

# Interplanetary Terminal Procedure Design Applied to Lunar Landing

David Zahn<sup>1</sup>

*National Aeronautics and Space Administration, Oklahoma City, OK, 73179, U.S.A.*

Sarah Eggum<sup>2</sup>

*National Aeronautics and Space Administration, Sim Labs III, Oklahoma City, OK, 73179, U.S.A*

**The impending NASA Artemis mission to the Moon will enable deep space exploration. The planned cadence of crewed Moon missions under Artemis necessitates scalable, safe lunar landings. This paper describes the development of Interplanetary Terminal Procedure Design (iTERP) which leverages current terminal procedure design criteria augmented with lunar physics to support the exploration of the Moon, Mars and beyond. The iTERPS model combines lessons learned from decades of commercial airspace operations with novelties of human space exploration on other worlds. This paper will highlight some of the key functional areas in procedure design safety, training, and operations reimaged for human space flight.**

## I. Nomenclature

$A$	= acceleration
$Alt_b$	= altitude beginning
$Alt_e$	= altitude ending
$Capture_{alt}$	= capture altitude
$Capture_{dmin}$	= minimum distance for descent angle capture
$Capture_{\theta}$	= descent angle capture
$d_{vert}$	= vertical distance between two points on glidepath
$FAS_{Length}$	= distance of final approach segment
$\ln$	= natural logarithm
$LTP_{elev}$	= landing touchdown point elevation
$r_{moon}$	= celestial radius of the Moon
$\tan(\theta)$	= tangent of glidepath angle
$V_f$	= final velocity
$V_i$	= initial velocity

## II. Introduction

The National Aeronautics and Space Administration (NASA) is preparing capabilities for a mission to the Moon for scientific discovery and economic benefits. The Artemis program will progress towards a future crewed mission from the Moon to Mars, for which a cadence of crewed Moon missions over the next decade will necessitate scalable, safe lunar landings. The U.S. Artemis program is targeting a maiden voyage to the lunar south pole for exploration of the Moon's ice cap, where the potential exists to harvest lunar water as fuel, oxygen, and for human consumption for both extended Moon habitation and deeper space exploration [1]. Reliable landings for the human landing system are the first measure of success towards these future missions.

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<sup>1</sup> NASA Research Pilot, Ames Research Center.

<sup>2</sup> NASA (Sim Labs III) Data Scientist, Ames Research Center.

To address the challenges associated with the landing locations and profiles expected for the Artemis mission, an innovative approach, Interplanetary Terminal Procedure Design (iTERPS), is proposed for consideration. iTERPS is a working concept to leverage current terminal procedure design (TERPS) criteria augmented with lunar physics to support the exploration of the Moon, Mars and beyond. The iTERPs concept leverages existing criteria and procedures for landing approaches and contingency abort processes for aircraft on Earth that are reimagined for the Moon. The concept described in this paper will provide a Moon-based construct which simultaneously accounts for Moon-referential datum and vehicle performance applied for lunar conditions.

This paper outlines how the iTERPS model can solve many of these challenges by employing proven terrestrial methods and reimagined approach plates tailored for lunar procedures. The paper provides an overview of the lunar terminal procedure design to accomplish safe and scalable lunar landings in section III, provides the specifics for the type of entry approach necessitated by lunar conditions in section IV, reviews how to transform procedures to a Moon-referenced system in section V, applies necessary calculations and adherences to lunar terminal procedures in section VI, and explores an innovative lunar approach plate for candidate procedure training and execution in section VII before concluding in section VIII. If implemented, iTERPS would change the current orbital landing ideology concept from Entry, Descent, and Landing (EDL) to Entry, Descent, Approach and Landing (EDAL). This paper will provide the rationale for the inclusion of precision TERPS “approach” methodology within the orbital landing construct.

### III. Background

In previous missions to the Moon under the NASA Apollo program, many of the targeted landing areas were upon the Sea of Tranquility, an equivalent of the Sahara Desert. The large, relatively flat surface allowed a pilot to visually acquire the expansive landing surface in relation to the Moon’s horizon within a low-profile vehicle to ensure a safe landing. Direct sunlight in the cabin was deliberately avoided during those missions because the vehicle was oriented to provide a visible shadow of the lander on the Moon’s surface, which acted as an additional altitude cue. The pilot could visually determine closing distance coupled with appropriate speed deceleration [2]. The lunar south pole creates a much more complex and challenging landing approach given rising terrain, boulders, shadows, lunar regolith, and the possibility of direct sunlight in the cabin. These factors would generate instrument meteorological conditions (IMC) and necessitate an instrument flight rules (IFR) framework from orbit to the ground.

The last U.S. lunar landing occurred on December 19, 1972, during the Apollo XVII mission. The precision approach to precision landing and hazard avoidance utilized a blind soft-landing method. From entry, a final targeting burn was initiated followed by a powered descent to a terminal descent over a non-specified landing area as seen in Fig. 1. The equipment consisted of an inertial measurement unit, an altimeter, and a radar velocimeter. This capability sufficed for the visual environment of the landing site, which required the acuity and dexterity of the astronaut pilots. The previous landings encountered environmental hazards including plume and sight alteration physics and lunar regolith (ejecta dynamics). Plume surface interaction on the lander can lead to aerodynamic destabilization and high convective heating during descent and landing. Plume-induced cratering can lead to the destabilization of the lander upon touchdown violating lander tilt requirements from a suitable/level landing area, such as occurred with Apollo and InSight landers. Lunar regolith has led to loss of instrumentation, degraded functionality, lack of visibility, and radar spoofing [3].

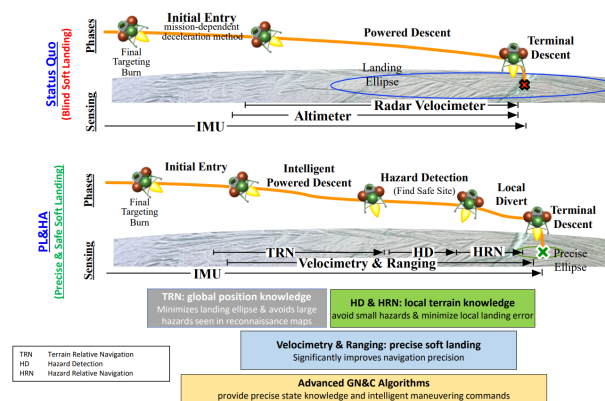


Fig. 1 Profile View Legacy Lunar Approach.

Underscoring the challenges associated with lunar approaches is the failed August 20, 2023 Russian Roskosmos lunar landing where the *Luna-25* spacecraft spun out of control in an unpredictable pre-landing orbit and crashed onto

the Moon's surface. Russia would have been the first of four countries (U.S., India, China, and Russia) to achieve a landing for advanced Moon missions [4]. The India Space Research Organization (ISRO) also successfully landed the spacecraft *Chandrayaan-3* August 23, 2023 in close proximity to the intended landing site of the Russian mission on the south pole of the Moon, The ISRO *Chandrayaan-2* crashed near the same site in 2019 [5]. In contrast, the U.S. mission intends not only to land in one location, but to 'hop' the habitat via rocket to several locations throughout a single lunar mission, all of which could benefit from a prescriptive landing methodology.

A solution is warranted that will deliver operational concepts which enable the safe execution of repeatable and precise landings on the Moon's surface as well as provide for training and viable infrastructure beyond Earth. The iTERPS concept explores the safety case of prescribed precision approaches terminating to a point in space (PinS) at the south pole of the Moon. There is a need to ensure spatial data integrity for the coding fed to a moon lander autopilot system in order to enable both piloted and autopiloted approaches from lunar orbit to the Moon's surface. A precision predictable approach will enable greater accuracy for budgeting of fuel. Another important requirement is to provide guidance for mission lander crews to ensure standardization of the human-machine interface via an approach plate for either manual procedures and navigation or for a pilot to cross monitor the performance of an autopilot system. The approach plate will leverage current practices for pilot training and display within a traditional format that has been properly vetted for human factors but reimagined for lunar operations. Current PinS approach research [6] within NASA's Aeronautic Research Mission Directorate (ARMD) was utilized to develop the iTERPS methodology for future lunar procedure construction, evaluation, validation and execution.

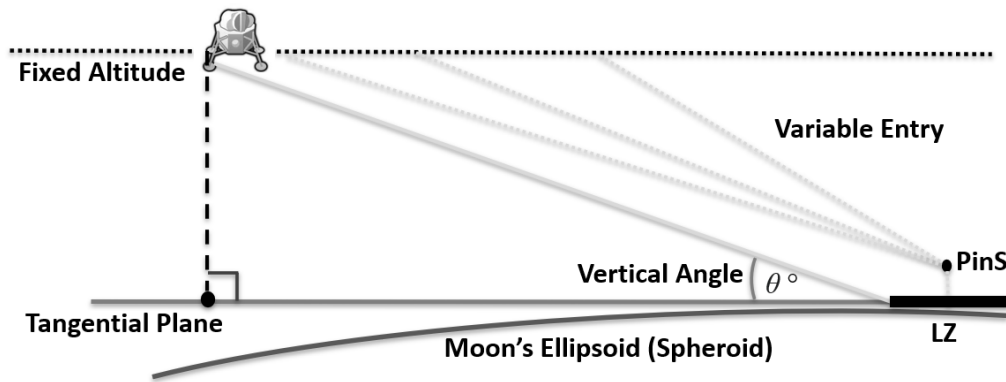
#### IV. Methodology

The solution proposed in this paper is to adapt IFR procedure construction used for aircraft on Earth to the lunar landing challenges. IFR is defined as a series of predetermined maneuvers that ensure adequate, safe separation from terrain and vertical obstructions given vehicle performance parameters. The dynamic generation of instrument procedures is a current research topic within the aeronautics field as a method to quickly assess and orchestrate a landing maneuver, piloted or autopiloted. The iTERPs approach is designed to account for variation among pilots, vehicles under operation, and for targeted landing conditions and environments. To standardize the design, a modular concept can be used to account for the performance variables and characteristics of each lander. The Artemis program has employed multiple piloted design variants such as: SpaceX *Starship* and Blue Origin *Blue Moon*, each with unique design and performance considerations [1]. The iTERPS model is designed to tailor a procedure for any vehicle configuration, location or operation to include automated robotic landers. As such, the methodological bridge is wide enough to bear the weight of future evolving technologies and designs. The intent is to avoid one-off landings in one-off locations that depend upon the experience, or the control touch, of a given pilot or pilots. A congruent level of expected safety performance can be realized through the introduction of a lunar approach plate aligned to critical information and content for precise lunar landings. An approach plate standardizes a maneuver from pilot to pilot through format and training. The method supports reverse engineering from multiple vehicles and pilots for a variety of landing conditions and environments.

##### A. Fixed Altitude-Variable Entry Approach

In order to construct a precision approach procedure, a precise touchdown point on the ground must be defined. From there, a terminal procedure designer builds the approach backwards from the intended point of landing. The touchdown point is defined by two values: one value expresses lateral positioning and the second informs vertical accuracy. For any lunar procedure using earth-based atmospheric data and criteria, many units must be converted to maintain the same ratios of safety. The first unit of conversion for any potential landing zone is the numerical location from latitude and longitude to the selenographic coordinate system from east and west of the Moon's prime meridian. Typically, a high precision latitude/longitude is defined by eight significant figures surveyed to a reference point for a runway threshold or the center of a helipad, but when a ground-based survey is not feasible, as is the case of the first polar lunar landing, a Digital Terrain Elevation Database (DTED) is used in lieu of the survey. The iTERPS model will rely on years of lunar satellite and laser imaging, detection, and ranging (LiDAR) mapping to generate a high-resolution model of the Moon's surface. Once the lateral positioning has been defined, vertical accuracy is typically measured against a field elevation that is based upon the height of a landing surface in reference to sea level. Once again, this is not feasible for lunar procedures, so a vertical datum must be used to measure the height of the potential landing surface from the theoretical center of the Moon's core derived from the constellation of satellites orbiting around the Moon. Once the height of the landing surface is referenced, the radius of the Moon is needed to generate precise movement between two points above an ellipsoidal surface. Because the Entry, Descent, Approach and Landing (EDAL) sequence will cover a large surface area, it is imperative that the Moon's ellipsoid, or oblate spheroid, is subtracted from the tangential plane for any vertical maneuvers to the intended point of landing. As depicted in Fig.

2, many approach paths can be evaluated once these values are determined and an appropriate lateral and vertical separation standard can be applied to terrain and any vertical obstructions (i.e., boulders, shadows, etc.) segmented along the approach.



**Fig. 2 Fixed Altitude-Variable Entry Approach.**

The dynamic approach construct enables a multitude of approach paths that can be generated from any vertical angle from the center reference point of the landing surface. An altitude plane or “gate” is selected to determine the glidepath angle the lunar vehicle will adhere to with a given corresponding approach path. Based upon the selenographic coordinates of the landing vehicle as it intersects the altitude plane or gateway, the combination will dictate a previously evaluated or pre-vetted glidepath angle intercept to the PinS termination established above the landing zone. This methodology will help manage glide path contingencies from orbit and provide a path record and flight guidance coding to adequately cross-monitor a pilot or autopilot conformance via the lunar approach plate through the final approach segment to a safe landing at the intended surface objective.

The iTERPS model will outline a safety use case that will revolutionize human space exploration and showcase iTERPS as an ideal methodology for astronaut safety and training by standardizing the evaluation of multiple landing locations while leveraging years of vetted approach procedure construction and validation. The paper will outline where existing practices can be leveraged and how lunar physics can be effectively intertwined with TERPS criteria.

The development of the iTERP model is described below, broken down into three major topics:

1. Lunar unit conversion for TERPS criteria
2. Lunar approach procedure construction from Low Lunar Orbit (LLO)
3. Lunar approach plate design

## V. Lunar Unit Conversion for TERPS Criteria

The following section outlines general units of measurement that are currently used for instrument approach procedure evaluations and how the iTERPS model maintains the same levels of safety achieved on Earth while scaling up or down to another planetary body.

### A. Selenographic Unit Conversion

The Moon uses selenographic coordinates much like Earth’s latitude and longitude, which is based on a prime meridian that connects the north and south poles. This line creates the east and west designations which is then incrementally sectioned by degrees minutes and seconds from a zero-degree reference point. The lunar equator similarly separates the zero degree north and south from the intersection of the lunar prime meridian. As described in Goddard Space Flight Center’s “A Standardized Lunar Coordinate System for the Lunar Reconnaissance Orbiter and Lunar Datasets”

The Mean Earth/Polar Axis (ME) reference system defines the z-axis as the mean rotational pole. The Prime Meridian (0° Longitude) is defined by the mean Earth direction. The intersection of the lunar Equator and Prime Meridian occurs at what can be called the Moon’s “mean sub-Earth point”. The concept of a lunar “sub-Earth point” derives from the fact that the Moon’s rotation is tidally locked to the Earth. For a landing reference point, a “mean sub-Earth point” will be used to define the target on the lunar surface where Longitude equals 0°. This point does not coincide with any prominent crater or other lunar surface feature. [7]

Additional research will be needed to confirm a one-to-one substitution of selenographic coordinates with TERPS criteria with respect to distance measurements, communication, and navigation that integrates lunar procedure design. Specifically, careful attention will need to be directed towards calculating cartesian coordinates for any arc radius turns required to maneuver to a final approach fix or terminating “hover” altitude .

### B. Ellipsoidal Height Conversion for a Spheroid

The goal of iTERPS is to provide a precision approach with vertical guidance applying equal or greater precision when on the Moon’s surface compared to what is achieved on Earth. As all current IFR procedures hinge on accurate spatial data, so will any conceived lunar approach. In order to have a precision approach within current instrument approach design, a precision survey within alignment of the landing location must be provided. Spatial data is important because it not only confirms the landing location lateral accuracy, but it enables vertical accuracy with respect to the celestial body’s datum, defines surrounding terrain and controlling obstacle heights, as well as serves as a backup for any onboard distance measuring equipment (such as a radar altimeter).

The first difference to be explored for developing iTERPS for the moon is the Earth’s ellipsoid correction for procedure design over great distances and altitude changes compared to the moon’s spheroid shape. In order to achieve the same level of precision achieved using traditional TERPS criteria, the  $d_{vert}$  (vertical distance between two points on glidepath) equation was created (derived from the  $d_{baro}$  formula used in FAA Order 8260.58C) to define the exact vertical distance traveled between two points over a curved surface [8]. This formula applies for subtracting out the curvature of the moon (radius) from a beginning ( $Alt_b$ ) and ending altitude ( $Alt_e$ ), as well as subtracting from the tangent of the glidepath angle taken between the two given points. This equation can be used to dynamically calculate vertical distances from LLO against multiple glide path angle tangents.

$$d_{vert} = \ln \left( \frac{r_{moon} + Alt_e}{r_{moon} + Alt_b} \right) \times \frac{r_{moon}}{\tan(\theta)} \quad (1)$$

### C. Lunar TERPS Criteria

Once unit conversions for vertical and lateral dimensions for iTERPS on the moon have been established, criteria for onboard processing of current and potential paths points to one or many locations can be evaluated with a standardized methodology. The resulting criteria will drive standards that may then build policy and regulations for multiple vehicles attempting to achieve the same level of precision from LLO throughout the EDAL sequence. One of the aspects worth exploring is the approach path angle or multiple angles required to execute a precision landing to a point on the moon’s surface. This approach angle may need to be captured dynamically from entry and given a set of constraints or criteria so a landing location’s suitability from any entry point can be determined. Without evaluating vehicle structural or pilot maneuvering limitations, iTERPS criteria will be used to assess the required descent angle of a candidate approach as well as the distance required to capture the descent angle that will include a descent and deceleration leg component. Additional lunar iTERPS criteria can be found in the Appendix.

The first criteria that iTERPS will leverage from the traditional IFR framework will be to determine a suitable capture leg descent angle for the approach portion of the landing sequence. Formula (2) was created to inform the pilot as well as mission control about the suitability of an approach angle to a specific location. Suitability can be defined by a variety of variables such as human factors, time, or fuel efficiency. Based on the fixed altitude variable entry approach construct, any  $Capture_{alt}$  can be selected, and any zero-velocity termination point can be input that is desired or deemed suitable. For this example, 300<sub>alt\_e</sub> feet was used as the deceleration altitude to achieve zero velocity above the lunar regolith plume over the intended landing location [9].

$$Capture_{\theta} = atan \left( \frac{Capture_{alt} - 300_{alt_e}}{d_{vert}} \right) \quad (2)$$

The second criteria that iTERPS will leverage from the traditional IFR framework will be the minimum required distance for a particular approach angle given current IFR procedure design criteria. The iTERPS model explores “taking what works and leaving what doesn’t work” approach (pun intended) when leveraging terrestrial procedure design concepts. The following formula is an example of how a minimum distance required for capturing an approach angle could work. The variables consist of the candidate approach angle as depicted by  $\theta$ , the intended landing

touchdown point elevation given a 300 ft. buffer as the hover or zero velocity termination point and the Final Approach Segment (FAS) length imagined for the course.

$$Capture_{Dmin} = \frac{r_{moon} \times \pi}{180} \times \left( 90 - \theta - \sin^{-1} \left[ \frac{\cos(\theta) \times (r_{moon} + LTP_{elev} + 300_{alt_e})}{r_{moon} + Capture_{alt}} \right] \right) - FAS_{Length} \quad (3)$$

## VI. Lunar Approach Procedure Construction

Once an established course inbound to the landing location is determined, the approach procedure can be constructed backwards from the LTP to the current altitude and location of the lunar landing module. Three areas covered within this section are the vehicle path to the landing site with respect to terrain and vertical obstructions, the projected required navigation performance of the vehicle while autopiloted or manually operated, and the potential touchdown conditions such as sink rate and visually degraded environmental conditions.

### A. Dynamic Obstacle Evaluation Assessment

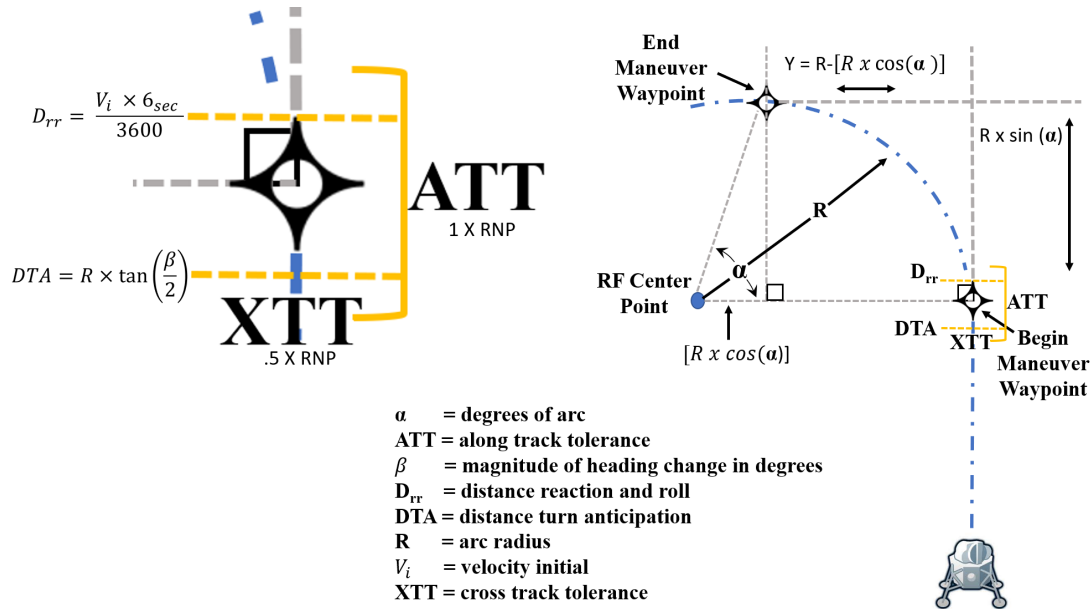
The purpose of using an IFR framework is to ensure all flight paths are free of obstructions that are hazardous to flight in lieu of pilot visual acquisition, or “see and avoid” capabilities, while maneuvering an aircraft. Given current restrictions for survey-grade assessments available for every potential landing site, a dynamic evaluation of the landing surface will greatly enhance the safe execution of the landing and egress of the lunar landing module. The approach path and landing area will need to be evaluated for slope gradients, rapidly rising or falling terrain, and boulders. This can be accomplished via mapping survey with the Lunar Orbiter Laser Altimeter aboard the Lunar Reconnaissance Orbiter, but with imaging limitations of 5-10 m per pixel, a large crater or boulder cannot be ruled out with mapping alone [10]. Using advanced imaging such as Synthetic Aperture Radar (SAR) coupled with iTERPS, automation can greatly enhance the safety and precision of the procedure while reducing workload on the pilot and mission control. Operationally, obstacle evaluation assessments can be done dynamically as the landing module descends closer to the surface and the situational awareness equipment aides in the fidelity of the landing surface and surrounding area resolutions. As the higher-fidelity imaging becomes available, iTERPS criteria can be applied to the information received and update position, required maneuvering, or power management via automation input to the pilot/operator given the dynamic approach plate (found within section VI). Ultimately, the landing area condenses from the current 50 x 50 meters down to 12 x 12 meters, which will allow greater access to previously restricted landing areas and could inform vehicle design requirements.

### B. Required Navigation Performance

Whether the landing module will utilize inertial navigation, satellites, or manually piloted operations, a required navigational performance (RNP) or positional accuracy will need to be established or assumed for the conformance of the intended vehicle flight path. One or all of the navigation methods can be applied to the procedure design with different containment values associated with each segment of control and for each phase of flight. Flight technical errors and total system errors will have significant contributions, however, mean pilot performance can be derived from advanced simulator testing, such as in the Vertical Motion Simulator (VMS) located at NASA Ames (see Appendix). The result of any containment area will create a volume of airspace or “hamster tube in the sky” with two-sigma (or greater) certainty for the vehicle flight path geometry. This flight path boundary can be broken down by method of control (INS, GPS, pilot, etc.) and phase of operation (glidepath capture, hover, vertical touchdown, etc.) to create and update a dynamically tailored approach procedure with primary and secondary measures of conformance for the cockpit crew to cross monitor the Automatic Landing Sequence (ALS) performance or cross monitor targeted lateral and vertical guidance parameters. The resulting metrics will establish specific along track, cross track, and vertical track tolerances (ATT, XTT, VTT) that will be used to calculate potential flight path/glide paths against known and potentially unknown flight hazards (as discussed in section IV).

Additional research will be required to determine hand flown/piloted operational values for lunar approach and landing containment areas comprised of bias errors discovered in astronaut training and eventual flight execution. Examples of these would include developing a reaction and roll distance ( $D_{rr}$ ), which currently exists with six seconds at velocity (three seconds given to the autopilot system to determine the input (deceleration, direction change, etc.) and three seconds given to the pilot to read the instrument/instruction and make the appropriate input). Another example for research that can be explored is the distance of turn anticipation (DTA) bias error that pilots have with “leading” a turn, which may behave differently when interacting with variable stability controls under lunar flight

physics. Fig. 3 below illustrates how a simple turn would incorporate several key RNP values that drive precision in today’s current IFR construct that can be leveraged for precision maneuver-to-land operations on the moon [11].



**Fig. 3 RNP Values Applied for Lunar iTERPS.**

**C. Compensating for Visually Degraded Environments**

Developing an autoland capability from a vertical descent with humans on board is an area of current NASA research under the Aeronautics Research Mission Directorate (ARMD) for precision helicopter/powered lift PinS approaches with vertical guidance similar to a CAT III ILS for fixed wing aircraft [12]. The key difference is the deceleration component coupled with the vertically defined descent. As rotorcraft or powered lift vehicle vortices sometimes disturb the dirt or sand creating a brown out or snow creating a white out condition, the need for an IFR approach, even under visual flight conditions, can be advantageous. Similarly with the lunar landing, lunar regolith average depths of 9-14 meters can create a hazardous “grey out” condition during the reverse thrust and touchdown sequence. Not only is the obscuration of the landing zone an impediment, the dangerous ionization via triboelectric charging of the lunar dust acts like a magnet potentially covering windows, sensors, and cameras to create an entire IFR environment in which the pilot will have to rely on a series of predetermined maneuvers through the flight guidance system (in the case of manual control). The second unique condition that a lunar landing crew may encounter is the angle of the sun, or in this case, the orientation of the lunar lander windows, cameras, or sensor system may be affected by direct sunlight during the final approach sequence. Given that both conditions of “grey out” and inopportune sun alignment result in the same ineffectiveness in the cockpit, the conditions can be mitigated through the iTERPS model by generating the most accurate procedure data during the approach, which update in real time up to and including loss of sensors and/or landing site. The information can be transmitted to the pilot via a lunar approach plate, similar to an instrument approach plate (which has a format with 70 years of vetted human factors and pilot familiarization) [13].

**VII. Lunar Approach Plate Design**

The instrument approach plate (IAP) has been the Rosetta Stone between pilots and air traffic controllers since instrument flight was developed. The IAP provides textual and graphic information that can explain in further details what the air traffic controller may not have the bandwidth to provide. This combination of aural, graphic, and written communication creates a trifecta of understanding to ensure the cockpit and controller are on the same page given language barriers, radio static, or loss communications during an approach to land in IFR. The iTERPS Lunar Approach Plate (LAP) provides a similar function as the IAP but allows maximum flexibility to the dynamic nature of the EDAL through landing. The main difference is the LAP is dynamically generated and updated through the procedure sequence. Secondly, the LAP is interactive, meaning the pilot and interface change views and system design

criteria/parameters throughout the approach. The iTERPS model leverages the format of the IAP to the greatest extent possible while allowing adjustments for information and needs required for navigating on another celestial body.

**A. Pilot Header Section**

The pilot header section is similar to the original IAP in format but provides entirely different information tailored to the landing location depicted as Landing Reference Point (LRP), azimuth, approach angle, and zero velocity termination point. This information is followed by the type of approach (fixed altitude variable entry, constant deceleration, etc.) with the textual description of the procedure and anticipated contingency for the missed approach. The last information line in the pilot section provides the standard control frequency and navigation information but has an ALS (autopilot) engagement option in negative symbology to indicate the feature is interactive. This feature may be used in the case where different RNP volumes are displayed for the pilot to cross monitor performance instead of manually engaging through flight controls. The last column is the iTERPS system-generated “next best” option for angle capture.

**B. Overhead View**

The overhead view is very similar to the traditional IAP but consists of three waypoint radii comprised of what can be imagined as the Initial Approach Fix (IAF) for the lunar procedure. The example in Fig. 4 is labeled OHZ followed by the direction and containment area of flight to the LRP. The second waypoint radius depicted is the deceleration to zero velocity at a point above the landing zone. This feature can be overlaid against lunar terrain or kept as a sterile background. The blue dot indicates the approximate location of the lunar lander for enhanced situational awareness. To the left of the overhead view is the alternate approach angle options. The bold column in the center depicts the current vehicle angle and the performance metrics. The greyed-out columns on the left and right indicate what the deltas would be from current performance given a change in approach angle.

**C. Profile Minima Section**

The profile view is most similar to the traditional IAP, provided it accounts for entry from LLO through the first altitude gateway OHZ. It depicts the VTT adherences through the descent to landing. This section provides the pilot with situational awareness of ‘distance to go’ information relative to the current segmented approach angle. Bold lettering in the profile view indicates the active sequence and the grey lettering indicates inactive approach angles.

**D. Airport Diagram Section**

Since there is no need for an airport diagram given the unique landing configuration, the section is used to dynamically depict the RNP values via mode of control during the approach. The dashed lines represent an eight-degree splay from the port and starboard sides of the LRP. The solid black lines represent a full 15-degree splay of the FAS to the LRP. Again, the reverse symbology references an interactive button that is imagined to be pressed to change the system of control, which may have different containment areas/splays for the given navigation source.

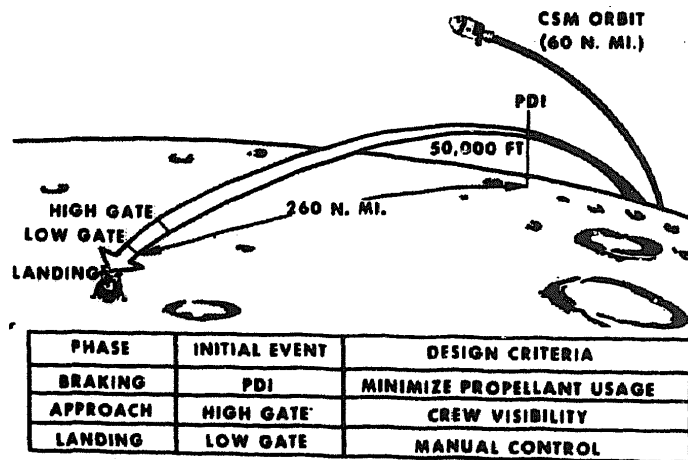


Fig. 4 Legacy Apollo Lunar Approach Construction [2].

Basecamp, Lunar South Pole

VMS-06 (NASA)

Vector	LRP	69°54.462'S 21°45.330'E
176°	TARGET GPA	18°
	TERM ALT	300 ft AGL

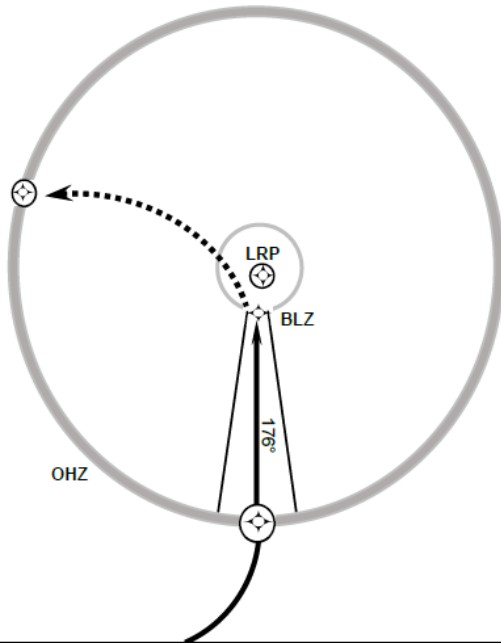
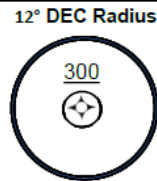
**Low Lunar Orbit: 14,000 ft / 18°**  
Fixed Altitude Variable Entry

**RNP .01:** Enter from LLO, descend to fixed altituded of 14,000 ft waypoint OHZ. At OHZ confirm approach angle, azimuth and monitor/maintain RNP. Initiate/monitor deceleration sequence at waypoint BLZ to touchdown.

**ABORT:** Over ride automatic landing sequence and maneuver LEFT to fixed altitude waypoint OHZ and re-engage landing sequence with new approach angle/azimuth.

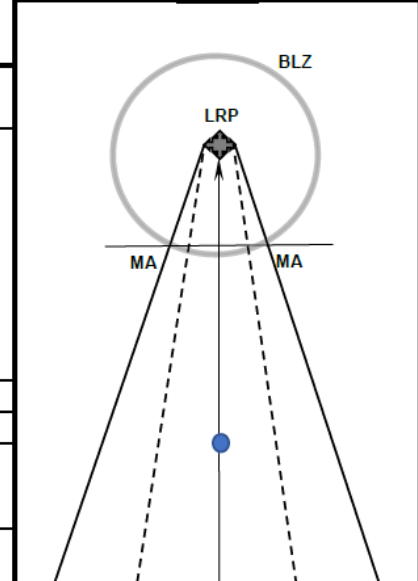
Control	MLS	Auto Landing Sequence	RECAP New GPA
134.025 / 258.025	133.0 / 251.15	<b>ENGAGED</b>	** 20° **

**FOR NASA SIMULATION EXERCISE ONLY**



Alternate GPA		
17°	18°	19°
Fuel (-)	Fuel	Fuel (+)
G (-)	G-force	G (+)
Time (+)	Time	Time (-)
Dist. (+)	Distance	Dist. (-)
*Δ	***	*Δ

ELEV	1276 ft	<b>ALS</b>	BLZ	300 ft
------	---------	------------	-----	--------



	17°	18°	19°	20°
APP ANGLE	17°	18°	19°	20°
MANUAL	300-3200 FPM	300-2800 FPM	300-1200 FPM	300-900 FPM
ALS	0-0 80kt	0-0 60kt	0-0 45kt	0-0 30kt

Basecamp, Lunar South Pole  
12SEP23

**EXPERIMENTAL**

69°54.462'S 21°45.330'E

Fixed Altitude Variable Entry  
**LLO: 14,000 ft / 18°**

NASA Ames Research Center 2023

NASA Ames Research Center 2023

Fig. 5 Lunar Approach Plate.

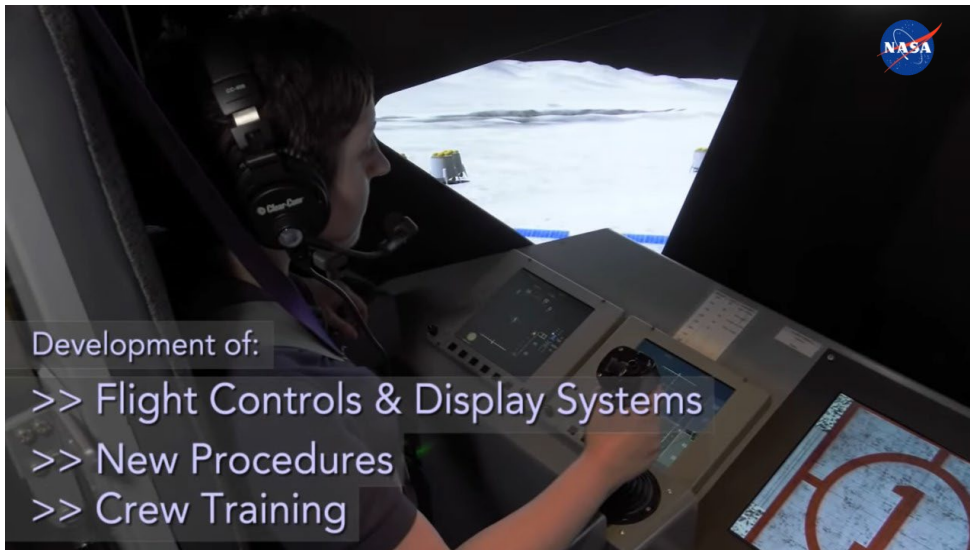
**VIII. Conclusion**

The iTERPS model leverages present-day terminal procedure methodology for approach procedure construction on the moon to enable safe, precise, and efficient human flight on another world. The concepts highlighted in this paper briefly showcase the widespread scalability of TERPS criteria applied for dynamic evaluations from LLO to the surface. Although this paper provides a high-level summary, additional research will be required with a detailed analysis and report of the initial findings. The unit conversions succeeded for the application of lunar geometry for trajectory management, which were modulated for the approach path/angle uncertainties in and around the potential landing areas. The paper applied an RNP approach, however, future lunar infrastructure leveraging ground-based navigational aids such instrument landing systems (ILS) or microwave landing systems (MLS) could be explored for viability to produce the same level of safety and precision [11]. Human factors testing will provide feedback to the lunar procedure design team as well as aide in standardized training for the crew office. There are many safety aspects to the iTERPS model in which concepts can be further broken down into individual constructs that may be leveraged in part or whole (such as the lunar approach plate or fixed altitude variable entry approach design). With a foundation of safety, the iTERPS framework can support scalable, safe space exploration on planetary bodies for decades to come.

**Appendix**

*Distance Baro Glidepath:	$d_{\text{Baro}} = \ln\left(\frac{r + \text{alt}_e}{r + \text{alt}_b}\right) \times \frac{r}{\tan(\theta)}$	
Deceleration:	$\frac{V_F^2 - V_I^2}{2D}$	
*Gravity:	$\text{FPS}^2 \div 32.17_{\text{SGA}}$	*MOON Radius 4952497.20504 ft
Time:	$\frac{V_F - V_I}{A}$	Gravity 5.3 FPS <sup>2</sup>

**Fig. 6 Lunar Approach Dynamics.**



**Fig. 7 NASA Ames Vertical Motion Simulator.**

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