Douglas Paper 3809

HIGH ENERGY MISSIONS FOR SATURN

By

T. J. GORDON

And

D. D. WHEELER
Advance Saturn and Large Launch Systems
Missiles & Space Systems Division
Douglas Aircraft Company, Inc.

Presented to
Society of Automotive Engineers
Advanced Launch Vehicle & Propulsion Systems Conference
Huntsville, Alabama
June 14-16, 1966

T. J. Gordon/D. D. Wheeler

HIGH ENERGY MISSIONS FOR SATURN

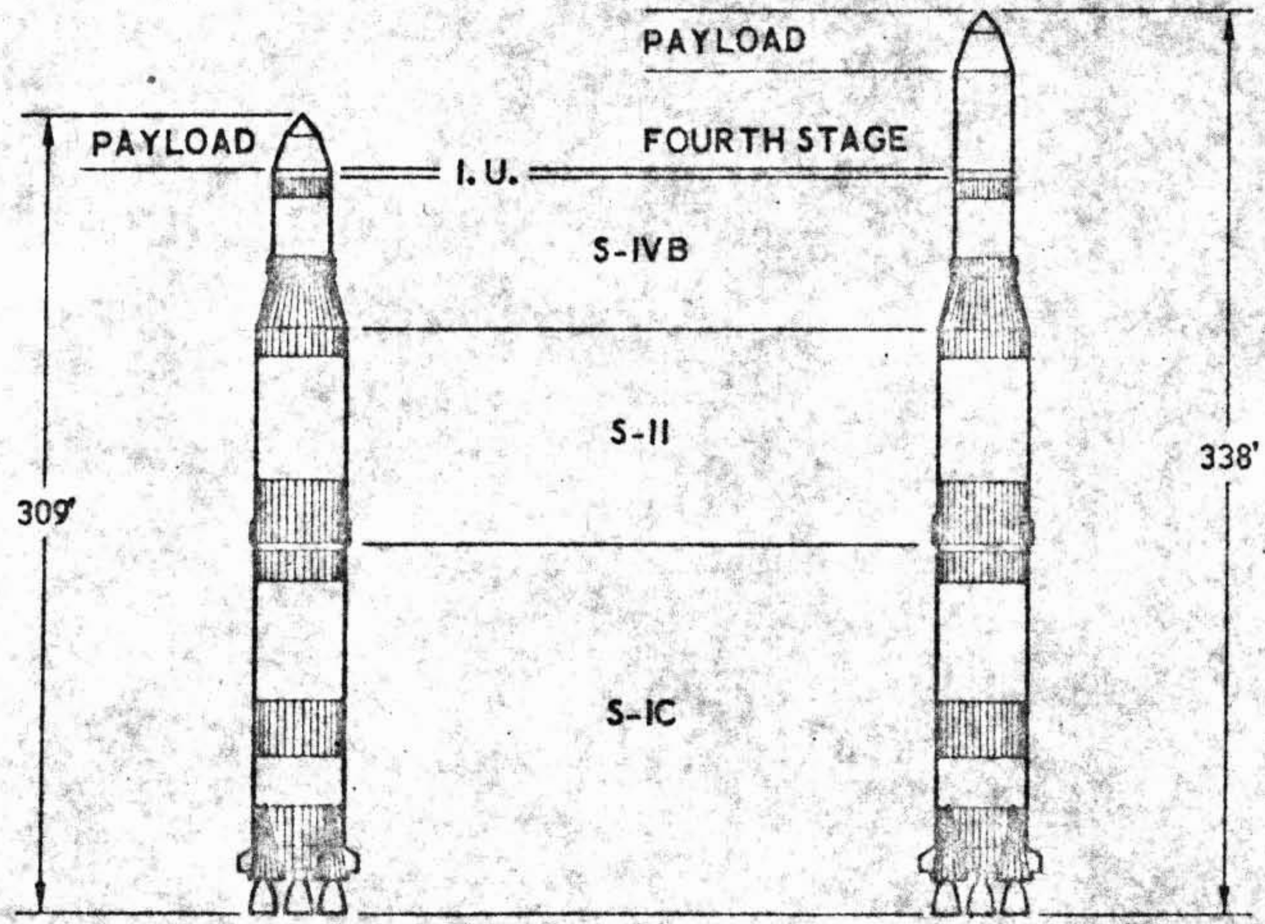
When the Apollo lunar landing project is complete, the Saturn and Apollo hardware will only have begun to realize their ultimate potential for space exploration. The immense reserve of Apollo technology, facilities, and booster capability can then be directed to the achievement of national goals which lie far beyond the initial lunar landing.

In achieving the Apollo lunar objectives, large investments will have been made in launch facilities, tracking systems, propulsion techniques, reentry systems, lunar landing systems and rendezvous technologies. Although development in these specialized areas has been tailored to the needs of Apollo, numerous studies by NASA and industry have demonstrated the feasibility of using the spacecraft, launch vehicles, and operating techniques for missions far more complex than lunar landings. Amortization of this hardware will prove cost-effective for missions of more sophisticated applications.

Saturn Configurations

This paper discusses the utilization of Saturn V for the accomplishment of high energy solar system exploration missions. Throughout the paper, the performance of two vehicles will be discussed. The vehicle configurations are shown in Figure 1. The first is a standard three-stage Saturn V with a hypothetical scientific payload replacing the Apollo. The second vehicle is a four-stage configuration of the Saturn V and uses the Centaur as a typical example of a fourth stage. The Centaur is mounted above the S-IVB Stage. This fourth stage could be used to provide additional velocity to the scientific payload mounted in the shroud surrounding the fourth stage.

SATURN V HIGH ENERGY MISSION CONFIGURATIONS



STANDARD SATURN V-
THREE STAGE
CONFIGURATION

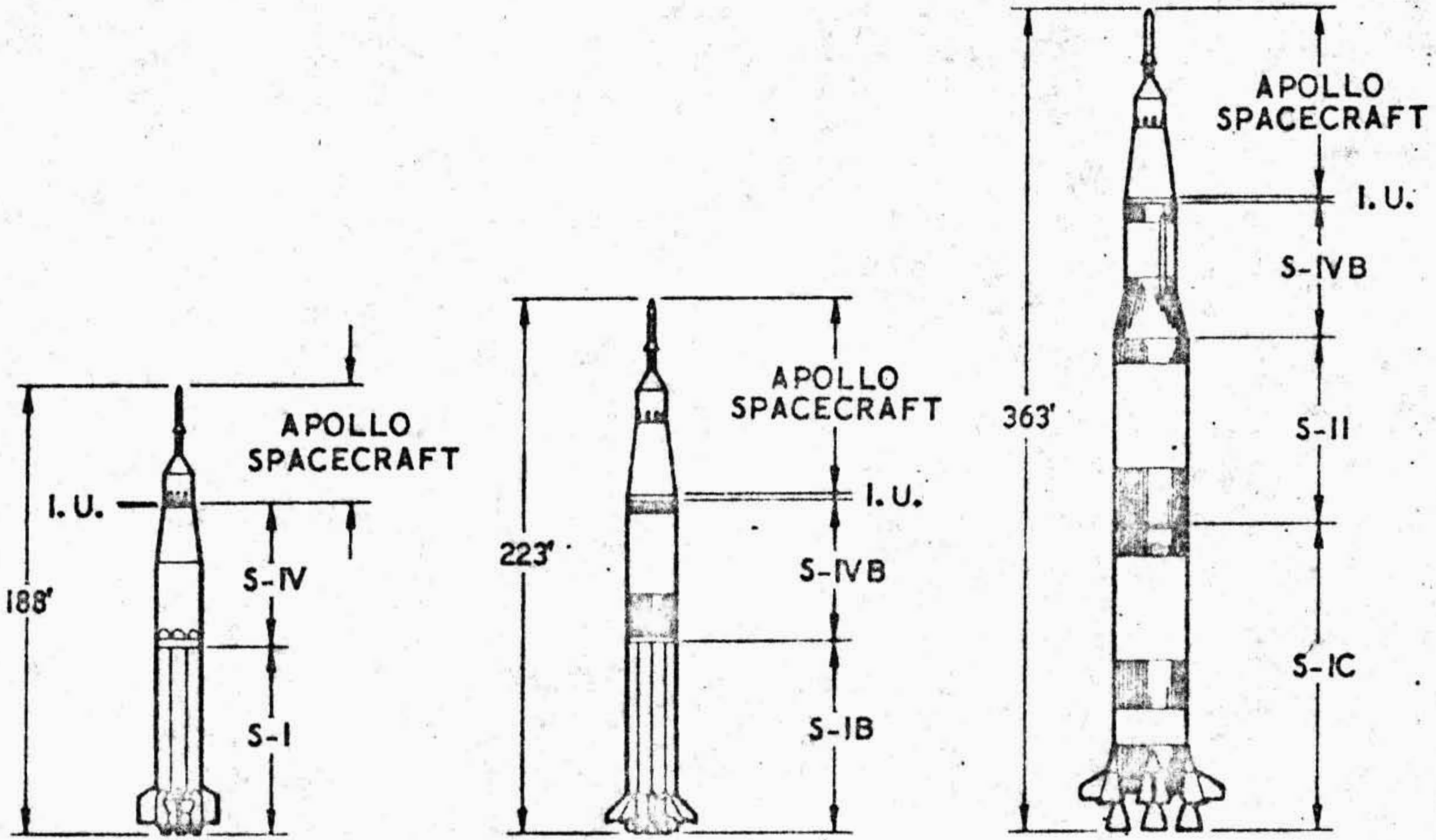
SATURN V - FOUR STAGE
CONFIGURATION

FIGURE 1

The Saturn V is the largest launch vehicle under development in the United States. Its relationship to earlier Saturn configurations is shown in Figure 2. The first Saturn V launch vehicle will be flown in 1967. The three-stage Saturn V, with payload, weighs approximately 3200 tons at lift-off. It can place up to 261,000 lbs. of payload into a 100-nautical mile circular earth orbit and can accelerate 98,000 lbs. to escape velocity. The first stage utilizes five Rocketdyne F-1 engines. These engines, burning RP-1 and liquid oxygen as propellants, generate a total thrust of 7.5 million pounds at sea level. The second stage, containing approximately 1 million lbs. of hydrogen/oxygen propellants, employs five J-2 engines which develop a combined thrust of about 1 million lbs. A third stage is the Douglas S-IVB which contains 230,000 lbs. of hydrogen and oxygen propellants and employs a single 205,000 lbs. thrust J-2 engine, (Figure 3). This stage is designed to burn into earth orbit, coast for as long as four and one-half hours and then restart to provide earth escape velocity.

In the Saturn V four-stage configuration, the stage above the S-IVB, in this case Centaur, contains approximately 30,000 lbs. of hydrogen/oxygen propellants and employs two RL-10 engines which develop a total thrust of 30,000 lbs. This upper stage is shown in Figure 4. The Centaur stage is encased in a shroud which extends from the forward end of the Instrument Unit, depicted in Figure 1, to the payload. This shroud carries the acceleration and bending loads from the payload around the fourth stage directly into the Instrument Unit/S-IVB structure.

SATURN LAUNCH VEHICLES



SATURN I
(BLOCK II)

SATURN IB
(2 STAGE)

SATURN V

FIGURE 2

SATURN V/S-IVB STAGE

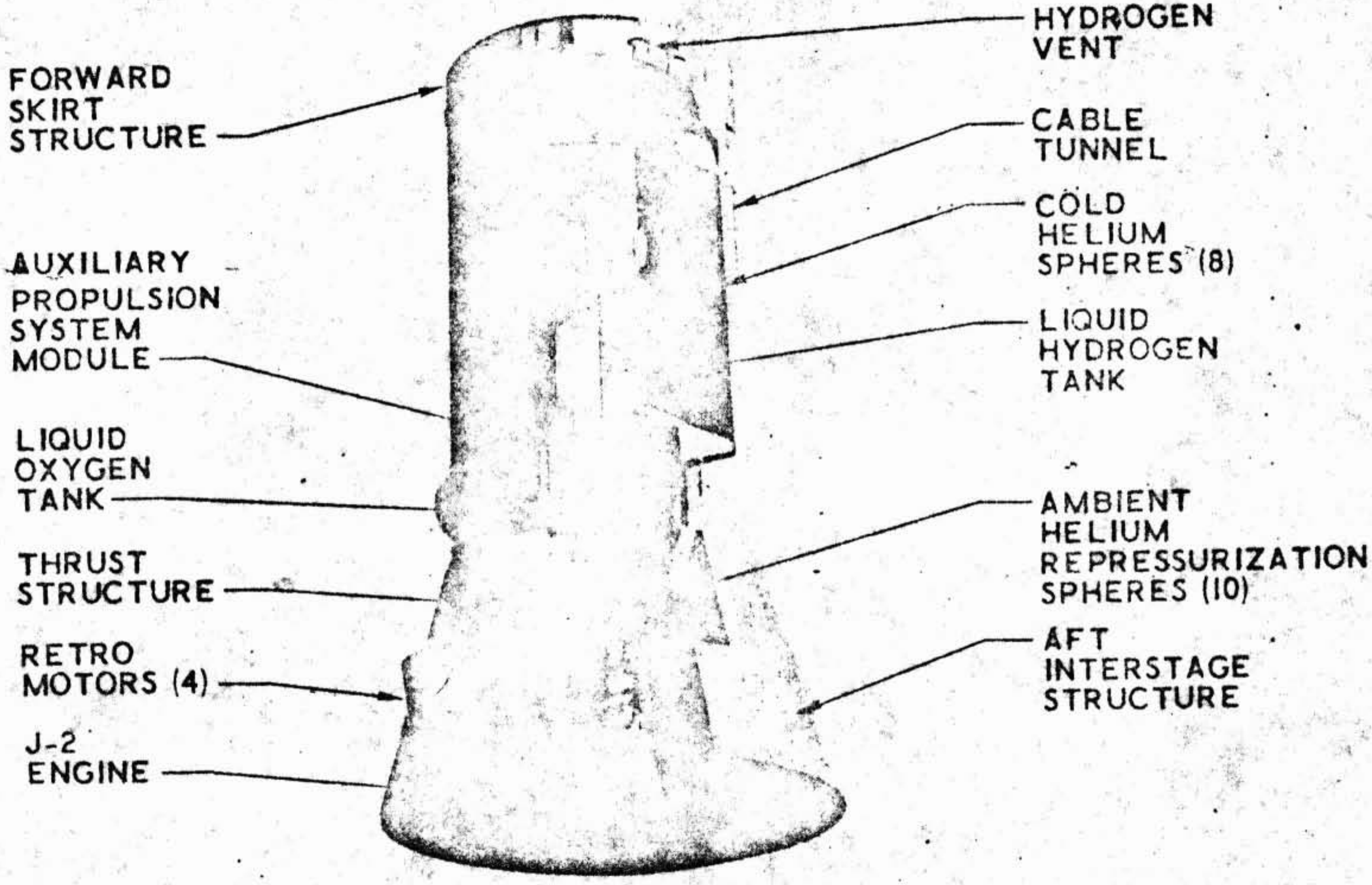


FIGURE 3

CENTAUR STAGE

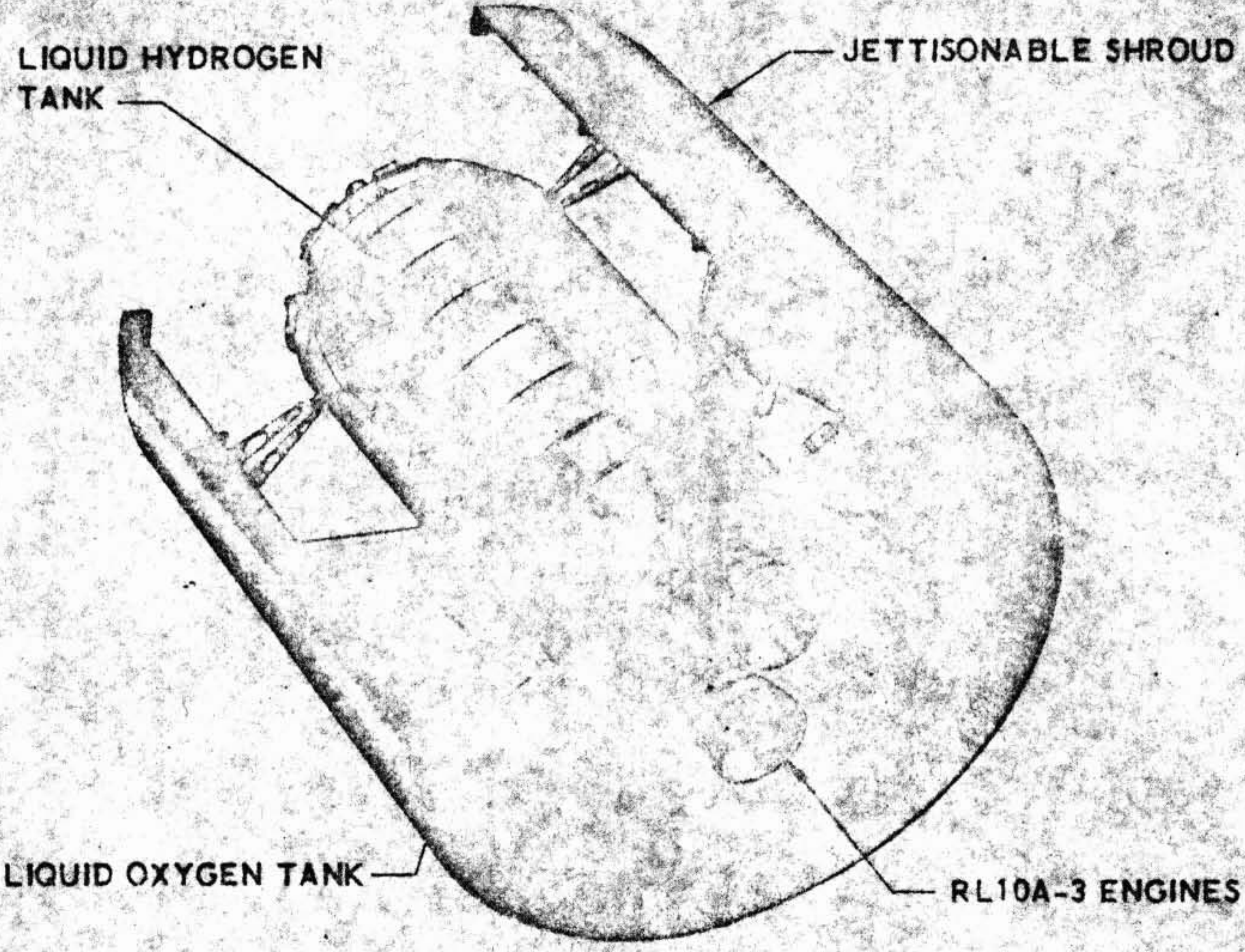


FIGURE 4

Figure 5 shows the payload capability of the three and four-stage Saturn V vehicle as a function of hyperbolic excess velocity (V_∞). The mission profile for the four-stage Saturn V (Figure 6) is similar to the three-stage application except that the shroud is jettisioned at an altitude of approximately 340,000 feet prior to injection into low earth orbit. As in the three-stage case, the S-IVB, using a portion of its propellants, would accomplish the injection into low earth orbit and then, after an appropriate coasting period, the S-IVB would be reignited to provide initial earth escape velocity. Following the S-IVB/fourth stage separation, the fourth stage would provide the remaining energy required to place the spacecraft in an escape trajectory. In some missions, the fourth stage would execute a dual burn to accomplish the required plane changes or velocity additions at the proper injection point.

Large Payload Advantages and Disadvantages

Clearly a vehicle of the Saturn V size is capable of boosting very large payloads to high velocities. However, is it appropriate to conduct explorations of the solar system with a relatively few number of large payloads or a greater number of smaller probes? This is a difficult system analysis problem. While there are arguments on both sides, the larger booster - larger payload offers the following advantages:

a. Perform missions during non-optimum times or varying trip time by trading payload for increased velocity.

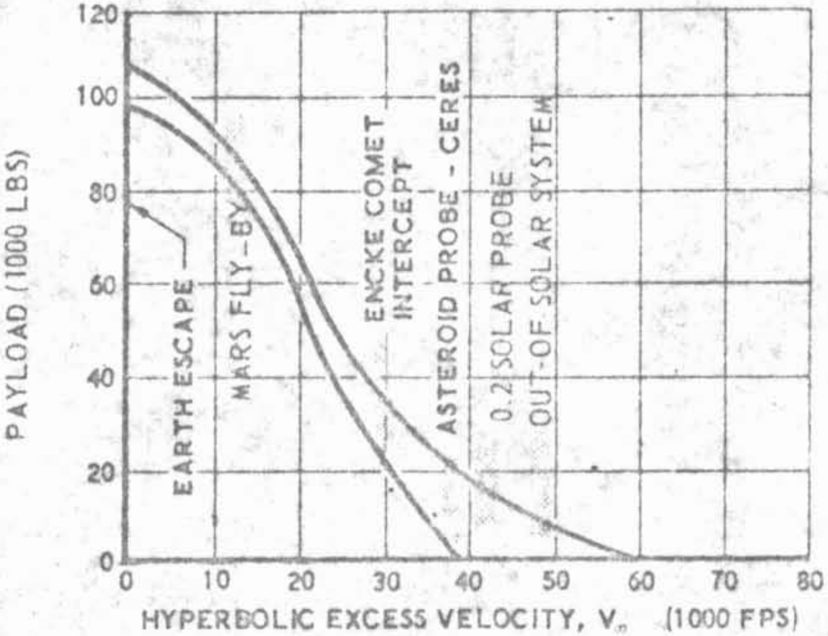
b. Avoid problems associated with pressing the state-of-the-art of microminiaturization.

c. Increase use of redundancy to enhance payload reliability.

d. Employ booster configurations which serve the manned and unmanned payload community.

SATURN V THREE & FOUR STAGE PERFORMANCE

(LAUNCH AZIMUTH 90° - ORBIT INCLINATION 28.5°)



NOTES:

1. COPLANAR DIRECT ASCENT LAUNCH FROM E. T. R.
2. PARKING ORBIT ALTITUDE = 100 N. MI.
3. $V_\infty = \sqrt{(V_f)^2 - (V_{esc})^2}$

WHERE:

V_f = VEHICLE CUT-OFF VELOCITY INERTIAL, (FT/SEC)

V_{esc} = ESCAPE VELOCITY AT A CUT-OFF ALTITUDE (FT/SEC)

$V_\infty = \sqrt{C_3}$ = ENERGY PARAMETER

FIGURE 5

SATURN V FOUR STAGE MISSION PROFILE-HOHMANN TRANSFER

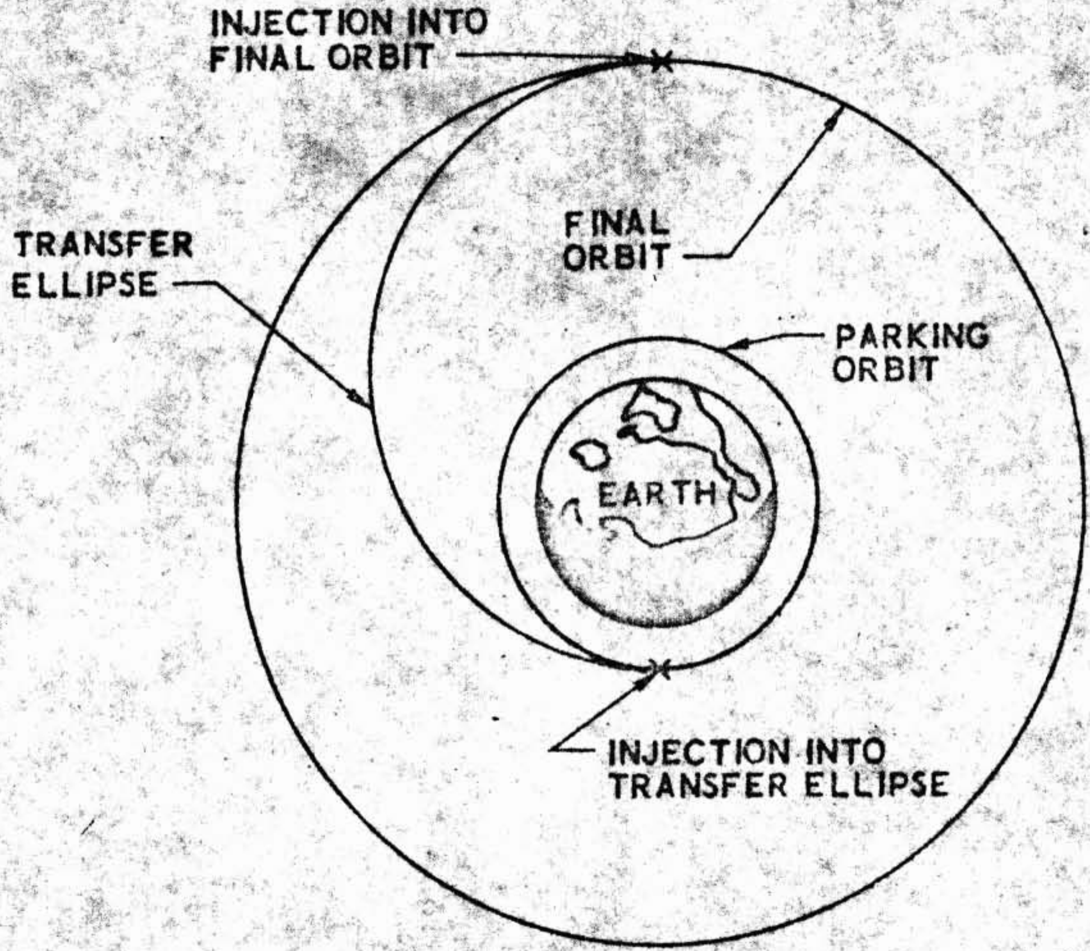


FIGURE 6

e. Employ higher powered data transmitters for increased bandwidth which leads to greater resolution, greater frequency response, and less delay in handling data.

f. Carry bulky payloads such as large aperture optics.

g. Utilize a portion of the payload weight for propulsive maneuvers such as plane change, mid-course corrections, deceleration in the vicinity of the destination.

h. Provide a multi-mission capability by mounting more than the payload on the launch vehicle; i.e. one to perform a solar probe and one to perform a planetary flyby.

Disadvantages

There are two major considerations which mitigate against the large booster - large payload concept. These can best be described as:

a. The "all the eggs in one basket" syndrome.

b. The high cost of heavy payloads.

The "all the eggs in one basket" argument states that if we build a heavy solar system probe and it fails, then the failure is very costly; however, a larger number of smaller probes are cheaper per unit success and some are bound to be successful. This argument might have had great force in earlier days of rocketry, but the outstanding performance of the Saturn class vehicles indicates that very high vehicle reliability is attainable with today's technology (eleven out of eleven shots). Furthermore, the large payload weights available should lead to less risk-taking in payload design, trading available weight for reliability so that performance of the payloads themselves should become more certain. The potential uses of large payloads will, almost instinctively, multiply a favorite figure for payload cost per unit weight by the total weight available and arrive at an astounding projected payload cost. Heavier payloads are undoubtedly more expensive, but past unmanned programs indicate that the cost per unit payload weight will diminish as the absolute payload weight increases (Figure 7). Also, heavier payloads makes it possible to (1) avoid undue sophistication and (2) use standard qualified parts, thus reducing the overall cost. Therefore, in providing for larger payloads, we can expect to see increasing payload reliability and reduce cost per unit of information returned. Many of the exploration opportunities are cyclic; big boosters provide the opportunity for maximizing data collection during periods of optimum planetary geometry and furthermore, the excess velocity capable of large boosters permits exploration during non-optimum periods.

Douglas Studies

Several studies have been conducted at Douglas applying the three and four-stage Saturn V vehicle to solar system exploration missions. Specific missions which have been investigated include:

Planetary Probes
Comet Intercepts
Asteroid Missions
Solar Probes
Out-of-the-ecliptic Probes
Exploration of the Earth-Moon Libration Points
Probes out of the Solar System

While advanced flight mechanics techniques have been employed in some current work (for example, utilizing the gravitational field of Venus or Jupiter to minimize the energy requirements for various interplanetary missions), the examples quoted in this paper employ conventional Hohmann transfer trajectories. Launch windows are considerably wider with this approach and the brute force energy available reduces the need for sophisticated

SPACECRAFT WEIGHT VS COST DATA

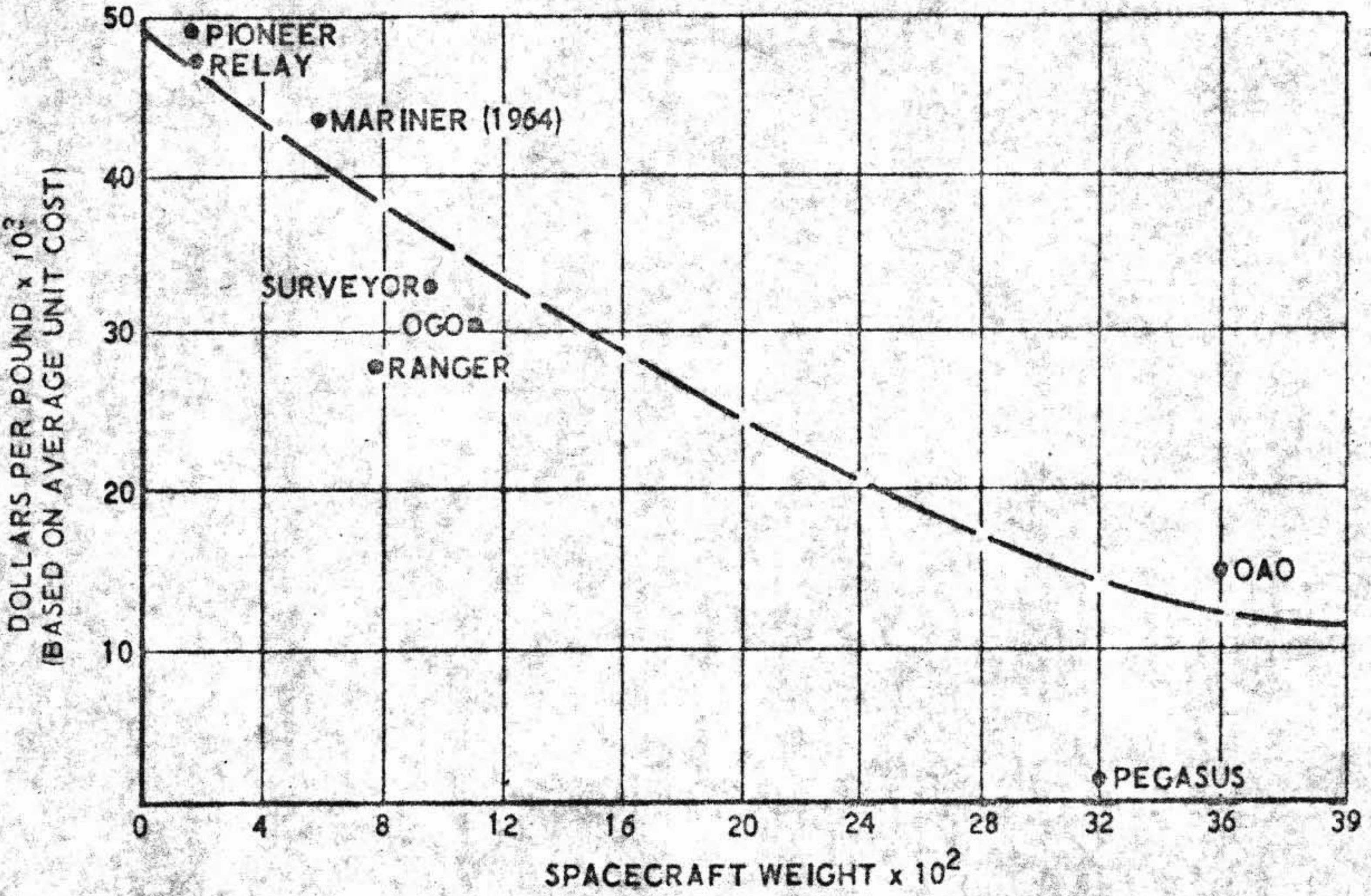


FIGURE 7

flight mechanics and its attendant guidance and propulsive problems.

The following paragraphs discuss the missions listed above, the possible experiments that could be performed during these missions and the payload capability of the three and four stage Saturn V for various typical missions.

Planetary Exploration

Exploration of the planets has of course already begun with small unmanned payloads which have been flown to the planets Mars and Venus. Beyond these initial experiments will come the requirement for flights of large scientific stations not only to Mars (e.g. Voyager) and Venus but to the more demanding planets of Mercury, Jupiter, and beyond. Geodetic observations of these planets will be required including determination of topography, gravitational field, and experiments relating the planet's internal structure. Geological experiments associated with the nature of the planetary surface and its composition, surface-atmospheric interaction and surface temperature. With each new planet, studies will be made of magnetic field, interactions between solar particles and the magnetosphere, determination of the micrometeoroid environment, albedo, optical and magnetic properties, electron density profile, etc. Since Jupiter is the most massive planet in the solar system, experiments peculiar to gravitational measurements will be required when Jupiter exploration is initiated. Measurements in magnetic field and gravitational phenomenon will be prominent. Investigations of the behavior and source of the non-thermal radiation originating from this planet undoubtedly will be conducted over a wide range of wave lengths. The micrometeoroid environment around Jupiter will also be of great interest.

The three-stage Saturn V can boost a 24,000 lb. payload on a 750-day Hohmann transfer mission to Jupiter. This payload can be increased to 36,000 lbs. by using the four-stage Saturn V. The mission assumes a hyperbolic excess velocity of 29,785 feet per second. If payloads of this magnitude are not required, higher velocities and appreciably shorter trip times can be achieved as shown in Figure 8. Note that with the four-stage Saturn V configuration the trip time can be reduced by one-half and a payload of 13,000 lbs. is still available.

Comet Intercept

Scientists believe that a definitive insight into the origin and formation of the universe could be gained by exploring comets. Much data must be collected in order to refine or reject present theories about the evolution of the solar system, about the physics of cometary bodies and about the dynamics of the interplanetary medium. The true nature of comets can be revealed only by (1) a direct probing of the coma and tail, (2) observations and eventual sampling of the nucleus.

The objective of Comet Intercept Missions is to measure the type and distribution of particles of matter and the distribution of the magnetic field through the coma, to observe the nucleus, to determine the chemical composition of cometary material. This will be accomplished by flying an instrumented probe through the coma and/or the tail of the comet.

Comets consist of a small nucleus, solid material a few miles in diameter, a gaseous envelope around the nucleus (the coma) generally in the range of 5,000 miles diameter, and a gaseous region called the tail that may range

TRIP TIME VS PAYLOAD CAPABILITY

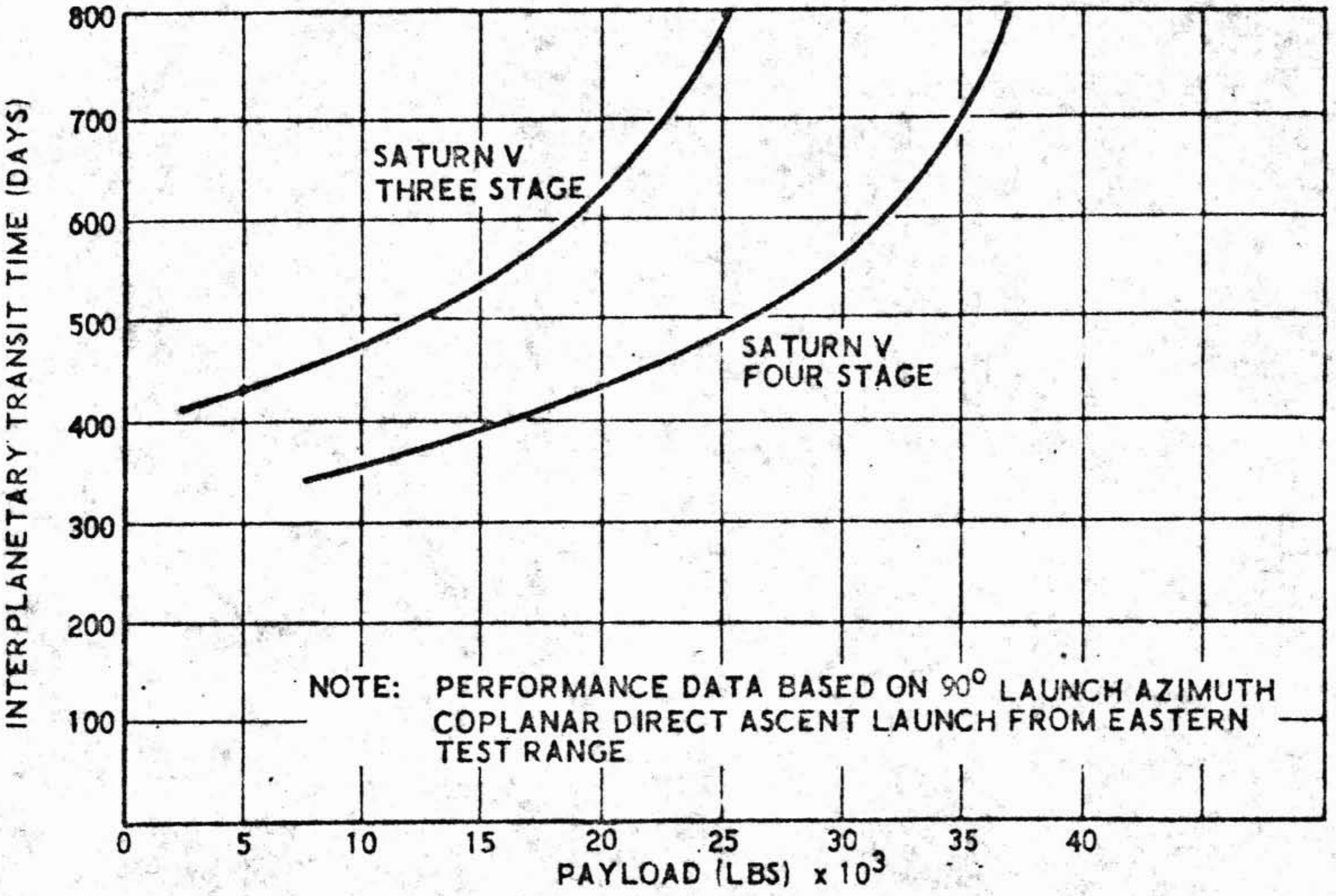


FIGURE 8

from 100,000 to many millions of miles in length. The mass of comets is generally small, between 10^{11} and 10^{14} tons. When the comet comes close to the sun, a tail develops which usually points away from the sun due to solar pressure. The intrinsic brightness of a comet increases as it gets closer to the sun. The velocity of the comets is on the order of 30 - 70 km/sec (98,400 - 229,600 fps). Orbits have been computed for more than 500 comets and of these only about 100 have yielded periods of revolution smaller than 100 years. Comets are sighted at a rate of 6 to 12 a year, but more than half of them are known, (short-period comets) to make an expected return. Most of the short-period comets return every six to seven years and have the aphelia close to Jupiter's orbit. They form the "Jupiter family" of comets, all of which have direct motion and orbits of moderate inclinations (not more than 31°). Comet orbits with aphelia well beyond Jupiter have inclinations distributed almost at random between 0° and 180°. The following Table I provides data on some of the most well known comets.

Encke is a good choice for a comet intercept mission because it is associated with four large meteor streams and thus with a large quantity of meteoritic material. It is also the closest to earth, a bright comet, and provides time, prior to perihelion, available for recovery. Encke has a short period which provides many launch opportunities. It should be emphasized that, en route to the comet, very valuable information can be collected on all aspects of space environment outside the plane-of-the-ecliptic.

COMET DATA

COMET	PERIOD (YRS)	MEAN EARTH-SUN DISTANCE, AU		ORBITAL ECCENTRICITY	ORBITAL INCLINATION TO ECLIPTIC (DEG)	PREDICATED DATE OF RECOVERY
		PERHELION	APHELION			
ENCKE	3.29	0.34	4.09	0.847	12.4	1967
TEMPEL 2	5.27	1.37	4.68	0.548	12.5	1967
TUTTLE-GIACABOBINI-KRESÁK	5.49	1.12	5.11	0.641	13.8	1967
PONS-WINNECKE	6.12	1.16	5.54	0.654	21.7	1969
SCHWASSMANN-WACHMANN I	16.16	5.52	7.25	0.136	9.5	1973
HALLEY	76.03	0.59	35.30	0.967	162.2	1986

TABLE I

Three principle categories of experiments would be performed relating to determination of the comet's structure, plasma interactions, and chemical composition.

1. Structure

The physical properties of the comet could be determined by using a TV device to photograph the nucleus of the comet. These pictures would be valuable in confirming or refuting the "icy conglomerate" model and in confirming present ideas of the nucleus size and mass. TV pictures could also observe the change in brightness and the formation of a tail as the comet approaches the sun.

Another experiment relating to determining the structure of a comet would entail the use of micrometeorite sensor to detect not only the momentum energy but also any residual charge of the particle. Micrometeoroid observations would determine the abundance and mass of the solid particles in the coma and tail. This would contribute to a knowledge of the nuclear structure and also possibly to the knowledge of the meteor streams. Since the polarization and intensity of the continuum portion of the cometary spectra as observed by terrestrial telescopes, depends on the nature, size, distribution and shape of the scattering particles, any information pertaining to these parameters would greatly enhance the interpretation of the spectrum.

2. Plasma Interaction

There are a great many plasma interaction experiments which could be performed. Only two will be discussed. An ion and electron trap can measure the temperature of thermal electrons as well as the densities, masses and temperatures of thermal ions. Such data could tell us a great deal about the interaction between the solar wind and cometary plasma and should be able to resolve the question as to whether the acceleration of ions into the tail is caused by electro-static instabilities in the plasma or by a hydromagnetic interaction. Also to help explain a molecular ionization phenomena and plasma interactions, a magnetometer could be used to determine the direction and magnitude of the magnetic field both in interplanetary space and as the probe approached, passed through and 'receded from the comet.

3. Chemical Composition

An ion mass spectrometer could be used to determine the molecular mass distribution as a function of distance from the nucleus. This data is useful in studying dissociation processes of the molecules. A measurement of the percentage ionization as a function of distance from the nucleus would provide valuable confirmation of the spectroscopic data; even more significant would be the determination of the percentage ionization for the individual molecules which would lead to a better interpretation of the various ionization mechanisms.

The three-stage Saturn V can boost 22,000 lbs. on an intercept trajectory with the comet Encke and the four-stage vehicle, 34,000 lbs. This flight path assumes an excess hyperbolic velocity of 30,273 fps and a trip time of approximately 100 days. The comet Schwassmann-Wackmann requires higher energies; an excess velocity of 41,016 fps. To this comet, the four-stage Saturn V can boost 16,500 lbs. on a 500-day trip.

Asteroid Missions

The asteroids present a number of basic questions of major scientific interest, both as applied to the origin of the solar system and to the evolution of the asteroid belt itself. In addition, investigation of the collision cross-section between the dust in the belt and future space vehicles is essential before missions to the outer planets can be considered. These scientific questions can best be answered by probes through the asteroid belt and probes to specific asteroids. The major objective of missions to the asteroid belt or specific asteroids are:

1. To determine the mass distribution in the belt.
2. To detect an original non-fragmented major asteroidal body, and obtain information about its internal construction and mass.
3. To inspect an asteroid suspected of being a collision fragment and determining its surface erosion since fragmentation, density and internal construction and mass.
4. To analyze a sample of asteroidal matter, determine its chemical constitution and density.
5. To find evidence for the existence of a biological history in the belt (detection of hydrocarbon, organic acids, etc.).

Between the orbits of Mars and Jupiter revolve thousands of small bodies called asteroids, planetoids or minor planets. Some are only a few miles or less in diameter; while Ceres, the largest, is nearly 500 miles across.

Typical asteroid experiments would include measurement of mass distribution, optical spectrographic experiments relating to physical properties of the asteroids, chemical analysis of the particles involving thermal neutron activity, neutron capture gamma ray analysis, gas chromatography, X-Ray fluorescence, etc., to determine organic and inorganic composition of some small captured asteroids. Measurement of interplanetary magnetic field, interaction of the solar plasma with the asteroids, equilibrium temperature in the belt - all will be of vital interest. Television pictures of the asteroids will not only be interesting but may lead to greater understanding of the processes of formation of these anomolous bodies and the solar system. Saturn V can place a 7,000 lb. payload past the asteroid Ceres and the four-stage version, 22,000 lbs. This mission involves an excess velocity of 36,621 fps and a trip time of 200 days.

Solar Probe

A probe toward the sun would have as its objectives the determination of:

1. Spatial and temporal variation of distribution, energy spectra, and trajectories of particles.
2. Type of particles, i.e., electrons, protons, neutrons and heavier ions.
3. The spatial and temporal variation of magentic and electrical field strengths and directions.
4. Interactions between particles and fields.
5. Extent of the lower frequency electromagnetic radiation from the sun.

Specific instrumentation aboard the probe would involve detail measurements of the corona to determine electron temperature, electron-ion densities in the corona, and their spatial distribution. Electromagnetic radiation measurements across the entire spectrum will be important. Visual observations of course will be possible with much greater resolution than possible from the earth. These observations will permit understanding of the nature and time variation of the photospheric granulation and sun spots, chromospheric prominences, and flares. These observations might also prove useful in determining solar oblateness for as in relativity calculations relating to the precession of the perihelion of Mercury. Undoubtedly measurements of solar wind would be accomplished also to determine the density, velocity, and temperature of the solar wind. Also measurements to determine magnitude and direction of the magnetic field is important. Observations of solar flares would be associated with intensities, energies, composition, spatial distribution, and time variation particles emitted by the sun. Distribution of magnetic field intensity would be determined, particularly during the on-set of a solar flare. A search could be conducted for solar neutrons (which have not been detected from the vicinity of the earth) and measurements could be made to determine whether or not low energy (<200 MEV) protons are emitted from the sun during quiet times.

A solar probe flown to .2 AU and boosted by a four-stage Saturn V can weigh 14,000 lbs. The hyperbolic excess velocity associated with this mission is 43,457 fps. A probe to .12 AU requires a hyperbolic excess velocity of 53,223 fps. A four-stage Saturn V can boost 5,500 lbs. on this trajectory. The trip time associated with these missions are 80 and 75 days respectively.

Out-of-the-ecliptic Probes

All planets orbit in planes that are inclined less than 7 degrees from the ecliptic plane except Pluto which is inclined 17 degrees. To date, scientific missions have been limited to near the ecliptic plane. Space exploration into higher inclined orbits (out-of-the-ecliptic) are most desirable, but very high velocities are required.

An out-of-the-ecliptic probe would determine whether solar phenomena, such as the solar wind, possess spherical symmetry or are confined chiefly to the plane of the ecliptic. The probe will measure solar phenomena, including solar storms, electromagnetic and electrostatic fields, high energy particles and perhaps, X and Gamma Ray measurements toward and away from the sun. By making these measurements in a plane significantly (10 - 45°) out-of-the-ecliptic, we could literally add another dimension to our knowledge of solar system physics.

The observations that could be performed with a probe, say at 1 AU from the sun and at a 90° inclination to the ecliptic, would be:

1. Solar wind dinsity, velocity and direction as a function of angle away from the ecliptic.
2. Magnitude and direction of the associated magentic field.
3. Intensity energy spectra and time-intensity profiles of solar cosmic ray events.
4. Properties of meteoroids, including intensity and velocity, as a function of angle away from ecliptic.
5. Intensity and energy spectra of galactic cosmic rays.

An instrumented probe through the "Asteroid Belt" could perform a combined out-of-the-ecliptic mission as well as an Asteroid mission. Also various interplanetary experiments could be performed en route to the "Belt."

A 1 AU mission incline 35° to the ecliptic requires a hyperbolic excess velocity of 56,641 fps and an associated trip time of 200 days. The four-stage Saturn V vehicle can boost 1,250 lbs. on this flight path. If the inclination is limited to 25°, the payload will rise to 12,000 lbs.

Exploration of Earth-Moon Libration Points

There exists stable gravitational points between the earth and moon. These points, known as the L_4/L_5 "Trojan" points, as established by the restricted three body problem, locates the points in the plane that includes the earth/moon axis line. Each point lies at the apex of an equilateral triangle on that plane with the moon and the earth at the other two apexes (see Figure 9). The most interesting examples of natural bodies that occupy points L_4 and L_5 are the "Trojan" asteroids, which are in the Sun-Jupiter system.

Access to earth/moon L_4 and L_5 would involve space flight from the earth similar to that to the moon, except that there would be an absence of attracting forces as the spacecraft approached the L point.

The mission envisioned would be to place a satellite at the L_4 and L_5 points. According to the restricted three body problem, a small satellite could persist in stable motion about the earth at these two points. The satellite would provide data on the gravitational fields surrounding the earth and moon and any cyclic phenomena associated with these fields. It might also make measurements to determine the concentration, size,

EARTH-MOON LIBRATION POINTS

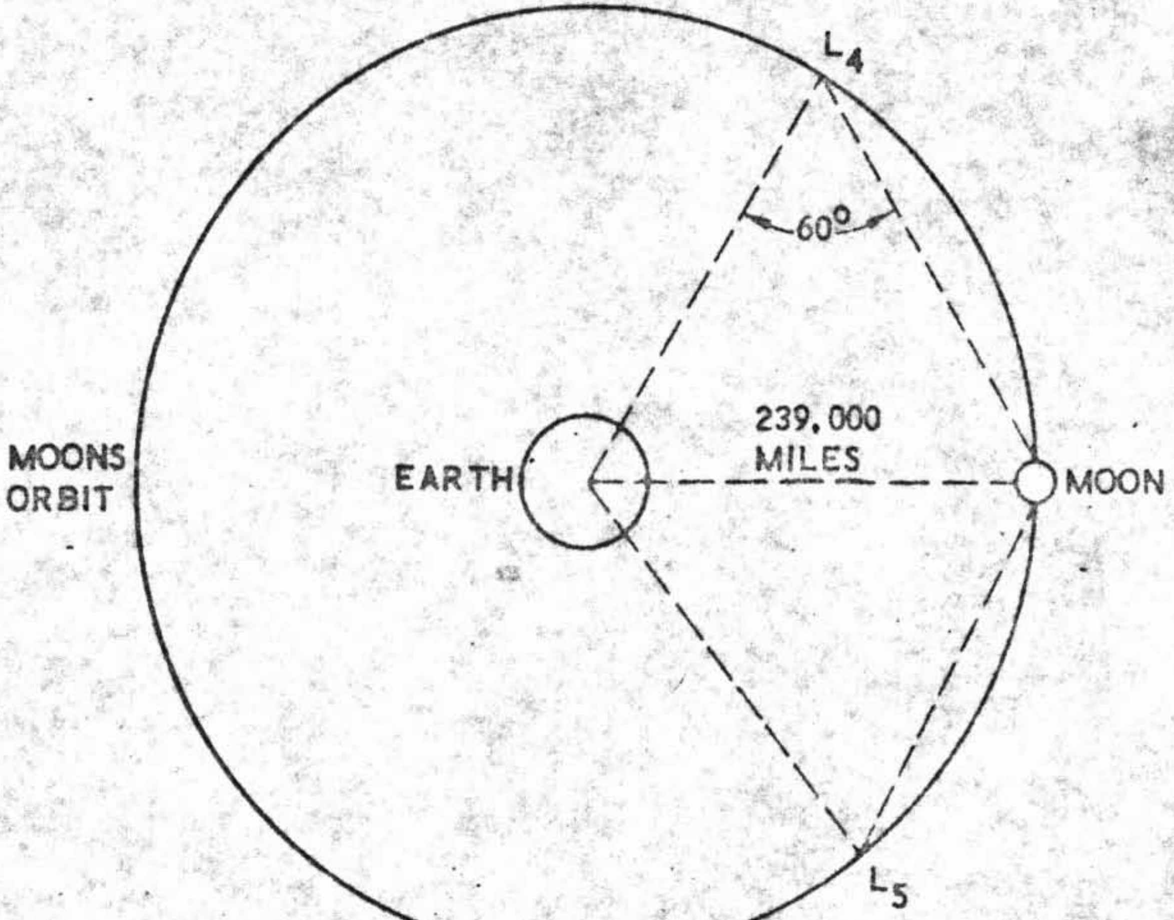


FIGURE 9

and mass of the possible dust clouds (cosmic debris) centered at this region. These experiments could provide valuable information about the origin of the moon and the solar system.

The libration points (L_4 and L_5) not only have scientific value, but also have possible practical applications. These points could be used as a communication relay station for deep-space probes or manned landings on other planets, thus minimizing the long distance communication problem. They may also be used as a "warehouse" to store equipment during the establishment of a lunar base.

The standard Saturn V can place 76,000 lbs. at the earth/moon libration points and the four-stage version, 85,000 lbs.

Probes-Out-of-the-Solar System

The next step beyond exploration of the solar system is exploration of interstellar space. This type of mission envisions an instrumented probe boosted to a very high velocity (55,000 ft/sec. min) which will allow it to escape the solar system. This type of probe will provide the first direct study of the interstellar medium. Such probes will collect scientific data on cosmic rays, stellar dust and other galactic phenomena and may provide new clues to the origin and nature of the universe. Also detailed tracking of the orbit of this probe may aid in the determination of additional solar system planets.

The scientific observations that could be performed on a probe escaping the solar system are essentially the same as those on the out-of-the-ecliptic probes. However, instead of observing the interplanetary medium as a function of angle from the ecliptic, the probe will study the interplanetary medium as a function of distance from the sun. These observations would include:

1. Velocity and density of the solar wind and the boundary between the solar wind and the interstellar medium.
2. Neutral gas atoms and molecules.
3. Gradients in the intensity of galactic cosmic rays.
4. Solar cosmic rays.
5. Magnetic field associated with solar wind, both before and beyond solar wind termination.
6. Galactic magnetic field.
7. Intensity and velocities of meteoroids.
8. Search for presence of trans-Pluto planets and planets located beyond Pluto.

The four-stage Saturn V can place 13,000 lbs. on an extra-solar system. However, with this payload weight the flight times to reach beyond the orbit of Pluto are quite large; approximately eleven years. In an excess velocity mission some of the payload could be traded for shorter flight time, for example, if the payload is restricted to 1,000 lbs. flight time to the orbit of Pluto drops to 7.5 years.

Conclusion

Saturn V in its three-stage or four-stage version satisfies the complex requirements presented by the goal of the exploration of our solar system. The performance of these vehicles is summarized in Table II for the missions previously discussed.

Saturn, the vehicle designed for one mission, will clearly meet many of the needs of the country in space exploration for many years to come. By using Saturn over the widest base of missions, the investment in Apollo will become an investment in the future which will pay rich dividends in new knowledge, prestige, and world leadership. Saturn has a future in space.

TYPICAL HIGH ENERGY MISSION EXAMPLES

MISSION CATEGORY	POSSIBLE MISSION					AVAILABLE PAYLOAD (LBS)	
	TARGET	ITD	ITT	α	V_∞	STANDARD SATURN V	STANDARD SATURN V/CENTAUR
PLANETARY PROBE	MARS FLY-BY	1.5	150	2°	13,379	78,000	86,000
	JUPITER FLY-BY	5.2	750	–	29,785	24,000	36,000
COMET INTERCEPT	ENCKE	.4	100	12°	30,273	22,000	34,000
	SCHWASSMANN-WACKMANN	5.5	500	9.5°	41,016	–	16.500
ASTEROID	CERES	2.6	200	10°	36,621	7,000	22.000
	ICARUS	.2	80	23°	52,246	–	6,000
SOLAR PROBE		.2	80	–	43,457	–	14,000
		.12	76	–	53,223	–	5,500
OUT-OF-THE-ECLIPTIC		1	200	25°	45.410	–	12,000
		1	200	35°	56,641	–	1,250
OUT-OF-THE-SOLAR-SYSTEM		40	4,000	–	44,433	–	13,000
		40	4,000	10°	49,316	–	8,500
LIBRATION POINT EXPLORATION	MOON-EARTH POINT	208,000 N. MI.	100 HRS	–	13,600 EQUIVALENT V_∞)	76,000	85,000

ITD - INTERPLANETARY TARGET DISTANCE FROM THE SUN (A.U.)

ITT - INTERPLANETARY TRANSIT TIME (DAYS)

α = INCLINATION OF THE FLIGHT PLANE TO THE ECLIPTIC PLANE

V_∞ = HYPERBOLIC EXCESS VELOCITY = $\sqrt{C_3}$

TABLE II