# Space: The Final Frontier

**Sample Mission Report (SMR)**
**Group-1**

# Apollo-11


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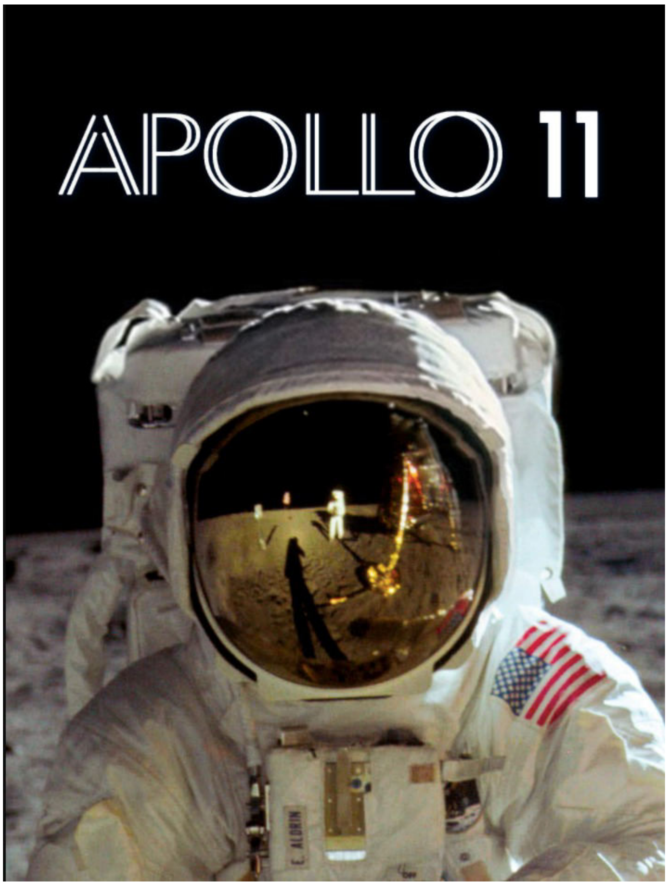
**Keywords:** *Apollo Rocket, Moon Missions, Saturn V, Rocket Engines, Lunar Transfer*

# INTRODUCTION




**Apollo 11** was launched from **Cape Kennedy** on **July 16, 1969**, carrying **Commander Neil Armstrong, Command Module Pilot Michael Collins and Lunar Module Pilot Edwin "Buzz" Aldrin** into an initial Earth-orbit of 114 by 116 miles. An estimated 650 million people watched Armstrong's televised image and heard his voice describe the event as he took "...one small step for a man, one giant leap for mankind" on July 20, 1969.
The primary objective of Apollo 11 was to complete a national goal set by President John F. Kennedy on May 25, 1961: perform a crewed lunar landing and return to Earth.

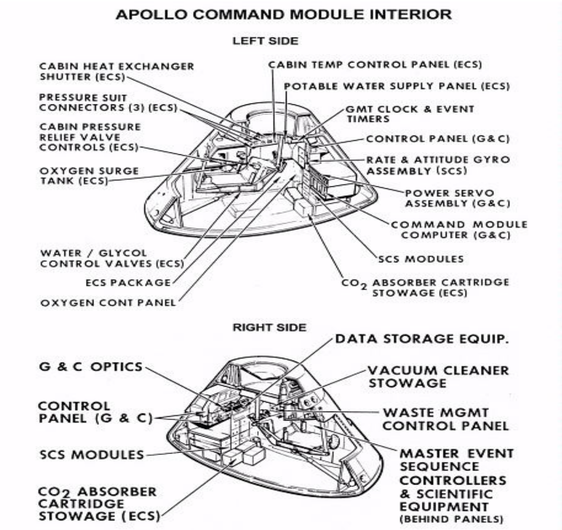
# 1. ROCKET DESIGN

The Apollo 11 mission primarily had 3 spacecraft:

## 1.1 Command Module - Columbia

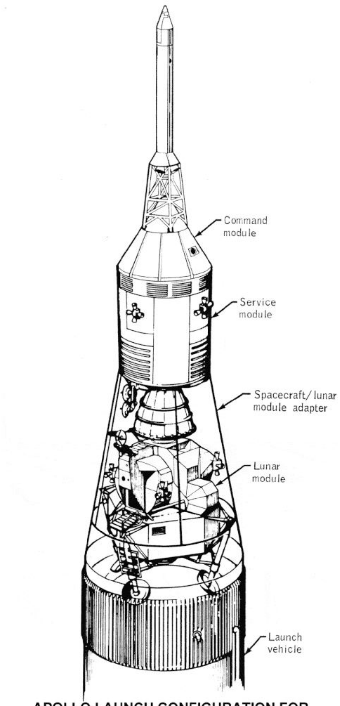
The Apollo 11 Command Module Columbia carried astronauts Neil Armstrong, Edwin Aldrin, and Michael Collins on their historic voyage to the Moon and back on July 16-24, 1969.

During the journey to and from the Moon, Columbia, having an interior space just around greater than an automobile, served as main quarters for the astronauts, a place for working and living. The blunt-end design for the Command Module was chosen to build upon experience gained with the similarly shaped Mercury and Gemini spacecraft.




**Command Module Specifications :**

- Height: 3.2 m (10 ft 7 in)
- Maximum Diameter: 3.9 m (12 ft 10 in)
- Weight: 5,900 kg (13,000 lb)
- Manufacturer: North American Rockwell for NASA
- Launch Vehicle: Saturn V




APOLLO LAUNCH CONFIGURATION FOR LUNAR LANDING MISSION

## 1.2 Service Module

A service module (also known as an equipment module or instrument compartment) is a component of a crewed space capsule containing a variety of support systems used for spacecraft operations. Usually located in the uninhabited area of the spacecraft, the service module serves a storehouse of critical subsystems and supplies for the mission such as electrical systems, environmental control, and propellant tanks.
The service module is jettisoned upon the completion of the mission and usually burns up during atmospheric re-entry.

## 1.3 Lunar Module - Eagle

Because lunar modules were designed to fly only in the vacuum of space, they did not have to be streamlined like an aircraft or carry a heat shield for protection during re-entry. Once a lunar module was launched into space, it could not return to Earth.

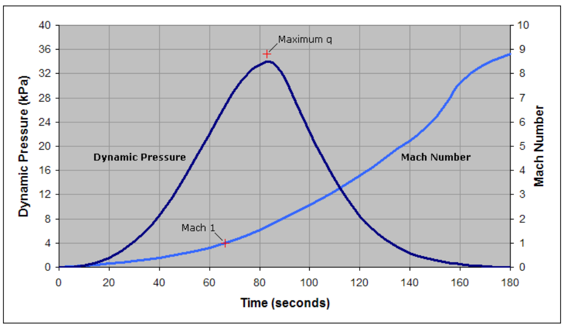
**Lunar Module Specifications**:

- Weight (empty): 3920 kg (8650 lb)
- Weight (with Crew & Propellant): 14,700 kg (32,500 lb)
- Height: 7.0 m (22 ft 11 in)
- Width: 9.4 m (31 ft 00 in)
- Descent Engine Thrust: 44,316 Newtons (9870 lb) maximum, 4710 Newtons (1050 lb) minimum
- Ascent Engine Thrust: 15,700 Newtons (3500 lb)
- Fuel: 50-50 mix of Unsymmetrical Dimethyl Hydrazine (UDMH) & Hydrazine
- Oxidizer: Nitrogen Tetroxide
- Prime Contractor: Grumman Aerospace Corporation

# 2. AERODYNAMICS

To be successful in the mission, the rocket must be able to withstand the value of maximum dynamic pressure or Max Q that the rocket experiences during its journey. If it is not able to do so, it results in buckling and the rocket collapsing, which causes a catastrophe.
The dynamic pressure experienced by the rocket is given by:

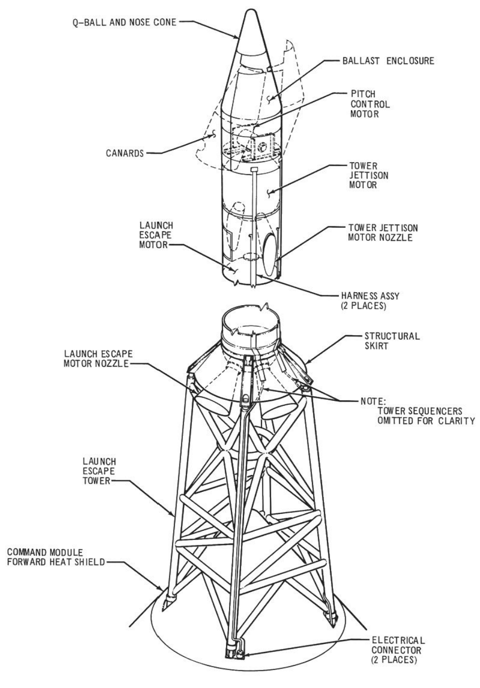
$$q = \frac{1}{2}\rho v^2$$




Suitable materials were used in order to avoid buckling like aerospace grade aluminum and titanium. The nose cone and fins of a rocket were designed to minimize drag (air resistance) and to provide stability and control (keep it pointing in the right direction without wobbling). Heat-resistant nickel and steel alloys were used in order to absorb heat when exposed to the sun and radiate to the blackness of deep space.

# 3. STRUCTURAL SYSTEM

The launch vehicle, AS-506 (Apollo Saturn), was used and was the fourth human-crewed Saturn V vehicle. The structural system consists of the fairings, cylindrical body, and control fins.
NASA made few modifications to the Apollo 11 space vehicle from the preceding configuration like the Lunar module (LM).




LAUNCH ESCAPE SYSTEM.

# 4. ABORT SYSTEM AND HEAT SHIELD

The **Apollo Launch abort system (LAS) or Launch escape system (LES)** was designed for the group to escape if a few failures occurred during the preliminary phase of launching.
It contained three solid-propellant rocket motors:

- Launch escape motor
- Pitch control motor.
- Tower jettison motor

The **Launch escape motor** (main motor) in the Abort system had a thrust of 155,000 pounds. It detaches the command module away from the path of the remaining portions of the launch vehicle if any malfunctioning occurs during launch.
The **Pitch control motor** was essential for establishing a safe trajectory for the launch abort system.

The **Tower jettison motor** was used to separate the launch abort system from the command module before the deployment of the parachutes.
**To protect the Apollo Command Module (Columbia**) *from the extreme heat throughout re-entry*, NASA selected an **Ablative heat shield AVCOAT** composed of a set metallic honeycomb substructure, a fiberglass honeycomb shell stuffed with phenolic epoxy glue. The material was designed such that it vaporized because of atmospheric friction, which prevents the heat from coming into the group compartment.
The **Lunar Module (LM)** was used for dropping to the lunar surface and served as a base camp while the astronauts were on the Moon for explorations. Several materials cover the spacecraft to defend its internal
structure against temperature and small meteoroids. The sheets soak up the heat when exposed to the Sun and radiate to space.
The Lunar module had two stages:

1. **Ascent stage**, containing the group's compartment that managed the entire spacecraft.

2. **Descent stage**, almost like the ascent stage, containing the rocket engine and tanks for fuel and oxidizer.

The descent (lower) stage contained a rocket motor to slow down the velocity of descent to the lunar surface.
It contained some scientific exploration equipment and remained on the Moon when the astronauts left for further research on the Moon.

# Lunar Module Ascent Stage (Control)

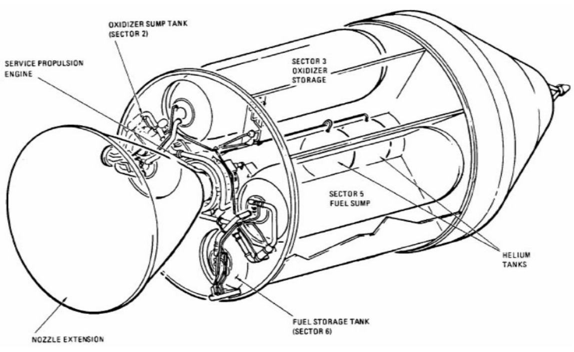
The crew compartment in the ascent stage included some essential things like the life support system, communication and navigation system for astronauts. The Controls and displays for the main engine allowed the crew member to fly the craft.
It contained its own Ascent Propulsion System (APS) engine for return to lunar orbit and a Reaction Control System (RCS) for altitude and translation control.
For rejoining with the Command Module (CM), the astronauts started the ascent-stage engine and lifted off from the Moon. Then the ascent stage docked with the CM in lunar orbit. The ascent stage engine then crashed into the Moon.

# 5. PROPULSION

**Propulsion is the action or process of pushing or pulling to drive an object forward. A propulsion system consists of a source of mechanical power and a *propulsor*(means of converting this power into propulsive force).In case of Apollo-11**, Liquid-Propulsion was used, and the service module propulsion system was reignited.

**Spacecraft and Subsystems**

The Apollo 11 Command and Service Module contains mass of 28,801 kg was the launch mass including propellants and expendables, of which the Command Module (CM 107) had a mass of 5557 kg and the Service Module (SM 107) 23,244 kg.



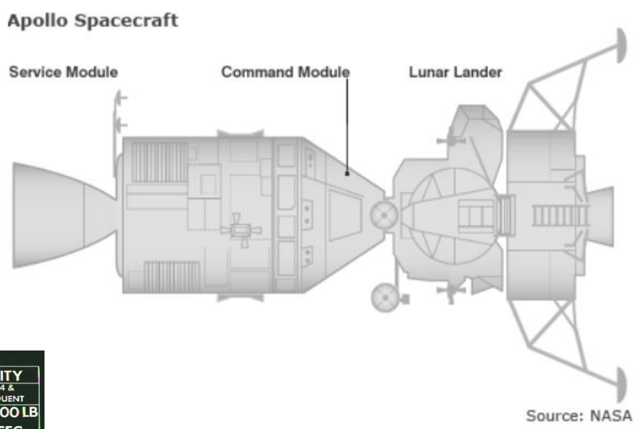
**Service Propulsion System (Service Module)**

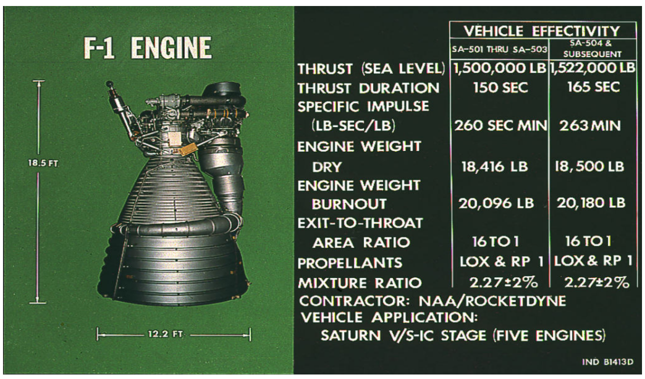
The SM was a cylinder 3.9 meters in diameter and 7.6 m long, which was attached to the back of the CM. The outer skin of the SM was formed of 2.5 cm thick aluminum honeycomb panels. The interior was divided by milled aluminum radial beams into six sections around a central cylinder. At the back of the SM mounted in the central cylinder was a gimbal mounted re-startable hypergolic liquid propellant 91,000 N engine and cone-shaped engine nozzle. Attitude control was provided by four identical banks of four 450 N reaction control thrusters, each spaced 90 degrees apart around the forward part of the SM. The six sections of the SM held three 31-cell hydrogen-oxygen fuel cells, which provided 28 volts, two cryogenic oxygen and two cryogenic hydrogen tanks, four tanks for the main propulsion engine, two for fuel and two for oxidizer, and the subsystems the main propulsion unit. Two helium tanks were mounted in the central cylinder.

# 6. ENGINE DESIGN

## F-1 Engine

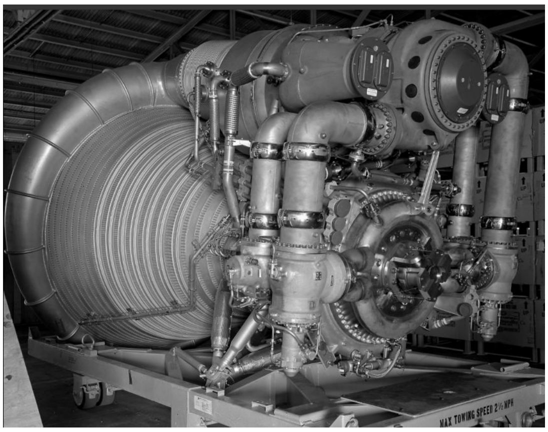
Five F-1 engines were used in the S-IC first stage of each Saturn V, which served as the main launch vehicle of the Apollo-11 mission. The F-1 remains the most powerful single combustion-chamber liquid-propellant rocket engine ever developed. It uses Gas-Generator cycle, which is an open cycle engine, easy to build and operate, but it loses efficiency due to discarded propellants. The F-1 engine is the most powerful single-nozzle liquid-fueled rocket engine ever flown. The F-1 burned RP-1 (rocket grade kerosene) as the fuel and used liquid oxygen (LOX) as the oxidizer.



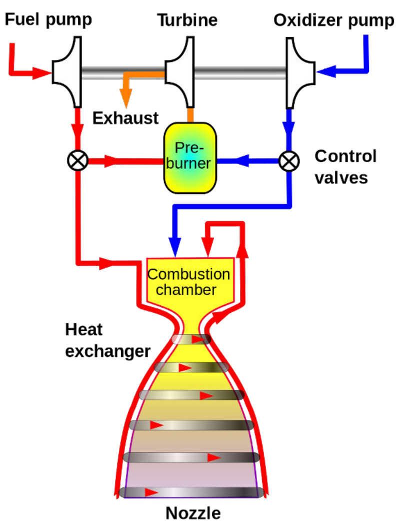

A turbo-pump was used to inject fuel and oxygen into the combustion chamber. Also, the RD-170 produces more thrust but has four

nozzles. One notable challenge in the construction of the F-1 was regenerative cooling of the thrust chamber. There was an issue known as 'starvation' due to hydrodynamic and thermodynamic characteristics of the F-1 which occurs when an imbalance of static pressure leads to 'hot spots in the manifolds.
The heart of the engine was the thrust chamber, which mixed and burned the fuel and oxidizer to produce thrust. A domed chamber at the top of the engine served as a manifold supplying liquid oxygen to the injectors, and also served as a mount for the gimbal bearing which transmitted the thrust to the body of the rocket. Below this dome was the injectors, which directed fuel and oxidizer into the thrust chamber in a way designed to promote mixing and combustion. Fuel was supplied to the injectors from a separate manifold; some of the fuel first traveled in 178 tubes down the length of the thrust chamber — which formed approximately the upper half of the exhaust nozzle — and back in order to cool the nozzle. A gas generator was used to drive a turbine which drove separate fuel and oxygen pumps, each feeding the thrust chamber assembly. Structurally, fuel was used to lubricate and cool the turbine bearings.



F-1 engine

Five huge F-1 engines used in Apollo-11




Gas-Generator Cycle


Diagram of a Saturn V launch vehicle

**Saturn V Launch Vehicle**

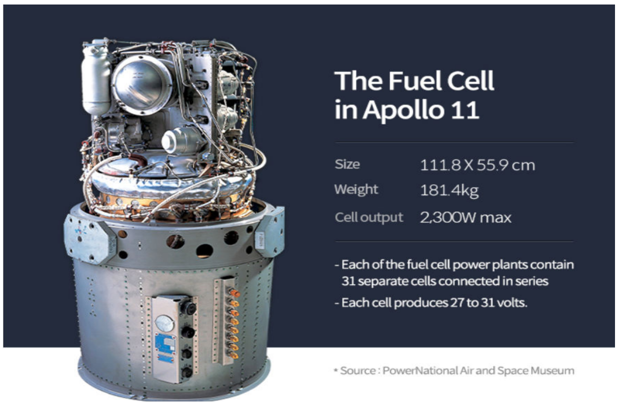
Saturn V launch vehicles and flights were designated with an AS-500 series number, "AS" indicating "Apollo Saturn" and the "5" indicating Saturn V.

The three-stage Saturn V was designed to send a fully fueled CSM and LM to the Moon. The S-IC first stage burned RP-1/LOX for a rated thrust of 7,500,000 pounds-force (33,400 kN), which was upgraded to 7,610,000 pounds-force (33,900 kN). The second and third stages burned liquid hydrogen;the third stage was a modified version of the S-IVB, with thrust increased to 230,000 pounds-force (1,020 kN) and the capability to restart the engine for translunar injection after reaching a parking orbit.

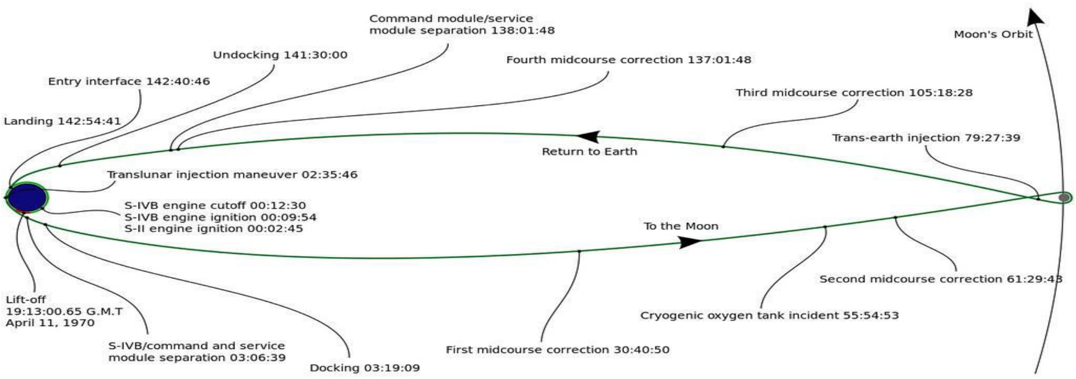
The Apollo 11 Saturn V rocket is being moved to the pad aboard the Mobile Launch Platform (MLP) at Cape Canaveral May, 1969.

**Fuel Cells**

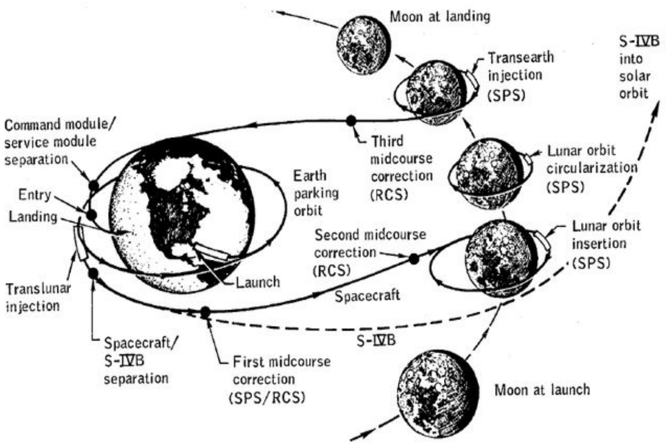
Both Gemini and Apollo spacecraft obtained electrical power from hydrogen-oxygen fuel cells. A fuel cell is like a battery. It converts energy released in a chemical reaction directly to electrical power. Unlike a storage battery, a fuel cell continues to supply current as long as chemical reactants are available or replenished (even while the cell is operating).




# 7. ORBITAL DYNAMICS



- Apollo 11 reached orbit around earth at around t=11 min 49 sec.
- Then in order to set a trajectory to the moon, a trans-lunar insertion orbit was done.
- **Atrans-lunar injection** (**TLI**) is a propulsive maneuver used to set a spacecraft on a trajectory that will cause it to arrive at the Moon.
- This maneuver happened at approximately t=2 hr 50 min 13 sec. For the Apollo lunar missions, TLI was performed by the restartable J-2engine in the S-IVB third stage of the Saturn V rocket.
- This particular TLI burn lasted approximately 350 seconds, providing 3.05 to 3.25 km/s of change in velocity, at which point the spacecraft was traveling at approximately 10.4 km/s relative to the Earth.
- The TLI placed Apollo on a "free-return trajectory" - often illustrated as a figure of eight shape, which would enable a return to Earth with no engine firing, providing a ready abort of the mission at any time prior to lunar orbit insertion.
- The command and service module, or CSM, Columbia separated from the stage, which included the spacecraft-lunar module adapter, or SLA, containing the lunar module, or LM, Eagle.
- The CSM docked with the LM. On July 19, after Apollo 11 had flown behind the moon out of contact with Earth, came the first lunar orbit insertion maneuver.
- At about 75 hours, 50 minutes into the flight, a retrograde firing for 357.5 seconds placed the spacecraft into an initial, elliptical-lunar orbit of 69 by 190 miles.
- Later, a second burn for 17 seconds placed the docked vehicles into a lunar orbit of 62 by 70.5 miles.
- At 100 hours, 12 minutes into the flight, the Eagle undocked and separated from Columbia for visual inspection.
- At 101 hours, 36 minutes, the LM descent engine fired for 30 seconds to provide retrograde thrust and commence descent orbit insertion, changing to an orbit of 9 by 67 miles.
- At 102 hours, 33 minutes, after Columbia and Eagle had reappeared from behind the




moon and when the LM was about 300 miles uprange, powered descent initiation was performed with the descent engine firing for 756.3 seconds.

- After eight minutes, the LM was at "high gate" about 26,000 feet above the surface and about five miles from the landing site. The descent engine continued to provide braking thrust until about 102 hours, 45 minutes into the mission.
- Partially piloted manually by Armstrong, the Eagle landed in the Sea of Tranquility.
- During liftoff from the moon, the ascent stage engine fired at 124 hours, 22 minutes.
- It was shut down 435 seconds later when the Eagle reached an initial orbit of 11 by 55 miles above the moon.
- As the ascent stage reached apolune at 125 hours, 19 minutes, the reaction control system, or RCS, fired so as to nearly circularize the Eagle orbit at about 56 miles, some 13 miles below and slightly behind Columbia.
- Subsequent firings of the LM RCS changed the orbit to 57 by 72 miles.
- Docking with Columbia occurred at 128 hours 3 minutes into the mission.
- Trans-Earth injection of the CSM began July 21 as the SPS fired for two-and-a-half minutes.
- Re-entry procedures were initiated July 24, 44 hours after leaving lunar orbit. The SM separated from the CM, which was re-oriented to a heat-shield-forward position.
- Parachute deployment occurred at 195 hours, 13 minutes.
- After a flight of 195 hours, 18 minutes, 35 seconds. Apollo 11 splashed down in the Pacific Ocean, 13 miles from the recovery ship USS Hornet.

# Radiation Protection methods

## Van Allen Belts:

Although the Apollo missions have placed men outside the protective geomagnetic shielding and have subjected them to types of ionizing radiation seldom encountered in earth environments, radiation doses to Apollo crewmen have been minimal.

Spacecraft transfer from low earth orbit to translunar coast necessitates traverse of the regions of geomagnetically trapped electrons and protons known as the Van Allen belts.

When beyond these belts, the spacecraft and crewmen are continuously subjected to high-energy cosmic rays and to varying probabilities of particle bursts from the sun.

The problem of protection against the natural radiations of the Van Allen belts was recognized before the advent of manned space flight.

The small amount of time spent in earth orbit and the rapid traverse of the radiation belts during Apollo missions have minimized astronaut radiation dose.

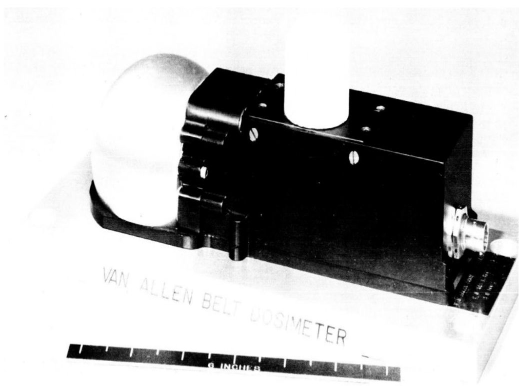



Figure 3. - Van Allen belt dosimeter.

The Van Allen belt dosimeter (VABD) (fig.3) was designed specifically for Apollo dosimetry within these radiation belts and has proved satisfactory because dose values derived from its greater than 180 degree radiation acceptance angle have correlated well with doses indicated by postflight analyses of passive dosimeters worn by the crewmen.

## Solar-Particle Events:

- No major solar-particle events have occurred during an Apollo mission.
- Although much effort has been expended in the field of solar -event forecasting, individual eruptions from the solar surface are impossible to forecast. The best that could be provided at that time was an estimate of particle dose, given radio frequency (RF) confirmation that an eruption has occurred.

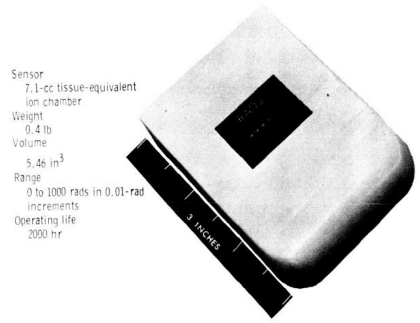



Figure 5. - Personal radiation dosimeter.

## Cosmic Rays:

- One particular effect possibly resulting from cosmic rays has been the light flash phenomenon reported on the Apollo 11 and subsequent missions.

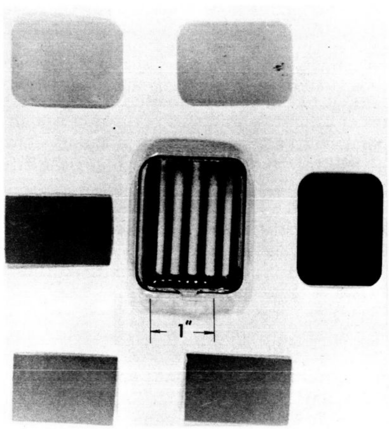



Figure 6. - Passive dosimeter with component parts.

- Although ionizing radiation can produce visual phosphenes (subjective sensations best described as flashes of light) of the types reported, a definite correlation has not been established between cosmic rays and the observation of flashes.
- The light flashes had been described as starlike flashes or streaks of light that apparently occur within the eye.
- The flashes were observed only when the spacecraft cabin was dark or when blindfolds were provided and the crewmen were concentrating on the detection of the flashes.

- There was a possibility that visual flashes may indicate the occurrence of damage to the brain or eye; however, no damage had been observed among crewmen who had experienced the light flash phenomenon.

**Neutrons:**

- Neutrons created by cosmic rays in collision with lunar materials were postulated to be a potential hazard to Apollo crewmen.
- Whole-body counting and neutron-resonant foil techniques had been initiated on the Apollo 11 mission.
- The results of these analyses indicated that neutron doses were significantly lower than had been anticipated.

**Overall Radiation Spectrum:**

- During a complete Apollo mission, astronauts are exposed to widely varying fractions of radiations from the Van Allen belts, cosmic rays, neutrons, and other subatomic particles created in high energy collisions of primary particles with spacecraft materials. In addition, the individual responsibilities of the crewmen differ, and, therefore, radiation exposure may differ.
- To allow accurate determination of radiation exposure of the crewman, each carried a personal radiation dosimeter (PRD) (fig. 5) and three passive dosimeters (fig. 6).
- The PRD provides a visual read-out of accumulated radiation dose to each crewman as the mission progresses.

**Conclusion:**

- Apollo missions had not undergone any major space radiation contingency.
- However, the development of spacecraft dosimetry systems, the use of a space radiation surveillance network, and the availability of individuals with a thorough knowledge of the space radiation environment have assured that any contingency would be recognized immediately and would be coped with in a manner most expedient for both crew member safety and mission objectives.
- It had been shown on the Apollo missions that the spacecraft and its crewmen had successfully avoided the large radiation doses that, before the Apollo missions, had been cited as a possible deterrent to manned space flight.

# 8. COMMUNICATIONS AND SYSTEM

The Apollo missions were incredibly complex, with multiple space vehicles performing intricate maneuvers in deep space, which required accurate tracking at extreme distances.
An S-Band Transponder was the only mode or link of communications between Apollo 11 Astronauts of NASA's control mission and millions of people watching on Earth, which was built by General Dynamics explicitly. The Unified S-band (USB) operated in the S-Band portion of the microwave spectrum, unifying voice communications, telemetry, command, television, tracking and ranging into a single system to save size and weight and simplify operations. This ground

communication network was managed by Goddard Space Flight Center (GSFC). In this, Collin Radio, Blaw-Knox, Motorola and Energy systems were the commercial contractors.

## DEVELOPMENT OF THE S-BAND TRANSPONDER FOR APOLLO

The equipment had to be designed to withstand the extreme cold, heat and radiation they would experience, and for Apollo 11, they also needed to transmit more data than previous NASA missions, including television and video.
Hundreds of employees in Scottsdale, AZ began developing the Unified S-Band Transponder in 1962, a new system that would accurately track the Apollo spacecraft, transmit and receive telemetry signals, communicate between ground stations and the spacecraft, and provide the link for the historic broadcast from the surface of the moon. The formal contract was awarded in 1963 to Motorola's Government Electronics Division, a legacy company of General Dynamics. The concept was presented by Lincoln Laboratory in an initial report on July 16, 1962, titled Interim Report on Development of an Internal On-Board RF Communications System for the Apollo Spacecraft. In thatreport,


it was shown that many on-board electronic functions could be performed very effectively by a single system that was a suitable adaptation of the transponder developed by Jet Propulsion Laboratory for use with the DSIF tracking stations. This was the origin of the Goal System for Apollo, later called the Integrated (or Integral) RF system, then later known as the Unified Carrier System. The idea behind the unified S-Band communications system was to reduce the number of systems previously used in the Mercury space program, which provided a multiplicity of electromagnetic transmitting and receiving equipment. In early flights, these operated at seven discrete frequencies within five widely separated frequency bands. Largely because of expediency, the following separate units were employed:

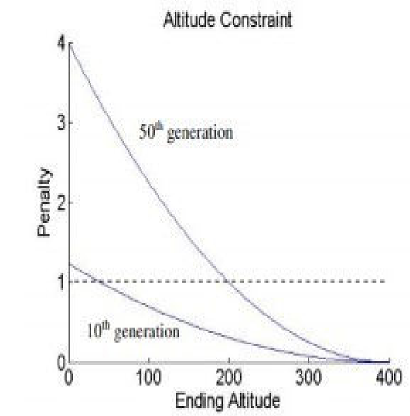
- HF voice transmitter and receiver
- UHF voice transmitter and receiver
- Command receiver
- Telemetry transmitter No. 1
- Telemetry transmitter No. 2
- C-band transponder beacon
- S-band transponder beacon

## JOURNEY TO THE MOON

The components produced by Scottsdale employees equipped the Apollo spacecraft with the fundamental communications capabilities to remain in contact with mission control throughout the journey.Once the spacecraft reached a distance of 30,000 miles from Earth, the astronauts completely relied on the Unified S-Band Transponder to stay connected. The Transponder was their only link to mission control and transmitted all voice and video communications, spacecraft status, mission data, distance, the astronauts' biomedical data and emergency communications.

# 9. MOGA Modelling

In order to populate a Pareto front, a multi-objective genetic algorithm (MOGA) was used. This heuristic technique was chosen because discrete design variables such as material type and propellant type were used, and genetic algorithms handle discrete variables well. The two objectives were to maximize J1 (payload mass) and minimize J2 (cost). The fitness function initialized at a maximum of 1 for each individual. Then it gave a small penalty of 0.01 to each design for each other design that dominated it by having a lower cost and higher payload capability. The fitness was then squared to increase the gap between the more and less dominated designs. Finally, it gave zero fitness for designs that were otherwise infeasible. This fitness value was then used to decide which designs carried on to the next generation of the genetic algorithm. The fitness function for a feasible point is given below:




$$F = max\{1.0 - 0.01 * n_{dom} + p(A_{final}), 0\}^2 \tag{1}$$

The penalty curve steepened with each generation. This is because a low curve would not penalize the infeasible designs enough, but a high curve would often cause the entire starting population to have zero fitness. By starting with a low curve and raising it, the MOGA was able to find the largest number of feasible designs.

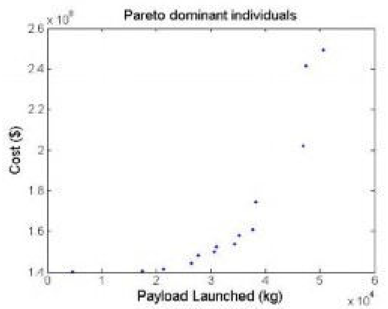



**Figure 6. Non-dominated individuals**

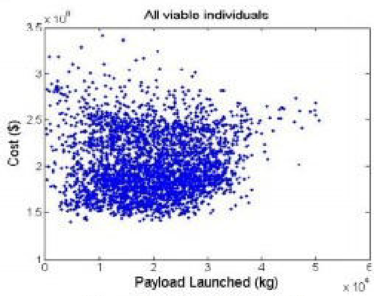



**Figure 5. All feasible individuals from a MOGA run.**

Notice that the Pareto front made is not very well distributed and has a couple steps. Running the MOGA multiple times would lead to covering different ranges and help fill out the Pareto front.

After many runs, the MOGA was able to form a well-populated and fairly smooth Pareto front. There is no guarantee that these points are truly optimal, and a look at the sensitivity analysis suggests that they could be improved, at least slightly. Since the final designs from the MOGA could be improved slightly by simply adjusting the design variables slightly, it would be interesting to examine the benefits of using a gradient-based optimizer as a final step. This could improve the designs slightly by guiding the Pareto points to local maxima.

## TRAJECTORY OPTIMIZATION EQUATION

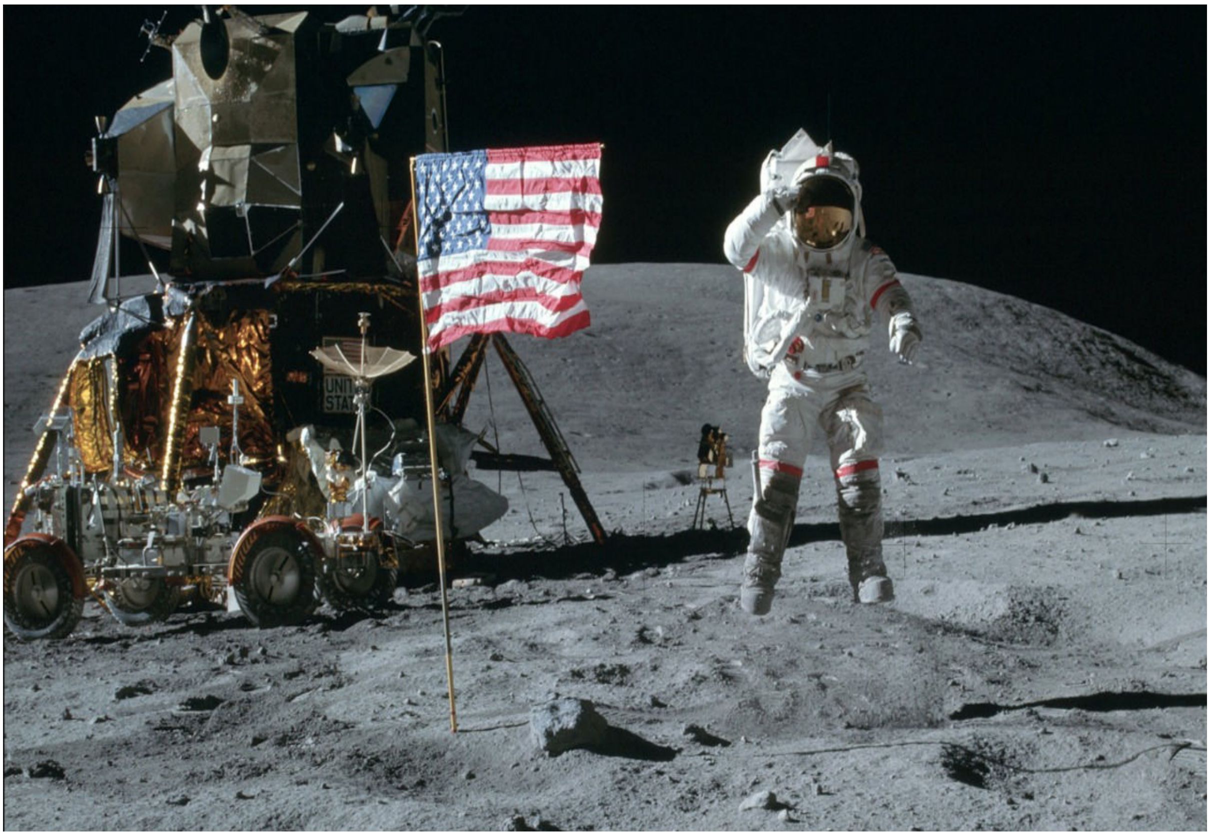
$$\frac{\mathrm{d}}{\mathrm{d}t}(r) = r' \tag{2}$$

$$\frac{\mathrm{d}}{\mathrm{d}t}(r) = -10^9\mu/r^2 + r * \theta^2 + (T[r, T_1....T_5] - D[r, v, \theta_c, R_r]) * \cos(\alpha[r, \alpha_1...\alpha_5])/m \tag{3}$$

$$\frac{\mathrm{d}}{\mathrm{d}t}(\theta) = \theta' \tag{4}$$

$$\frac{\mathrm{d}}{\mathrm{d}t}(\theta') = (T[r, T_1....T_5] - D[r, v, \theta_c, R_r]) * \sin(\alpha[r, \alpha_1...\alpha_5])/(r * m) \tag{5}$$

$$\frac{\mathrm{d}}{\mathrm{d}t}(m) = -T[r, T_1....T_5]/(I_{sp} * g_0) \tag{6}$$



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