ARTEMIS

ASTRO IIT KANPUR

Humanity's Return to the Moon

Summer Project
Space Mission Report

Space Mission: Artemis Program

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July, 2021

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1. Why ARTEMIS

1.1 Introduction

It has been almost 50 years since astronauts last walked on the lunar surface during the Apollo Program. Since then, the robotic exploration of deep space has seen decades of technological advancement and scientific discoveries. For the last 20 years, humans have continuously lived and worked aboard the International Space Station 250 miles above Earth, preparing for the day we move farther into the solar system. NASA's Artemis Program, built on a half-century of experience and preparation to establish a robust human-robotic presence on and around the Moon, will lead humanity forward and prepare us for the next giant leap, the exploration of Mars.

1.2 Mission Aim/Vision

The Moon plan is twofold: it's focused on achieving the goal of an initial human landing by 2024 with acceptable technical risks while simultaneously working toward sustainable lunar exploration in the mid-to-late 2020s. With the confidence and experience gained through moon missions and explorations, will seed our way to the exploration of our nearest neighbour, Mars. NASA has the vision of making a sustainable lunar economy, in partnership with U.S. commercial companies and international partners, one where they benefit from and build on what we learn. NASA also established the Commercial Lunar Payload Services or CLPS initiative in 2018, encouraging the U.S. commercial space industry to introduce new lander technologies to deliver NASA and commercial payloads to the surface of the Moon. It has already selected more than two dozen instruments to study the Moon and test new technologies for these early CLPS flights, including VIPER. It also aims to land the first woman on the Moon by 2024, in the process achieving many other firsts.

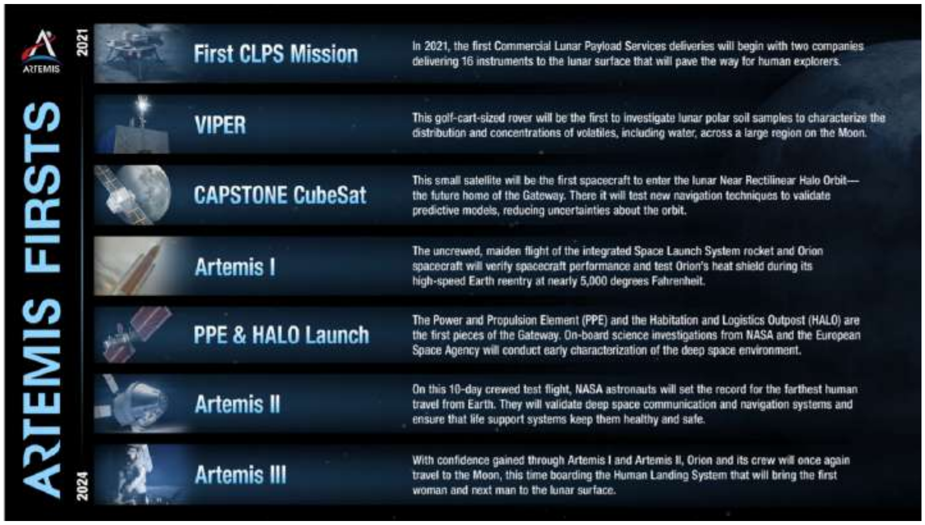


Figure 1.1: Firsts aimed for Artemis

2. Launch Vehicle: SLS

In order to design the rocket for our mission we must keep these checkpoints- know what your rocket needs to do, establish mission parameters, call in experts, start drawing, whittle down the possibilities and pick the best design. For the Artemis Mission Program, the SLS (Space Launching System), is the launch vehicle used to launch the Artemis I and henceforth Artemis flights.

Basic description of SLS Rocket as follows:

SLS is the most powerful rocket ever built, the backbone for a permanent human presence in deep space. It offers more payload mass, volume capability, and energy to speed missions through space than any current launch vehicle. SLS is designed to be flexible and evolvable and will open new possibilities for payloads, including robotic scientific missions to places like the Moon, Mars, Saturn, and Jupiter. In order to make the SLS spacecraft as light as possible, it is constructed with lightweight, strong materials, such as aluminum alloys and composites. It has a ABORT vehicle system which can deploy easily even faster than its speed when there is an error or critical circumstances which basically provides a proper safety to our astronomers. The engineering design challenge focuses on the thrust structure, which attaches the four liquid fuel engines to the body of the rocket. The thrust structure is an essential part of the spacecraft, which must be kept lightweight.

SLS Rocket

2.1 Basic components of SLS rocket

- **ICPS:** The Interim Cryogenic Propulsion Stage (ICPS) for SLS Block 1 is the initial configuration that can deliver 27 metric tons of payload to the moon. Based on the proven Delta Cryogenic Second Stage and powered by one Aerojet Rocketdyne RL10 engine, ICPS will propel an uncrewed Orion spacecraft to fly beyond the moon and back on the Artemis I mission.

ICPS

- **LVSA:** The Launch Vehicle Stage Adapter (LVSA) connects the Block 1 core stage to the upper stage while providing structural, electrical and communication paths. It separates the core stage from the second stage that includes astronauts in the Orion crew vehicle.

LVSA

- **Forward Skirt:** It houses flight computers, cameras and avionics — the routers, processors, power, other boxes and software that control stage functions and communications. Along with the liquid oxygen tank and the intertank, it makes up the top half of the core stage.

Forward Skirt

- **LOX tank:** The liquid oxygen (LOX) tank holds 196,000 gallons (742,000 liters) of liquid oxygen cooled to minus 297 degrees Fahrenheit. Its thermal foam coating protects it from extreme temperatures — the cold of the propellants and the heat of friction.

LOX Tank

- **LH2 Tank:** The liquid hydrogen (LH2) tank comprises two-thirds of the core stage, weighs 150,000 pounds (68,000 kilograms) and holds 537,000 gallons (2 million liters) of liquid hydrogen cooled to minus 423 degrees Fahrenheit.

LH2 Tank

- **Solid Rocket Boosters:** The largest human-rated solid rocket boosters ever built for flight, the SLS twin boosters stand 17 stories tall and burn about six tons of propellant every second. Each booster generates more thrust than 14 four-engine jumbo commercial airliners. Together, the SLS twin boosters provide more than 75% of the total thrust at launch.

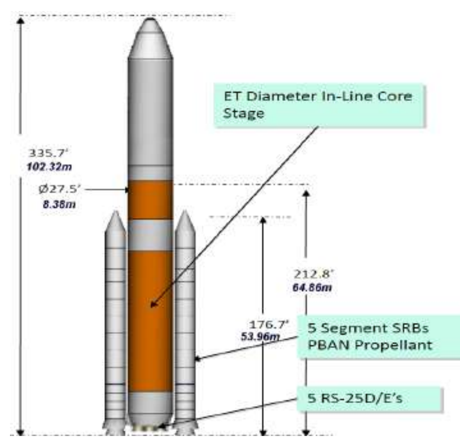
Solid Rocket Boosters

- **Engine Section:** The engine section is a crucial attachment point for the four RS-25 engines that work with two solid rocket boosters to produce a combined 8.8 million pounds of thrust at liftoff. Four RS-25 engines will deliver more than 2 million pounds of thrust at altitude. Combined with two five-segment solid rocket boosters, the propulsion system will give SLS about 8.8 million pounds of thrust at launch — more lift than any current rocket and 15% more than the Saturn V.

RS-25 Engine

2.2 Dimension and Properties

The design is 212 Feet tall, 27.6 Feet in diameter and has 2.3 pounds with propellant, rated safe for humans. It reaches MACH 23, faster than 17000 mph in just 8.5 minutes. The model initially in 2017-21 was capable of 70 metric tons; serves as primary transportation for Orion and exploration missions and also provides back-up capability for crew/cargo to ISS. Post 2021, the model can be evolved to be capable of 105 tons and 130 tons, thus offering large volume for science missions and payloads; it is modular and flexible, just right-sized for mission requirements. With maximum use of common elements and existing assets, infrastructure and workforce, make the model affordable.



Dimensions marked for SLS Rocket

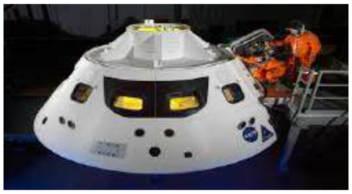
3. SpaceCraft

3.1 ORION Capsule

Compilation of Orion Spacecraft

Orion (officially **Orion Multi-Purpose Crew Vehicle** or **Orion MPCV**) is a class of partially reusable space capsules to be used in NASA's human spaceflight programs.Capable of supporting a crew of six beyond low Earth orbit, Orion can last up to 21 days undocked and up to six months docked. Orion is primarily designed to launch atop a Space Launch System (SLS) rocket, with a tower launch escape system. The spacecraft consists of a crew module, service module and a launch abort system.

3.1.1 Crew Module



Orion Crew Module

Orion Crew Module, manufactured by Lockheed Martin Corporation, is a reusable transportation capsule that provides a habitat for the crew, provides storage for consumables and research instruments and contains the docking port for crew transfers. Orion's CM uses the latest technologies, including glass cockpit, autodock feature, improved waste-management facilities, a nitrogen/oxygen atmosphere at sea level and reduced pressures, etc.

3.1.2 Service Module

Orion Service Module

European Service Module, ESM based on ESA's Automated Transfer Vehicle (ATV), is the service module component of Orion Spacecraft, serving as its primary power and propulsion component until discarded at the end of each mission. Manufactured by Airbus Defence and Space (in Bremen), there are two **spacecraft adapters**, connecting the service module to the crew module and to the upper stage of the SLS, are ultimately discarded during staging; the three fairing panels are jettisoned after protecting the service module during launch and ascent.

3.1.3 Launch Abort System

The Launch Abort System, or LAS, is positioned atop the Orion crew module,designed to protect astronauts if a problem arises during launch by pulling the spacecraft away from a failing rocket. Weighing approximately 16,000 pounds, the LAS can activate within milliseconds to pull the vehicle to safety and position the module for a safe landing. It consists of the following parts :

- **Jettison Motor**:The jettison motor will pull the crew module,allowing Orion's Parachutes to deploy and the spacecraft to safely land on the ocean.
- **Altitude Control Motor**:The Motor can exert up to 7000 pounds of steering force in any direction upon command from the Orion crew module.
- **ABORT Motor**:Capable of producing about 400000 pounds of thrust to quickly pull the crew module away from danger if problems develop on the launch pad or during the ascent.
- **Fairing Assembly**:It is a lightweight composite structure that protects the capsule from the environment around it-whether it's heat,wind or acoustics.

With the incorporation of an abort system in the module, the programmatic cost is reduced and the crew safety is ensured in support of NASA's explorations.

Orion Crew Module

3.2 Gateway

The Gateway, a vital component of NASA's Artemis program, will serve as a multi-purpose outpost orbiting the Moon that provides essential support for sustainable, long-term human return to the lunar surface and serve as a staging point for deep space exploration. The Gateway is planned to be deployed in a highly elliptical seven-day near-rectilinear halo orbit (NRHO) around the Moon. NASA is working with commercial and international partners like SpaceX to establish the gateway orbitor. NASA has selected SpaceX's Falcon Heavy to deliver the first two segments of the moon-orbiter gateway space station of its Artemis program somewhere in 2024. The pair of modules SpaceX will ferry into space are the power and propulsion element (PPE) and the habitation and logistics outpost (HALO).The PPE will provide the Gateway with power, enabling communications as well as helping the station move to various lunar orbits, while HALO will give astronauts a place to stay on their way to the moon and HALO will also provide docking support for space vehicles. Once deposited in lunar orbit, the Gateway will serve as an outpost for astronauts and equipment heading to the moon as part of NASA's Artemis program. Roughly one-sixth the size of the International Space Station, the Gateway will support research investigations, crew, and expeditions to the lunar surface. The outpost will serve as a docking station for visiting spacecraft, such as NASA's Orion spacecraft and will orbit the moon, tens of thousands of miles away.

Figure 3.1: Gateway Demonstration

Figure 3.2: Dragon XL Spacecraft

3.3 Dragon XL

The Dragon XL resupply spacecraft has been designed to carry pressurized and unpressurized cargo, experiments and other supplies to NASA's planned Gateway under a NASA Gateway Logistics Services (GLS) contract. The equipment delivered by Dragon XL missions could include sample collection materials, spacesuits and other items astronauts may need on the Gateway and the surface of the Moon, according to NASA. Its payload capacity is expected to be more than 5,000 kg (11,000 lb) to lunar orbit.It will launch on SpaceX's Falcon Heavy launch vehicle from pad LC-39A at the Kennedy Space Center in Florida.

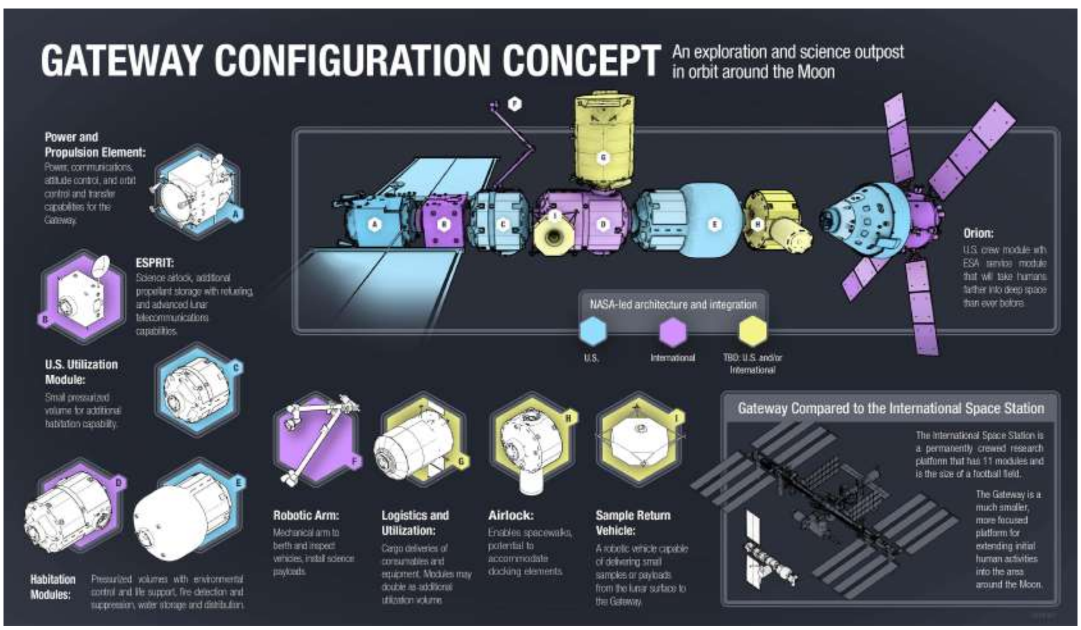


Figure 3.3: Gateway Configuration

4. Lander

4.1 Human Landing System (HLS)

Starship HLS, a lunar lander variant of the Starship spacecraft being developed by SpaceX under a contract with NASA; intends to dock in lunar orbit with either the NASA Orion spacecraft or NASA lunar Gateway space station, in order to take on passengers before descending to the lunar surface. The design of the HLS being optimized to operate exclusively in the vacuum of space, has no heat shield nor airbrakes, both of which are an integral component of the main Starship design. Further equipped with a complement of the high-thrust oxygen- and methane-fueled thrusters located mid-body on the lander, to assist in the lunar descent and liftoff from the lunar surface. The HLS is supplied with electrical power by a band of solar panels around the circumference of the vehicle. It would be launched using the Super Heavy booster and then serve as its own second stage to complete the ascent to low-Earth orbit (LEO). On orbit, it would be refueled before climbing out to lunar orbit to meet the Gateway and Orion crew capsule. It has been chosen to transport two NASA Artemis 3 astronauts along with cargo to and from the lunar surface, each time it lands on the moon.

4.2 HERACLES

HERACLES (Human-Enhanced Robotic Architecture and Capability for Lunar Exploration and Science) is a planned robotic transport system to and from the moon by Europe (ESA), Japan (JAXA) and Canada (CSA) that will feature a lander called the European Large Logistic Lander (or EL3), further constituted by Lunar Descent Element (LDE), which will be provided by Japan's JAXA,the ESA-built Interface Element that will house the rover, and the European Lunar Ascent Element (LAE) that will return the samples to the Lunar Gateway. The lander can be configured for different operations such as up to 1.5 tons of cargo delivery, sample-returns, or prospecting resources found on the Moon. The system is planned to support the Artemis program and perform lunar exploration using the Lunar Gateway space station as a staging point.

Figure 4.1: Starship HLS by SpaceX

Figure 4.2: HERACLES(Spacecraft)

5. Staging

Every payload needs an extra kick of thrust to overcome the weight of the rocket and payload to get it into space. It's a tricky balancing act. It's not just the payload that has mass, there's also a need to cancel out with thrust against the downward force of gravity. The rocket's body has mass as well, as does the fuel on board. The payload is typically the smallest portion of mass on a launch. The propellants — the fuel and oxidizer — weigh the most. Staging is a way of getting rid of dead weight so the energy of the burning engine is transferred to the payload so it gets into orbit. SLS rocket, used for launch in the Artemis program has been doubly staged with a Core Stage and Upper Stage.

5.1 Core Stage

SLS core stage is the world's tallest and most powerful rocket stage. Towering 212 feet with a diameter of 27.6 feet, it stores cryogenic liquid hydrogen and liquid oxygen and all the systems that will feed the stage's four RS-25 engines. The core stage is designed to operate for approximately 500 seconds, reaching nearly Mach 23 and more than 530,000 feet in altitude before it separates from the upper stage and Orion spacecraft.

5.2 Upper Stage

The main components of the stage are ICPS and Orion Spacecraft. The Exploration Upper Stage (EUS) is being developed as a large second stage for Block 1B of the Space Launch System(SLS), succeeding Block 1's Interim Cryogenic Propulsion Stage(ICPS). The EUS is to complete the SLS's ascent phase and then re-ignite to send its payload to destinations beyond low Earth orbit. This is a similar function to the S-IVB stage of the old Saturn V rocket. The design of the EUS, allowing Boeing to proceed with development of the stage, including hardware fabrication.

Figure 5.1: Demonstartion of seperation of stages. For more details on its parts, refer Figure 7.4

6. Aerodynamics

Aerodynamic support for the Artemis (SLS) requires the use of both wind-tunnel tests and computational simulations to develop aerodynamic databases across the flight mission profile, seen in Fig. below. These data are generated for a range of flight regimes including launch, liftoff, ascent, and booster separation. Flight conditions for the SLS vary from low-speed conditions on or near the launchpad to supersonic speeds during ascent. Because of this wide range of flight conditions, numerous tools are required to accurately capture the properties of the complex flowfields that evolve over time. In order to accurately capture the massively-separated flowfields that arise during launch of the vehicles, an unsteady CFD(Computational Fluid Dynamics) solver is utilized. These unsteady IDDES (improved delayed detached eddy simulation) CFD calculations yield a wealth of information that can be interrogated to provide visualizations of the evolving flowfield. As an example, a solution animation in which isosurfaces of constant **Q criterion** are colored by the magnitude of vorticity is shown in figures below:

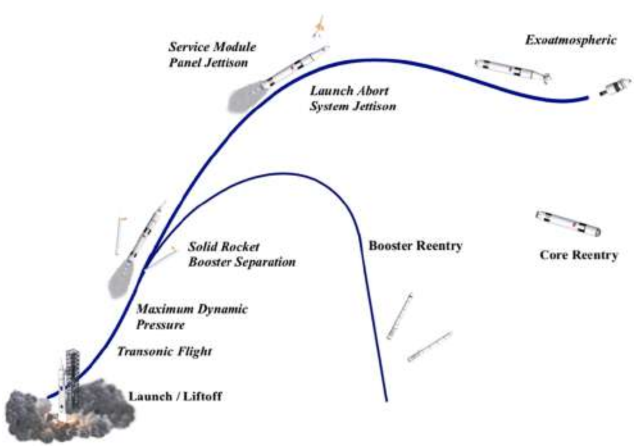


Figure 6.1: Aerodynamic Databases.

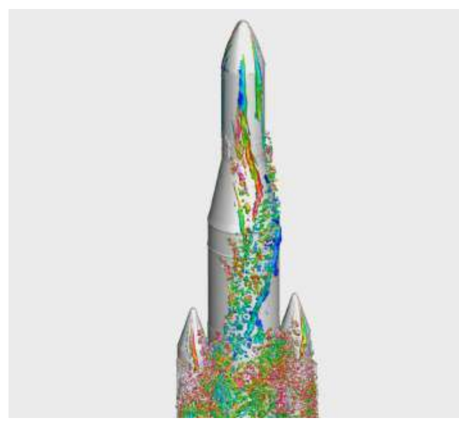


Figure 6.2: Isosurfaces of constant Q criterion.

Ascent Aerodynamics Run Matrix: Mach 0.5 to 5.0

From roughly sea level to very high dynamic pressure to near vacuum simulate out to $\alpha = \pm 8°$, even though flight is mostly close to 0. 6.3 is the graph of dynamic pressure variation with respect to mach number and 6.4 is the graph of α with respect to β.

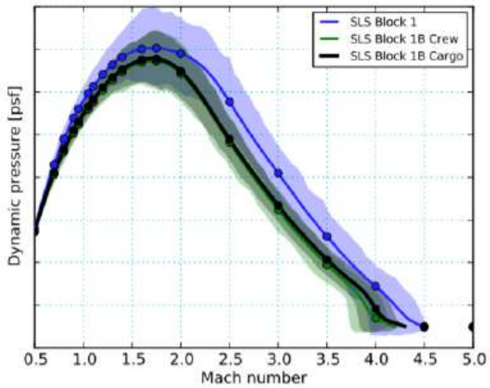


Figure 6.3: Dynamic Pressure Vs Mach Number.

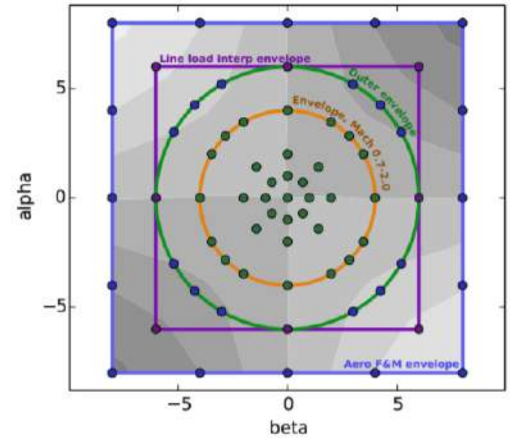


Figure 6.4: alpha Vs beta

Shock waves are formed when a pressure front moves at supersonic speeds(Speed more than that of sound) and pushes the air surrounding it. At that particular region, sound waves travelling against the flow reach a point where they are unable to travel any further upstream.6.5, 6.6 and 6.7 are the shock wave profiles at different Mach numbers ranging from 0.5 to 5.0. The proposed shock waves profiles are:

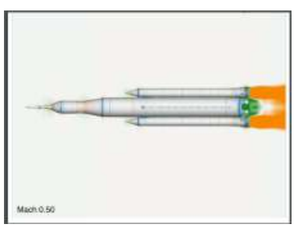


Figure 6.5: Shock Wave Profile at 0.5 mach.

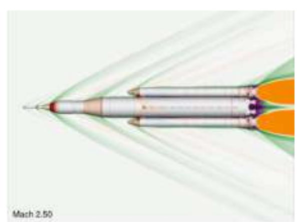


Figure 6.6: Shock Wave Profile at 2.0 mach

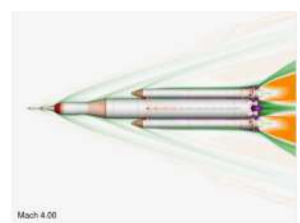
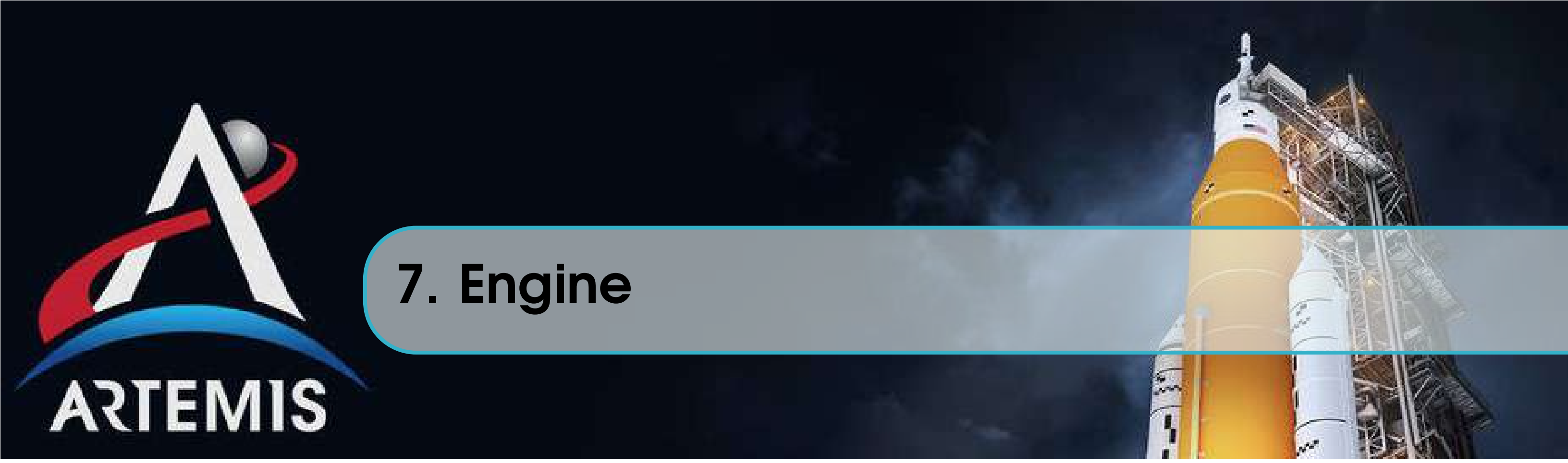


Figure 6.7: Shock Wave Profile at 4.0 mach



7. Engine

Preparations for Artemis I are in full swing. The production is already complete for the SLS engines- which is going to comprise four RS-25 liquid rocket engines(core stage) and RL10 engines(upper stage), two solid rocket boosters, a massive core stage, and an interim cryogenic propulsion stage that would provide Orion final push toward the Moon.

7.1 RS-25 Engine

The RS-25 engine has one of the most storied histories in spaceflight. As the space shuttle main engine, it has a proven record of launching 135 missions over 3 decades, including building the ISS and deploying the Hubble Space Telescope. Hence, the RS-25 engine offered an opportunity to forgo the costs of developing a new engine and bringing superb capabilities and experience to the table at the same time.

RS-25 burns cryogenic liquid hydrogen and liquid oxygen propellants, with each engine producing 1,859 kN (418,000 lbf) of thrust at liftoff. Thanks to this, during liftoff, the Block 1 configuration of SLS will produce 8.8 million pounds of thrust — 15% more than the Saturn V rockets that launched astronauts on journeys to the Moon.

Several Components of the RS-25 Engine are:

1. **Turbopumps:**
   (a) **Oxidizer System**:The low-pressure oxidizer turbopump (LPOTP) is an axial-flow pump that operates at approximately 5,150 rpm driven by a six-stage turbine powered by high-pressure liquid oxygen from the high-pressure oxidizer turbopump (HPOTP).
   (b) **Fuel System**: The low-pressure fuel turbopump (LPFTP) is an axial-flow pump driven by a two-stage turbine powered by gaseous hydrogen.
2. **Powerhead:**
   (a) **Pre Burners**:The oxidizer and fuel pre-burners are welded to the hot-gas manifold. The fuel and oxidizer enter the pre-burners and are mixed so that efficient combustion can occur.
   (b) **Main Combustion Chamber**: It uses Staged Combustion Mechanism. The engine's main combustion chamber (MCC) receives fuel-rich hot gas from a hot-gas manifold cooling circuit. The gaseous hydrogen and liquid oxygen enter the chamber at the injector, which mixes the propellants. The mixture is ignited by the "Augmented Spark Igniter", an H2/O2 flame at the centre of the injector head.
3. **Nozzle**: The nozzle is a bell-shaped extension bolted to the main combustion chamber, referred to as a de Laval nozzle. The RS-25 nozzle has an unusually large expansion ratio (about 69:1) for the chamber pressure.
4. **Controller**: Each engine is equipped with a main engine controller (MEC), an integrated computer that controls all of the engine's functions (through the use of valves) and monitors its performance.

5. **Main Valves**: To control the engine's output, the MEC operates five hydraulically actuated propellant valves on each engine; the oxidizer pre-burner oxidizer, fuel pre-burner oxidizer, main oxidizer, main fuel, and chamber coolant valves.

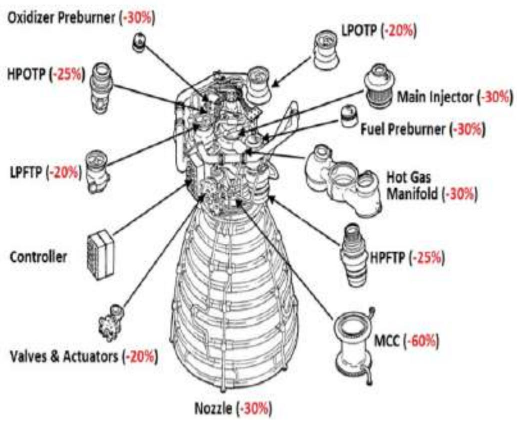


Figure 7.1: RS-25 components and cost reduction objectives

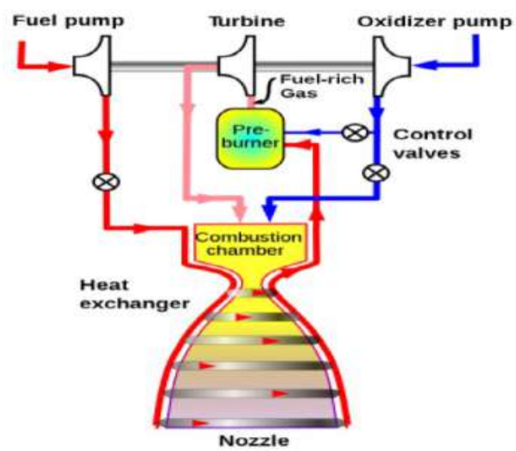


Figure 7.2: Staged Combustion

6. **Gimbal**: Each engine is installed with a gimbal bearing, a universal ball and socket joint which is bolted to the launch vehicle by its upper flange and to the engine by its lower flange.
7. **Helium System**: The launch vehicle's main propulsion system is also equipped with a helium system consisting of ten storage tanks. The system is used in-flight to purge the engine and provides pressure for actuating engine valves within the propellant management system and during emergency shutdowns.

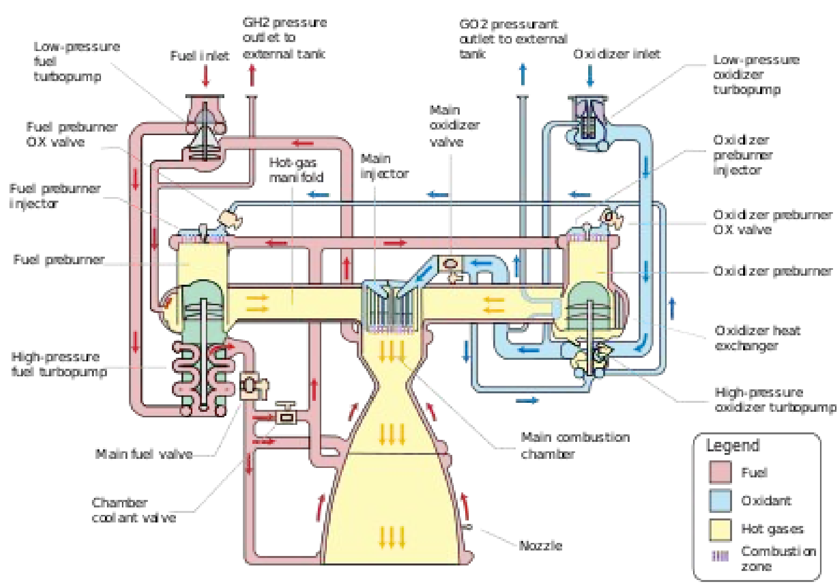


Figure 7.3: Working Mechanism of RS-25

7.2 RL 10 B-2 Engine

The RL10 B-2 is a liquid-fuel cryogenic rocket engine built in the United States by Aerojet Rocketdyne that burns cryogenic liquid hydrogen and liquid oxygen propellants. Modern versions produce up to 110 kN (24,729 lbf) of thrust per engine in vacuum. The expander cycle that the engine uses drives the turbopump with waste heat absorbed by the engine combustion chamber, throat, and nozzle.

RS-25 Engine Facts	
Thrust	512,300 lbs. (vacuum) 416,300 lbs. (sea level)
Size	4.2m x 2.4m (14 ft x 8 ft)
Weight	3.49 t (7,800 lbs.)
Operational Thrust	109 percent
Operational Time	approximately 8 minutes
Operational Temp Range	-423 to +6000 degrees F

RL-10 B2 Engine Facts	
Thrust	24,750 lbf (110.1 kN)
Height	4.14m (163.5 in)
Diameter	2.21m (84.5 in)
Weight	301.2kg (664 lb)
Specific Impulse	465.5 s (4565 km/s)
Expansion Ratio	280 to 1

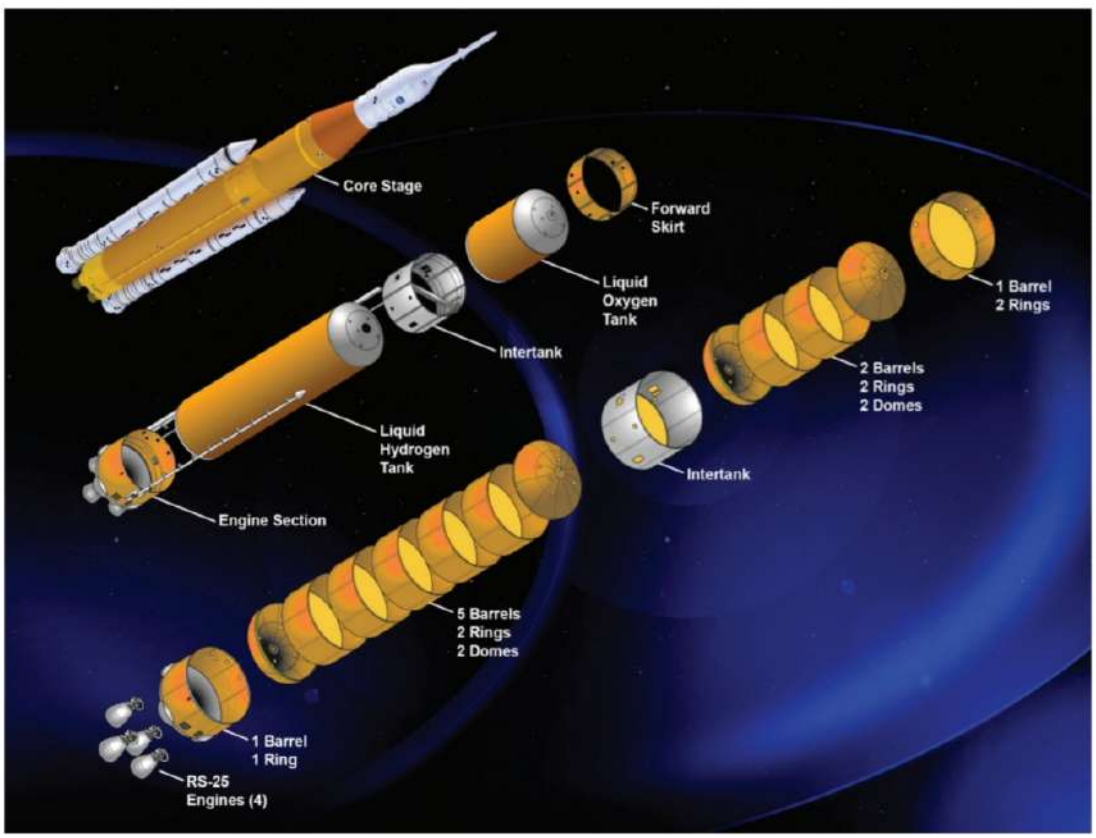


Figure 7.4: SLS Stages

8. Propellant

Rocket propellant is the reaction mass of a rocket. This reaction mass is ejected at the highest achievable velocity from a rocket engine to produce thrust. The energy required can either come from the propellants themselves, as with a chemical rocket, or from an external source, as with ion engines.The Reaction mass is stored in the Fuel Tanks of the rocket,which account for more than 70% volume of a rocket. In our mission we are dealing with both SOLID and LIQUID Propellants.

8.1 Solid Propellant

In **Boosters** solid propellant will be used - ammonium perchlorate composite propellant **(APCP)** (which uses a mixture of 70% granular ammonium perchlorate as an oxidiser, with **20%** aluminium powder as a fuel), bound together using 10% polybutadiene acrylonitrile **(PBAN)**. PBAN, Polybutadiene acrylonitrile copolymer, also noted as polybutadiene—acrylic acid—acrylonitrile terpolymer is a copolymer compound used most frequently as a rocket propellant fuel mixed with ammonium perchlorate oxidizer. APCP,Ammonium perchlorate composite propellant (APCP) is a modern fuel used in solid-propellant rocket vehicles It differs from many traditional solid rocket propellants such as black powder or **zinc-sulfur**. It is cast into shape, as opposed to powder pressing as with black powder.

8.2 Liquid Propellant

In **Core** stage **ISPC** and **Upper** Stage exploration Liquid Hydrogen and Liquid Oxygen will be used as propellants. The combination of **LOX and LH2** is mostly used for the upper stages that propel a vehicle into orbit. The lower density of the liquid hydrogen requires higher expansion ratios (gas pressure – atmospheric pressure) and therefore works more efficiently at higher altitudes. **Liquid hydrogen** fuelled rockets generally produce the lightest design and are therefore used on those parts of the spacecraft that actually need to be propelled into orbit or escape Earth's gravity to venture into deep space.

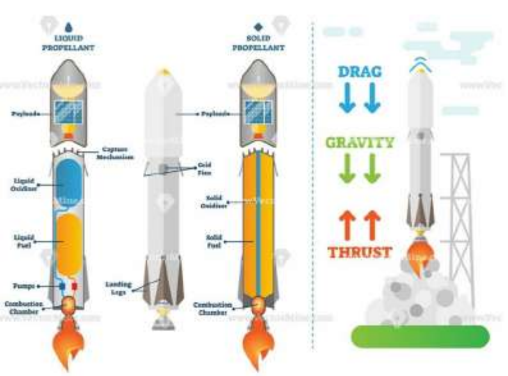


Figure 8.1: Demonstrating location of propellants in the rocket

9. Orbital Dynamics, Trajectory Optimisation

For Artemis I, an uncrewed Orion will fly a round-trip mission to a lunar Distant Retrograde Orbit(DRO) on a trajectory that includes two lunar flyby maneuvers, several burns and earth entry from Earth Entry Interface(EI) . The Artemis I mission is optimized with NASA's **Copernicus spacecraft trajectory design and optimization application** using the SNOPT optimization method. Copernicus makes use of a multiple-shooting approach, and the mission is designed using numerous coast and burn trajectory segments that are numerically integrated both backwards and forwards in time.In Copernicus, all mission phases are integrated explicitly using the DDEABM integration method (a variable-step size variable-order Adams-Bashforth-Moulton implementation) with a 10-12 error tolerance .For this trajectory design and optimization, only the CM and SM of Orion are included.The major burns in trajectory are : Upper Stage Separation (USS), Outbound Trajectory Correction (OTC)-1, Outbound Trajectory Correction (OTC)-2, Outbound Powered Flyby (OPF), DRO Insertion (DRI), DRO Plane Change (DPC), DRO Departure (DRD) and Return Powered Flyby (RPF), as demonstrated:

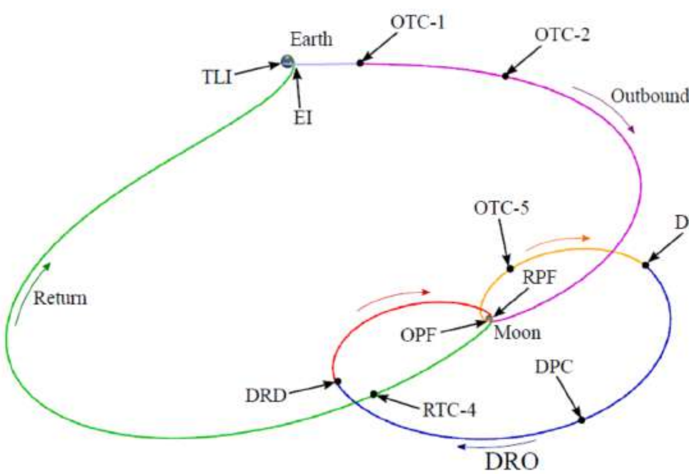


Figure 9.1: An overview of nominal mission trajectory

9.1 Tracing the Trajectory

In the following figures from 9.2 to 9.5, we trace the trajectory, demonstrating the orbit maneuvers and significant burns:

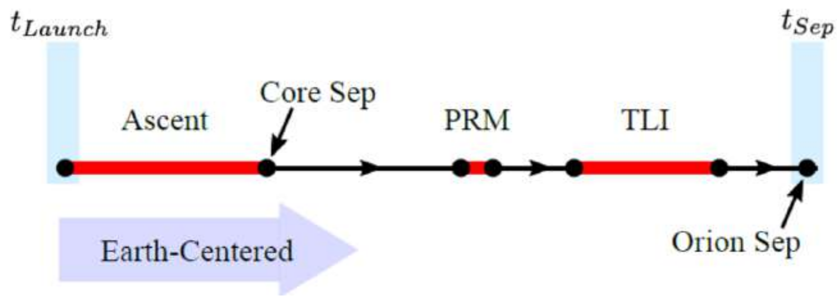


Figure 9.2: Launch to Orion Spring Separation. Ascent is performed by the SLS and the Perigee Raise Maneuver (PRM) and Trans Lunar Injection (TLI) are performed by the ICPS.

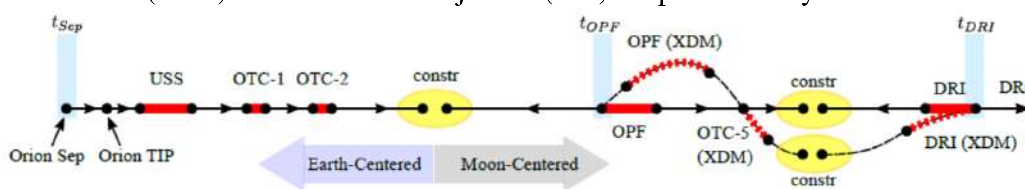


Figure 9.3: Orion Spring Separation to DRO Insertion. The outbound part of the mission includes two major burns: OPF and DRI.

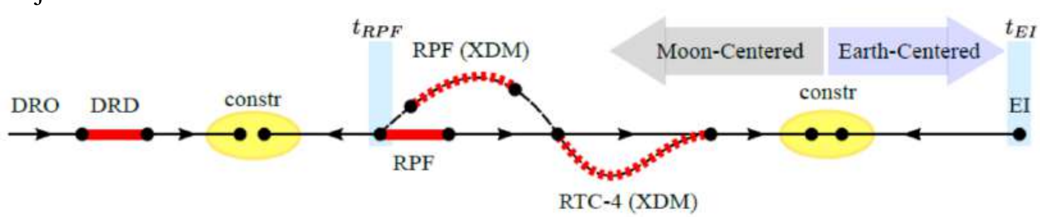


Figure 9.4: DRO Stay Time and Mission Duration for Different Mission Classes. Extended missions can be used to achieve desired landing lighting conditions not otherwise possible with the nominal mission of approximately 26 days.

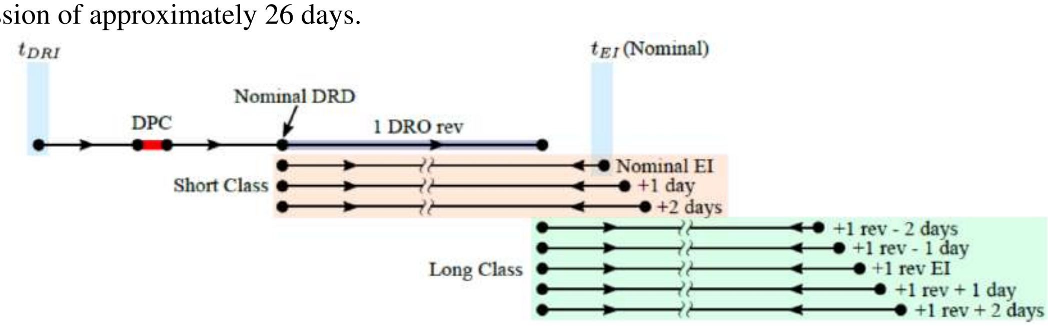


Figure 9.5: DRO Departure to Earth EI. The return part of the mission includes two major burns: DRD and RPF.

9.2 ORION on orbit trajectory

Orion in-space portion of the trajectory begins at the Space Launch System(SLS) core separation and ends at the Orion service module Earth Entry Interface(EI) point. In the above diagrams, the arrows indicate the direction of propagation of the mission phases in the Copernicus multiple-shooting transcription. The segments from the mission timeline integrated forward from one time(ex- tOPF) and backward from later time(ex-tDRI), with the required constraints imposed to make a continuous trajectory.

Once the ascent to Orion separation mission phase is completed, the objective function for the on-orbit trajectory comes out to be the combined ICPS(Interim Cryogenic Propulsion Stage) and Orion total (delta)v required, which is to be minimized.

The thrust directions for all burns are modeled by the spherical angles- α(right ascension) and β (declination), as functions of time:

$$\alpha(t) = \alpha_0 + \dot{\alpha}_0(t - t_0) \tag{9.1}$$
$$\beta(t) = \beta_0 + \dot{\beta}_0(t - t_0) \tag{9.2}$$

where t_0 is the burn start time, and the direction of thrust vector $\hat{u}$ at time t is given by:

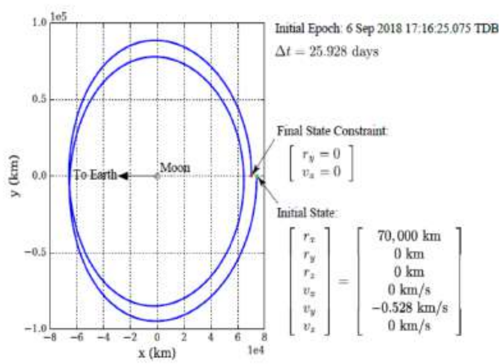
$$\hat{u}(t) = [\cos\alpha(t).\cos\beta(t)]\hat{e_1} + [\sin\alpha(t).\cos\beta(t)]\hat{e_2} + [\sin\beta(t)]\hat{e_3} \tag{9.3}$$

where the basis vectors $[\hat{e_1}\ \hat{e_2}\ \hat{e_3}]$ can be:
- the *IJK* frame($\hat{e_1}$ = **i** $\hat{e_2}$ = **j** $\hat{e_3}$ = **k**)
- the Copernicus *VUW* controls frame ($\hat{e_1}$ = **v/||v||** $\hat{e_3}$ = **h/||h||** $\hat{e_2} = \hat{e_3} x \hat{e_1}$)
- the Copernicus *VNC* controls frame ($\hat{e_1}$ = **v/||v||** $\hat{e_2}$ = **h/||h||** $\hat{e_3} = \hat{e_1}$x$\hat{e_2}$)

Note that these frames can be defined in either an inertial or rotating reference frame.

9.3 Launch Window Trajectories

For missions targeting a very specific orbit, the concept of launch window trajectories are used, which are programmed into launch vehicles prior to launch. The destination orbit for all Artemis missions is lunar DRO. The DRO is computed along with the nominal mission as part of the Orion on orbit trajectory optimization . The initial state of the DRO is propagated backwards in time to serve as the target for the DRO Insertion (DRI) burn. Note that the nominal DRO is planar (i.e., in the Earth-Moon plane), but during the eclipse mitigation process, it may be inclined.



Representation of Distant Retrograde Orbit(DRO)

9.3.1 Optimisation Variables

The major optimization variables are:
- The finite burn control law parameters α_0, β_0, for each of the optimized maneuvers.
- The burn time Δt for each of the optimized maneuvers.
- The various intermediate flight times.
- The launch epoch.
- The OPF and RPF flyby epochs.
- The OPF and RPF flyby state parameters (periapsis radius, eccentricity, inclination, ascending node, argument of periapsis, and true anomaly).
- The EI epoch.
- The EI longitude, latitude, velocity, azimuth, and flight path angle.

9.3.2 Constraints

- The various time and state continuity conditions along the trajectory.
- There is a minimum 5.15 day outbound (launch to OPF) flight time constraint in order to maximize flight time and ensure consistency for the secondary payloads on board ICPS.
- The EI longitude, azimuth, and flight path angle are constrained to be on the EI target line.
- The total propellant mass used by the XDM OPF through DRI segments is constrained to be equal to the propellant mass used by the nominal OPF through DRI segment burns.
- The total propellant used by the XDM RPF through RTC-4 segments is constrained to be equal to the propellant mass used by the nominal RPF segment burn.
- Maximum and minimum bounds for distance traveled between EI and splashdown site.
- Sunrise and sunset time constraints for landing.
- Maximum eclipse durations throughout the trajectory.
- Non-viable latitude locations for EI - between 14 and 21.9 latitude, due to the SM disposal requirements near the Hawaiian islands.

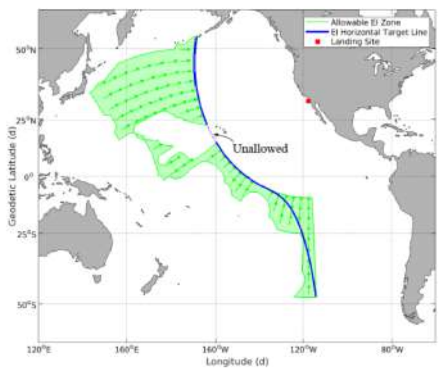


Figure 9.6: EI Target Line with Allowable Zone. The blue target line approximates the green region in the optimization problem.

9.3.3 Optimisation Algorithm

To generate launch window trajectories, the "optimal point" is found first, which is the optimal launch azimuth point per day corresponding to the minimum ICPS plus Orion total (delta)v. An appropriate mission class and length is selected based on Orion constraints and any additional constraints are added in order to mitigate violations. The final optimized trajectory is used as the origin to compute the launch window. The optimization problem is then proceeded as follows :

- The launch epoch is fixed.
- The secondary payload outbound transit time with a minimum bound of 5.15 day from launch to OPF is removed.
- The OPF epoch tOPF is fixed to ensure a variable launch azimuth mission design approach is achieved. This helps to ensure more consistent outbound transit times.
- OTC-2 is enabled as an optimized burn.
- The DRO insertion state and time (tDRI) is locked down. This helps to ensure the same DRO is achieved during the entire window.

Note that, since the launch window scan is done using the TLI database (beginning at the Orion Sep

point), only the Orion v is being minimized in the objective function. The launch scan continues (forward and backwards) until any of the following conditions are violated:
- The problem does not converge (i.e., the mission is infeasible).
- Orion exhausts its available propellant for major burns.
- The launch to OPF duration is < 4 days.

A continuation method is used to perform epoch scans of the basic mission, mission classes, and computation of the launch window. There are three kinds of scans: epoch scan, mission class scan, and launch window scan. During the scan, the lunar geometry is used in various ways to update the initial guess to provide robust convergence. In order to make Earth- Moon geometry similar, for epoch steps, rather than using integer days, a better time step is computed for each epoch using a simple lunar ephemeris.

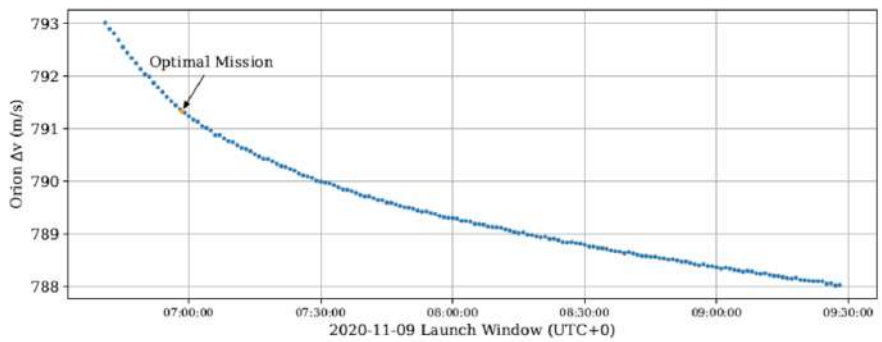


Figure 9.7: Graph obtained after Launch Window Optimization

9.4 Off-Normal Trajectories

For every nominal mission trajectory, the Artemis I mission design team will create a set of off nominal missions. They can be broken into three categories depending on the goal of the off-nominal trajectory:
- An alternate mission is a response to a failure that occurs prior to the Orion-ICPS separation. In this scenario, the baseline mission is infeasible and is replaced with a scenario within vehicle constraints.
- A return to the nominal trajectory is a response to a relatively small failure, such as a missed or partial Orion burn. In this scenario, a burn did not perform as expected due to a failure or operational constraint. A recovery burn is used to return Orion to the baseline Artemis I trajectory and ensures all intended mission objectives are met.
- An abort trajectory is a response to a significant failure. It is used in the event the vehicle cannot complete the nominal mission and must abort to ensure vehicle recovery.

10. MOGA Modelling

Invoking the Trajectory Optimisation equations from the data obtained from Altitude Testing of the Space Launch System would have been the basic pre-requisite to proceed with the application of the Multi-Objective Genetic Algorithm(MOGA). But due to the unavailability of that data publicly at present, we can only obtain rough estimates about the Thrust and Angle profiles based on the initial parameters we know. The plots obtained by the spline interpolation of tentative Thrust and Angle data in MATLAB come out to be:

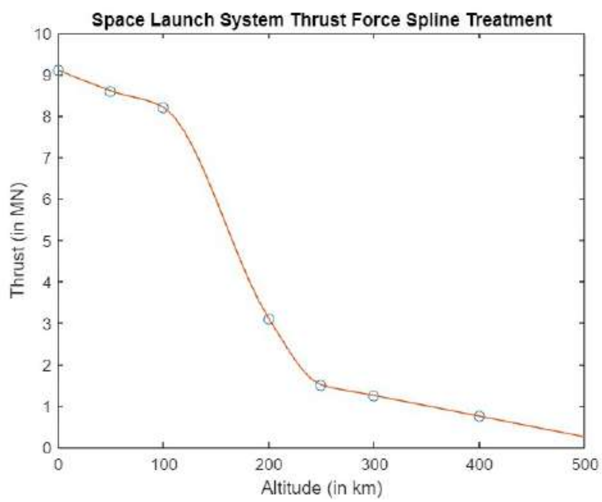


Figure 10.1: Spline Interpolation in MATLAB

Due to lack of data, it is also not possible to plot Pareto Fronts to obtain the high-payload and low-cost optimised individuals. But, there is another technique via which several other parameters can be taken into consideration and the GA can be applied to the functions generated to get the optimised results and the Pareto fronts.

This technique is very well explained in this research paper by Mehran Mirshams, Hasan Naseh, H.R. Fazeley.

For this mission, a new multi-objective technique using Holistic Concurrent Design(HCD) and Multi-Objective Genetic Algorithm(MOGA) is applied to optimize the multidisciplinary design of Space Launch System(SLS).

This method reduces the multi-objective constrained optimization problem to a single-objective unconstrained optimization. The design problem is established using the fuzzy rule set based on the designer's expert knowledge with a holistic approach. The independent design variables in this model are nozzle exit pressure, combustion chamber pressure, oxidizer to fuel mass flow rate(O/F), stringer thickness, ring thickness, shell thickness. To handle the mentioned problems, a fuzzy–MOGA optimization methodology is developed based on the Pareto optimal set.

Taking Propulsion and Structure as base, objective functions are formed with certain range constraints on few parameters. This is followed by plotting of Pareto Fronts by the GA for several generations. And thus, ultimately getting the optimum design solutions, which are depicted in the Table below:

Design variables						
	P_{CC} (bar)	O/F	P_{ex} (bar)	t_{st} (mm)	t_r (mm)	t (mm)
Initial	69.64	2.25	0.7716	5.57	5.68	5.20
Final	70.75	2.27	0.7255	5.45	5.5	5.17
Attitude parameters			Wish design attributes			
	$[p, q, \alpha]$		W_{Tank} (ton)	W_{eng} (ton)	I_{SP} (s)	
Initial	[9.0, 1.6, 0.6]		33.5	8.245	245.0	
Final	[10.77, 1.32, 0.58]		32.8	8.440	263.0	
Overall must satisfaction ($\mu_M^{(p)}$)			Overall satisfaction ($\mu^{(p,q,\alpha)}$)			
Initial	0.356		0.255			
Final	0.580		0.555			

Figure 10.2: Initial and Final design solutions

Also, the Pareto Fronts obtained for the objective functions have been plotted in the research paper as well:

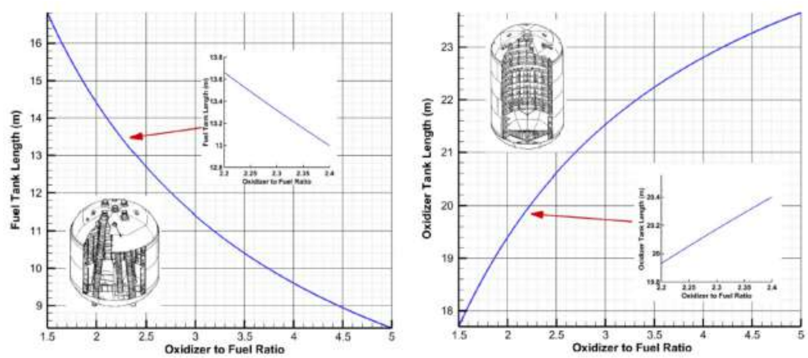


Figure 10.3: Fuel Tank weight and Oxidizer Tank length vs O/F

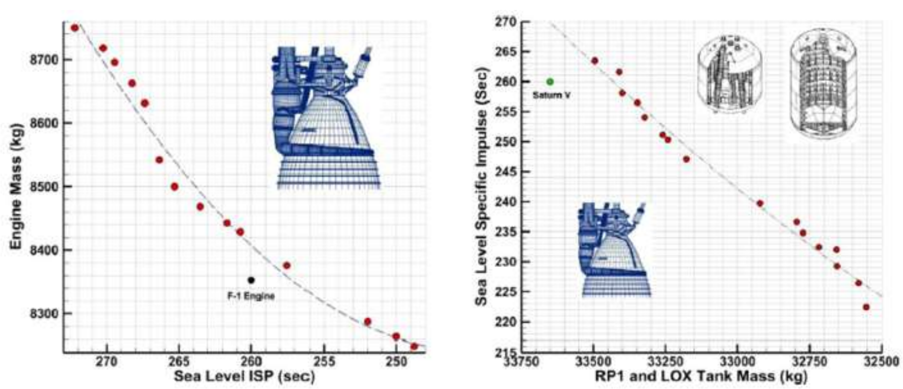


Figure 10.4: Pareto Frontier for objective functions (Specific Impulse, Engine Weight, Tank Weight)

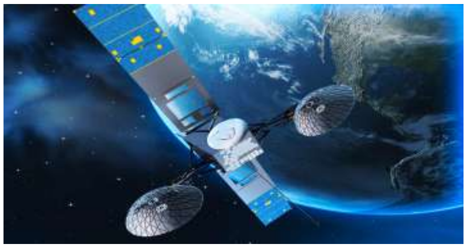
So, finally, the optimum values for the considered parameters are obtained. Hence, this methodology provides an interesting decision-making approach to design multi-product batch plants under conflicting goals.

11. Communication

Artemis I will demonstrate NASA's networks' comprehensive services for journeys to lunar orbit. The mission requires all of NASA's space communications and navigation networks to work in tandem, providing different communications and tracking service levels as Orion leaves Earth, orbits the Moon, and returns safely home. Communications services allow flight controllers in mission control centers to send commands to the spacecraft and receive data from Orion and SLS systems. Tracking, or navigation, services enable the flight controllers to see where the spacecraft are along their trajectory through space.

11.1 ARTEMIS I Navigation

Navigation services enable flight controllers to track where spacecraft are along their trajectory through space. On the journey to the Moon and in orbit around the Moon, the Deep Space Network's large ground antennas will provide primary tracking data. Near Space Network ground stations in Chile and South Africa will supplement this tracking data.



Navigation Sattelite.

11.2 Network Support for ARTEMIS I

11.2.1 Near Space Network(NSN)

NASA's Near Space Network provides a comprehensive suite of communications and navigation services through commercial and government-owned, contractor-operated network infrastructure. It's mainly divided into two components:

1. **NSN DTE**- Near Space Network DTE services are provided by a worldwide network of ground stations
2. **NSN TDRS**- The Near Space Network's TDRS constellation can provide near-continuous communications services to spacecraft near Earth.

11.2.2 Deep Space Network(DSN)

The Deep Space Network will handle Artemis I communications beyond Near Space Network coverage, en route to and in orbit around the Moon. Additionally, the network will facilitate communications during the deployment of CubeSat payloads that will provide additional research opportunities for Artemis I.

Figure 11.1: NSN Equipment.

Figure 11.2: DSN Ground Equipment.

11.3 Search And Rescue (SAR)

The Orion spacecraft is equipped with an emergency beacon designed by NASA's Search and Rescue office. Using Cospas-Sarsat, the international satellite-aided search and rescue network, this beacon will help NASA to quickly locate Orion upon activation of the beacon during splashdown or in the unlikely event of an abort scenario.

Future Internet Like Search and Rescue Network.

11.4 ARTEMIS Mission Support

NASA's Space Communications and Navigation (SCaN) program provides strategic oversight and funding to NASA's networks and to the development of new communications and navigation technologies. SCaN will support all Artemis missions while providing astronauts with revolutionary communications capabilities. SCaN is also developing LunaNet, a exible lunar communications and navigation architecture that will play a key role in NASA's ambitious exploration initiatives under the Artemis program. LunaNet will allow NASA to extend internet-like service to the Moon

ANGEL:Developed By Nasa.

12. Re-entry

When NASA's Orion spacecraft is nearing its return to Earth after its Artemis I mission to the Moon, it will attempt the first skip entry for a human spacecraft – a maneuver designed to pinpoint its landing spot in the Pacific Ocean.During this skip entry, Orion will dip into the upper part of Earth's atmosphere and use that atmosphere, along with the lift of the capsule, to skip back out of the atmosphere, then re-enter for final descent under parachutes and splashdown. It's a little like skipping a rock across the water in a river or lake.This skip entry has various benefits over the classical entry method used. It will divide the impact thus reducing the G force experienced by astronauts Eventually making the ride more safer and smoother. Dividing the impact will affect the friction heating caused. It will be reduced. Also skip entry will make the landing more accurate thus reducing the recovery coast, as now the navy won't have to deploy various ships in the target sea/ocean.

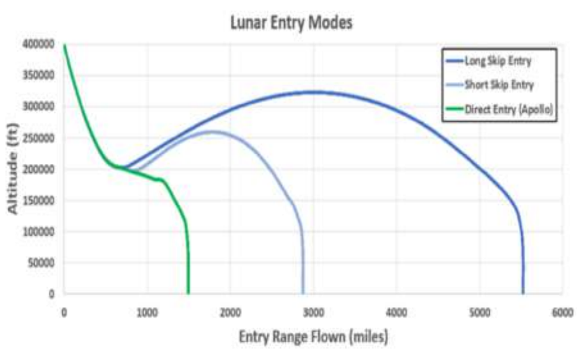


Figure 12.1: Entry Range Vs Altitude Graph.

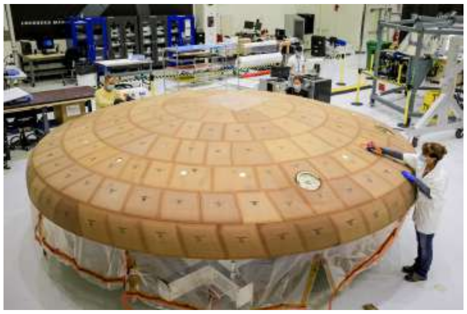


Figure 12.2: Orion Heat Shield.

12.1 Heat Shield

Orion returns on a high-speed Earth reentry at Mach 32, or 24,500 miles per hour, thus heating the module to nearly 5,000 degrees Fahrenheit before splashing down in the Pacific Ocean for retrieval and post-flight engineering assessment.To protect the Crew Module during Earth re-entry, the dish shaped AVCOAT heat shield ablator system, in a honeycomb structure was selected as heat shields. Licensed by Textron, AVCOAT material is produced at New Orleans's Michoud Assembly Facility by Lockheed Martin. This heat shield will be installed at the base of the crew module to provide a controlled erosion moving heat away from the crew module into the atmosphere.Its honeycomb structure prevents the module from ablation. It was after rigorous testing and study of its structure, that NASA approved of them to be installed on the crew module.

13. Interstellar Voyage and Conclusion

With confidence based on the Artemis I mission and the thousands of hours put into the prior flight and ground testing, NASA plans to send the Artemis II crew who will board Orion atop the SLS for an approximate 10-day mission. It will be the first crewed flight of SLS and Orion that will send four astronauts to the lunar environment for the first time in more than 50 years. They will set a record for the farthest human travel beyond the far side of the Moon in a hybrid free return trajectory.

Further, by 2024 NASA plans to send Artemis III, culmination of the rigorous testing and more than two million miles accumulated in space on NASA's deep space transportation systems during Artemis I and II. This time, Orion and its crew of four will travel to the Moon again, but to make history with the first woman and next man to walk on its surface.

Gateway is a crucial part of Artemis program, which will seed our future deep space explorations. Gaining new experiences on and around the Moon will prepare NASA to send the first humans to Mars in the coming years, and the Gateway will play a vital role for all the landers and spacecraft enroute to destinations beyond Moon. The Gateway-to-surface operational system is also analogous to how a human Mars mission may work—with the ability for the crew to remain in orbit and deploy to the surface. It is crucial to gain operational confidence in this system at the Moon before the first human missions to Mars.

This incremental build-up of capabilities and robotic presence on and around the Moon is essential to establishing long-term exploration of Earth's nearest neighbor Mars. With our arrowhead pointed to Mars, we aim to explore deep into space, and bring back the information and knowledge collected back to earth. By partnering with several native and international partners, NASA aims to build a sustainable space economy, alongwith making space accessible for humans to probe for knowledge and explorations. This mission, seed from minds with a vision, backed by perspicacity and technology, will open paths to deep space, thus help uncover space mysteries and paths to trace back our existence in the Universe.

14. References

1. The Artemis Plan: NASA's Lunar Exploration Program Overview, Link to the Document

2. Boeing's Page for SLS Description, Link to the page

3. NASA's Page on SLS, Link to the page

4. Amelia L. Batcha, Jacob Williams, Timothy F. Dawn, Jeffrey P. Gutkowski, Maxon V. Widner, Sarah L. Smallwoodk, Brian J. Killeen, Elizabeth C. Williams, and Robert E. Harpold. *Artemis I Trajectory Design and Optimization,* Link to the Paper

5. Mehran Mirshams, Hasan Naseh, H.R. Fazeley. *Multi-objective multidisciplinary design of Space Launch System using Holistic Concurrent Design*. Aerospace Science and Technology, Volume 33, Issue 1. Link to the Paper

6. Derek J. Dalle. *Launch Vehicle Aerodynamics Database Development for SLS,* Link to the Paper

7. NASA Guide on Spacecraft Structures, Link to the Guide

8. eoPortal Directory on Artemis I, Link to the Directory

9. Artemis Communication Systems and Networks, Link to the page

10. New Re-entry techniques for Orion, Link to the page

11. NASAfacts: Orion Launch Abort System, Link to the Fact Sheet

12. William J. Koenig, Carlos Garcia, Lisa D. Akers, Richard F. Harris. *Artemis Innovative Assembly and Integration Operations of the Launch Abort System at KSC,* Link to the Paper