MANNED SPACE FLIGHT

FROM

MERCURY TO APOLLO

by

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Gilruth - Log

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We are now on the eve of the Apollo flight program. We have completed only two previous manned space flight programs - - Mercury and Gemini. Apollo will place a man on a trip to the Moon 240,000 miles away. The Mercury and Gemini programs placed men in Earth orbit 100 to 800 miles away. This simple comparison of the distances from Earth involved in our three programs gives one indication of the differences in their scope. I will, in the next half hour, be trying to give you a more precise impression of the significant differences between these programs by noting some of the quantitative and qualitative changes we have been dealing with as we have progressed from Mercury to Apollo.

So let us look at how our manned space flight programs developed. On the next chart we have presented, in outline form, the principal characteristics of the three programs - - Mercury, Gemini and Apollo. As noted in the first line, Mercury was a program dominated by defining man's survivability in space; Gemini was created to define man's operational capability; and Apollo will be the first utilization of space for manned exploration.

To progress in ten short years from exploring survivability to utilization on the most difficult exploration mission ever undertaken implies a rate of change in technical capability which has no real parallel in history. The best comparison is with that of the history of aviation - or more precisely - of manned atmospheric flight. In a very important sense, we could equate the Mercury program with the first flights of man in balloons in that both placed man in a totally

new and a possibly inimical environment for the first time. The parallel extends even to the fact that our first space shot lofted animals so that we could assess the possible effects of the unknown environment on the human physiology. That is, of course, precisely what the early balloonists did, since they, too, were faced with the fears of a totally unknown and unexplored regime. But balloons, like Mercury, were sufficient only to get man into the environment and did not have sufficient capability to allow him to do anything useful there. They could not be controlled. Thus, our Gemini program with its greater capability for maneuvering, for on-board guidance, for navigation, for docking, for precise change of orbit, etc., added those elements to man's space capability that the airplane added by providing a mechanism which could be both controlled and powered. The prime force in the development of aircraft technology was war. We are fortunate in that, in space flight, it is not a military requirement which is pushing us, but rather the urge to explore. The Apollo program is the culmination of that urge and in it man will cross his widest "ocean." The only event in the history of aviation which has had perhaps many of the same emotional effects on the world that can be expected on successful completion of a lunar landing, was Lindbergh's initial crossing of the Atlantic. They are both bold steps - - both thrusts forward with a relatively new technology to conquer a significant natural barrier. Thus, in a certain sense, man's effort to fly in space has, in ten years, accomplished what flights in the atmosphere took over 140 years to

accomplish. After Apollo we will be ready - as aviation was after Lindbergh's flight - to use our new tool for the direct benefit of man in a variety of different ways.

As the next chart indicates, Mercury - - being the first program - - concentrated on dealing with fundamental unknowns. These concerned both man and the design solutions which should be employed to conquer this new domain. How would man's body react to weightlessness?; to the high stresses of reentry acceleration?; to the problem of radiation in space? Of these three problems only the radiation effects could be argued away analytically, based on the data from unmanned satellites and probes. We were able to relieve our fears about the reentry acceleration effects through the bravery of experimenters riding centrifuges. It should be remembered here that it was not the extended period of 8 "g's" required for a normal reentry which posed the real problem - but rather the possible emergency level of 20 "g's" that gave us pause. The third problem - weightlessness - remained a question of indeterminate scope until our first astronaut stepped from the Mercury capsule. This was, of course, because we could not simulate zero "g" for more than seconds in any other way than by going into orbit.

If we examine the very fundamental design solutions which were solved by Mercury and which have persisted in our three space programs to date, we find that the majority of them were concerned with the problems of reentry into the Earth's atmosphere and recovery from that reentry onto the surface. The choice of a reentry rocket for establishing the entry trajectory was rather straight forward. The blunt body

was created to withstand the extreme heats of reentry with the lightest possible amount of heat protection, and this has continued to be the most economical way in which to perform this function. The supine couch was invented to support the astronaut evenly and in correct relationship to the very high acceleration vectors caused by reentry and all of our spacecraft to date employ them. Another major system choice was in the use of parachutes to allow the capsule to descend onto the water after having come through the high deceleration and high heat period of the return. The only one of the fundamental design solutions I have noted that was not concerned with the reentry problem is the launch escape system. This was a unique creation required by space flight because of the requirement to protect the astronauts from possible disaster occurring on the launch pad or during the period of booster acceleration.

Let me again note that all these features are found in the Apollo, and all except the Mercury-type of rocket launch escape system were found in the Gemini spacecraft as well. Because of their fundamental nature, they will likely be with us on the next spacecraft also.

The Mercury did not only deal with the basics of man's adaptability or survivability in space, or with the engineering problems associated with getting there and returning safely, but it had to deal simultaneously with the creation of an operational capability. This operational capability had to be able to control the flight during its

orbiting period and during its reentry and its recovery on water. This required the creation of a world network which could send information rapidly to a central point and from which information could be sent back to the spacecraft, no matter what part of the orbit it was in.

Thus, Mercury had to pioneer in all three areas simultaneously. The basic problems facing Gemini were simpler in regard to these fundamentals, but it was just because these fundamental problems were solved that it was possible to plan to do more with the Gemini program. The Gemini program did face some fundamental uncertainties, principally the effect of weightlessness for two weeks in space and, of course, the effects of extra-vehicular operations on man's capability to orient in them and to perform useful tasks during them. The major purpose of the program was, however, to use the current spacecraft concept with enough additional capability - - additional systems and additional controls - - so that it could serve to develop the required complex operations which would be needed in the Apollo program. The additional systems were, as you can see on the figure to the side, the translational thrusters, the inertial platform and computer, the rendezvous radar, a new power system - fuel cells - a docking system and an EVA hatch. The essence of the Gemini program, however, was contained in the complex operations which it was to attempt and demonstrate. These are the precision changes of orbit, rendezvous, docking and for the first time, controlled reentry. These operations required a close knit interaction between the crew in orbit and the operational complex on the ground. Such operations will be required in the Apollo program and the solutions

which were tested in the Gemini program have become a part of the Apollo technique.

In the Apollo program we are faced with two new major dimensions to our space capabilities, namely, deep space operations and lunar operations. The most obvious effect of this need to escape the Earth has been the creation of the Saturn V booster which weighs, at take-off, some 6 million pounds, which is 100 times more weight than the Redstone booster which lofted Mercury on its first test flights. The energy requirement of the Apollo mission lies behind most of the differences between Apollo and its predecessor programs. I will have more to say about this in a later slide.

In addition to needing huge amounts of energy, operating in deep space requires extremely precise navigation so we can hit the target at the Moon and hit the reentry corridor coming back to Earth. Operating outside the Van Allen belt, we are faced with meeting the problems of radiation protection and we face a statistical chance that we will be exposed to the radiation from a solar flare. Of course, we must also reenter our spacecraft at 36,000 ft/sec as opposed to the orbital speed of 25,000 ft/sec.

I am very happy to be able to report to you that our design solution for this latter problem of reentry heating was proven extremely satisfactory, as indicated by the results of our Saturn V reentry test. Among

the many, many firsts accomplished on this mission was the attainment of full-scale, full-speed reentry conditions--36,537 ft/sec for 25,000 mph. As is shown on the next chart, the Apollo reentry flight path is significantly different from the direct Earth orbital flight path of Gemini or Mercury. This so-called skip-out trajectory was chosen for Apollo so that the range from Earth entry at 400,000 feet to the landing point could be varied a maximum amount to meet lunar return landing site conditions. The skip-out trajectory flown by Apollo 4 represented 1-1/2 times the maximum heating rates the Apollo spacecraft will have to face, 620 BTU/ft^2/sec, as noted on the chart. The total heat load experienced (36,000 BTU/ft^2), over three times that obtained on the Gemini flights, is equivalent to that expected of lunar Apollo return conditions.

Less concrete than the type of new problems described above that we are facing and solving in Apollo, but certainly as real, is the fact that the sheer distance of the Moon creates conditions which will not allow instantaneous return to the Earth's surface over extended periods of time. This lack of immediate abort capability puts even more stress on system reliability and system redundancy than was necessary in the Mercury and Gemini programs.

We are also facing entirely new problems in the lunar mission in all of those operations around, near, and on the surface of the Moon which are required to carry out the exploration of the Moon. In response to these problems, we have created our first true space vehicle--the LM--the first vehicle designed to operate entirely outside the Earth's

atmosphere. This new type of space vehicle has had several problems which dominated its design. First, the requirement that it descend to and ascend from the lunar surface caused a two-stage design. This same problem required the utmost in propulsion reliability while, at the same time, required the relative sophistication of a throttleable engine. The answer lay in the development of the pressure fed, ablatively cooled engines we have in the LM. Note also that when it returns from the surface, the LM must be launched by the two men inside without the help of the thousands of technicians which assist in getting boosters away from the surface of the Earth. In addition, the navigational problems associated with leaving the orbit around the Moon, landing. returning and rendezvousing in orbit caused requirements for very precise navigational components which included our first space sextant, as well as a highly efficient inertial unit.

Operations at 1/6 "g", while more amenable than zero "g" operations to Earth simulations, required development of new devices such as the Apollo backpacks, capable of allowing the astronaut 3 to 4 hours of surface operation. Since the objective of the Apollo program is the scientific exploration of the Moon, it is developing payloads capable of being placed on the surface of the Moon and lasting there for a year. This has forced us into the far from trivial problems associated with integrating a radioisotope power source onto the LM. Other specialized devices have also been required such as rockboxes, in which samples of the lunar material can be packed and brought to Earth in conditions

similar to those under which they were gathered, and a set of geological tools which can be used by the astronaut in a pressure-suited condition under the peculiar conditions which will be found on the Moon.

But these new requirements and these new systems do not really tell the story of how big the step between Mercury and Gemini and the Apollo programs really is. Even the comparison between the vehicles required for the flight programs, shown on the next chart, does not fully acquaint you with the magnitudes that are involved. As can be seen on the figure, the Apollo spacecraft, which weighs about 95,000 lbs as compared to the 7,000 lbs of Gemini and 3,000 lbs of Mercury, is about three times the previous systems in length. The comparison in booster sizes shown on the left of the chart is, of course, even more expressive of the changes in magnitude involved.

Increased inert weight is a better indication of engineering difficulty than size. The next figure compares just the Apollo spacecraft stack with the total Mercury/Atlas system. As can be seen, the hardware weight of the Apollo spacecraft is nearly 50% more than the Mercury/Atlas combined.

The quantum jump we have taken with the Apollo program can be illustrated in still another way by comparing the velocities and energies produced by the boosters and spacecraft of our three programs. The next figure presents a curve of in-flight weight as a function of velocity for the Mercury, Gemini, and Apollo systems. First, note that

the Apollo system was assumed to be flown in a manner to produce the maximum possible velocity from its available propulsion systems. This is not the way it will be flown on the lunar mission, but is presented here for comparison purposes only. Second, note that the velocity scale is not linear; in fact, it is actually plotted proportional to the velocity squared. Thus, the areas under the curve represent the total energy utilized in reaching that velocity. If we had plotted the total Apollo launch on the figure, we would have had to extend the weight scale which now goes to 300,000 lbs up to 6,400,000 lbs. If we compared the area under that curve with the shaded curves which start at about 300,000 lbs and which represent the Mercury and Gemini programs, we would have a comparison of the total energy. The ratios involved are expressed in the inset on the right, where you can see that the Apollo mission demands 18 times the total energy of the Mercury program and some 10 times that of the Gemini. But to really bring home to you how much greater the Apollo booster system is than the earlier launch vehicles, note that the Saturn V booster places in orbit around the Earth a booster system which weighs as much as the total Mercury/Atlas or Gemini/Titan booster systems did on the ground. This is indeed an impressive indication of how far we have come in one short decade.

There are other facts about the Apollo program which indicate its complexity relative to the two previous efforts. Some of these have grown with equal rapidity to the growth in performance indicated here on the next two figures. On the left we have plotted a comparison of system complexity which uses for illustration the number of rockets

involved in the programs and the number of miles of wire in the spacecraft. The complexity growth implied by each is impressive. First, it must be realized that all of these rockets have to work for a completely successful mission. There is some redundancy, of course, but in general that statement is true. Even more generally indicative of system complexity are the number of miles of wire involved in spacecraft. When you realize that our spacecraft are about 1/400 of a mile in length, you can begin to get an idea of how many vehicle circumferences a mile of wire will cover and how many systems it must service. The fact that the Command Module alone is nearly double that of the Gemini Module and triple that of the Mercury is a very good indication of the number and complexity of the systems that have had to be placed aboard to do the assigned tasks. System complexity is also shown in the chart on the right, which indicates - on the left of that chart - the number of computer bits which are incorporated in the spacecraft computers and, on the left, the number of computer bits which are incorporated into the ground control systems for the three programs. There was, of course, no computer capability in the Mercury spacecraft and the capability of the Gemini spacecraft was rudimentary compared to that of the two elements of the Apollo program.

Perhaps by now you will be prepared to admit that in undertaking the Apollo program we have had to create a system with considerably more performance and considerably more complexity than the two programs which preceded it. What are we getting for all this complexity and all this

performance? In other words, on the day that we have returned the first lunar samples to our Receiving Laboratory in Houston, what will have been accomplished in our manned space program up to that time? First of all, man will have accomplished an age-old dream and visited his nearest neighbor in space. Man will have acquired a key to the riddle of Earth's relation to its nearest neighbor in space and, with that key, a chance of understanding the creative forces that formed his own home - Earth. For the first time he will have soared beyond the confines of Earth's gravity and felt the pull of a foreign planet. For the first time he will have personally viewed our whole planet as a small bluish ball only four times the span of the lunar disk. These experiences may well produce profound changes in man's attitude towards himself and his world comparable to those wrought by Galileo's dramatic demonstration of the Copernican theory, changes which should tend to inspire man to place the affairs of his very small house in order.

While it would be interesting and most valuable to pursue these somewhat metaphysical speculations further, time forces me to speak next of what we will have accomplished in the way of man space flight technology.

First, as shown on the next figure, by the end of the third lunar mission, 6,044 manhours in space will have been completed. This will be three times what we had completed by the end of the Gemini program. Manhours in space are perhaps the best measure of the amount of learning accomplished in the piloting and operational aspects of space flight.

It is this factor which will give us not only the confidence but the imagination to utilize manned space flight for whatever goals are selected in the future.

But there are other tangible and intangible products of the manned space flight program which will have even greater bearing on the paths of the future. We will have, by the end of the Apollo program, developed an enormous capability in all the areas pertinent to manned space flight. These areas are noted on the next chart. I will make a few comments about some of them. First, I think it very important to note that in the spacecraft field we will have created a Government team which has created four basic spacecraft. The engineering and manufacturing has been accomplished, of course, largely by industry and in doing this, three major industrial firms have served as systems engineer for manned spacecraft. Thus we have created a significant Government-industry base for the development of any new spacecraft which might be needed and, with it, the assurance that we will be able to resort to a meaningful competition for the creation of our next spacecraft. The situation with launch vehicles is similar. There have been created a total of five stages which have been major jobs of six contractors and thus again we have created a considerable base for competition for the development of any future new devices.

A great deal of our effort and development has gone into the development and operation of ground control facilities. The world-wide network with its instantaneous communication capability and its very large

computer capacity is there waiting for new assignments. In launch and checkout facilities, the same is true. The locations and capacity created for the Apollo program should be quite sufficient to handle future flights of whatever nature for quite sometime to come.

But most important in terms of what we will have accomplished will have been the number of people who have been involved in the space program over the period of time in which it has operated. I think you have heard the number many times, but it is a fact that nearly 400,000 people have been working on the program for the last five to six years. And it is in these people who have developed the skills required to place our men and machinery into space that we have our most valuable asset. It is this base on which we must plan to build if we are to go forward in this area.

My deepest feelings about what we will have achieved by our efforts in the manned space flight program, particularly Apollo, and what it portends for the future, have been very well expressed by another. Dr. Norman Topping, President of the University of Southern California, made the following statement in a recent conference:

> "Men have never pursued excellence in any work to the degree or the massive concentration that is being sought in the Apollo program. When this goal is achieved, this will not just mean that two Americans have walked the ragged surface of the Moon.
>
> "It will mean that for the first time, man has sought and achieved a costly goal, the most costly in his history, for

purely peaceful purposes, and that he is now ready to 'interact' with society and bring to all men the benefits inherent in achieving this goal."

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MANNED FLIGHT PROGRAM CHARACTERISTICS

MERCURY	GEMINI	APOLLO
MAN'S SURVIVABILITY	MANNED OPERATIONS	MANNED EXPLORATION
FUNDAMENTAL BIOPHYSICAL UNKNOWNS	COMPLEX OPERATIONS	DEEP SPACE OPERATIONS
FUNDAMENTAL DESIGN SOLUTIONS	EXTENSIONS OF MAN'S FUNDAMENTAL CAPABILITIES	LUNAR OPERATIONS
OPERATIONAL SOLUTIONS	ADDITIONAL SYSTEMS	ADDITIONAL SYSTEMS

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MERCURY

MAN'S SURVIVABILITY

- FUNDAMENTAL BIOPHYSICAL UNKNOWNS
  - WEIGHTLESSNESS
  - REENTRY ACCELERATION EFFECTS
  - RADIATION EFFECTS
- FUNDAMENTAL DESIGN SOLUTIONS
  - BLUNT BODY
  - SUPINE COUCH
  - LAUNCH ESCAPE SYSTEMS
  - REENTRY ROCKET
  - PARACHUTES
- OPERATIONAL SOLUTIONS
  - FLIGHT CONTROL
  - WATER RECOVERY
  - WORLD NETWORK

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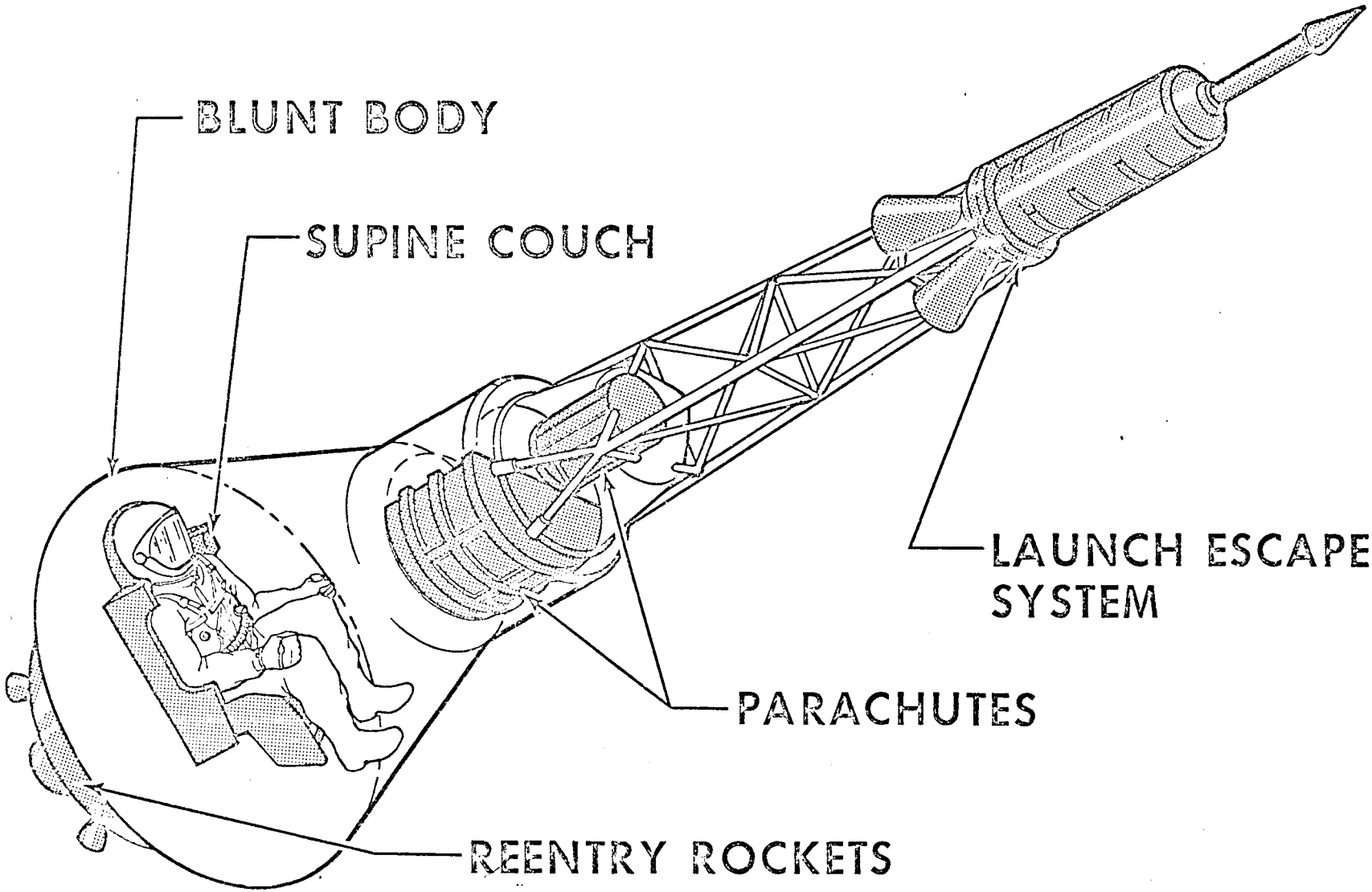
MERCURY FUNDEMENTAL DESIGN SOLUTIONS



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GEMINI

MANNED OPERATIONS

- COMPLEX OPERATIONS
  - PRECISE CHANGE OF ORBIT
  - RENDEZVOUS
  - DOCKING
  - CONTROLLED REENTRY
- EXTENSIONS OF MAN'S FUNDAMENTAL CAPABILITIES
  - 2-WEEKS DURATION
  - EXTRA-VEHICULAR OPERATIONS
- ADDITIONAL SYSTEMS
  - TRANSLATIONAL THRUSTERS
  - INERTIAL PLATFORM AND COMPUTER
  - RENDEZVOUS RADAR
  - FUEL CELLS
  - DOCKING SYSTEM
  - EVA HATCH

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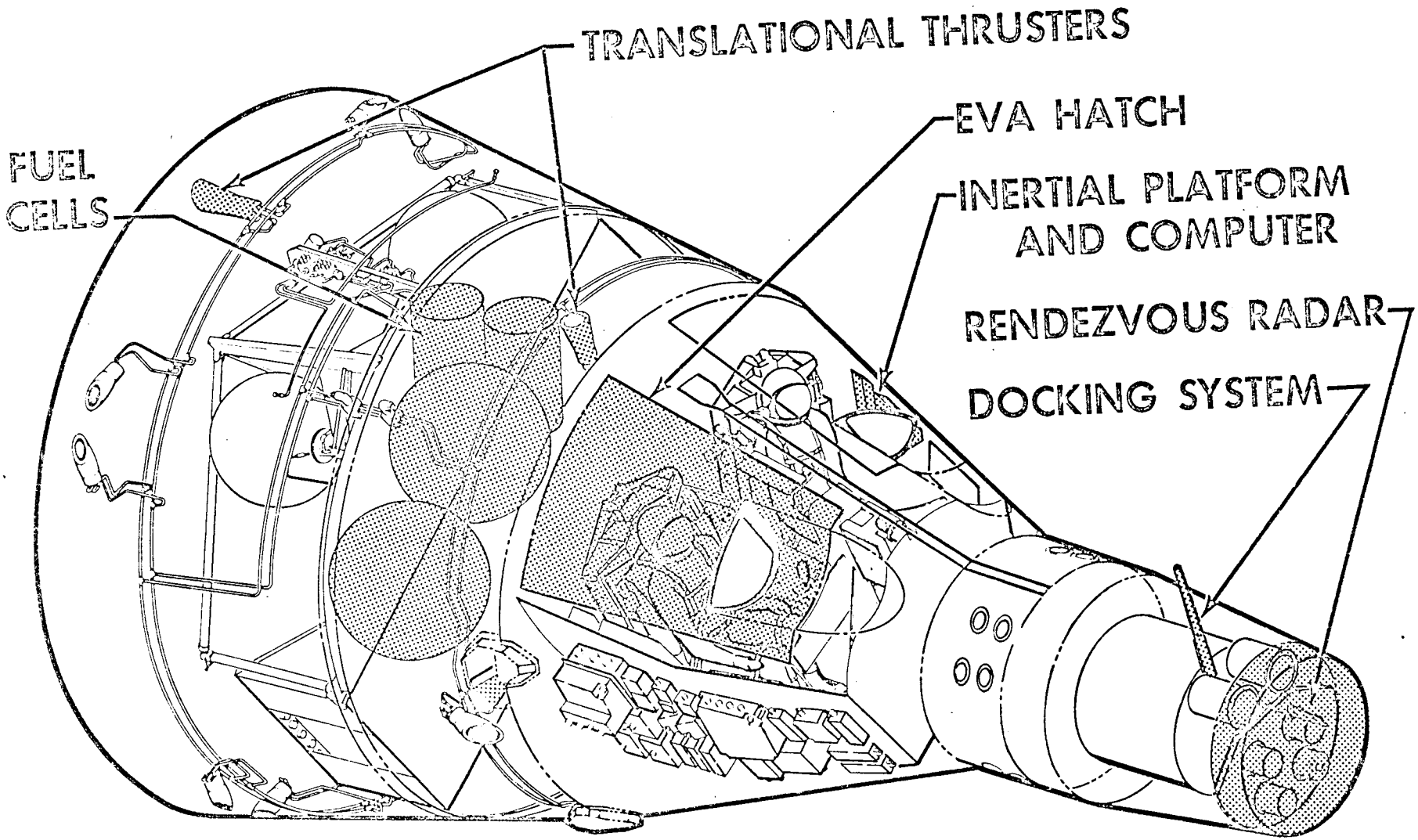
GEMINI ADDITIONAL SYSTEMS



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APOLLO
MANNED EXPLORATION

- DEEP SPACE OPERATIONS
  - MAJOR ENERGY REQUIREMENTS
  - PRECISE NAVIGATION
  - RADIATION PROTECTION
  - INCREASED REENTRY SPEEDS
- LUNAR OPERATIONS
  - LANDING AND TAKE-OFF
  - 1/6 'g' EVA
  - LUNAR EXPLORATION
  - LUNAR ENVIRONMENT
- ADDITIONAL SYSTEMS
  - VARIABLE THRUST LUNAR LANDING ENGINE
  - DEEP SPACE DIRECTIONAL ANTENNA
  - HIGH THRUST PRESSURE FED ABLATIVE ENGINES
  - LANDING RADAR
  - LANDING GEAR

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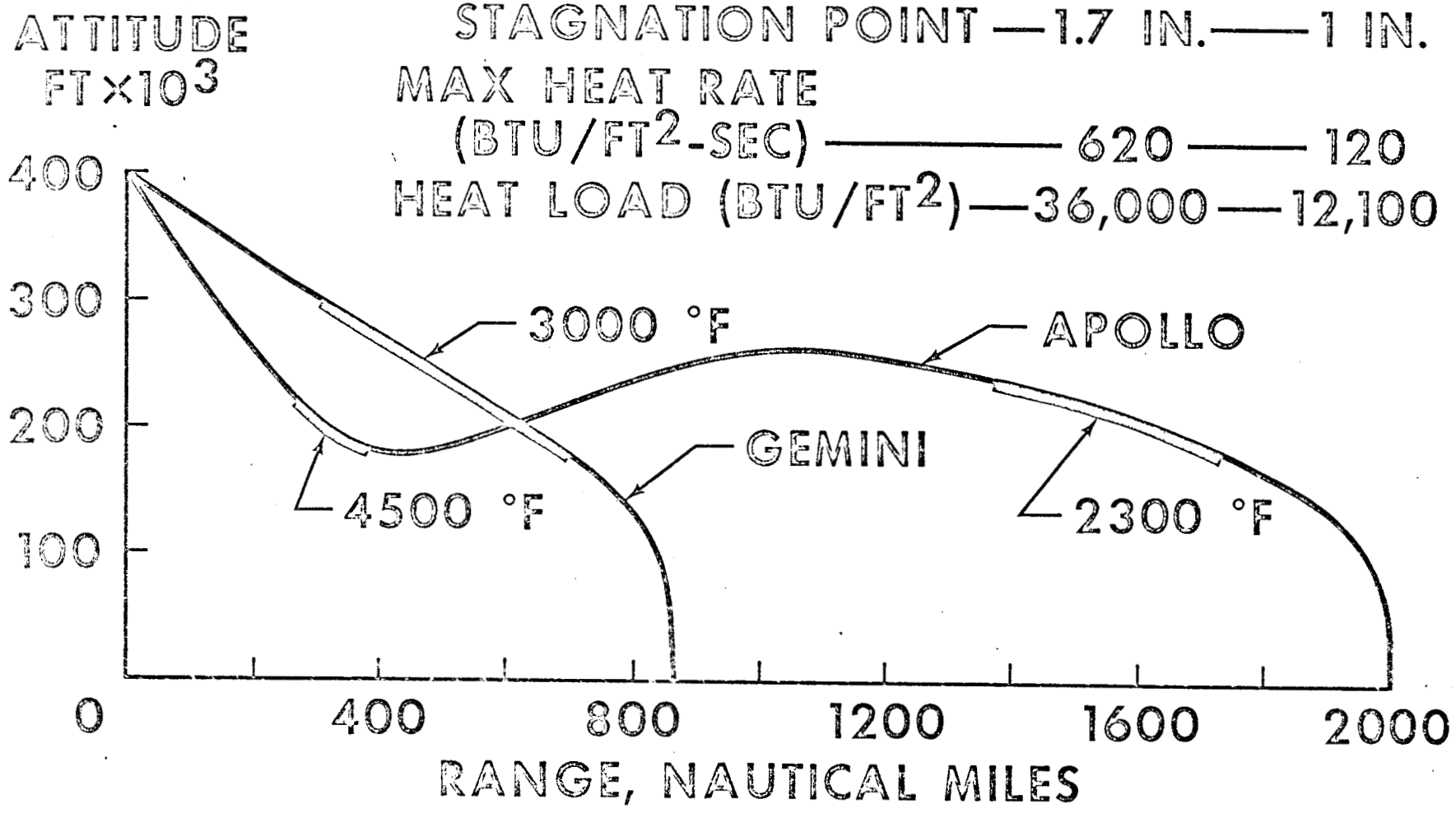
APOLLO AND GEMINI REENTRY CONDITIONS

	APOLLO	GEMINI
THICKNESS AT STAGNATION POINT	1.7 IN.	1 IN.
MAX HEAT RATE (BTU/FT^2-SEC)	620	120
HEAT LOAD (BTU/FT^2)	36,000	12,100



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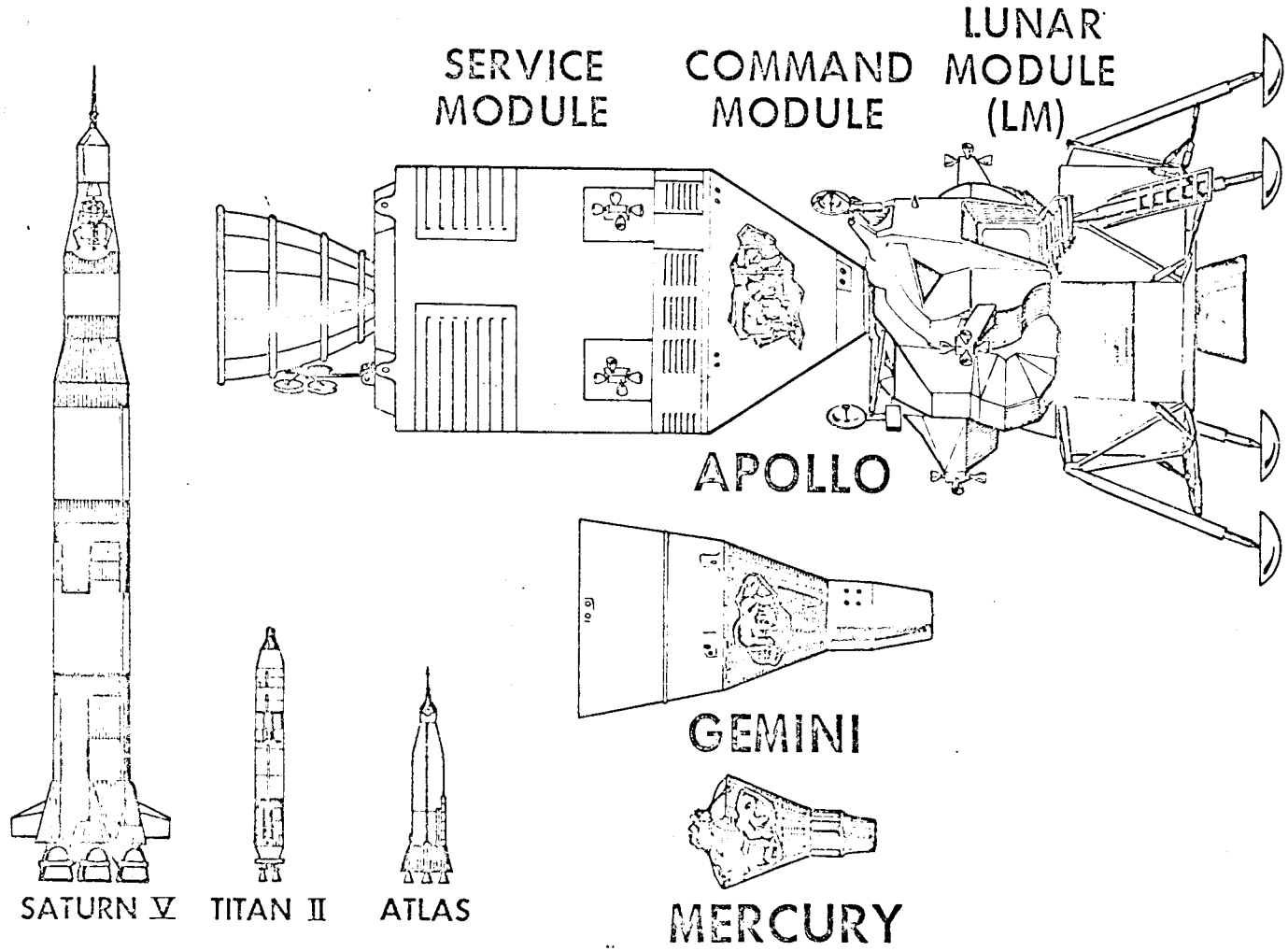
COMPARISON OF SPACECRAFT AND LAUNCH VEHICLE CONFIGURATIONS



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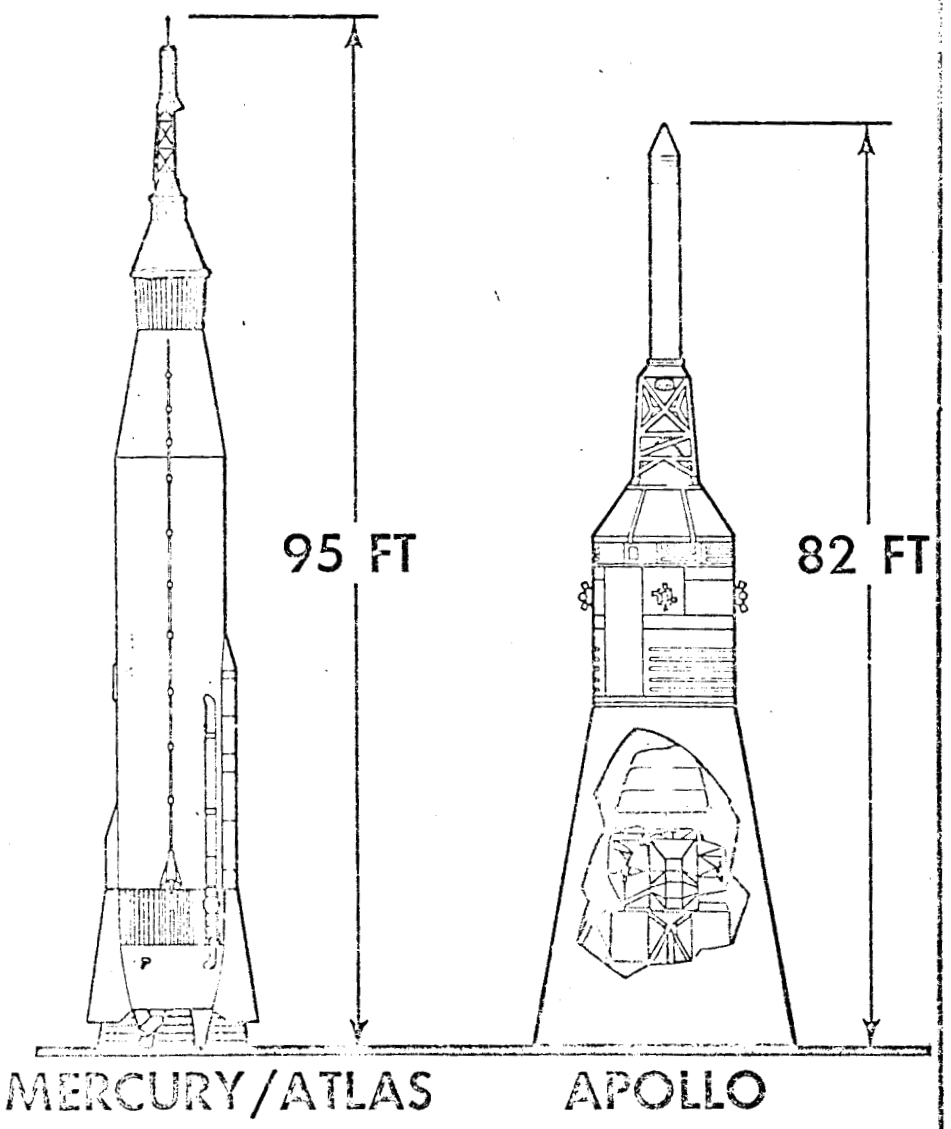
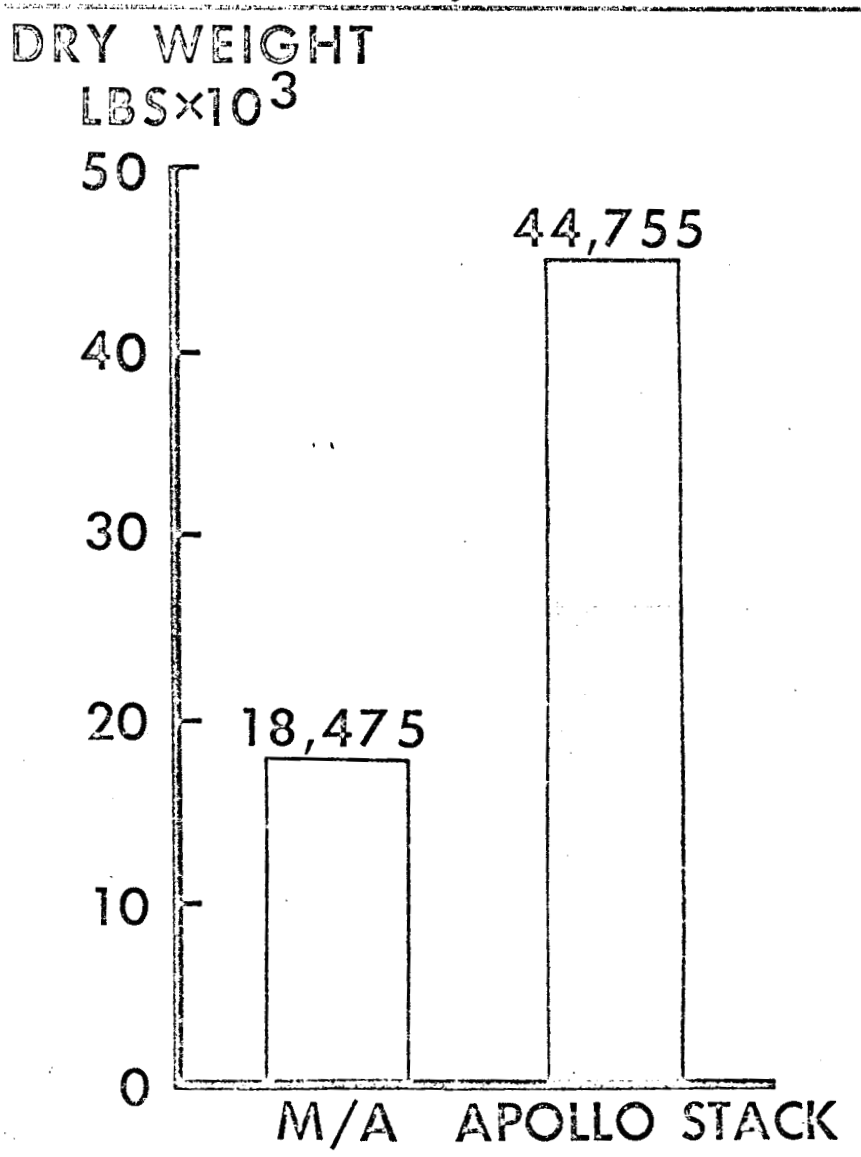
APOLLO SPACECRAFT COMPARED WITH TOTAL MERCURY/ATLAS





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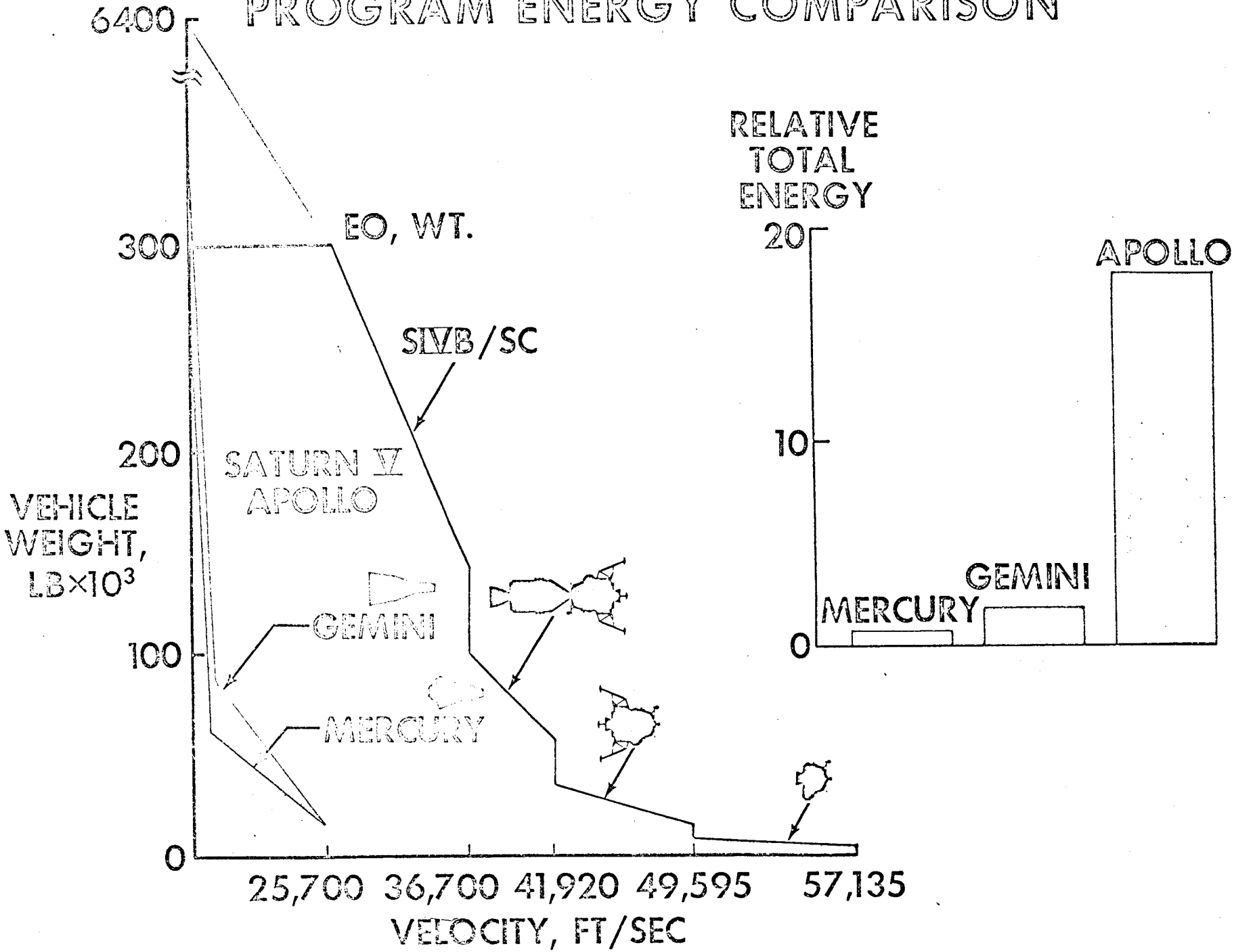
PROGRAM ENERGY COMPARISON



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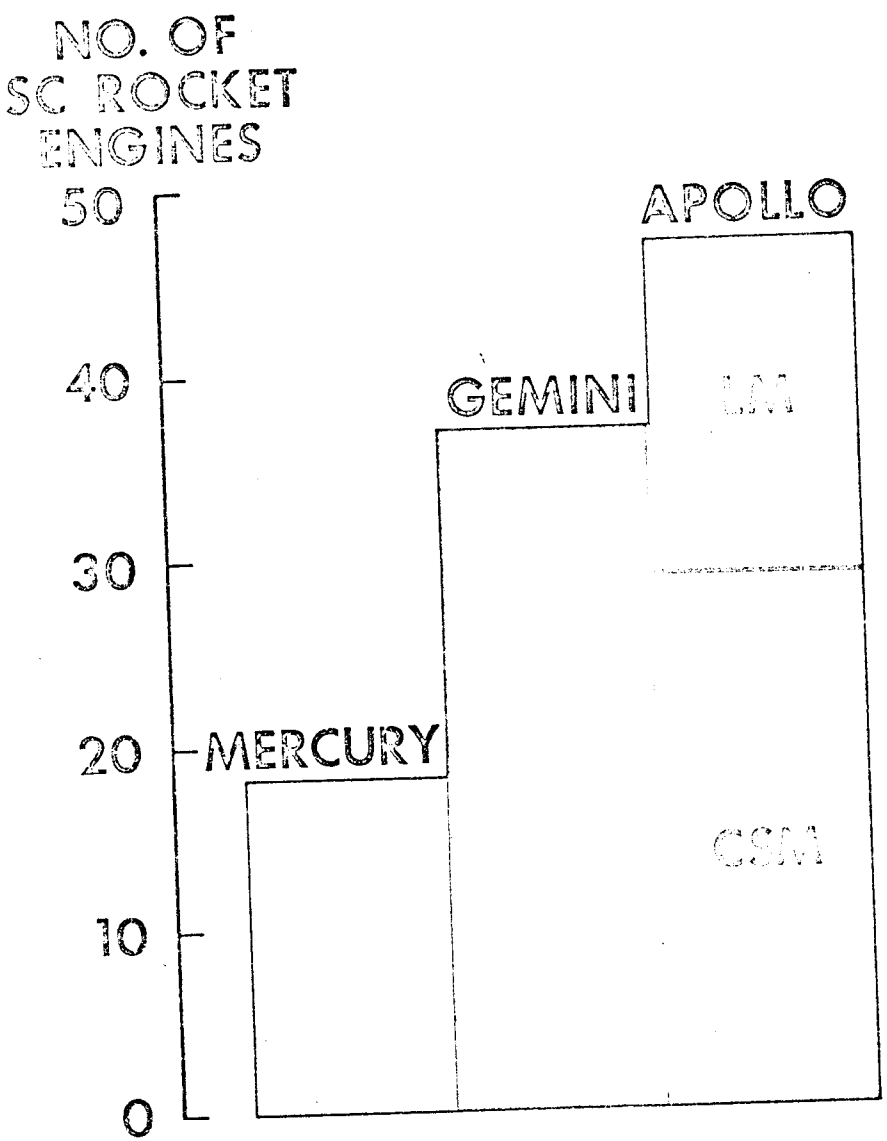
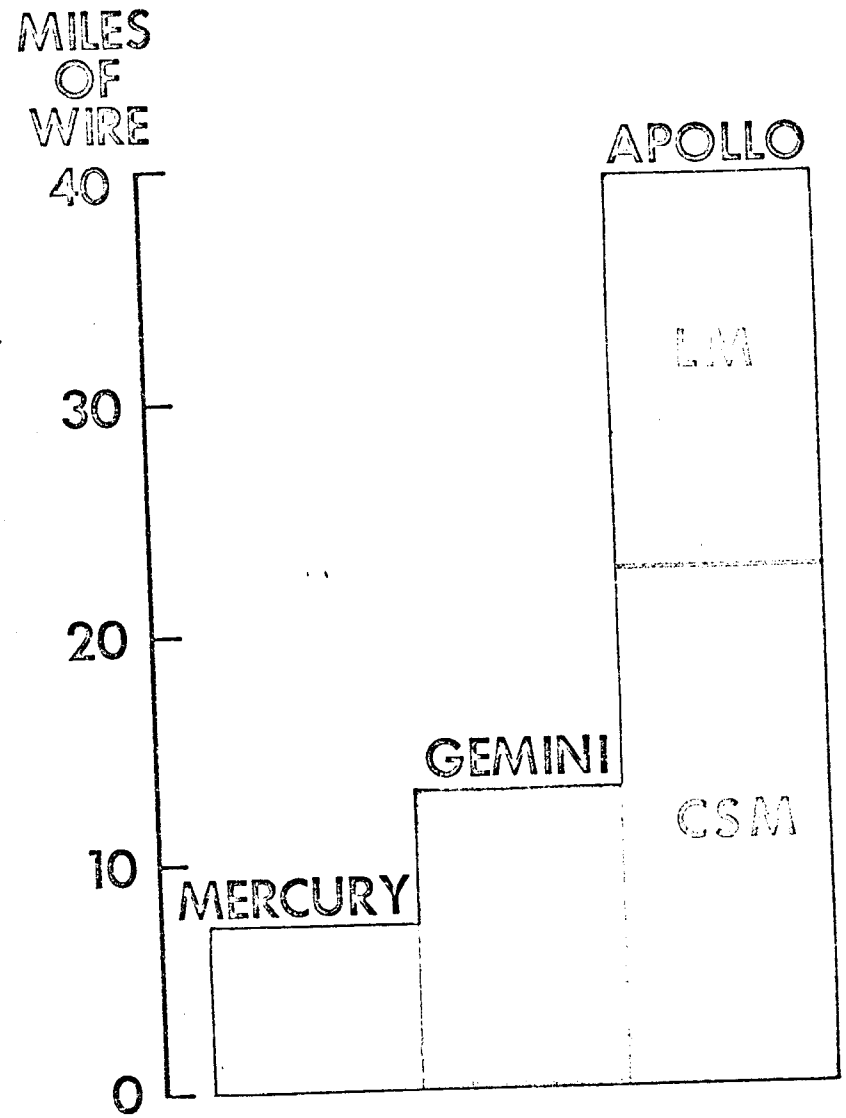
VEHICLE SYSTEM COMPLEXITY INDICATORS





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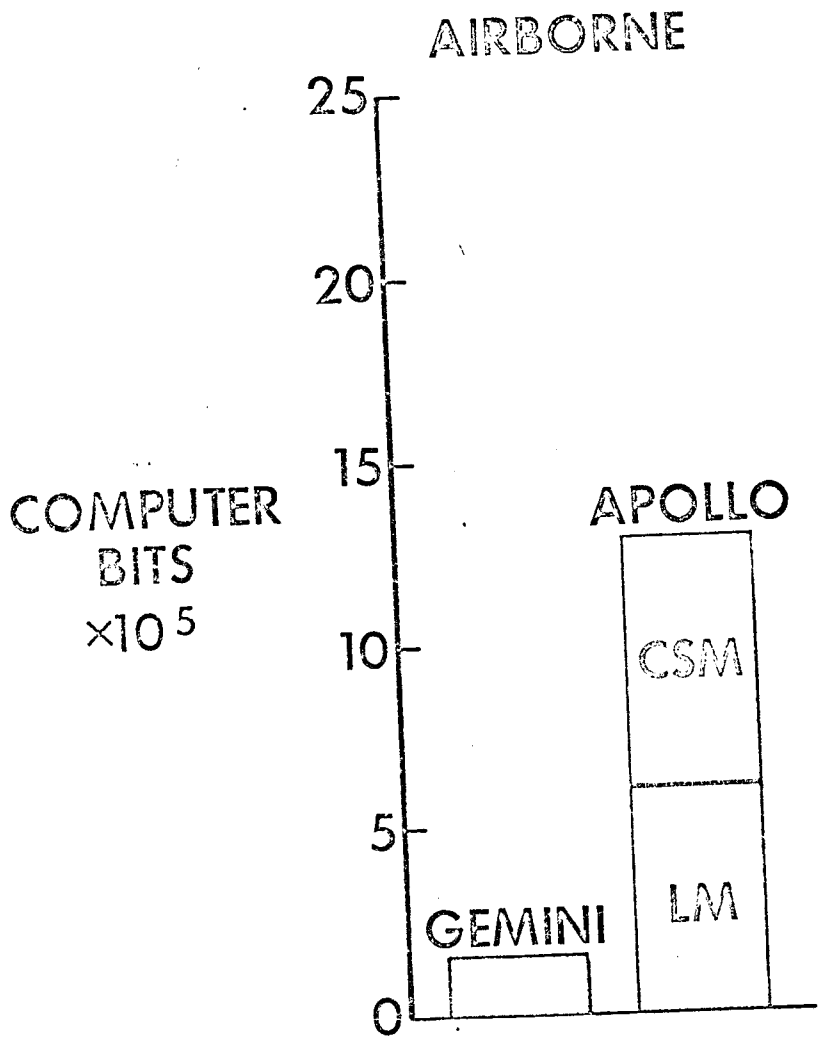
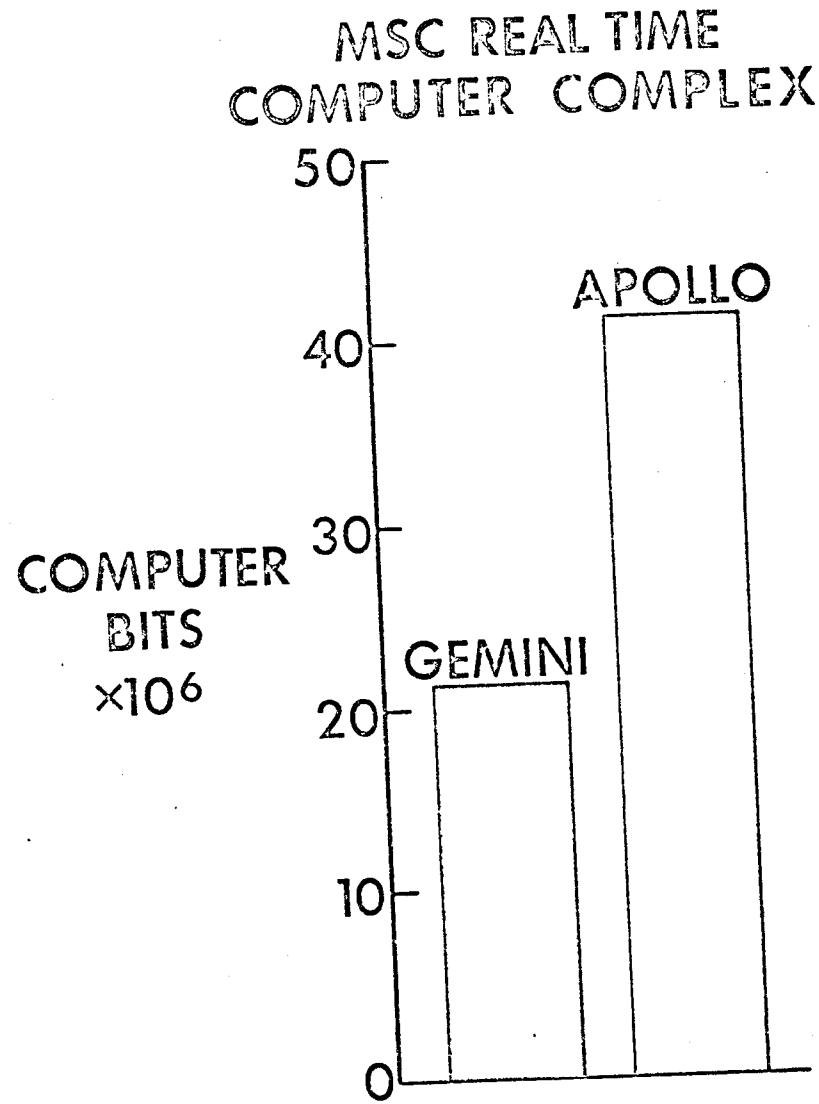
VEHICLE SYSTEM COMPLEXITY INDICATORS





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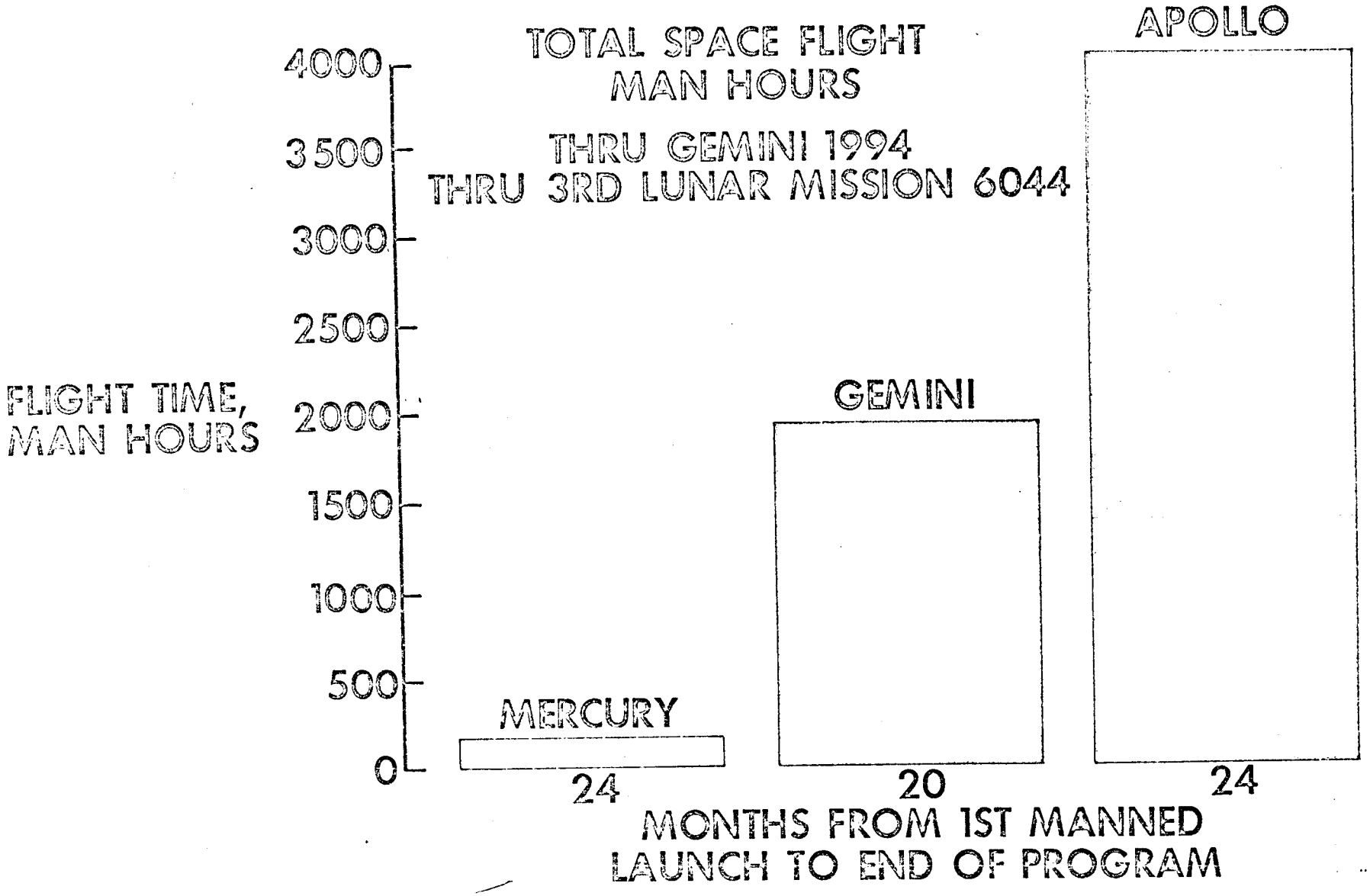
ACCUMULATED MAN HOURS IN SPACE



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FOUNDATIONS FOR FUTURE MANNED SPACEFLIGHT PROGRAMS

- SPACECRAFT
- LAUNCH VEHICLE
- GROUND CONTROL FACILITIES
- LAUNCH FACILITIES
- CHECKOUT FACILITIES
- PEOPLE