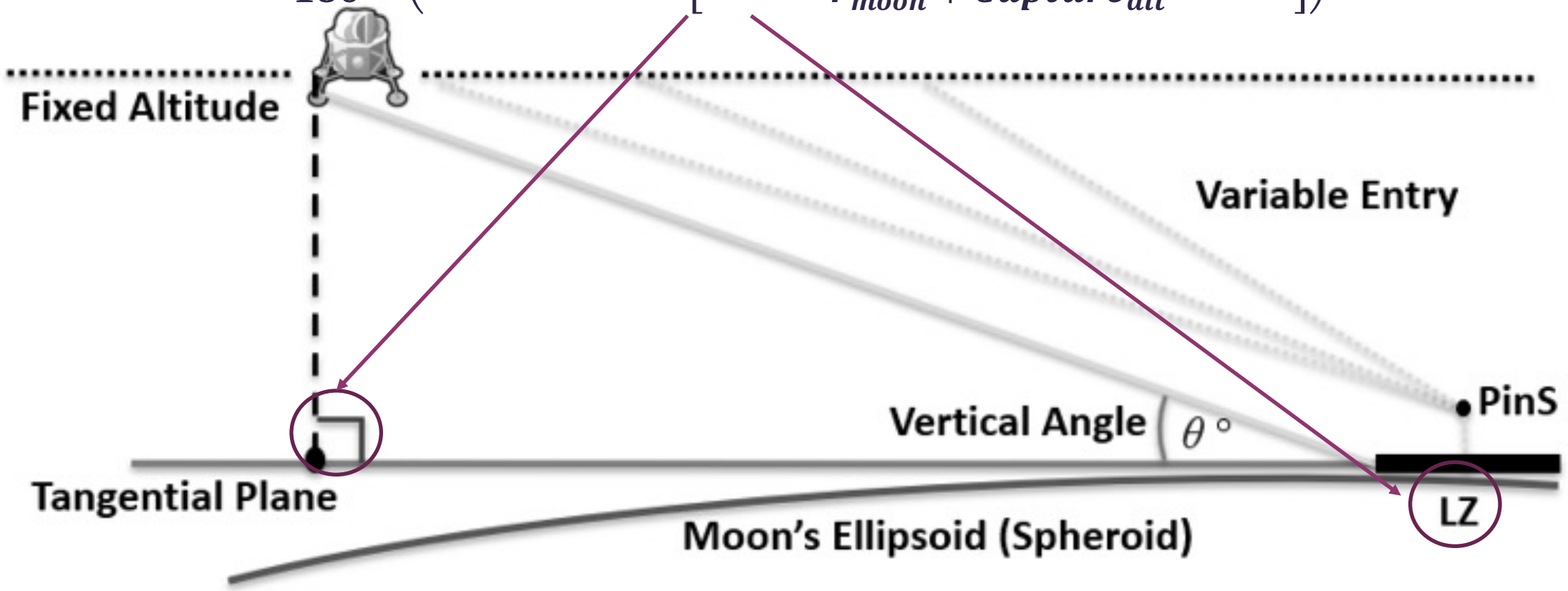
$$Capture_{\theta} = atan\left(\frac{Capture_{alt} - 300_{alt_e}}{d_{vert}}\right)$$



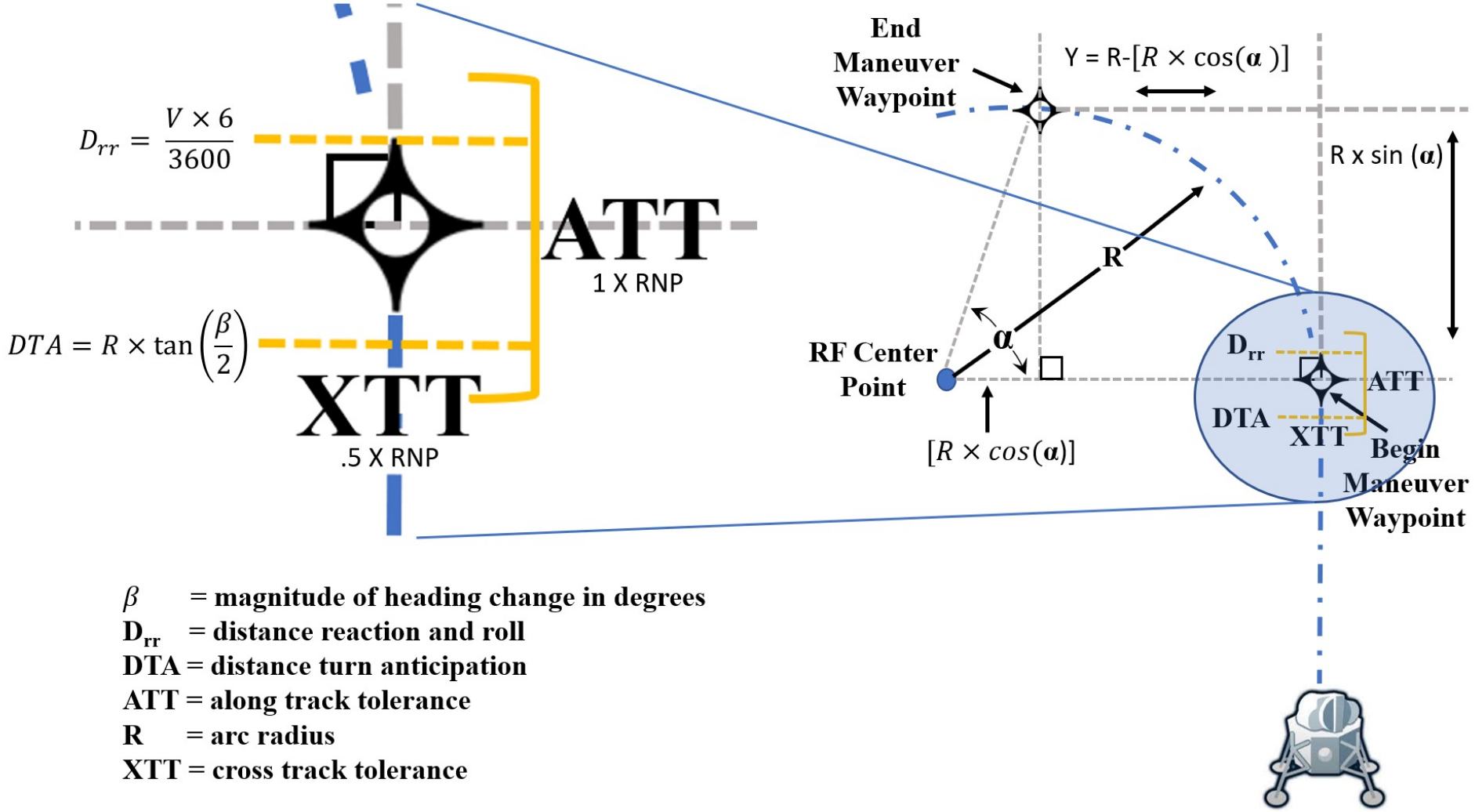
EDAL Fixed Altitude - Variable Entry Approach Concept

Minimum distance for descent angle capture

$$Capture_{Dmin} = \frac{\pi\, r_{moon}}{180}\left(90 - \theta - sin^{-1}\left[\frac{cos(\theta)(r_{moon} + LTP_{elev} + 300_{alt_e})}{r_{moon} + Capture_{alt}}\right]\right) - FAS_{Length}$$



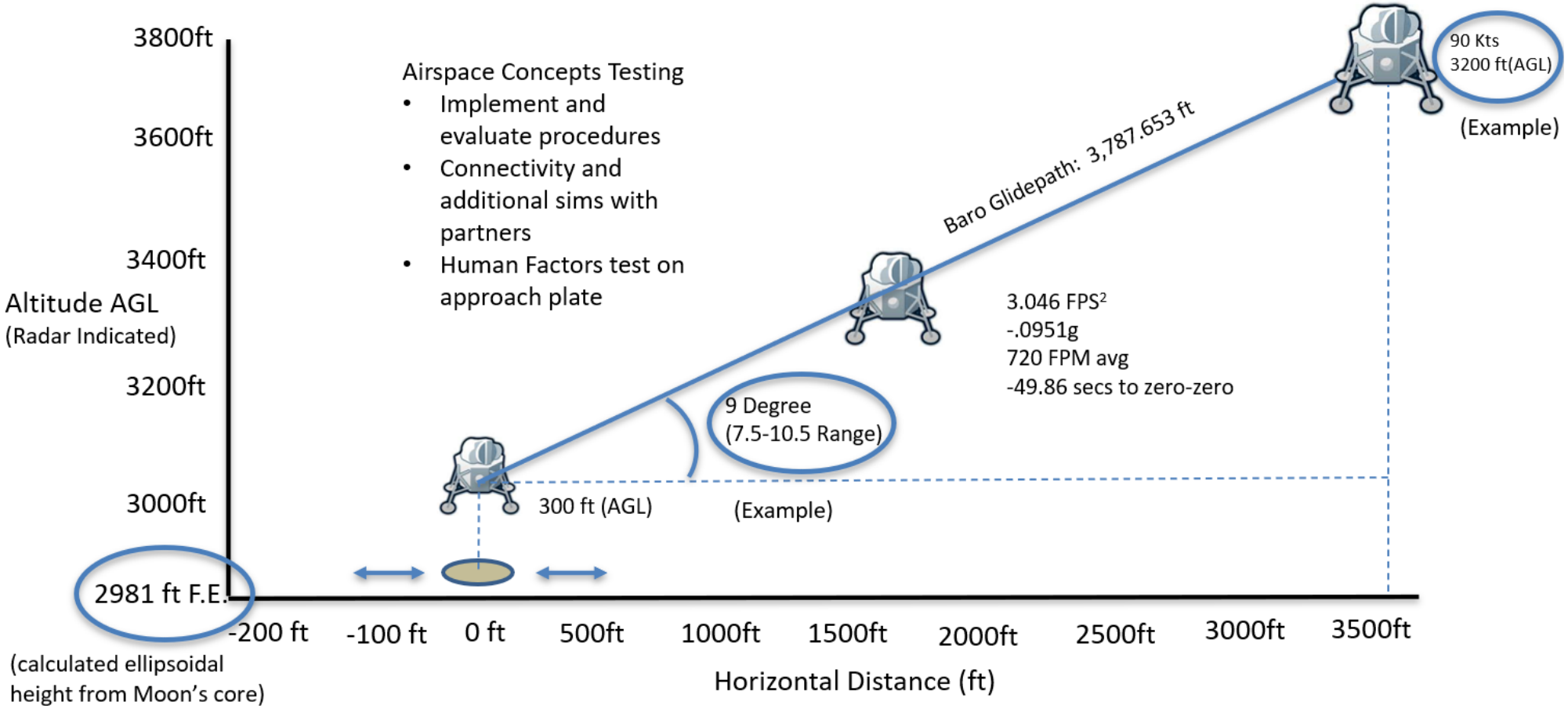
EDAL Fixed Altitude - Variable Entry Concept



β = magnitude of heading change in degrees
D_{rr} = distance reaction and roll
DTA = distance turn anticipation
ATT = along track tolerance
R = arc radius
XTT = cross track tolerance

EDAL PinS Approach

Lunar Quad-Zero PinS Approach



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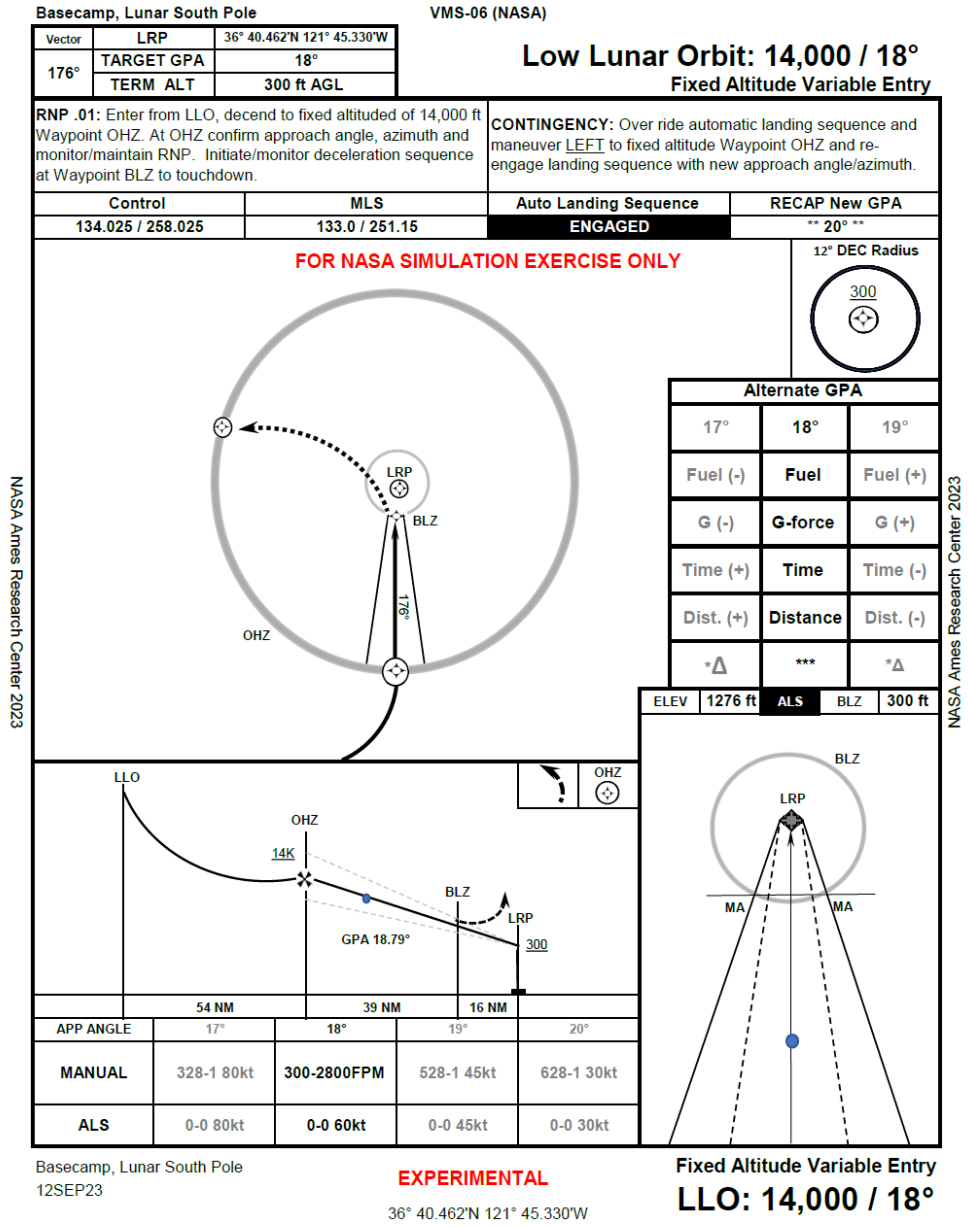
iTERPS Approach Plate

- Lunar Approach Plate Design
- Pilot Training

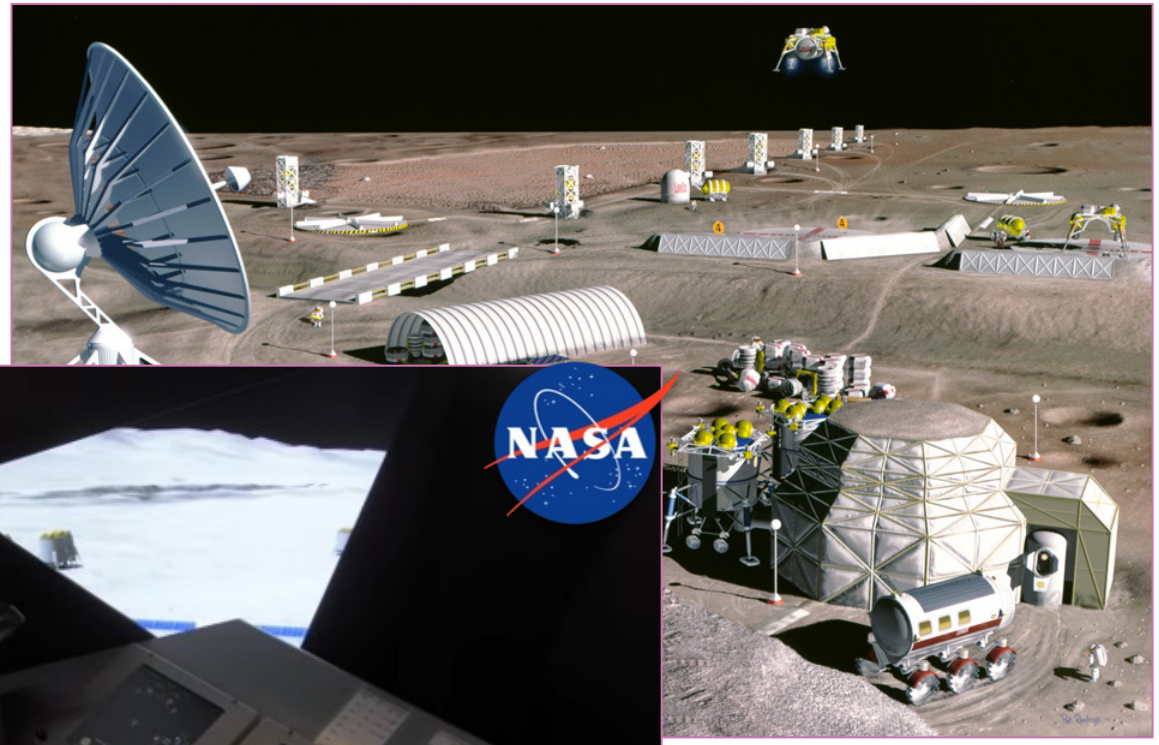
iTERPS Approach Plate

- Cross-monitor pilot/autopilot performance
- Human factors-vetted format
- Novel fixed altitude variable entry approach
- Contingency management through dynamically-generated approach



iTERPS Implementation

- Safety
- Standardized Training
- Scalability



Envisioned Lunar Base

NASA Ames Research Center Vertical Motion Simulator (VMS)

Conclusion

- Interplanetary Terminal Procedure Design
- Construction, Evaluation, Validation, and Execution
- Lunar Approach Plate
- Entry Descent “Approach” and Landing (EDAL)

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