Document I-8

Topics of the Times

New York Times, January 18, 1920, p. 12 col. 5.

A Severe Stain on Credulity

As a method of sending a missile to the higher, and even to the highest, part of the earth's atmospheric envelope, Professor Goddard's multiple-charge rocket is a practicable, and therefore promising device. Such a rocket, too, might carry self-recording instruments to be released at the limit of its flight, and conceivably parachutes would bring them safely to the ground. It is not obvious, however, that the instruments would return to the point of departure; indeed, it is obvious that they would not, for parachutes drift exactly as balloons do. And the rocket, or what was left of it after the last explosion, would have to be aimed with amazing skill, and in a dead calm, to fall on the spot whence it started.

But that is a slight inconvenience, at least from the scientific standpoint, though it might be serious enough from that of the always innocent bystander a few hundred or thousand yards away from the firing line. It is when one considers the multiple-charge rocket as a traveler to the moon that one begins to doubt and looks again, to see if the dispatch announcing the professor's purposes and hopes says that he is working under the auspices of the Smithsonian Institution. It does say so, and therefore the impulse to do more than doubt the practicability of such a device for such a purpose must be—well, controlled. Still, to be filled with uneasy wonder and to express it will be safe enough, for after the rocket quits our air and really starts on its longer journey, its flight would be neither accelerated nor maintained by the explosion of the charges it then might have left. To claim that it would be is to deny a fundamental law of dynamics, and only **Dr. Einstein** and his chosen dozen, so few and fit, are licensed to do that.

His Plan Is Not Original

That Professor **Goddard**, with his "chair" in Clark College and the countenancing of the Smithsonian Institution, does not know the relation of action to reaction, and of the need to have something better than a vacuum against which to react—to say that would be absurd. Of course he only seems to lack the knowledge ladled out daily in high schools.

But there are such things as Intentional mistakes or oversights, and, as it happens, **Jules Verne**, who also knew a thing or two in assorted sciences—and had, besides, a surprising amount of prophetic power—deliberately seemed to make the same mistake that Professor **Goddard** seems to make. For the Frenchman, having got his travelers to go toward the moon into the desperate fix of riding a tiny satellite of the satellite, saved them from circling it forever by means of an explosion, rocket fashion, where an explosion would not have had in the slightest degree the effect of releasing them from their dreadful slavery. That was one of **Verne's** few scientific slips, or else it was a deliberate step aside from scientific accuracy, pardonable enough in him as a romancer, but its like is not so easily explained when made by a savant who isn't writing a novel of adventure.

All the same, if Professor **Goddard's** rocket attains sufficient speed before it passes out of our atmosphere—and if its aiming takes into account all of the many deflective forces that will affect its flight, it may reach the moon. That the rocket could carry enough explosive to make on impact a flash large and bright enough to be seen from the earth by the biggest of our telescopes—that will be believed when it is done.

Document I-9

Document title: Robert H. Goddard, *Liquid-propellant Rocket Development*, Smithsonian Miscellaneous Collections, Volume 95, Number 3 (Washington, DC: Smithsonian Institution Press, 1936). The plates have been omitted from this document.

Goddard was conducting tests with liquid-fueled rockets in seclusion in the New Mexican desert when his friend, Charles Lindbergh, began urging him to publish the results. Lindbergh encouraged Goddard to accept an invitation to address an annual convention of the American Association for the Advancement of Science (AAAS). Goddard presented the results of his liquid-propellant rocket experiments at the AAAS convention in St. Louis on December 31, 1935. Goddard was genuinely pleased with the warm reception his work received and was finally convinced by Lindbergh to publish the results. The subsequent paper published by the Smithsonian Institution on March 16, 1936, consisted of ten pages of test and twelve pages of plates illustrating his experiments. It was his first published paper since his previous Smithsonian publication in 1919. The response was overwhelmingly favorable, for Goddard had demonstrated the practicality and scientific basis for rocket research and development.

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[1] Liquid-propellant Rocket Development

The following is a report made by the writer to The Daniel and Florence Guggenheim Foundation concerning the rocket development carried out under his direction in Roswell, New Mexico, from July 1930 to July 1932 and from September 1934 to September 1935, supported by this Foundation.

This report is a presentation of the general plan of attack on the problem of developing a sounding rocket, and the results obtained. Further details will be set forth in a later paper, after the main objects of the research have been attained.

Introduction

In a previous paper[1] the author developed a theory of rocket performance and made calculations regarding the heights that might reasonably be expected for a rocket having a high velocity of the ejected gases and a mass at all times small in proportion to the weight of propellant material. It was shown that these conditions would be satisfied by having a tapered nozzle through which the gaseous products of combustion were discharged,[2] by feeding successive portions of propellant material into the rocket combustion chambers,[3] and further by employing a series of rockets, of decreasing size, each fired when the rocket immediately below was employ of fuel.[2] Experimental results with power rockets were also presented in this paper.

Since the above was published, work has been carried on for the purpose of making practical a plan of rocket propulsion set forth in 1914[3] which may be called the liquid-propellant type of rocket. In this rocket, a liquid fuel and combustion-supporting liquid are fed under pressure into a combustion chamber provided with a conical nozzle through which the products of combustion are discharged. [2] The advantages of the liquid-propellant rocket are that the propellant materials possess several times the energy of powders, per unit mass, and that moderate pressures may be employed, thus avoiding the weight of the strong combustion chambers that would be necessary if propulsion took place by successive explosions.

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1. Smithsonian Misc. Coll., vol. 71, no. 2, 1919.
2. U.S. Patent, "Rocket Apparatus," No. 1,102,653, July 7, 1914.
3. U.S. Patent, "Rocket Apparatus," No. 1,103,503, July 14, 1914.

Experiments with liquid oxygen and various liquid hydrocarbons, including gasoline and liquid propane, as well as ether, were made during the writer's spare time from 1920 to 1922, under a grant by Clark University. Although oxygen and hydrogen, as earlier suggested,[4] possess the greatest heat energy per unit mass, it seems likely that liquid oxygen and liquid methane would afford the greatest heat value of the combinations which could be used without considerable difficulty. The most practical combination, however, appears to be liquid oxygen and gasoline.

In these experiments it was shown that a rocket chamber and nozzle, since termed a "rocket motor," could use liquid oxygen together with a liquid fuel, and could exert a lifting force without danger of explosion and without damage to the chamber and nozzle. These rockets were held by springs in a testing frame, and the liquids were forced into the chamber by the pressure of a noninflammable gas.

The experiments were continued from 1922 to 1930, chiefly under grants from the Smithsonian Institution. Although this work will be made the subject of a later report, it is desirable in the present paper to call attention to some of the results obtained.

On November 1, 1923, a rocket motor operated in the testing frame, using liquid oxygen and gasoline, both supplied by pumps on the rocket.

In December 1925 the simpler plan previously employed of having the liquids fed to the chamber under the pressure of an inert gas in a tank on the rocket was again employed, and the rocket developed by means of the tests was constructed so that it could be operated independently of the testing frame.

The first flight of a liquid-oxygen-gasoline rocket was obtained on March 16, 1926 in Auburn, Massachusetts, and was reported to the Smithsonian Institution May 5, 1926. This rocket is shown in the frame from which it was fired, in Plate 1, Fig. 1. Pressure was produced initially by an outside pressure tank, and after launching by an alcohol heater on the rocket.

It will be seen from the photograph that the combustion chamber and nozzle were located forward of the remainder of the rocket, to which connection was made by two pipes. This plan was of advantage [3] in keeping the flame away from the tanks, but was of no value in producing stabilization. This is evident from the fact that the direction of the propelling force lay along the axis of the rocket, and not in the direction in which it was intended the rocket should travel, the condition therefore being the same as that in which the chamber is at the rear of the rocket. The case is altogether different from pulling an object upward by a force which is constantly vertical, when stability depends merely on having the force applied above the center of gravity.

Plate 1, Fig. 2, shows an assistant igniting the rocket, and Plate 2, Fig. 1, shows the group that witnessed the flight, except for the camera operator. The rocket traveled a distance of 184 feet in 2.5 seconds, as timed by a stopwatch, making the speed along the trajectory about 60 miles per hour.

Other short flights of liquid oxygen-gasoline rockets were made in Auburn, that of July 17, 1929 happening to attract public attention owing to a report from someone who witnessed the flight from a distance and mistook the rocket for a flaming airplane. In this flight the rocket carried a small barometer and a camera, both of which were retrieved intact after the flight (Plate 2, Fig. 2). The combustion chamber was located at the rear of the rocket, which is, incidentally, the best location, inasmuch as no part of the rocket is in the high-velocity stream of ejected gases, and none of the gases are directed at an angle with the rocket axis.

During the college year 1929-1930 tests were carried on at Fort Devens, Massachusetts, on a location which was kindly placed at the disposal of the writer by the War Department. Progress was made, however, with difficulty, chiefly owing to transportation conditions in the winter.

At about this time Col. Charles A. Lindbergh became interested in the work and brought the matter to the attention of the late Daniel Guggenheim. The latter made a grant which permitted the research to be continued under ideal conditions, namely, in

[4] Smithsonian Misc.Coll., vol 71, no. 2, 1919.

eastern New Mexico; and Clark University at the same time granted the writer leave of absence. An additional grant was made by the Carnegie Institution of Washington to help in getting established.

It was decided that the development should be carried on for two years, at the end of which time a grant making possible two further years' work would be made if an advisory committee, formed at the time the grant was made, should decide that this was justified by the results obtained during the first two years. This advisory committee [4] was as follows: Dr. John C. Merriam, chairman; Dr. C.G. Abbot; Dr. Walter S. Adams; Dr. Wallace W. Atwood; Colonel Henry Breckinridge; Dr. John A. Fleming; Col. Charles A. Lindbergh; Dr. C.F. Marvin; and Dr. Robert A. Millikan.

The Establishment in New Mexico

Although much of the eastern part of New Mexico appeared to be suitable country for flights because of clear air, few storms, moderate winds, and level terrain, it was decided to locate in Roswell, where power and transportation facilities were available.

A shop 30 by 55 feet was erected in September 1930 (Plate 3, Figs. 1, 2), and the 60-foot tower previously used in Auburn at Fort Devens was erected about 15 miles away (Plate 4, Fig. 1). A second tower, 20 feet high (Plate 4, Fig. 2), was built near the shop for static tests, that is, those in which the rocket was prevented from rising by heavy weights, so that the lift and general performance could be studied. These static tests may be thought of as "idling" the rocket motor. A cement gas deflector was constructed under each tower, as may be seen in Plate 4, Figs. 1, 2, whereby the gases from the rocket were directed toward the rear, thus avoiding a cloud of dust which might otherwise hide the rocket during a test.

Static Tests of 1930-1932

Although, as has been stated combustion chambers which operated satisfactorily had been constructed at Clark University, it appeared desirable to conduct a series of thorough tests in which the operating conditions were varied, the lift being recorded as a function of the time. Various modifications in the manner of feeding the liquids under pressure to the combustion chamber were tested, as well as variations in the proportions of the liquids, and in the size and shape of the chambers. The chief conclusions reached were that satisfactory operation of the combustion chambers could be obtained with considerable variation of conditions, and that larger chambers afforded better operation than those of smaller size.

As will be seen from Plate 4, Fig. 2, the supporting frame for the rocket was held down by four steel barrels containing water. Either two of for barrels could be filled, and in the latter case the total weight was about 2000 pounds. This weight was supported by a strong compression spring, which made possible the recording of the lift on a revolving drum (Plate 5, Fig. 1) driven by clockwork.

[5] The combustion chamber finally decided upon for use in flights was 5 $^{3}/_{4}$ inches in diameter and weighed 5 pounds. The maximum lift obtained was 289 pounds, and the period of combustion usually exceeded 20 seconds. The shifting force was forced to be very steady, the variation of lift being within 5 percent.

The masses of liquids used during the lifting period were the quantities most difficult to determine. Using the largest likely value of the total mass of liquids ejected and the integral of the lift-time curve obtained mechanically, the velocity of the ejected gases was estimated to be over 5000 feet per second. This gave for the mechanical horsepower of the jet 1030 horsepower, and the horsepower per pound of the combustion chamber, considered as a rocket motor, 206 horsepower. It was found possible to use the chambers repeatedly.

The results of this part of the development were very important, for a rocket to reach great heights can obviously not be made unless a combustion chamber, or rocket motor, can be constructed that is both extremely light and can be used without danger of burning through or exploding.

Flights During the Period 1930-1932

The first flight obtained during this period was on December 30, 1930, with a rocket 11 feet long, weighing 33.5 pounds. The height obtained was 2000 feet, and the maximum speed was about 500 miles per hour. A gas pressure tank was used on the rocket to force the liquid oxygen and the gasoline into the combustion chamber.

In further flights pressure was obtained by gas pressure on the rocket, and also by pumping liquid nitrogen through a vaporizer, the latter means first being employed in a flight on April 19, 1932.

In order to avoid accident, a remote-control system was constructed in September 1931, whereby the operator and observers could be stationed 1000 feet from the tower, and the rocket fired and released at will from this point. This arrangement has proved very satisfactory. Plate 5, Fig. 2, shows the cable being unwound between the tower and the 1000-foot shelter, the latter being seen in the distance, and Plate 6, Fig. 1, shows the control keys being operated at the shelter, which is provided with sandbags on the roof as protection against possible accident. Plate 5, Fig. 2, shows also the level and open nature of the country.

One observer was stationed 3000 feet from the tower, in the rear of the 1000-foot shelter, with a recording telescope (Plate 6, Fig. 2). Two pencils attached to his telescope gave a record of altitude and azimuth respectively, of the rocket, the records being made on a paper [6] strip, moved at a constant speed by clockwork. The sights at the front and rear of the telescope, similar to those on a rifle, were used in following the rocket when the speed was high. In Plate 7, Fig. 1, which shows the clock mechanism in detail, the observer is indicating the altitude trace. This device proved satisfactory except when the trajectory of the rocket was in the plane of the tower and the telescope. For great heights, shortwave radio direction finders, for following the rocket during the decent, will be preferable to telescopes.

During this period a number of flights were made for the purpose of testing the regulation of the nitrogen gas pressure. A beginning on the problem of automatically stabilized vertical flight was also made, and the first flight with gyroscopically controlled vanes was obtained on April 19, 1932 which the same model that employed the first liquid-nitrogen tank. The method of stabilization consisted in forcing vanes into the blast of the rocket[5] by means of gas pressure, this pressure being controlled by a small gyroscope.

As has been found by later tests, the vanes used in the flight of April 19, 1932 were too small to produce sufficiently rapid correction. Nevertheless, the two vanes which, by entering the rocket blast, should have moved the rocket back to the vertical position were found to be warmer than the others after the rocket landed.

This part of the development work, being for the purpose of obtaining satisfactory and reproducible performance of the rocket in the air, was conducted without any special attempt to secure great lightness, and therefore great altitudes.

In May 1932 the result that had been obtained were placed before the advisory committee, which voted to recommend the two additional years of development. Owing to the economic conditions then existing, however, it was found impossible to continue the flights in New Mexico.

A grant from the Smithsonian Institution enabled the writer, who resumed full-time teaching in Clark University in the fall of 1932, to carry out tests that did not require flights, in the physics laboratories of the University during 1932-1933, and a grant was received from the Daniel and Florence Guggenheim Foundation which made possible a more extended program of the same nature in 1933-1934.

Resumption of Flights in New Mexico

A grant made by the Daniel and Florence Guggenheim Foundation in August 1934, together with leave of absence for the writer granted [7] by the Trustees of Clark

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[5] U.S. Patent, "Mechanism for Directing Flight," No. 1, 879, 187, September 1932.

University, made it possible to continue the development on a scale permitting actual flights to be made. This was very desirable, as further laboratory work could not be carried out effectively without flights in which to test performance under practical conditions.

Work was begun in September 1934, the shop being put in running order and the equipment at the tower for the flights being replaced. The system of remote control previously used was further improved and simplified, and a concrete dugout (Plate 7, Fig. 2) was constructed 50 feet from the launching tower in order to make it possible for an observer to watch the launching of the rocket at close range....

Development of Stabilized Flight

It was of the first importance to perfect the means of keeping the rockets in a vertical course automatically, work on which was begun in the preceding series of flights, since a rocket cannot rise vertically to a very great height without a correction being made when it deviates from the vertical course. Such correction is especially important at the time the rocket starts to rise, for a rocket of very great range [8] must be loaded with a maximum amount of propellant and consequently must start with as small an acceleration as possible. At these small initial velocities fixed air vanes, especially those of large size, are worse than useless, as they increase the deviations due to the wind. It should be remarked that fixed air vanes should preferably be small, or dispensed with entirely, it automatic stabilization is employed, to minimize air resistance.

In order to make the construction of the rockets as rapid as possible, combustion chambers were used of the same size as those in the work of 1930-1932, together with the simplest means of supplying pressure, namely, the use of a tank of compressed nitrogen gas on the rocket. The rockets were, at the same time, made as nearly streamline as possible without resorting to special means for forming the jacket or casing.

Pendulum Stabilizer

A pendulum stabilizer was used in the first of the new series of flights to test the directing vanes, for the reason that such a stabilizer could be more easily constructed and repaired than a gyroscope stabilizer, and would require very little adjustment. A pendulum stabilizer could correct the flight for the first few hundred feet, where the acceleration is small, but it would not be satisfactory where the acceleration is large, since the axis of the pendulum extends in a direction which is the resultant of the acceleration of the rocket and the acceleration of gravity, and is therefore inclined from the vertical as soon as the rocket ceases to move in a vertical direction. The pendulum stabilizer, as was expected, gave an indication of operating the vanes for the first few hundred feet, but not thereafter. The rocket rose about 1000 feet continued in a horizontal direction for a time, and finally landed 11,000 feet from the tower, traveling at a velocity of over 700 miles per hour near the end of the period of propulsion, as observed with the recording telescope.

Gyroscope Stabilizer

Inasmuch as control by a small gyroscope is the best as well as the lightest means of operating the directing vanes, the action of the gyroscope being independent of the direction and acceleration of the rocket, a gyroscope having the necessary characteristics was developed after numerous tests.

The gyroscope, shown in Plate 8, Fig. 1, was set to apply controlling force when the axis of the rocket deviated 10° or more from the vertical. In the first flight of the present series of tests with gyroscopic [9] control, on March 28, 1935, the rocket as viewed from the 1000-foot shelter traveled first to the left and then to the right, thereafter describing a smooth and rather flat trajectory. This result was encouraging, as it indicated the presence of an actual stabilizing force of sufficient magnitude to turn the rocket back to a vertical course. The greatest height in this flight was 4800 feet, the horizontal distance 13,000 feet, and the maximum speed 550 miles per hour.

In subsequent flights, with adjustments and improvements in the stabilizing arrangements, the rockets have been stabilized up to the time propulsion ceased, the trajectory being a smooth curve beyond this point. In the rockets so far used, the vanes have moved only during the period of propulsion, but with a continuation of the supply of compressed gas the vanes could evidently act against the slipstream of air as long as the rocket was in motion in air of appreciable density. The oscillations each side of the vertical varied from 10° to 30° and occupied from 1 to 2 seconds. Inasmuch as the rockets started slowly, the first few hundred feet of the flight reminded one of a fish swimming in a vertical direction. The gyroscope and directing vanes were tested carefully before each flight, by inclining and rotating the rocket while it was suspended from the 20-foot tower (Plate 8, Fig. 2). The rocket is shown in the launching tower, ready for a flight, in the close-up (Plate 9, Fig. 1) and also in Plate 9, Fig. 2, which shows the entire tower.

The behavior of the rocket in stabilized flight is shown in Plates 10 and 11, which are enlarged from 16-mm motion-picture films of the flights. The time intervals are 1.0 second for the first 5 seconds, and 0.5 second thereafter. The 60-foot tower from which the rockets rise (Plate 9, Fig. 2) appears small in the first few of each set of motion pictures, since the camera was 1000 feet away, at the shelter shown in Plate 6, Fig. 1. The continually increasing speed of the rockets, with the accompanying steady roar, makes the flights very impressive. In the two flights for which the moving pictures are shown, the rocket left a smoke trail and had a small, intensely white flame issuing from the nozzle, which at times nearly disappeared with no decrease in roar or propelling force. This smoke may be avoided by varying the proportion of the fluids used in the rocket, but is of advantage in following the path of the rocket. The occasional white flashes below the rocket, seen in the photographs are explosions of gasoline vapor in the air.

Plate 10 shows the flight of October 29, 1935, in which the rocket rose 4000 feet, and Plate 11 shows the flight of May 31, 1935, in which the rocket rose 7500 feet. The oscillations from side to side, [10] above mentioned, are evident in the two sets of photographs. These photographs also show the slow rise of the rocket from the launching tower, but do not show the very great increase in speed that takes place a few seconds after leaving the tower, for the reason that the motion picture camera followed the rockets in flight.

A lengthwise quadrant of the rocket casing was painted red in order to show to what extent rotation about the long axis occurred in flight. Such rotation as was observed was always slow, being at the rate of 20 to 60 seconds for one rotation.

As in the flights of 1930-1932 to study rocket performance in the air, no attempt was made in the flights of 1934-1935 to reduce the weight of the rockets, which varied from 58 to 85 pounds. A reduction of weight would be useless before a vertical course of the rocket could be maintained automatically. The speed of 700 miles per hour, although high, was not as much as could be obtained by a light rocket, and the heights, also, were much less than could be obtained by a light rocket of the same power.

It is worth mentioning that inasmuch as the delicate directional apparatus functioned while their rockets were in flight, it would be possible to carry recording instruments on the rocket without damage or changes in adjustment.

Further Development

The next step in the development of the liquid-propellant rocket is the reduction of weight to a minimum. Some progress along this line has already been made. This work, when completed, will be made the subject of a later report.

Conclusion

The chief accomplishments to date are the development of a combustion chamber, or rocket motor, that is extremely light and powerful and can be used repeatedly, and of a means of stabilization that operates automatically while the rocket is in flight.

I wish to express my deep appreciation for the grants from Daniel Guggenheim, The Daniel and Florence Guggenheim Foundation, and the Carnegie Institution of Washington, which have made this work possible, and to President Atwood and the Trustees of Clark University for leave of absence. I wish also to express my indebtedness to Dr. John C. Merriam and the members of the advisory committee, especially to Col. Charles A. Lindbergh for his active interests in the work and to Dr. Charles G. Abbot, Secretary of the Smithsonian Institution, for his help in the early stages of the development and his continued interest.

Document I-10

Document title: H.E. Ross, "The B.I.S. Space-ship," *Journal of the British Interplanetary Society*, 5 (January 1939), 4-9.

The British Interplanetary Society was formed in 1933. This article, by H.E. Ross, one of the society's leaders, outlined the society's most important and well-known contribution to spaceflight, a manned lunar mission. Casual meetings on the subject began in London, leading to the formation of a Technical Committee in February 1937. The committee was split into smaller task groups, including one assigned to conduct extremely crude propellant tests. The result was a solid-propellant spaceship for carrying humans to the Moon and returning them to Earth. Despite the proposal's reliance upon solid propulsion (the committee, ignorant of von Braun's ongoing secret research in Germany, had determined that the pumps and cooling systems required for liquid propulsion were too complex and expensive to develop), it effectively outlined the lunar mission conducted by the United States thirty years later.

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The B.I.S. Space-ship

by H. E. Ross

The B.I.S. space-ship design, as shown on the cover of this issue, is such a radical departure from all previously conceived ideas of a space-ship that a full explanation is called for.

In designing a space-ship the designer has a completely different problem to that involved in the design of any other means of transport. A motor car, railway train, aeroplane or ship consists basically of a vessel and a fuel tank, in the latter being placed the fuel required for a journey or journeys. The shortest space-ship voyage, however, is the journey to the Moon, and with the most optimistic estimates of the fuel energy and motor efficiency the quantity of fuel required will still be such that the fuel tank would require to be much larger than the rest of the ship. Consequently we must revert to the old system of petrol cars, so designing our ship that the cans can be attached outside the ship and thrown away when empty. The last condition does not mean that the cans are cheap—they are actually precision engineering jobs, and horribly expensive—but the cost of the fuel needed to bring them back would be even greater. We find by careful calculation that with the best fuels and motors that we can afford it will require about 1,000 tonnes (metric[1]) of fuel to take a 1 tonne [5] vessel to the moon and back, so our designers' problem has been to design a 1 tonne space-ship with containers for 1,000 tonnes of fuel attached outside and detachable.

The nature of rocket motors has also affected the design considerably. With such motors as aero-engines a larger unit can be made lighter in proportion to its power than a small unit, but in the case of rocket motors quite the reverse is the case; in fact the

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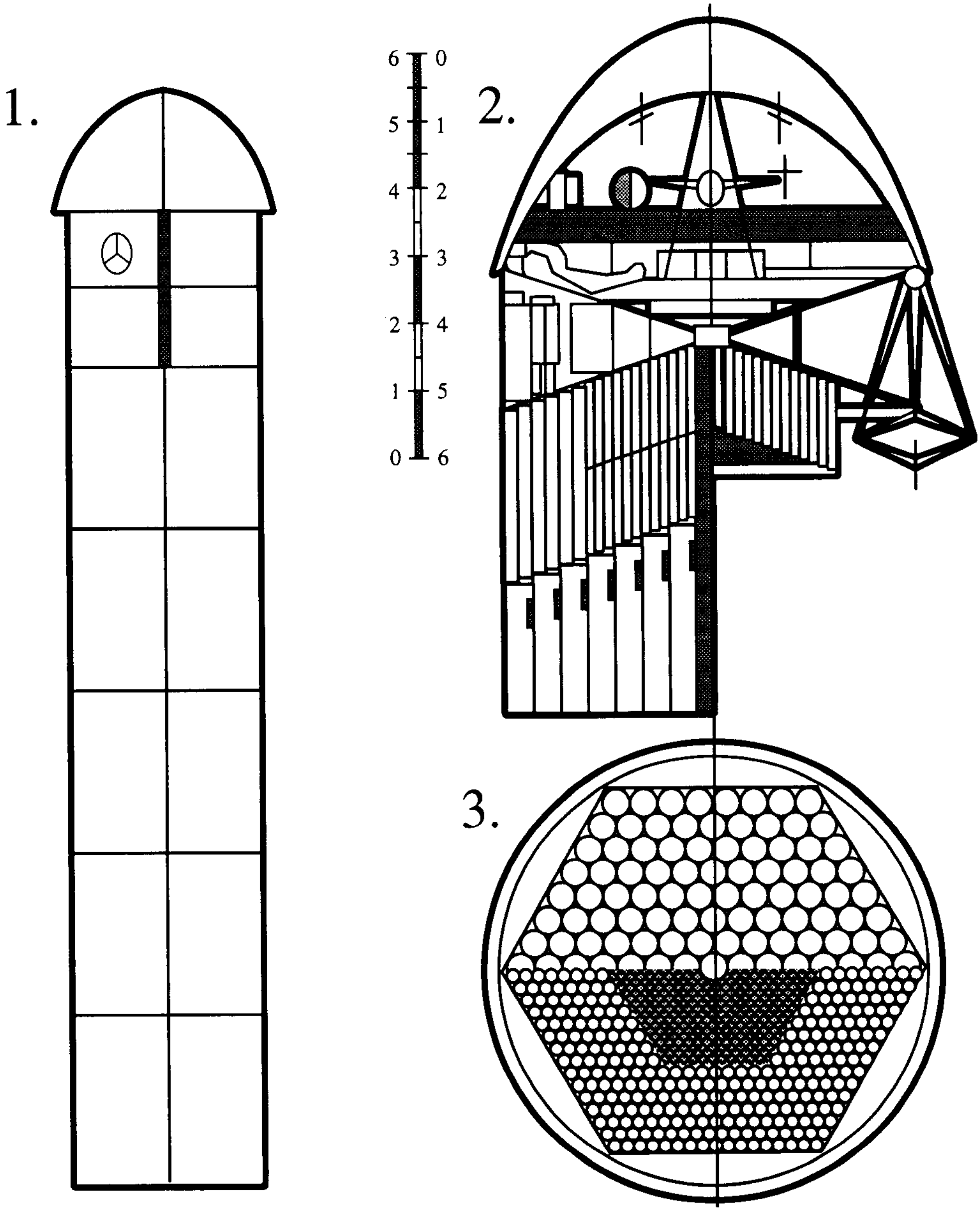
[1] A metric tonne is roughly equivalent to an English ton.



Design for a Lunar Space-ship.

proportionate weight of rocket motors rises so steeply that a motor of more than about 100,000 H.P. is hardly feasible, and as the lifting of the 1,000 tonnes at the start calls for many millions of H.P. this requires a considerable number of small units. Again, since the cost of the motors is less than the cost of the fuel required to bring them back, and as only a few small motors will be required to land the one tonne ship on its return against over a hundred large ones at the start, the motors are jettisoned after use.

For a maximum fuel economy, anything which is to be jettisoned should be jettisoned as soon as possible, and this has led to the cellular space-ship design, with hundreds of small units each comprising a motor and its fuel tank, and each so attached that as soon as it ceases to thrust it falls off. This early detachment of all dead weight has resulted in an enormous increase of efficiency over earlier designs, and has reduced the fuel required for a return voyage to the moon from millions of tonnes to thousands of tonnes.

Owing to the large number of small units, it is possible to start a motor and run it till its load of fuel is exhausted, controlling both thrust and direction by the rate at which fresh tubes are fired. This makes it possible to use solid fuel for the main thrust, with consequent considerable saving in weight, and giving the additional advantages that the strength of the fuel helps to support the parts above and its high density makes the ship very compact. Liquid fuel motors are, however, provide for stages requiring fine control, and also steam jet motors for steering.

Diagram 2 (right) shows the spaceship as it reaches the moon. The approximately hemispherical portion (to the downward pointing cone) is the life container. The portion between the two cones contains the air-lock, air-conditioning plant, heavy stores, batteries and liquid fuel and steam jet motors, etc. Below this are the solid fuel tubes for the return voyage. The whole of the remainder of the vessel (diagrams 1 and 3, consists of the tubes for the outward voyage, which have to be jettisoned by the time of arrival at the moon.

It will be seen that the streamlining is conspicuous by its absence. The form of the ship has been largely dictated by other considerations, and as compared to the terrific power needed to [6] lift the vessel out of the earth's gravitational field the total air resistance is quite negligible (less than 1%), this does not matter greatly. The diameter of the front of the ship is determined as being the smallest reasonable size for the life container. (It should be noted that this design is for a very small space-ship, about the overall size of a large barge. On larger ships this restriction will be somewhat modified). The diameter of the rear of the ship is determined by the firing area required. Too small an area calls for excessive pressures in the motors, and consequently excessively heavy construction. The two diameters being approximately the same has led to the straight-sided form. An increase in central diameter would mean improved streamlining, but this would only decrease the resistance below the velocity of sound, and this is only a small proportion of the whole. On the other hand, the straight-sided form gives the greatest strength, which is of major importance, and also serves to minimize frictional heating. The main body of the space-ship, comprising the motor tubes, is hexagonal in shape; this form giving the closest possible stacking of the tubes.

The form of the nose is intended not so much to reduce the resistance at low velocities, as to split the air at high velocities (several times the velocity of sound), so as to maintain a partial vacuum along the sides. The frontal paraboloidal portion, seen in diagrams 1, 2 and 3, is a reinforced ceramic carapace, capable of withstanding a temperature of 1500°C in air, and by its form the frictional heating is made a maximum on this portion and minimized on the sides. The carapace (which, of course, has no portholes) is detached once the vessel has got away from the earth.

The tubes are stacked in conical layers for greater structural stability, since, apart from the vessel proper—the top portion—the whole strength lies in the tubes, and these are not rigidly fixed together, but simply stacked and held in position by one-way bolts and light webs.

The firing order of the tubes is in rings starting from outside and progressing inwards towards the center. While the motors are firing their thrust holds them in place; when expended, the acceleration of the ship causes them to release from position and they drop off. Those in the inner rings of the bank not yet used do not position themselves for release until their firing thrust carries them a fractional distance up the release bolts. A light metal sheath embraces the outermost ring of tubes; this and the webs are discarded when the whole of the previous bank of motors has been jettisoned.

Diagram 4 gives sections through the vessel at various levels and shows maximum periphery of the carapace. The top half of the diagram represents a section through the large motor tubes [7] stacked in banks A to E; these are used to obtain release from Earth. The lower half of diagram 4 shows the medium and small tubes used for deceleration of the moon (the ship, having been turned end to end, approaches stern first). Fine control for the actual landing is provided by the vertical liquid fuel motors seen within the two cones in diagram 2 and about the hexagon angles in diagram 5. The inner small tubes in diagram 4 are shown in a section through two banks (ref. diagram 2), the lower of these being used for control of deceleration when approaching the moon and the upper bank (ref. diagram 2, right), being used for the return journey.

[8] Adjacent to the top of the liquid fuel motors (diagram 2), are shown four of the tangential tubes. These are necessary in order to provide the crew with artificial gravitation, which is achieved by rotating the ship (approximately 1 revolution in 3 ½ seconds). The g value desired is therefor under control of the crew. Not only is this artificial gravitation considered a necessary precaution (the physical affect of long periods of non-gravitation being at present unknown), but in any case haphazard rotation of the vessel would almost certainly take place, making navigational observations impossible. Hence control of rotation is essential. Again, before the moon landing can be attempted it is necessary to stop rotation in order to prevent disaster to the ship when it touches ground.

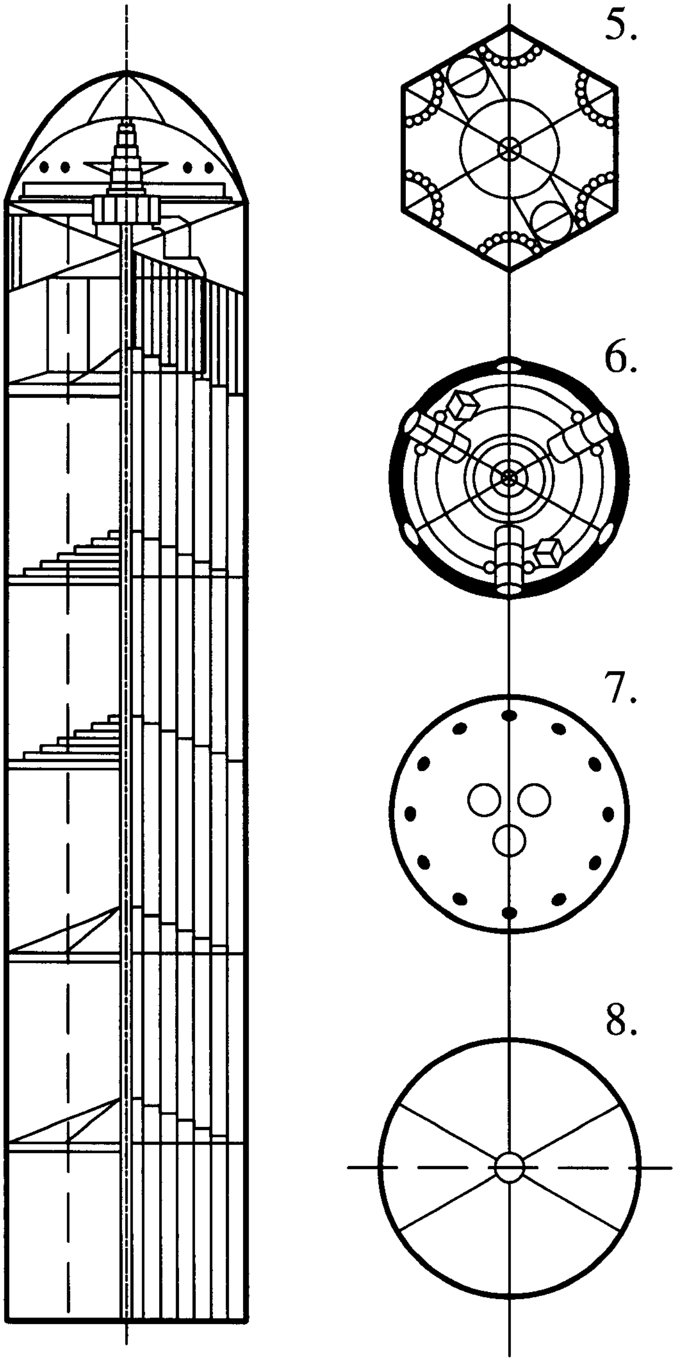
It is not anticipated that the space-ship can be so accurately manoeuvred that its landing will be without shock. Hydraulic shock absorber arms are therefor incorporated; one of these being shown attached to the frame on the right hand side of diagram 2. These are normally collapsed within the hull, and are extended just prior to landing.

The firing of the motor tubes is carried out by an automatic electrical selector system, but manual control is used for navigational corrections. The ship, being in rotation, is kept thrusting in the correct direction, but this does not prevent "wobble" if firing is not equal on all sides. Manual control of stability is maintained during the first few seconds of ascent, and after that a pendulum conductor automatically controls stability. The main wiring cable to the tubes is led down a central column, provided at each band level with a plug connection which brakes away when its purpose has been served and is then jettisoned.

The hemispherical front of the life-compartment (diagram 2 and 3), is of very light nature; this being made possible on account of the protective carapace above. The segmented carapace (diagram 8), is, of course, discarded after passing out of Earth's atmosphere, and protection of the life-compartment shell is not [9] needed for the ascent from Moon. The return into Earth's atmosphere will be done at low velocities, hence heating of its shell will not be excessive.

Owing to the small scale of the diagrams it has not been possible to show many of the filaments and accessories within the life-compartment, but the following can be noted. Diagram 2 shows one of the seats for the crew of three. These can also be seen pointing radially in diagram 6. The controls for firing are placed on the arms of the chairs, and the chairs themselves move on rails around the life-compartment. The crew recline on these chairs with their heads towards the center of the ship and a circular catwalk is provided for them and around the circumference of the chamber (diagram 2 and 3).

For observation purposes ports are provided in the dome of the life compartment (one shown in diagram 2 and twelve in diagram 7). Under the flange of the carapace, in the rim of the floor of the life-compartment (diagram 1, 2, and 6) are the back-viewing ports; these are covered during thrusting periods. Three forward-viewing ports in the top of the life compartment shell are also provided, see diagram 2 and 7. It should be noted that observation of direction cannot be made during the initial thrusting period in ascent from Earth—it being impossible to see backwards through the tail-blast of the ship—the carapace prevents vision in other directions, and in any case the period is too short to allow of stellar observations. Therefore navigation during this period must be done entirely by means of internal instruments, which consist of an altimeter, speedometer and accelerometer. Another essential is, of course, a chronometer and gyroscope ensures maintenance of direction. A suspended pendulum provides indication of "wobble" and modi-



fied sextants and rangefinders are used to determine position. These instruments are placed in convenient juxtaposition to the crew. The cylindrical objects shown just above the catwalk, against the ports (diagram 2) are coelostats. These are synchronized, motor-driven mirror devices something similar to a stroboscope, and it is by means of these that a stationary view of the heavens is provided for navigational observations while the ship is in rotation. The girder structure in the center of the live-compartment is a support for the light shell and also serves to carry navigation instruments. In diagram 1 beneath the carapace and in diagram 6 can be seen the spidered outer and inner doors respectively of the air-lock shown in diagram 5.

A launching device for this ship is necessary on its take-off from Earth, but, being accessory to the ship and somewhat complicated, this will be discussed in a subsequent issue of the Journal.

Document I-11

Document title: Frank J. Malina and A.M.O. Smith, "Flight Analysis of the Sounding Rocket," *Journal of Aeronautical Sciences*, 5 (1938): 199-202.

Frank Malina was a Ph.D. student at Caltech in 1936 when he persuaded the Guggenheim Aeronautical Laboratory, California Institute of Technology (GALCIT), to develop a sounding rocket. He received support in this effort in part because the president of Caltech, Robert A. Millikan, wanted to use rockets for cosmic ray research. In late 1936, a research team began experimenting with rocket engines in the canyons above the Rose Bowl. The tests met with limited success. But by 1938, enough information had been gathered for Malina and a colleague, A.M.O. Smith, to publish GALCIT's first scholarly paper on rocket research. The paper demonstrated that a rocket capable of taking a payload up to 1,000 miles altitude could be developed.

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Flight Analysis of the Sounding Rocket

Frank J. Malina and A. M. O. Smith, *California Institute of Technology*

Presented at the Aerodynamics Session, Sixth Annual Meeting, I.Ae.S.
January 26, 1938

Introduction

In attempting to reach altitudes above those obtainable by sounding balloons, the rocket motor may be utilized to propel a suitable body. In this analysis a wingless shell of revolution will be considered in vertical flight. It was felt that, before entering into practical experimentation, it was desirable to have a preliminary performance analysis based on simplified assumptions, using the most recent data for air resistance at high speeds. As a matter of fact, this analysis was completed without the knowledge of a similar investigation.[1] However, as this treatment is more general in discussing the influence of the design parameters and more suitable for application to particular cases, the authors believe it is worth while to present the analysis.

The equations of motion for flight *in vacuo* have been included to show the optimum performance and for comparison purposes. After developing similar expressions for flight with air resistance, a series of calculations was carried out using the method of step-by-step integration. The dimensions of the rocket chosen were felt to be feasible for practical

[1] Ley, Willy, and Schaefer, Herbert, *Les Fusees Volomes Meteorologiques*, L'Aerophile, Vol. 44, No. 10, p. 228-232, October, 1936.

construction. The motor efficiencies for the two cases were chosen to match closely the reported results of R. H. Goddard[2] and Eugene Sänger.[3]

The calculations have not been extended to further cases, as the amount of labor that would be required was not felt justified at the present time.

Assumptions and Notation

Throughout this analysis, the assumption will be made that the rocket motor supplies a thrust of constant magnitude for the period of powered flight. This means that the rate of flow of combustibles and the effective exhaust velocity remain constant. This assumption is of a conservative nature, as theoretical considerations show that the thermal efficiency of the rocket motor and, therefore, the thrust, will increase as the ratio between chamber pressure and exhaust pressure increases.

It has been assumed that the acceleration due to gravity remains constant. This assumption is also conservative.

The following notation has been used for the quantities involved:

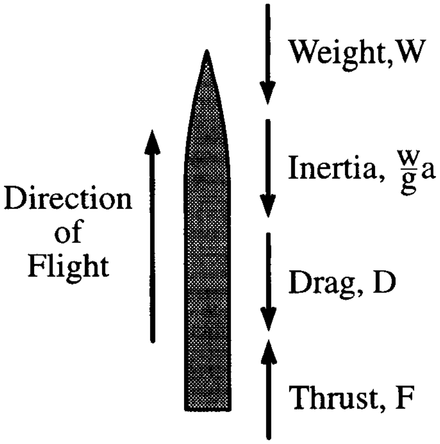

Fig. 1. Forces acting on a rocket in vertical flight.

F = thrust in lbs.
m = mass of exhaust gases flowing per second
c = F/m = effective exhaust velocity in ft./sec.
W_0 = initial weight of rocket, lbs.
W = instantaneous weight of rocket, lbs.
W_{FO} = weight of fuel and oxidizer carried, lbs.
ζ = W_{FO}/W_0, ratio of weight of fuel plus oxidizer to initial weight of rocket
a_0 = initial acceleration, ft./sec.^{2}
a = instantaneous acceleration, ft./sec.^{2}
g = acceleration of gravity, ft./sec.^{2}
V = instantaneous velocity, ft./sec.
V_s = velocity of sound, ft./sec.
h = altitude above sea level, ft.
t = time, sec.
A = largest cross-sectional area of rocket, sq. ft.

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[2] Africano, Alfred, *Rocket Motor Efficiencies*, Astronautics, No. 34, p. 5, June, 1936.

[3] Sänger, Eugen, *Neuere Ergebnisse der Raketenflugiechnik*, Flug, Special Publication No. 1, pp. 6-9, December, 1934.

D = drag due to air resistance, lbs.
σ = air density ratio
ρ_0 = mass density of air at sea level

In Fig. 1 the forces acting on the rocket in vertical flight are shown. Summing the forces:

$$\Sigma \text{ Forces} = 0 = F - W - D - (W/g)a \qquad (1)$$

The thrust developed by the motor is expressed by

$$F = mc \qquad (2)$$

Then from Eqs. (1) and (2):

$$a = (mc - W - D)g/W \qquad (3)$$

[200] If the rate of flow of combustibles is constant during powered flight, one can write:

$$W = W_0 - mgt \qquad (4)$$

At the start of the flight,

$$W = W_0,\ a = a_0,\ V = 0,\ D = 0 \qquad (5)$$

Then Eq. (3) becomes

$$a_0 = mc - W_0 g/W \qquad (6)$$

and

$$m = W_0 a_0 + g)/cg \qquad (7)$$

Eq. (3) can now be evaluated, using Eq. (4) and Eq. (7), and for the acceleration at any instant

$$a = -g + \frac{(a_0 + g)}{1 - \frac{t(a_0 + g)}{c}} - \frac{g}{1 - \frac{t(a_0 + g)}{c}} \frac{D}{W_0} \qquad (8)$$

Flight *in Vacuo*

With no air resistance, the third term of Eq. (8) vanishes so that

$$a = \frac{dV}{dt} = -g + \frac{(a_0 + g)}{1 - \frac{t(a_0 + g)}{c}} \qquad (9)$$

Integrating Eq. (9) one has, for the velocity at any instant:

$$V = \frac{dh}{dt} = -gt - c \log\left[1 - \frac{t(a_0 + g)}{c}\right] + V_0 \qquad (10)$$

Integrating Eq. (10) one has, for the height at any instant:

$$h = -\frac{1}{2}gt^2 + ct + \left(\frac{c^2}{a_0+g} - ct\right)\log\left[1 - \frac{t(a_0+g)}{c}\right] + V_0t + h_0 \qquad (11)$$

The maximum acceleration and maximum velocity will occur at the time that the fuel is exhausted. The time at which thrust ceases is expressed, using Eq. (4), by the relation

$$(1-\zeta)W_0 = W_0 - mgt_p \qquad (12)$$

Introducing Eq. (7) into Eq. (12), one obtains, for the duration of powered flight:

$$t_p = \zeta c/(a_0+g) \qquad (13)$$

If, at the start of the flight, $V_0 = 0$ and $h_0 = 0$, then

$$a_{\text{max.}} = -g + \frac{a_0+g}{c-\zeta} \qquad (14)$$

$$V_{\text{max.}} = -c\left[\frac{g\zeta}{a_0+g} + \log(1-\zeta)\right] \qquad (15)$$

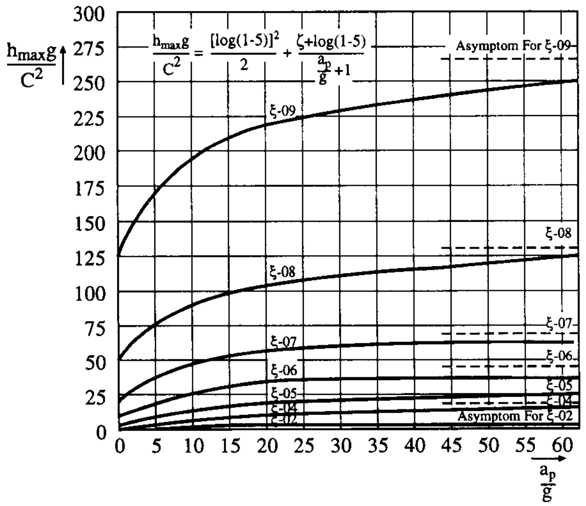

Fig. 2. Variation of $h_{\text{max.}}\, g/c^2$ with a_0/g for various ζ for flight *in vacuo*.

The maximum height reached will be the sum of the height at the time the fuel is exhausted and the height resulting from coasting. The height resulting from coasting is given by the expression:

$$h_c = V_{\text{max.}}{}^2/2g \qquad (16)$$

Adding this to Eq. (11) and evaluating t_p from Eq. (13), the maximum height reached is

$$h_{\text{max.}} = \frac{c^2}{g}\left\{\frac{\left[\log(1-\zeta)\right]^2}{2} + \frac{\zeta + \log(1-\zeta)}{(a_0/g)+1}\right\} \qquad (17)$$

Eq. (17) shows that three parameters determine the rocket performance *in vacuo.* They are a_0, ζ, and c. In Fig. 2 the variation of $h_{max}g/c^2$ is plotted for various values of a_0/g and ζ. The importance of having a large percentage of combustibles is clearly shown. The initial acceleration, a_0, is important until values in the neighborhood of $6g$ are reached.

Flight through a Resisting Medium

Considering flight through the air, the drag of the rocket can be expressed in the form

$$D = p_0 \sigma V^2 C_D A/2 \qquad (18)$$

which, substituted in Eq. (8), gives

$$a = -g + \frac{(a_0+g)}{1-\dfrac{t(a_0+g)}{c}} - \frac{gp_0\sigma V^2}{2\left[1-\dfrac{t(a_0+g)}{c}\right]}\cdot\frac{C_D A}{W_0} \qquad (19)$$

This is the fundamental equation for vertical rocket flight. In addition to the performance parameters for flight *in vacuo,* the ratio $C_D A/W_0$ also has important significance in the construction of the sounding rocket. As it appears in a term which reduces the acceleration of the rocket, it should be as small as possible. A rocket [201] of given initial weight should have as small a cross-section as possible and be of a shape that minimizes the drag coefficient.

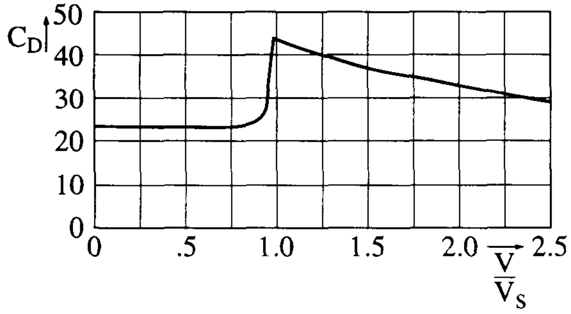

Fig. 3. Variation of the drag coefficient, C_p, with V/V_s.

As the density ratio, σ, and the drag coefficient, C_D, will be subject to great changes during flight, and are difficult to express accurately analytically, two ways of solving Eq. (19) are open. First, approximations can be made for the variation of σ and C_D to make an analytic solution possible, or second, a step-by-step method of integration of any degree of accuracy can be applied. The first method is quite likely to lead to extremely large errors, so that the second method has been chosen.

The variation of σ with height was obtained from references (4) and (5). The variation of C_D with the velocity of flight was taken from reference (6). It has been assumed, due to the lack of information, that the drag of the rocket was identical to the drag of a shell without a jet issuing at its base. The variation of the drag coefficient is reproduced from reference (6) in Fig. 3.

To describe the rocket flight, the following equations were used in the numerical calculations:

$$a_n = -g + \frac{(a_0 + g)}{1 - \frac{t_n(a_0 + g)}{c}} - \frac{g p_0 \sigma_n V^2{}_{n-1}}{2\left[1 - \frac{t_n(a_0 + g)}{c}\right]} \cdot \frac{C_D A}{W_0} \tag{20}$$

$$V_n = V_{n-1} + a_{n-1}\Delta t \tag{21}$$

$$h_n = h_{n-1} + V_{n-1}\,\Delta t + (a_{n-1}/2)(\Delta t)^2 \tag{22}$$

where

Δt = time interval under consideration
n = number of the interval in the r steps of the calculation

The acceleration during coasting is given by

$$a_{c_n} = \frac{F_c}{m} \tag{23}$$

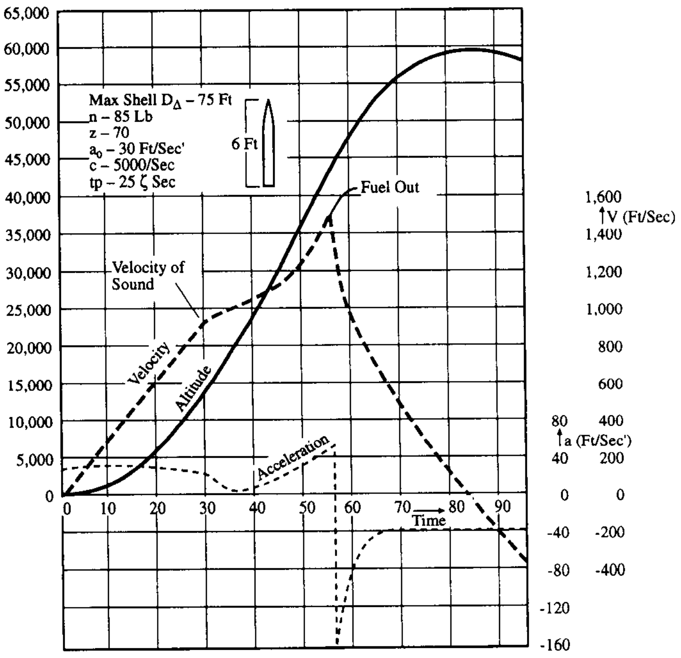

Fig. 4. Rocket performance for flight with air resistance, using a motor giving an effective exhaust velocity of 5000 ft./sec.

where

F_c = weight of the empty rocket plus air resistance or

$$a_{c_n} = -\left[g + \frac{p_0 \sigma_n V^2{}_{n\text{-}1} g}{2(1-\zeta)} \frac{C_D A}{W_0} \right] \qquad (24)$$

In the following results to be presented, it was necessary to select dimensions of what may be called a typical sounding rocket. Therefore, the results will apply only to rockets having the same value of the ratio $C_D A/W_0$. For rockets with a different value of the ratio, this analysis serves only as a guide to the performance to be expected.

In Fig. 4 are shown the performance curves of a rocket with $c = 5000$ ft./sec., $\zeta = 0.70$, and 120 = 30 ft./sec.^{2}. The retarding influence of the air is made evident [202] by the decrease in the acceleration as the velocity of sound is approached. The high density of the air at the time the fuel was exhausted prevented the rocket from coasting very high.

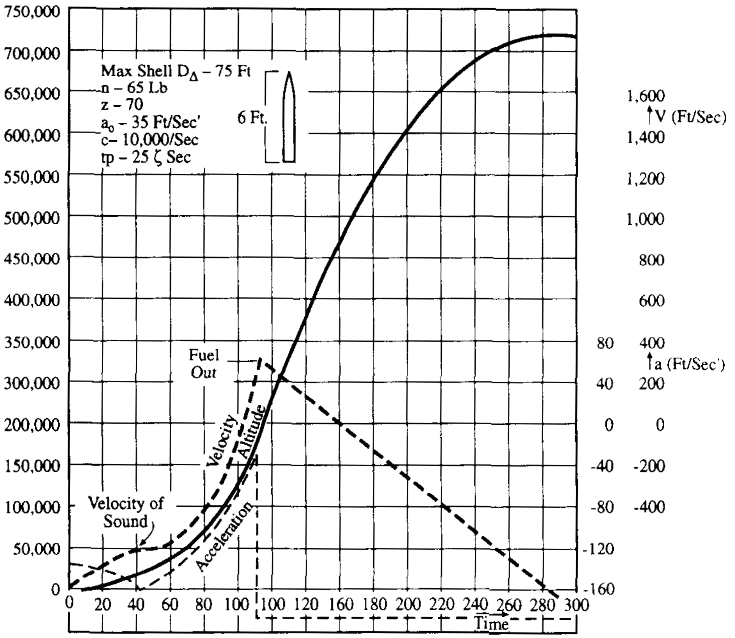

Fig. 5. Rocket performance for flight with air resistance, using a motor giving an effective exhaust velocity of 10,000 ft./sec.

The performance curves shown in Fig. 5 are those for an identical rocket, but with a much more efficient motor which gives an exhaust velocity, *c*, of 10,000 ft./sec. For the same amount of thrust, the rate of flow of combustible is much smaller, so that the period of powered flight is greatly prolonged. This allows the rocket to get over the hump of the drag curve, and also to travel through less dense air. The velocity at the end of the powered flight will thus be much higher than before, causing the rocket to coast to a much higher altitude.

In Fig. 6 the variation of altitude with the initial acceleration is shown for the two cases. The importance of a high value of the exhaust velocity, *c*, is clearly evident. This

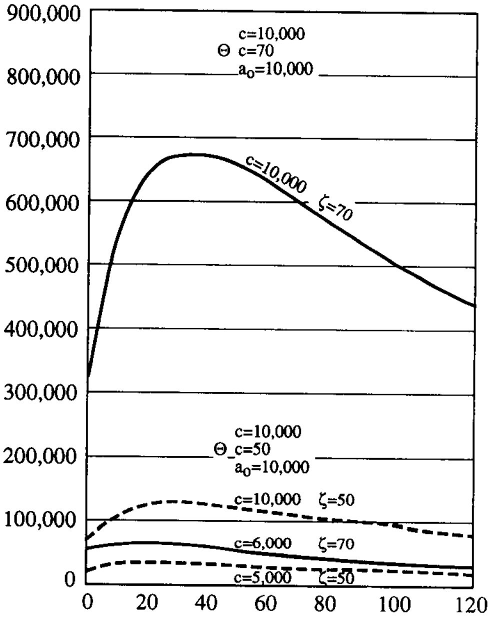

Fig. 6. Effect of a_0 on altitude to be reached for several performance parameter combinations.

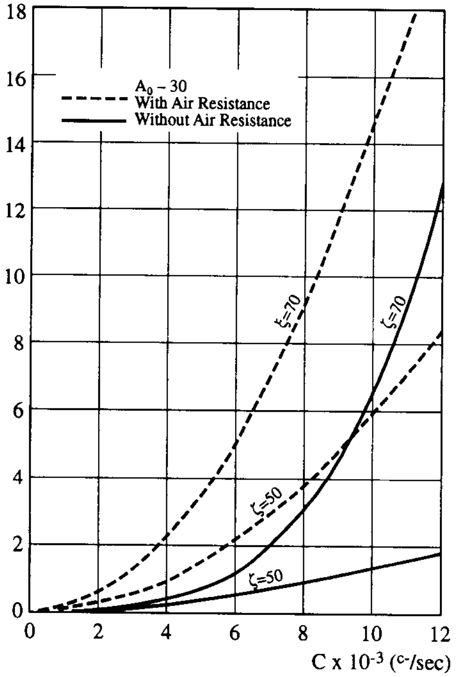

Fig. 7. Variation of altitude with c for a_0=30, with and without air resistance.

shows that effort should be directed to develop a motor of high efficiency before flight attempts are made.

This figure also shows that there is a definite initial acceleration corresponding to the maximum possible height. This differs from flight *in vacuo* for which the height reached continually increases with the initial acceleration (see Fig. 2). A high velocity of flight through the dense lower levels of the atmosphere causes the combustibles to be rapidly "eaten up." The advantage to be gained by starting the rocket from a high point is shown in the figure by the calculated height for a rocket started from an initial altitude of 10,000 ft.

The variation of maximum height to be reached with the exhaust velocity, *c*, for flight *in vacuo* and in air, is shown in Fig. 7. This figure clearly illustrates the amount of height lost due to resistance of the air.

Higher altitudes may be reached by using this step-rocket. A rocket made up of three steps, respectively, of 600, 200, and 100 lbs., the lightest being fired last, with *c* of 10,000 ft./sec., a_0 of 40 ft./sec.2, and ζ for each step of 0.70, starting from sea level, reaches a calculated altitude of 5,100,000 ft. and a maximum velocity of 11,000 m.p.h.

This analysis definitely shows that, if a rocket motor of high efficiency can be constructed, far greater altitudes can be reached than is possible by any other known means.

Document I-12

Document title: Theodore von Kármán, "Memorandum on the Possibilities of Long-Range Rocket Projectiles," and H.S. Tsien and F.J. Malina, "A Review and Preliminary Analysis of Long-Range Rocket Projectiles," Jet Propulsion Laboratory, California Institute of Technology, November 20, 1943.

Initially, Frank Malina started rocketry research in 1936 with the intention of lofting scientific payloads to high altitudes. But by 1938 GALCIT started receiving money from the National Academy of Sciences, at Army General Henry H. (Hap) Arnold's urging, to develop rockets for assisting heavily-laden aircraft and seaplanes during takeoff. This initial military research later advanced, during World War II, to the study of rockets as weapons of war. In 1943 GALCIT was renamed the Jet Propulsion Laboratory. This report to the Army Air Forces, with a cover letter by Theodore von Kármán, the director of GALCIT and then JPL, concluded that the development of long-range rocket projectiles was feasible and recommended their development at once. By this time, the Germans had already developed and tested the V-2.

H.S. Tsien, the co-author of this secret report, was a Chinese national who was later deported back to China, where he was instrumental in the development of the Chinese ICBM program.

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[1]

Memorandum
on

The Possibilities of Long-Range Rocket Projects

by Th. von Kármán

Recent progress in the field of jet propulsion by the Air Corps Jet Propulsion Research Project, the National Defense Research Committee and the Aerojet Engineering Corporation indicates that the development of a long-range rocket projectile is within engineering feasibility. During the past year reports reached this country crediting the Germans with the possession of extremely large rocket projectiles capable of transmitted to me by the Material Command, Experimental Engineering Division, for Study and

Comment. Comments were submitted in a later dated August 2, 1943.

At the instance of Col W. H. Joiner, A.A.F. Materiel Command Liaison Officer at the California Institute of Technology, two of my associates, Drs. F. J. Malina and H. S. Tsien, prepared a preliminary review and analysis of performance and design of long-rang projectiles which constitutes the substance of this Memorandum. The results of this study show that ranges in excess of 100 miles cannot be realized with propulsive equipment now available in this country. However, with the equipment already developed for super-performance of aircraft, rocket projectiles can be constructed which have a greater range and a much larger explosive load than rocket projectiles currently being used by the Armed Forces. Furthermore, by developing a special type of propulsive [2] equipment of the "athodyd" which utilizes atmospheric air, rangers comparable to those claimed by the Germans might be reached.

It is certain that the solution of the engineering problems connected with such a special jet unit requires considerable time. On the other hand, a large amount of information of immediate usefulness can be accumulated by experimentation with projectiles utilizing aircraft super-performance equipment. The development program should consist of the following coordinated phases:

First, firing tests of a projectile propelled by a restricted burning solid propellant unit produced by the Aerojet Engineering Corporation and accelerated during launching by unrestricted burning solid propellant rockets developed by the NDRC. This projectile would weight approximately 350 lbs and would carry a 50 lb explosive load for a distance of about 10 miles. The firing tests would supply information on problems of launching, stability and control, and for the verification of performance calculations.

Second, the design of a 2000 lb rocket projectile propelled by a liquid propellant jet unit of the type developed by the Air Corps Jet Propulsion Research Project and manufactured by the Aerojet Engineering Corporation. This projectile would carry an explosive load of 200 lbs for approximately 12 miles. This phase should be started as soon as sufficient information has been obtained from Phase I on the design of the projectile shape, stabilization fins and launching technique. At this point the program under Phase I should initiate experiments on the effect of adding wings to the projectile.

Third, it is desirable simultaneously with the first and second phases of projectile development to make a study of the design and [3] characteristics of the "athodyd" type propulsion unit. The "athodyd" or aero-thermodynamic duct jet unit is similar to other thermal jet units that have been developed, with the exception that pressure in the combustion chamber is obtained directly from the dynamic pressure of air resulting from the velocity of flight. The "athodyd" is expected to be more efficient at flight velocities that exceed the velocity of sound. The best means of investigating this type of unit would be to make a ground installation in which tests would be carried out using a compressor unit which is capable of blowing through a duct and combustion chamber system a considerable quantity of air. It appears that such compressor units could be made available in the Los Angeles area. The development of the "athodyd" type unit is not only important of the long range projectile but also has important implications in the general propulsion of aircraft at very high speeds.

Fourth, upon obtaining design information from the first two phases on projectile development and results of the special jet unit development program mentioned under Phase 3, the design and construction of a projectile of 10,000 lbs weight or larger with a range of the order of 75 miles would be undertaken.

It is believed that the projectiles developed in the first two phases would possess immediate military usefulness which would justify the effort expended independently of the general development program. Furthermore, the knowledge that would be obtained on the behavior of wings and control surfaces at supersonic velocities would be most valuable to the designer of high speed aircraft and remotely controlled unmanned missiles. It [4] is understood that missiles such as glide bombs now being developed will be equipped with jet propulsion units. The studies described above will give important information on the possibilities of accelerating such devices up to and beyond sonic velocities. On the other hand, the results collected from the ground launching tests will give important data also for the case of launching rocket propelled devices from aircraft and from surface vessels. In fact, the absence of recoil forces opens up a wide field for application of jet propulsion units. The studies described above will give important information on the possibilities of accelerating such devices up to and beyond sonic velocities. On the other hand, the results collected from the ground launching tests will give important data also for the case of launching rocket propelled devices from aircraft and from surface vessels. In fact, the absence of recoil forces opens up a wide field for application of jet propulsion to large caliber and long range missiles.

[5]

A Review and Preliminary Analysis of Long-Range Rocket Projectiles

by H. S. Tsien and F. J. Malina

I. Consideration of Various Jet Propulsion Methods

The propulsion of missiles or projectiles for military purposes has been the subject of intensive development for many centuries. Perhaps the oldest method that does not utilize muscular energy is that of rocket or jet propulsion. The propulsive force in jet propulsion is obtained from the reaction of a high speed gaseous mass ejected from the body to be propelled. The first jet propelled missiles used black powder for the generation of a high pressure gas. Although the black powder rocket reached a fairly high state of development, it was handicapped by incorrect design features and a propellant of low energy content. Its use as a military weapon was discontinued during the middle of the 19th century.

During the last twenty-five years, jet propulsion has staged a comeback with the assistance of new engineering knowledge and better propellants. Several jet propulsion methods are available, each with its own advantages and limitations. The methods can be divided into two main classes, characterized by independence or dependence on atmospheric air.

These two classes can be further subdivided as follows:

Methods independent of atmospheric air

1. **Solid propellant types**
    a. Unrestricted burning, short duration (0.01 to 2 seconds)
    b. Restricted burning, long duration (5 to 60 seconds)
2. **Liquid propellant types**
    a. Nitric acid type oxidizers (duration limited only by amount of propellant carried) [6]
    b. Liquid oxygen oxidizer (duration limited only by amount of propellant carried)

Methods dependent on atmospheric air

3. **Thermal jet propulsion types**
    a. Air compressor type
    b. Aero-thermodynamic duct type

The salient points of the above types will now be discussed to support the analyses of the long range rocket projectiles in the following parts of this Memorandum.

1. Solid propellant types

a. Unrestricted burning, short duration jet units

The unrestricted burning solid propellant jet unit has been developed to a high degree of perfection by the NDRC. This type uses a smokeless powder (ballistite) grain which has a large burning surface. The jet unit is capable of delivering a high thrust for a short period of time. Units have been tested that deliver as high as 100,000 lb thrust for a very small fraction of a second. The duration is limited by the grain web thickness that can practically be produced and the feasible dimensions of the jet unit.

The fact that this type of jet unit gives a high impulse in a very short time makes it especially suitable for short range missiles such as the Bazooka shell, anti-aircraft rockets, etc. The use of the unrestricted burning jet unit for projectiles whose range exceeds 7 or 8 miles does not appear practical because of the excessive impulse required. [7] The short duration jet unit would become very large in cross section and also the initial acceleration of the projectile would introduce difficult engineering problems. However, as will be pointed out later, the use of the short duration rocket is required in launching a long range projectile.

The general specifications of two short duration jet units developed by the NDRC are listed in Table I.

b. Restricted burning, long duration jet units

The restricted burning solid propellant jet unit was developed by the Air Corps Jet Propulsion Research Project at the California Institute of Technology especially for assisting the take-off of aircraft. The development has been extended to production types by the Aerojet Engineering Corporation. The units utilize an asphalt-base propellant charge which burns on one surface only. The burning takes place in parallel layers perpendicular to the axis of the jet unit. Jet units have been tested that deliver 1000 lb thrust for as long as 45 seconds. Durations of this order of magnitude are near the maximum practically attainable. Thrusts of between 2000 and 3000 lb are believed feasible.

The propellant developed for the restricted burning jet unit is not as effective as the ballistite charges of the unrestricted burning units. At a chamber pressure of 2000 lb per sq in, the former type gives an exhaust velocity of approximately 5500 ft per sec, whereas the latter type gives approximately 6300 ft per sec. On the other hand, [8] the asphalt base propellant is much less sensitive to ambient temperature changes, which is of prime importance in assisted take-off applications and also in projectiles propelled over a large fraction of their flight path.

The specifications of two Aerojet restricted burning solid propellant jet units are listed in Table II, and a drawing is shown in Figure 1.

2. Liquid propellant types

a. Nitric acid type oxidizers

Liquid propellant type jet units that have reached the highest stage of development utilize a propellant consisting of two components — an oxidizer and a fuel. Single liquid compounds exist which contain enough oxygen to sustain combustion; however, their investigation is in preliminary stages. The Germans are reported to have such a propellant.

The ACJP Project, the Navy Bureau of Aeronautics Project, and the Aerojet Engineering Corporation have carried the development of a liquid propellant jet until utilizing nitric acid type oxidizers and fuels spontaneously ignitable with the oxidizers to a high degree of reliability. The jet units have been developed primarily for assisting the take-off of aircraft.

Jet units have been tested by the ACJP Project in which a single motor delivered 6000 lb thrust for 20 seconds, and a motor which delivered 1000 lb thrust for a continuous period exceeding 5 minutes.

[9] At the optimum propellant mixture ratio, and effective exhaust velocity of 6000 ft per sec can be expected at a chamber pressure of 300 psi abs and 6400 ft per sec at 500 psi abs. The chamber pressure attained is controlled by the feed pressure applied to the propellant components. Two methods are available for obtaining feed pressure — compressed gas and pumps. The proper choice of a feed system requires a detailed analysis of the application in mind, and the only general rule that can be safely formulated states that for durations exceeding one minute, the pump system is the lightest.

As mentioned above, effective exhaust velocities of the order of 6400 ft per sec can be reached at chamber pressures around 500 psi abs. However, this velocity is obtained at the price of increasing the feed pressure by 200 psi, which is likely to nullify the improved propellant consumption by the additional weight required in the feed system.

The specifications of the Aerojet production unit 25 ALD-1000 and the Aerojet X40ALJ-6000 unit, which has been designed but not built, together with estimates of a 4000 lb thrust 35 second unit, are listed in Table III. The estimates of the 4000 lb thrust unit are believed to be too conservative and that the duration could be increased by 5 seconds by reducing the empty weight of the unit and increasing the propellant weight carried. At the same time the diameter of the tanks could be reduced from 24 in to 20 in.

b. Liquid oxygen type oxidizer

Work with liquid oxygen in combination with various fuels [10] as a propellant for liquid type jet units has been carried out by Goddard, the American Rocket Society, the Navy Bureau of Aeronautics Project and the ACJP Project. The discussion in connection with nitric acid type oxidizers in the preceding section holds when liquid oxygen is used with the exceptions that will be noted.

Tests at the ACJP Project with the liquid oxygen-gasoline combination have shown that effective exhaust velocities as high as 8500 ft per sec can be obtained at chamber pressures around 500 psi abs as compared to 6400 ft per sec for the nitric acid oxidizer. The design of a liquid oxygen-gasoline jet motor that can operate at the high combustion temperatures attendant with high exhaust velocities has not as yet been satisfactorily accomplished.

The utilization of liquid oxygen in military projectiles is believed to be of doubtful feasibility since it cannot be stored in closed containers because of its very low boiling temperature.

3. Thermal Jet Propulsions Types

a. Air compressor type

The jet units so far discussed made use of a propellant whose oxidizer was carried within the body to be propelled. For that reason the propulsion did not depend on the presence of atmospheric air, and operation could be maintained in empty space.

When flight is to be performed within the lower layers of the atmosphere, it does not seem logical to carry an [11] oxidizer when oxygen is on all sides during the flight. However, it is unfortunate from the point of view of propulsion that the oxygen in air is only available at such a low density and pressure.

Jet propulsion units have been developed that use the oxygen in air to burn a fuel. In general, the thermal jet propulsion unit consists of the following components: an inlet duct to a compressor, a compressor, a combustion chamber, a gas turbine, and an outlet duct or nozzle. In the following section on the aero-thermodynamic duct jet unit it will be shown that under certain conditions the dynamic pressure of air due to the motion of a body can be utilized without the addition of a compressor and a gas turbine.

In the thermal jet propulsion unit the compressor is inserted in order to increase the pressure in the combustion chamber and thus improve the thermodynamic efficiency of the unit at low flight velocities. After the air passes through the compressor, it enters the combustion chamber where a fuel such as gasoline is injected. The fuel burns, and heats the air. The hot air at high pressure then drives the gas turbine which furnishes the power for the compressor. The exhaust from the turbine, being still at a higher pressure than that of the atmosphere, discharges through the nozzle and a net propulsive thrust is imparted to the body.

A number of systems similar to the one described have [12] been developed and thrusts as high as 2700 lb have been obtained from thermal jet units. The thermal jet unit is a complex heavy piece of machinery involving the use of a high speed compressor driven by a gas turbine. It is believed that this type of propulsive unit is not at the present time suitable for the propulsion of projectiles, even though the propellant consumption is 6 to 10 times lower than for jet units utilizing a liquid or solid oxidizer.

b. Aero-thermodynamic duct type (athodyd) (Ramjet)

If flight is to be carried out at velocities near and above the velocity of sound, it may be possible to dispense with the necessity of a compressor in a thermal jet propulsion unit. The Germans are reported to have developed a device of this type referred to as an "athodyd." Pressure in a combustion chamber is obtained directly from the dynamic pressure of air resulting from the velocity of flight. Air is taken in the forward end of the tube, slowed down by means of a diffusor before entering the combustion chamber, and permitted to escape through a nozzle after its temperature has been raised by injecting fuel into the combustion chamber.

There may be possibilities of installing such devices in large projectiles. Propulsion from them is obtained after the projectile has reached a high velocity by some other form of propulsion. In the part of this Memorandum on the reported German projectiles a further discussion of the aero-theromo-dynamic duct will be made.

[13]

II. Specifications and Performance of Two Projectiles Using Available Jet Units

1. Specifications

Due to the novelty of the subject of long range rocket projectiles, it seems desirable to work out a program of accelerated development starting with projectiles that can be designed with available jet propulsion units. The problems of launching, stability and other engineering problems can be studied with these projectiles. After an analysis of the available design information concerning both the solid propellant and the liquid propellant units, it is concluded that the following two models of long range rocket projectiles are within immediate possibility:

LRRP-I: (Fig 2) Solid Propellant

Initial weight	350 lb
Thrust	1150 lb
Propellant weight	130 lb
Empty Weight	220 lb
Explosive load	50 lb
Duration of thrust	20 sec
Maximum diameter	10 in
Length	81 in

LRRP-II: (Fig 3) Liquid Propellant

Initial weight	2000 lb
Thrust	4000 lb
Propellant weight	830 lb

Empty Weight	970 lb
Explosive load	200 lb
Duration of thrust	35 sec
Maximum diameter	2 ft
Length	16 ft

2. Equations of Motion of a Rocket Projectile

For the calculation of performance of the projectile, the following assumptions are made:

a. The resistance is always that of a projectile whose [14] axis is tangent to the trajectory.
b. The gravitational acceleration is a constant, invariant with altitude.
c. The density and temperature of the atmosphere are functions of the altitude as given by Table IV according to the Standard Atmosphere.

For a satisfactorily stabilized projectile, the deviation of the axis of the projectile from the tangent to the trajectory must be small. Furthermore, it is known that the increase in air resistance due to small yaw is negligible. Therefore, the first assumption is justified. The second assumption is quite accurate due to the small altitudes involved compared with the radius of the earth.

If *M* is the mass of the projectile, *v* the velocity and *O* the inclination of the trajectory at the time instant t, the equations of motion of the projectile are

$$M\frac{dv}{dt} = F - D - Mg\ \sin \ominus \qquad (1)$$

$$Mv\frac{d\ominus}{dt} = -Mg\ \cos\ominus \qquad (2)$$

where *g* is the gravitational acceleration, *F* the thrust, and *D* the air resistance. The first equation expresses the acceleration along the trajectory while the second equation expresses the balance of centrifugal forces (Fig 4). For the time being, the projectile is assumed to be without wings. The effect of the addition of wings will be considered in a later paragraph. The value of *F* during the [15] powered flight is a constant, neglecting the effect of reduction of atmospheric pressure on the operation of the rocket motor.

The air resistance *D* can be expressed as

$$D = \frac{1}{2}\underset{\zeta}{\wp} V^2 C_D \frac{\pi}{4} d^2 \qquad (3)$$

where ζ is the density, C_D the drag coefficient and d the maximum diameter of the projectile. The drag coefficient is a function of Mach number or the ratio of the flight velocity to the velocity of sound at the altitude. Variations in the Reynolds' number or the variation in the kinematical viscosity of air will also influence the drag coefficient, but this effect is not large and will be neglected. The values of C_D for the projectiles concerned are given in the Table V and plotted in Figure 5. These values are obtained by adding an appropriate amount of skin friction to the resistance coefficient of a modern artillery shell. The additional skin friction is necessary in order to account for the length of the rocket projectile and the tail fins.

During the powered flight, those values of drag coefficient are conservative. This is due to the fact that an appreciable fraction of the total resistance of an artillery shell comes from the suction at the base of the shell. This suction is certainly absent during the discharge of gases from the rocket motor. Hence the estimated drag coefficient of the shell is too high for the powered flight.

[16] Let:
M_0= the initial mass of the projectile
v_0= the launching velocity of the projectile
$\ominus_0$= the launching angle of the projectile
$\xi = v / v_0$ ratio of the flight velocity to the launching velocity

then Eq (2) can be integrated as

$$\frac{1+\sin\ominus}{1-\sin\ominus}=\frac{1+\sin\ominus_0}{1-\sin\ominus_0}e-\frac{2g}{v_0}\int_0\frac{dt}{\xi} \qquad (4)$$

The equation gives the angle of inclination, if ξ is obtained as a function of time *t*. To obtain the latter relation, Eq (1) has to be solved. That equation can be written in the more convenient form as

$$\frac{d\xi}{dt}=\frac{g}{V_0}\left[\frac{1}{1-\frac{m}{M_0}t}\left\{\frac{F}{M_0 g}-\left(\frac{1}{2}\frac{\wp_0 V_0^2\frac{\pi}{4}d^2}{M_0 g}\right)\sigma C_D\xi^2\right\}-\sin\ominus\right] \qquad (5)$$

where *m* is the mass discharge of the rocket motor per second, and σ is the ratio of the densities at sea-level and at altitude $\wp / \wp_0$.

At the end of the powered flight, the thrust is zero, and the mass of the projectile is M^1, equal to the sum of the empty mass and the explosive mass. Therefore, Eq (5) reduces to the following form for coasting

$$\frac{d\xi}{dt}=-\frac{g}{V_0}\left[\frac{1}{\frac{M_1}{M_0}}\left(\frac{1}{2}\frac{\wp_0 V_0^2\frac{\pi}{4}d^2}{M_0 g}\right)\sigma C_D\xi^2+\sin^{\ominus}\right] \qquad (6)$$

Eqs (4), (5), and (6) determine completely the performance of the projectile of the launching conditions are given.

3. Performance without Wings

To obtain the performance, Eqs (4), (5), and (6) have to be integrated numerically; assuming values for v_0 and $\ominus_0$, the main results for the two models for long range rocket projectiles are the following:

[17] LRRP-I:
v_0 = 160 ft/sec
$\ominus_0$ = 66°
Range = 52,700 ft = 9.98 miles
Altitude reached = 18,200 ft
Velocity at end of powered flight = 1,623 ft/sec

LRRP-II:
v_0 = 160 ft/sec
$\ominus_0$ = 82°
Range = 61,600 ft = 11.66 miles
Altitude reached = 29,200 ft
Velocity at end of powered flight = 1,428 ft/sec

The details of the performance are given in Tables VI and VII. This performance calculation is of course conservative in the sense that the launching angles Θ_0 are reasonably chosen but not the optimum. It is interesting to notice that the actual range during coasting is approximately 50% of the theoretical coasting distance without air resistance. This fact will be used in the next section of the Memorandum.

The launching angle is a very high compared with ordinary artillery practice. The reason is that due to the rather small launching velocity of these projectiles, the gravitational pull makes the initial part of the trajectory highly curved. On the other hand, in order to extend the coasting range, the inclination of the projectile at the beginning of coasting should be between 30° and 40°. This condition can only be met by using very large launching angles. The trajectories for the two cases investigated are plotted in Figs 6 and 7.

4. **Performance with Wings**

All the calculations made above are made under the assumption that the projectile is without wings. The addition of wings produces a life force which is perpendicular to the trajectory, a wing resistance along the trajectory and an aerodynamic moment. The lift force (Fig 8) tends to balance the component of gravitational pull normal to the trajectory. If the forces normal to the trajectory are completely [18] balanced, then the trajectory will be a straight line. In general, the curvanture of the trajectory will be much smaller than that without wings. This effect is beneficial in reaching altitude, as the arc length of the trajectory that the projectile has to travel is smaller and hence the work done for a given resistance is also smaller. However, the addition of wings does increase the drag of the projectile, because of the added skin friction and the induced drag of the wings. Therefore, these two effects tend to cancel each other and in absence of complete data for airfoils at very high speeds, it is reasonable to assume that the maximum altitude reached the distance covered up to the maximum altitude are approximately the same as those for wingless projectiles.

After the maximum altitude is reached, the projectile will glide toward its target. This part of the flight path can be approximated by a straight line with a slope equal to the average value of the ratio between the drag force and the lift force. In subsonic flight, the ratio is quite small due to the efficiency of the wing at lower velocities. A study of available test data on airfoils in supersonic flow shows that this ratio is about 1:4. As an approximation then, the guide will be taken as straight line with a slope equal to 1:4. Then the range estimate of winged projectiles with fundamental designs similar to LRRP-I and LRRP-II is as follows:

LRRP-I-W	Range = 19.7 miles
LRRP-II-W:	Range = 28.8 miles

Thus the addition of wings to the projectile is capable of greatly extending the range of the projectile. However, there are several disadvantages which must be considered. First of all, the striking speed of the projectile is greatly reduced due to the extended coasting. Secondly, the addition of wings involves also [19] an increase in structural weight of the projectile and therefore a reduction in payload of a fixed initial gross weight. Finally, the problem of stability and control is greatly complicated, which may require intensive study and research.

[20] III. General Performance Estimate and Related Problems

To study the possible development of the long range rocket projectile, a general performance estimate has to be made. However, the problem is quite complicated and involves many variables. To simplify the problem, a basic model of wingless projectile is assumed and its performance is analyzed. Then by using the results obtained for this basic model, the effect of the variation on propellant consumption is calculated approximately.

The final result will be presented as the ratio of total impulse and initial weight plotted against range for different values of propellant consumption.

1. **Performance of a Basic Projectile**

Take an improved design of the projectile as follows:

Initial weight	= 10,000 lb
Maximum diameter	= 2.52 ft
Length	= 25.2 ft
Propellant consumption	= 5.03 lb/sec for 1,000 lb thrust
Effective exhaust velocity of rocket monitor	= 6400 ft/sec
Launching velocity	= 160 ft/sec

The drag coefficient C_D for this projectile is assumed to be slightly lower than that for LRRP-I and LRRP-II due to improved design and reduction in skin friction at higher Reynolds numbers. The values of C_D are given in Table VIII and Fig 9.

Previous experience obtained in analyzing the performance of sounding rockets* shows that the magnitude of acceleration during the powered flight does not influence the range drastically. Therefore, for the convenience of calculation the acceleration will be assumed to be constant and equal to twice the gravitational acceleration or $2g$. In other words,

[21]
$$v = v_0 + 2gt \tag{7}$$

Then the trajectory during the powered flight can be immediately deduced from Eq (2). The horizontal distance x at the instant t is given by

$$x = \frac{v_0^2}{2g} 4k \left\{ \frac{1}{3}(\xi^{\frac{3}{2}} - 1) - k^2(\sqrt{\xi} - 1) + k^3(\tan^{-1}\frac{\sqrt{\xi}}{k} - \tan^{-1}\frac{1}{k}) \right\} \tag{8}$$

where

$$k = \cot\left(\frac{\pi}{4} - \frac{\Theta_0}{2}\right) \tag{9}$$

$$\xi = v / v_0 = 1 + \frac{2g}{v_0} t \tag{10}$$

The altitude y at the instant t is given by

$$y = \frac{v_0^2}{2g} \left\{ 2k^2(\xi - 1) - \frac{1}{2}(\xi^2 - 1) - 2k^4 \log \frac{k^2 + \xi}{k^2 + 1} \right\} \tag{11}$$

These formulae determine the velocity and altitude at any instant t, and hence the air resistance D. By denoting $D / M_0 g$ by r:

$$r = \frac{1}{2} \frac{\wp_0 v_0^2 \frac{\pi}{4} d^2}{M_0 g} \sigma C_D \xi^2 = 0.01516\, \sigma\, C_D \xi^2 \tag{12}$$

then Eq (1) can be used to calculate the ratio of mass M at the instant t and the initial mass, M_0. The result is

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* F. J. "Malina and A. M. O. Smith, "Flight Analysis of the Sounding Rocket." J. AE. Sc., Vol. 5. pp. 199-202,(1938).

$$\frac{M}{M_0}=\frac{1}{2}\frac{e^{-\frac{\xi}{80}}}{(k^2+\xi)^{\frac{k^2}{40}}}\left\{2(k^2+1)^{\frac{k^2}{40}}e^{\frac{1}{80}}-\frac{1}{40}\int_1 r(k^2+\xi)^{\frac{k^2}{40}}e^{\frac{\xi}{80}}d\xi\right\} \qquad (13)$$

The ratio ζ of propellant discharged to the initial mass is of course $1-\frac{M}{M_0}$. Therefore if c = effective exhaust velocity of the jet motor, the ratio Ω of the total impulse up to the instant t to the initial weight is given by

$$\Omega=(1-\frac{M}{M_0})\frac{c}{32.2}=\frac{\zeta c}{32.2}\ \text{(seconds)} \qquad (14)$$

The result calculated for $\ominus_0$ = 78° is given in Table IX.

[22] In Table IX, the values of v, sin $\ominus$, x, and y are given together with Ω. If the propulsion is stopped at the instant t, the projectile will coast with an initial velocity v and inclination $\ominus$. The distance covered by coasting, neglecting air resistance can then be easily determined. According to the analysis in Part II, the air resistance will reduce this distance by 50%. By applying this reduction factor, the range of the projectile by stopping propulsion at various t can be calculated. Fig 10 shows the impulse ratio Ω plotted against range. This can be taken as an estimate of the performance of a long range rocket projectile. This estimate is of course somewhat conservative as no attempt is made to the vary the launching angel $\ominus_0$ to obtain its optimum value.

2. **Performance at other Values of Propellant Consumption**

If the propellant consumption is different from the value 5.03 lb/sec per 1000 lb thrust, or the effective exhaust velocity c is different from 6400 ft/sec, then the mass at the end of the powered flight will also be different assuming the same initial weight, acceleration and duration of the thrust. Let Ω, and ζ, be the impulse ratio and fuel weight ratio corresponding to $c = c_1$ = 6400 ft/sec respectively, taken by Eq (14)

$$\Omega_1=\zeta_1\frac{6400}{32.2} \qquad (15)$$

$$\Omega=\zeta\frac{c}{32.2}$$

Now if the projectile with exhaust velocity c has the same launching angle and acceleration as the basic projectile, the trajectory, the velocity and the inclination at the end of powered flight will be the same. Hence the range obtained is also approximately the same. However, the impulse ratio will be different. First of all the mass at the end of the powered flight is now $M_0(1-\zeta)$ instead of $M_0(1-\zeta_1)$. The thrust towards the end of powered flight is therefore $M_0(1-\zeta)(a+g\ \sin\ominus)$ instead [23] of $M_0(1-\zeta_1)(a+g\ \sin\ominus)$ where a is the acceleration along the trajectory. The difference is $M_0(.\zeta_1-\zeta)(a+g\ \sin\ominus)$. At the initial instant, this difference does not exist as the initial mass is taken as the same. Hence if t is the duration of powered flight the additional impulse necessary is approximately $\frac{1}{2}M_0(\zeta_1-\zeta)(a+g\ \sin\ominus)t$. But $g=\frac{1}{2}a$ for the basic projectile, and $\sin{}^\circ\leq 1$, hence the additional impulse is less than $\frac{1}{2}M_0(\zeta_1-\zeta)\frac{3}{2}at=0.75\ M_0(\zeta_1-\zeta)(v_c-v_0)$ where v_c is the velocity at the end of powered flight. v_0 is much smaller than v_c therefore it can be neglected in comparison with v_c. Then the impulse ratio can be written as

$$\Omega=\Omega_1+0.75(\zeta_1-\zeta)\frac{v_c}{g} \qquad 16$$

Eqs (15) and (16) then given

$$\frac{\Omega}{\Omega_1} = \frac{1+0.75\frac{v_c}{C_1}}{1+0.75\frac{v_c}{C}} \qquad 17$$

This relation can then be used to calculate the impulse weight ratio necessary for a given range at various values of *c*. The result is plotted in Fig 10. An example of how to use this chart will be given in Section III(4) of this memorandum.

3. Launching of the Projectile

In all the performance analyses carried out in the preceding sections, the launching velocity of the projectile is assumed to be 160 ft/sec. This speed is chosen from the consideration of stability. It is felt that for speeds lower then 160 ft/sec, the tail fins can hardly be expected to give the necessary restoring force when the projectile is disturbed into a yaw. To obtain this launching velocity and to aim the projectile a launcher is necessary. For quick aiming of the projectile and easy transportation, [24] the length of the launcher should be made as short as possible. This means that the projectile should be accelerated as quickly as possible. Quick accelerations can be achieved by using a very large launching thrust. This thrust, being of very short duration, can best be supplied by the unrestricted burning solid propellant rocket.

If M^0 is the mass of the projectile during the launching run, which can be assumed to be constant, a the constant acceleration, Θ_0 the launching angle and v_0 the launching velocity, then the thrust F^0 required for launching is

$$F^\circ = M^\circ a + M^\circ g \sin\Theta_0 \qquad (18)$$

But $a = v_0^2 / 2L$ where L is the length of the launching run.
Hence

$$F^\circ = M^\circ \left[\frac{v_0^2}{2L} + g \sin\Theta_0 \right] \qquad (19)$$

The duration T of the launching run is of course given by

$$T = 2\frac{L}{v_0} \qquad (20)$$

Let L=25 ft, v_0 =160 ft/sec, the T = 0.312 sec, a = 15.9 Assuming M^0= 1.2 M_0 and sin $\Theta_0 \approx$ 1 then

$$F^\circ / M_0 g = 20.3 \qquad (21)$$

In other words, the launching thrust should be approximately 20 times the weight of the projectile at the beginning of flight. For LRRP-I, the thrust is then 7,000 lb while for LRRP-II, this thrust is 40,000 lb. Thus, the unrestricted burning solid propellant rocket is well suited for the launching purpose.

[25] A preliminary design for the LRRP-1 launcher is shown in Figs 11 and 12.

4. Application of the Analysis

Fig 10 can be used to estimate the range of different projectiles of similar proportions to the basic projectile of 10,000 lb initial weight. For instance, if the effective exhaust velocity c is 6400 ft/sec, then with a propellant weight 62% of the initial weight, Eq (15) gives Ω =123.2. By using the curve in Fig 10 labeled c = 6400 ft/sec, the range is determined as 57.5 miles.

This value of propellant weight is rather high and may be difficult to achieve in a practical construction. To obtain a range in excess of 100 miles, it may be necessary to reduce the propellant consumption or to increase the effective exhaust velocity. With an exhaust velocity c = 9600 ft/sec, a 100 mile range requires Ω = 152 according to Fig 10. The propellant weight is then only 51% of the initial weight. This may well be within the realm of possibility.

The launching thrust for such a projectile is, according to Eq (21) about 200,000 lbs. The time duration of launching run is 0.312 sec and length 25 ft.

5. The Effect of Wings

The addition of wings to the projectile can greatly reduce the guide angle during the coasting flight of the projectile as discussed in Part III. If sufficient wing area is added, the range can be extended by as much as 100%. However, as stated in Part III there are several disadvantages to this practice. The main objections are the reduction in striking speed of the projectile and the increase in structural weight. It then seems that the compromise solution would be the addition of a stub wing to the projectile. The range can then be extended by approximately [26] 50% of that without wings, and at the same time the striking velocity and low structural weight can be maintained.

Another possible solution is to drop the wings at an altitude of about 20,000 ft; after the major portion of coasting flight is completed. This can be accomplished by a time fuse or relay which acts automatically at predetermined time. After dropping the wings, the projectile gains speed rapidly and thus will be able to strike the target with necessary velocity.

6. Stability and Control

For the wingless projectile, the problem of stability is relatively well-known. The experience and knowledge gained in bomb design and in the design of short range rocket projectiles can be immediately utilized. If the projectile is launched with a sufficient velocity for the fins to act, it is believed that the projectile will be inherently stable and the stability problem in connection with optimum fin design can be solved within a reasonably short time by a series of firing tests.

In the case of winged projectiles remote control might especially be required in applications in which a small evasive target is to be attacked. It is understood that both the Army Air Forces and the Navy are investigating control methods and devices and full collaboration with the groups concerned with this problem would be highly desirable.

The problem of stability and control for a winged projectile is believed to be much more difficult due to lack of knowledge and experience on wing design for supersonic speeds. A carefully laid program is necessary for a coordinated investigation of wings by both theoretical analysis and experimental observations.

[27]

IV. Analysis of Information Available on the German Long-Range Rocket Projectile

In this part an attempt is made to reconstruct the German long range rocket projectile on the basis of prisoner of war reports contained in the following British Intelligence reports: A.I. (K) Report No. 184A/1943, A.I. (K) Report No. 227A/1943, and A.I. (K)

Report No. 246B/1943. Upon reconstructing the LRRP an analysis of performance is made along the lines discussed in Part III of this Memorandum.

In Table X the specifications of the LRRP as given by various prisoners of war are listed.

In addition to the data in Table X the following information on the propulsive methods utilized is given:

(i) Projectile propelled by athodyds or rockets or combination of both. When the rocket is nearly burnt out a fuse ignites the burner in the athodyds.

(ii) Around the circumference of the rocket container there are a number of rearward - firing jets, probably six, which function from 10 to 70 seconds according to setting. When they have burned out, the propulsion of the projectile is taken over by the athodyds and the rocket portion falls off in one piece.

(iii) In one flight rockets burned for 18 or 19 seconds and the rocket - container became detached after the projectile had traveled a distance of about 9.3 miles.

(iv) The speed of the rocket gases is about 11.500 ft/sec and the athodyds take over propulsion when the projectile reaches a speed of 3280 ft/sec. with an initial acceleration of 8*g*.

[28] (v) When the athodyds cease functioning the projectile would have reached a speed of 6500 to 9200 ft/sec and the projectile would have covered half its course.

(vi) The athodyds were said to consume about 125 liters of fuel per second and to have an initial efficiency of 65%, rising to a terminal efficiency of 68 to 70%.

(vii) The pressure in the combustion chambers is between 80 and 100 atmospheres and the maximum temperatures probably of the order of 3,400 to 3,800° C. To prevent overheating of the combustion chambers the nozzles are made to function alternately in two sets of three, so that while one set of three is propelling the projectile, the other set is cooling off.

(viii) The combustion chambers are cooled by means of an air jacket with the intake in front and the venting rearwards. It is claimed that this jacket reduces the efficiency of the athodyds only by some 4%.

(ix) The combustion chambers on the projectile were ellipsoidal. There were six athodyds, each of which was housed in a cylinder, and the six cylinders in turn were filled into a larger cylinder which exactly fitted the rear portion of the projectile.

(x) The fuel reservoir extended down the center of the projectile between the athodyd housings.

A drawing of the projectile made by one of the prisoners of war is reproduced in Fig 13.

The following information is given on the fuel utilized:

(i) The new fuel looks like water, and the specific gravity of its various modifications varies between 0.5 and 0.7; it burns without the addition of oxygen to CO_2 and H_2O, and its heat of combustion is 43,600 Btu per lb, most of which is heat of [29] decomposition.

(ii) The new fuel is slightly yellowish in color, and is translucent. The specific gravity is thought to be 0.92.

(iii) Its general formula is $C_xH_{2x}0_{3x}$ and if a benzene ring is considered as monoplanar the first step in the synthesis is to interlock three such rings mutually at right angles and to substitute oxygen as necessary.

(iv) The lowest calorific content of the fuel is 63,000 Btu per pound.

(v) The rocket attachment is the athodyd—propelled projectile is provided with a normal propellant in solid form, but the athodyds in the main portion of the projectile are fed by the new fuel in liquid form.

From the information above the following specifications will be chosen for the German projectile and then its performance estimated.

Initial weight, lb	132,000
Athodyd propellent weight, lb	33,000
Booster rocket section, lb	55,000
Weight of projectile after booster rocket section dropped, lb	77,000
Explosive load, lb (10% of above)	7,700
Diameter, ft	7.5
Length, ft	20
Initial acceleration, ft/sec^2	36

If we assume that the projectile is launched at an initial velocity of 160 ft per sec the launching run required is

$$L = \frac{v_0^2}{2a} = \frac{160^2}{2 \times 36} = 356 \text{ Ft, say } 350 \text{ Ft}$$

[30] This value checks with the size of launching pit described by the prisoners of war. The initial thrust required can be calculated from the equation Eq (19)

$$F^\circ = M^\circ\left(\frac{v_0^2}{2L} + g \sin \ominus_0\right)$$

Let us assume that $\ominus_0 \approx 90^\circ$ so that $\sin \ominus_0 \approx 1$, then

$$F^\circ = \frac{132{,}000}{32.2}\left(\frac{160^2}{2 \times 350} + 32.2\right) = 282{,}000 \text{ lbs.}$$

If six solid propellant rockets are used as boosters then each rocket must deliver 47,000 lb. The exhaust velocity of the rockets is said to be 11,500 ft per sec, and the rockets act for a period of 10 to 70 seconds. Let us assume that they act for 20 seconds, then the weight of propellant in the rockets will be

$$W = \frac{F^\circ g}{c} t = \frac{282{,}000}{11{,}500} \times 32.2 \times 20 = 15{,}800 \text{ lbs.}$$

If the rockets act for 60 seconds then the propellant weight would be

$$W = 15{,}000 \times 3 = 47{,}000 \text{ lbs.}$$

One of the prisoners of war states that the booster rockets, which are dropped when the rockets cease, weights 55,000 lb. This would check with the above calculation for a duration of 60 seconds. However, it is believed that an exhaust velocity of 11,500 ft per sec is excessive and a more probable value is 6,500 ft per sec. On this basis for a 20 second duration

$$W = \frac{282{,}000}{6{,}500} \times 32.2 \times 20 = 28{,}000 \text{ lbs.}$$

If one half of the weight of the booster rockets is in the form of propellant the value of 55,000 lb checks with the 2 × 28,000 = 56,000 lb very well. This will be used for later calculations.

[31] It will therefore be assumed that there are six solid propellant rockets each delivering 47,400 lb thrust for 20 seconds. At this point it should be a noted that a solid propellant rocket that delivers 47,400 lb thrust with an exhaust velocity of 6,500 ft per sec would have a diameter of 4.25 ft if the density of the propellant is 100 lb per cu ft and its rate of burning 2 in per sec.

The athodyds are said to take over propulsion when the rocket container drops off. If the athodyds deliver a thrust to give the same ratio of thrust to initial projectile weight as the rockets then their thrust is

$$F = \frac{282{,}000 \times 77{,}000}{132{,}000} = 165{,}000 \text{ lbs.}$$

If there are six athodyds then each athodyd must deliver 27,500 lb thrust.

The athodyds are said to consume about 125 liters of fuel per second. If the density is 0.92 then this corresponds to 250 lb per sec. It is not stated if all six or each one consumes this amount of fuel. If all consume this amount then the effective exhaust velocity based on the fuel above is

$$c = \frac{165{,}000 \times 32.2}{250} = 21{,}300 \text{ Ft / sec.}$$

This value of effective exhaust velocity is believed to be too high. A reasonable estimate shows that c is probably around 12,000 ft/sec. By assuming the same fuel consumption as before the thrust of the athodyds becomes 93,000 lbs. If the total weight of the propellant is 33,000 lbs, the duration would be 33,000/250 = 132 seconds.

Then impulse imparted to the projectile by the athodyds is then 93,000 × 132 = 12,270,000 lb sec. The impulse imparted to the projectile, excluding the booster rockets, after the launching run is then 282,000 × 77,000/132,000 × 10 = 1,643,000 lb sec. The total impulse imparted to [32] the projectile alone after the launching run is then 12,270,000 + 1,643,000 = 13,910,000 lb sec. The impulse weight ratio Ω is then 13,910,000/77,000 = 180.6. By using Fig 10 the ragne is estimated to be 140 to 150 miles. This checks very closely with the information given by the prisoners of war.

From the above analysis, a summary of the data for the German long range rocket projectile is given in Table XI. The velocities are estimated from the thrust data and are, of course, only a rough approximation.

[33]

Table I

Jet Unit	NDRC-CIT 3A	NDRC Budd 4.5"
Ave. Thrust, lb	2,000	6,000
Duration, sec	0.90	0.18
Impulse, lb sec	1,800	1,080
Eff. exhaust velocity, ft/sec	6,300	6,700
Propellant weight, lb	8.5	4.8
Motor weight (full), lb	41.5	30
Motor length, in	40.0	23.25
Motor 0. D., in	3.25	4.5

Table II

Jet Unit	Aerojet X20AS-1000	Aerojet X30AS-1000
Ave. Thrust, lb	1,000	1,000
Duration, sec	20	30
Impulse, lb sec	23,000	34,500
Eff. exhaust velocity, ft/sec	5,500	5,500
Propellant weight, lb	130	195
Motor weight (full), lb	270	385
Motor length, in	56.5	73.5
Motor O.D., in	9.625	9.625

Table III

Jet Unit	Aerojet 25ALD-1000	Aerojet X40ALJ-6000	Estimated Projectile 4000 lb-Thrust 30 sec Unit
Ave. Thrust, lb	1,000	6,000	4,000
Duration, sec	25	40	35
Impulse, lb sec	28,000	240,000	140,000
Eff. exhaust velocity, ft/sec	5,500	5,800	5,800
Propellant and nitrogen wt., lb	173	1,500	830
Jet unit weight (full), lb	420	2,900	1,700
Length of unit, in	69.0	104	144
Diameter of unit, in	—	—	24
Max. width, in	22.5	38	—
Max. height, in	24.0	47	—

[34]

Table IV

Altitude Ft.	Temp. °F, abs	Vel. of Sound ft/sec	Pressure Ratio	Density Ratio
0	519.0	1120	1.0000	1.0000
1000	515.4	1116	.9643	.9710
2000	511.8	1112	.9297	.9428
3000	508.4	1109	.8962	.9151
4000	504.8	1105	.8636	.8881
5000	501.2	1101	.8320	.8616
6000	497.6	1097	.8013	.8358
7000	494.0	1093	.7716	.8106
8000	490.6	1089	.7426	.7859
9000	487.0	1085	.7147	.7618
10000	483.4	1081	.6876	.7364
11000	479.8	1077	.6613	.7154
12000	476.2	1073	.6366	.6931
13000	472.6	1069	.6112	.6712
14000	469.1	1065	.5874	.6499
15000	465.5	1061	.5642	..6291
16000	461.9	1057	.5418	.6088
17000	458.3	1053	.5201	.5891
18000	454.7	1048	.4992	.5693
19000	451.3	1044	.4789	.5509
20000	447.7	1040	.4593	.5327
21000	444.1	1036	.4404	.5148
22000	440.5	1032	.4221	.4974
23000	436.9	1028	.4045	.4805
24000	433.5	1023	.3874	.4640
25000	429.9	1019	.3709	.4480
26000	426.3	1015	.3550	.4323
27000	422.7	1011	.3396	.4171
28000	419.1	1007	.3249	.4023
29000	415.5	1002	.3105	.3879
30000	412.1	997.9	.2968	.3740
31000	408.5	993.5	.2836	.3603
32000	404.9	989.1	.2708	.3472
33000	401.3	984.7	.2584	.3343
34000	397.7	980.3	.2466	.3218
35000	394.3	976.1	.2351	.3098
36000	393.0	974.5	.2242	.2962
37000	393.0	974.5	.2137	.2824
38000	393.0	974.5	.2038	.2692
39000	393.0	974.5	.1942	.2566
40000	393.0	974.5	.1851	.2447

[35]

Altitude Ft.	Temp. °F, abs	Vel. of Sound ft/sec	Pressure Ratio	Density Ratio
41000	393.0	974.5	.1766	.2332
42000	393.0	974.5	.1683	.2224
43000	393.0	974.5	.1605	.2120
43000	393.0	974.5	.1530	.2121
45000	393.0	974.5	.1458	.1926
46000	393.0	974.5	.1391	.1837
47000	393.0	974.5	.1325	.1751
48000	393.0	974.5	.1264	.1669
49000	393.0	974.5	.1205	.1591
50000	393.0	974.5	.1149	.1517
51000	393.0	974.5	.1095	.1446
52000	393.0	974.5	.1044	.1379
53000	393.0	974.5	.09953	.1315
54000	393.0	974.5	.09489	.1254
55000	393.0	974.5	.09047	.1195
56000	393.0	974.5	.08625	.1139
57000	393.0	974.5	.08222	.1086
58000	393.0	974.5	.07839	.1036
59000	393.0	974.5	.07474	.09872
60000	393.0	974.5	.07125	.09412
61000	393.0	974.5	.06793	.08974
62000	393.0	974.5	.06476	.08555
63000	393.0	974.5	.06174	.08155
64000	393.0	974.5	.05886	.07775
65000	393.0	974.5	.05612	.07413
66000	393.0	974.5	.05350	.07067
67000	393.0	974.5	.05100	.06737
68000	393.0	974.5	.04862	.06422
69000	393.0	974.5	.04636	.06123
70000	393.0	974.5	.04420	.05838
71000	393.0	974.5	.04345	.05739
72000	393.0	974.5	.04017	.05306
73000	393.0	974.5	.03829	.05058
74000	393.0	974.5	.03651	.04823
75000	393.0	974.5	.03480	.04597
76000	393.0	974.5	.03318	.04383
77000	393.0	974.5	.03163	.04178
78000	393.0	974.5	.03016	.03984
79000	393.0	974.5	.02875	.03798
80000	393.0	974.5	.02741	.03621

[36]

Altitude Ft.	Temp. °F, abs	Vel. of Sound ft/sec	Pressure Ratio	Density Ratio
81000	393.0	974.5	.02613	.03452
82000	393.0	974.5	.02491	.03291
83000	393.0	974.5	.02375	.03160
84000	393.0	974.5	.02265	.02991
85000	393.0	974.5	.02159	.02852
86000	393.0	974.5	.02058	.02719
87000	393.0	974.5	.01962	.02592
88000	393.0	974.5	.01871	.02471
89000	393.0	974.5	.01783	.02356
90000	393.0	974.5	.01700	.02246
91000	393.0	974.5	.01621	.02141
92000	393.0	974.5	.01545	.02041
93000	393.0	974.5	.01473	.01946
94000	393.0	974.5	.01405	.01855
95000	393.0	974.5	.01339	.01769
96000	393.0	974.5	.01277	.01686
97000	393.0	974.5	.01217	.01608
98000	393.0	974.5	.01160	.01533
99000	393.0	974.5	.01106	.01461
100000	393.0	974.5	.01055	.01393
101000	393.0	974.5	.01005	.01328
102000	393.0	974.5	.009585	.01266
103000	393.0	974.5	.009138	.01207
104000	393.0	974.5	.008712	.01151
105000	393.0	974.5	.008306	.01097
106000	393.0	974.5	.007919	.01046
107000	393.0	974.5	.007549	.009972
108000	393.0	974.5	.007197	.009507
109000	393.0	974.5	.006862	.009064
110000	393.0	974.5	.006541	.008641
111000	393.0	974.5	.006236	.008238
112000	393.0	974.5	.005946	.007854
113000	393.0	974.5	.005668	.007488
114000	393.0	974.5	.005404	.007138
115000	393.0	974.5	.005152	.006805
116000	393.0	974.5	.004912	.006488
117000	393.0	974.5	.004683	.006185
118000	393.0	974.5	.004464	.005897
119000	393.0	974.5	.004256	.005622
120000	393.0	974.5	.004058	.005360
121000	393.0	974.5	.003868	.005110
122000	393.0	974.5	.003688	.004871
123000	393.0	974.5	.003516	.004644
124000	393.0	974.5	.003352	.004428
125000	393.0	974.5	.003196	.004221

[37] Table V

Drag Coefficient C_D for LRRP-I & LRRP-II

Mach Number, v/v_s	Drag Coefficient, C_D
0	0.3636
0.25	0.3568
0.50	0.3317
0.75	0.2974
0.95	0.3889
1.00	0.5354
1.10	0.5444
1.50	0.4910
2.00	0.4274
2.50	0.3944
3.00	0.3684
3.50	0.3434
4.00	0.3224

[38] Table VI

Performance of LRRP-I

Launching Velocity vo, ft/sec	160
Launching Angle	66°
m/M_{01} $\sec^{-1}$	0.01856
$F/M^0 g$	3.288
$\frac{1}{2}\zeta_0 v_0^2 \frac{\pi}{4} d^2 / M_0 g$	0.05225
Altitude at end of Powered Flight, ft	12,063
Distance at end of Powered Flight, ft	14,340
Velocity at end of Powered Flight, ft/sec	1,623
Inclination of Trajectory at end of Powered Flight	31.2°
Maximum Altitude reached, ft	18,200
Range, ft	52,700
Distance Covered by Coasting, ft	38,360
Distance Covered by Coasting, No Air Resistance, ft	88,700
Ratio of Coasting Distance with and without Air-Resistance	0.433

[39]

Table VII

Performance of LRRP-II

Launching Velocity v_0, ft/sec	160
Launching Angle,	82°
m/M_{01} $\sec^{-1}$	0.01185
$F/M^0 g$	2.000
$\frac{1}{2}\zeta_0 v_0^2 \frac{\pi}{4} d^2 / M_0 g$	0.0478
Altitude at end of Powered Flight, ft	21,606
Distance at end of Powered Flight, ft	17,190
Velocity at end of Powered Flight, ft/sec	1,428
Inclination at end of Powered Flight	37.0°
Maximum Altitude reached, ft	29,200
Range, ft	61,600
Distance covered by Coasting, ft	43,410
Distance covered by Coasting, No Air Resistance, ft	82,100
Ratio of Coasting Distance with and without Air Resistance	0.528

[40]

Table VIII

Drag Coefficient C_D for the Basic Projectile

Mach Number, v/v_s	Drag Coefficient, C_D
0	0.3353
0.25	0.3285
0.50	0.3034
0.75	0.2691
0.95	0.3606
1.00	0.5071
1.10	0.5161
1.50	0.4627
2.00	0.3991
2.50	0.3661
3.00	0.3401
3.50	0.3151
4.00	0.2941

[41]

Table IX

Performance of the Basic Projectile

$v_0 = 160$ ft/sec
$\Theta_0 = 78^\circ$

t,sec	x, ft	y, ft	vc, ft/sec	Ω	sinΘ	cosΘ	Range, Miles
39.75	79,470	80,490	2720	118.9	0.580	0.815	43.3
44.72	87,520	86,050	3040	121.4	0.567	0.823	50.7
49.69	95,810	91,770	3360	123.8	0.553	0.833	58.5
54.66	104,700	97,510	3680	126.2	0.540	0.841	67.0
59.63	113,930	103,330	4000	128.5	0.5275	0.849	75.9
64.60	123,580	109,270	4320	130.7	0.5185	0.855	85.5
69.57	133,670	115,210	4640	133.0	0.502	0.865	95.2
74.53	144,270	121,250	4960	135.0	0.490	0.872	105.1

[42]

Table X

Initial Wt. lb	Prop. Wt. lb	Explosive lb	Max. Dia. ft	Length ft	Flight Speed ft/sec	Range miles	Initial Accel ft/sec^2	Rocket Container Wt., lb	Rocket Container Dia., ft	Rocket Container Length, ft	Launching Distance ft
220,000	33,000		8.2	16.4 - 19.6	3280	310	36.0				
132,000	33,000					155	257.6 8G	55,000	9.8 - 11.5	13.1	394 (pit)
132,000			7.4		6560 (Ave.)	125	257.6 8G				
		308		19.8		125					

[43] Table XI

Estimated Performance of a German Long Range Rocket Projectile

Items	Magnitude
Initial Weight, lb	132,000
Rocket Booster Weight, lb	55,000
Projectile Weight, Booster Rejected, lb	77,000
Rocket Propellant Weight, lb	28,000
Athodyd Propellant Weight, lb	33,000
Effective Exhaust Velocity of Rockets, ft/sec	6,500
Effective Exhaust Velocity of Athodyd, ft/sec	12,000
Duration of Rockets, sec	20
Duraction of Athodyds, sec	132
Launching Velocity, ft/sec	160
Velocity at Instant of Rejection of Rockets, ft/sec	800
Maximum Velocity of Projectile, ft/sec	6000
Distance Travelled before Rocket Rejection, miles	1.8
Range, Miles	145

Document I-13

Document title: The Editors of *Collier's*, "What Are We Waiting For?," and Dr. Wernher von Braun, "Crossing the Last Frontier," *Collier's*, March 22, 1952, pp. 23-29, 27-73.

Document I-14

Document title: Dr. Wernher von Braun, "Man on the Moon: The Journey," *Collier's*, October 18, 1952, pp. 52-59.

Document I-15

Document title: Dr. Fred L. Whipple, "Is There Life on Mars?," *Collier's*, April 30, 1954, p. 21.

Document I-16

Document title: Dr. Wernher von Braun with Cornelius Ryan, "Can We Get to Mars?," *Collier's*, April 30, 1954, pp. 22-29.

Collier's was a popular, family-oriented information magazine similar to *Life* and *The Saturday Evening Post.* Such magazines flourished in the post-war period until the advent of television and at its peak, *Collier's* had a circulation of over 3 million. On Columbus Day 1951, a Space Travel Symposium was held at the Hayden Planetarium of the New York, Museum of Natural History. The event had been organized by Willy Ley, a German emigré and author of the 1949 best-selling book, *The Conquest of Space.* Two journalists from *Collier's* were present at the symposium and notified their managing editor, Gordon Manning, about what was discussed there. His interest piqued, Manning sent associate editor Cornelius

Ryan to a conference on space medicine held in San Antonio, Texas, in November 1951. After talking to Wernher von Braun, Fred Whipple, and Joseph Kaplan at the conference, Ryan became enthusiastic about the prospects of space travel. Ryan convinced Manning to hold an internal *Collier's* symposium on the subject. Based on this internal symposium, a series of eight feature articles appeared in the magazine from 1952 to 1954. The articles were authored by noted experts such as von Braun, James Van Allen, Fred Whipple, Fritz Haber, and Joseph Kaplan. The articles were accompanied by illustrations by Chesley Bonestell, who had illustrated Ley's book, as well as by Fred Freeman and Rolf Klep.

These articles were the first to be published in a mainstream publication exposing the American public to the details of space exploration. They later led to a series of Disney animated films on the same subject and contributed to the popular historical image of space exploration.

Document I-13

[23]

What Are We Waiting For?

On the following pages Collier's presents what may be one of the most important scientific symposiums ever published by an national magazine. It is the story of the inevitability of man's conquest of space.

What you will read is not science fiction. It is serious fact. Moreover, it is an urgent warning that the U.S. must immediately embark on a long-range development program to secure for the West "space superiority." If we do not, somebody else will. That somebody else very probably would be the Soviet Union.

The scientists of the Soviet Union, like those of the U.S., have reached the conclusion that it is now possible to establish an artificial satellite or "space station" in which man can live and work far beyond the earth's atmosphere. In the past it has been correctly said that the first nation to do this will control the earth. And it is too much to assume that Moscow's military planners have overlooked the military potentialities of such an instrument.

A ruthless foe established on a space station could actually subjugate the peoples of the world. Sweeping around the earth in a fixed orbit. Like a second moon, this man-made island in the heavens could be used as a platform from which to launch guided missiles. Armed with atomic war heads, radar-controlled projectiles could be aimed at any target on the earth's surface with devastating accuracy.

Furthermore, because of the enormous speeds and relatively small size, it would be almost impossible to intercept them. In other words: whoever is the first to build a station in space can prevent any other nation from doing likewise.

We know that the Soviet Union, like the U.S., has an extensive guided missile and rocket program under way. Recently, however the Soviets, intimated that they were investigating the development of huge rockets capable of leaving the earth's atmosphere. One of their top scientists, Dr. M. K. Tikhonravov, a member of the Red Army's Military Academy of Artillery, let it be known that on the basis of Soviet scientific development such rocket ships could be built and, also, that the creation of a space station was not only feasible but definitely probable. Soviet engineers could even now, he declared, calculate precisely the characteristics of such space vehicles; and be added that Soviet developments in this field equaled, if not exceeded, those of the Western World.

We have already learned, to our sorrow, that Soviet scientists and engineers should never be underestimated. They produced the atomic bomb years earlier than was anticipated. Our air superiority over the Korean battlefields is being challenged by their excellent MIG-15 jet fighters which, at certain altitudes, have proved much faster than ours. And while it is not believed that the Soviet Union has actually begun work on a major project to capture space superiority, U.S. scientists point out that the basic knowledge for such a program has been available for the last 20 years.

What is the U.S. doing, if anything, in this field?

In December, 1948, the late James Forrestal, then Secretary of Defense, spoke of the existence of an "earth satellite vehicle program." But in the opinion of competent military observers this was little more than a preliminary study. And so far as is known today, little further progress has been made. Collier's feels justified in asking; What are we waiting for?

We have the scientists and the engineers. We enjoy industrial superiority. We have the inventive genius. Why therefore, have we not embarked on a major space program equivalent to that which was undertaken in developing the atomic bomb? The issue is virtually the same.

The atomic bomb was enabled the U.S. to buy time since the end of World War II. Speaking in Boston 1949, Winston Churchill put it this way: "Europe would have been communized and London under bombardment sometime ago but for the deterrent of the atomic bomb in the hands of the United States." The same could be said for a space station. In the hands of the West a space station, permanently established beyond the atmosphere, would be the greatest hope for peace the world has ever known. No nation could undertake preparations for war without the certain knowledge that it was being observed by the ever-watching eyes aboard the "sentinel in space." It would be the end of Iron Curtains wherever they might be.

Furthermore, the establishment of a space station would mean the dawning of a new era for mankind. For the first time, exploration of the heavens would be possible, and the great secrets of the universe would be revealed.

When the atomic bomb program—the Manhattan Project—was initiated, nobody really knew whether such a weapon could actually be made. The famous Smyth Report on atomic energy tells us that among the scientists where were many who had grave and fundamental doubts of the success of the undertaking. It was a two-billion-dollar technical gamble.

Such would not be the case with a space program. The claim that huge rocket shops can be built and a space station created still stands unchallenged by any serious scientist. Our engineers can spell out right now (as you will see) the technical specifications for the rocket ship and space station in cut-and-dried figures. And they detail the design features. All they need is time (about 10 years), money and authority.

Even the cost has been estimated: $4,000,000,000. And when one considers that we have spent nearly $54,000,000,000 on rearmament since the Korean war began, the expenditure of $4,000,000,000 to produce an instrument which would guarantee the peace of the world seems negligible.

Collier's became interested in this whole program last October when members of our editorial staff attended the First Annual Symposium on Space Travel, held at New York's Hayden Planetarium. On the basis of their findings. Collier's invited the top scientists in the field of space research to New York for a series of discussions. The magazine symposium on these pages was born of these round table sessions.

The scientists who have worked with us over the last five months on this project and whose views are presented in succeeding pages are:

- **Dr. Wernher von Braun**, Technical Director of the Army Ordnance Guided Missiles Development Group. At forty, he is considered the foremost rocket engineer in the world today. He was brought to this country from Germany by the U.S. government in 1945.
- **Dr. Fred L. Whipple**, Chairman Department of Astronomy, Harvard University. One of the nations outstanding astronomers, he has spent most of his forty-five years studying the behavior of meteorites.
- **Dr. Joseph Kaplan**, Professor of Physics at UCLA. One of the nation's top physicists and a world renowned authority on the upper atmosphere, the forty-nine-year-old scientists was decorated in 1947 for work in connection with B-29 bomber operations.
- **Dr. Heinz Haber**, of the U.S. Air Force's Department of Space Medicine. Author of more than 25 scientific papers since our government brought him to this country from Germany in 1947. Dr. Haber, thirty-eight, is one of a small group of scientists working on the medical aspects of man in space.

- **Willy Ley**, who acted as adviser to Collier's in the preparation of this project. Mr. Ley, forty-six is perhaps the best-known magazine science writer in the U.S. today. Originally a paleontologist, he was one of the founders of the German Rocket Society in 1927 and was Dr. Wernher von Braun's first tutor in rocket research.

Others who made outstanding contributions to this issue include:

- **Oscar Schachter**, Deputy Director of the UN Legal department. A recognized authority on international law, this thirty-six-year-old lawyer has frequently given legal advice on matters pertaining to international scientific questions, which lately have included the problems of space travel.
- **Chesley Bonestell**, whose art has appeared in the pages of Collier's many times before. Famous for his astronomical painting, Mr. Bonestell began his career as an architect, but has spent most of his life painting for magazines and lately for Hollywood.
- Artists **Fred Freeman** and **Rolf Klep**. Both spent many months working in conjunction with the scientists.

For Collier's, associate editor Cornelius Ryan supervised assembly of the material for the symposium. The views expressed by the contributors are necessarily their own and in no way reflect those of the organizations to which they are attached.

Collier's believes that the time has come for Washington to give priority of attention to the matter of space superiority. The rearmament gap between the East and West has been steadily closing. And nothing, in our opinion, should be left undone that might guarantee the peace of the world. It's as simple as that.

THE EDITORS

[25]

Crossing the Last Frontier

By Dr. Wernher von Braun

Technical Director, Army Ordnance Guided Missiles
Development Group, Huntsville, Alabama

Scientists and engineers now how to build a station in Space that would circle the earth 1,075 miles up. The job would take 10 years, and cost twice as much as the atom bomb. If we do it, we can not only preserve the peace but we can take a long step toward uniting mankind.

[26] Within the next 10 or 15 years, the Earth will have a new companion in the skies, a man-made satellite that could be either the greatest force for peace ever devised, or one of the most terrible weapons of war—depending on who makes and controls it. Inhabited by humans, and visible from the ground as a fast -moving star, it will sweep around the earth at an incredible rate of speed in that dark void beyond the atmosphere which is known as "space."

In the opinion of many top experts, this artificial moon—which will be carried into space, piece by piece, by rocket ships—will travel along a celestial route 1,075 miles above the earth, completing a trip around the globe every two hours. Nature will provide the motive power; a neat balance between its speed and the earth's gravitational pull will keep it on course (just as the moon is fixed in its orbit by the same two factors). The speed at which the 250 foot-wide, "wheel"-shaped satellite will move will be an almost unbelievable 4.4 miles per second, or 15,840 miles per hour—20 time the speed of sound. However, this terrific velocity will not be apparent to its occupants. To them, the space station will appear to be a perfectly steady platform.

From this platform, a trip to the moon itself will be just a step, as scientists reckon distance in space.

The choice of the so-called "two-hour" orbit—in preference to a faster one, closer to the earth or a slower one like the 29-day orbit of the moon—has one major advantage:

although far enough up to avoid the hazards of the earth's atmosphere it is close enough to afford a superb observation post.

Technicians in this space station—using specially designed, powerful telescopes attached to large optical screen radarscopes and cameras—will keep under constant inspection every ocean, content, country and city. Even small towns will be clearly visible through optical instruments that will give the watchers in space the same vantage point enjoyed by a man in an observation plane only 5,000 feet off the ground.

Nothing will go unobserved. Within each two-hour period as the earth revolves inside the satellite's orbit one twelfth of the globe's territory will pass into the view of the space station occupants within each 24-hour period the entire surface of the earth will have been visible.

Over North America for example, the space station might pass over the East Coast at say 10:00 am and after having completed a full revolution around the earth would—because the [27] earth itself has turned meanwhile—pass over the West Coast two hours later. In the course of that one revolution it would have been north as far as Nome, Alaska, and south almost to Little America on the Antarctic Continent. At 10:00 am the next day, it would appear once again over the East Coast.

Despite the vast territory thus covered, selected spots on the earth could receive pinpoint examination. For example, troop maneuvers, planes being readied on the flight deck of an aircraft carrier, or bombers forming into groups over an airfield will be clearly discernible. Because of the telescopic eyes and cameras of the space station, it will be almost impossible for any nation to hide warlike preparations for any length of time.

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These things we know from High-altitude photographs and astronomical studies: to the naked eye, the earth, more than 1,000 miles below, will appear an awe-inspiring sight. One the earth's "day" side, the space station's crew will see glaring white patches of overcast reflecting the light of the sun. The continents will stand out in shades of gray and brown bordering the brilliant blue of the seas. North America will look like a great patchwork of brown, gray and green reaching all the way to the snow-covered Rockies. And one polar cap—whichever happens to be enjoying summer at the time—will show as a blinding white, too brilliant to look at with the naked eye.

On the earth's "night" side, the world's cities will be clearly visible as twinkling points of light. Surrounded by the hazy aura of its atmosphere—that great ocean of air in which we live—the earth will be framed by the absolute black of space.

Development of the space station is as inevitable as the rising of the sun; man has already poked his nose into space and he is not likely to pull it back.

On the 14th of September, 1944, a German V-2 rocket, launched from a small island in the Baltic, soared to a peak altitude of 109 miles. Two years later on December 17, 1946, another V-2, fired at the Army Ordnance's White Sands Proving Ground, New Mexico, reached a height of 114 miles—more then five times the highest altitude ever attained by a metrological sounding balloon. And on the 24th of February, 1949, a "two-stage rocket" (small rocket names the "WAC Corporal" fired from the nose of a V-2 acting as carrier or "first stage") soared up to a height of 250 miles—roughly the distance between New York and Washington, but straight up!

These projectiles utilized the same principle of propulsion as the jet airplane. It is based on Isaac Newton's third law of motion, which can be stated in this way: for every action there most be a reaction of equal force, but in the opposite direction. A good example is the firing of a bullet from a rifle. When you pull the trigger the bullet speeds out of the barrel, there is a recoil which slams the rifle butt back against your shoulder. If the rifle were lighter and the explosion of the cartridge more powerful, the gun might go flying over your shoulder for a considerable distance.

This is the way a rocket works. The body of the rocket is like the rifle barrel; the gasses ejected from its tail are like the bullet. And the power of a rocket is measured not in horsepower, but in pounds or tons of recoil—called "thrust." Because it depends on the recoil principle, this method of propulsion does not require air.

There is nothing mysterious about making use of this principle as the first step toward making our space station a reality. On the basis of present engineering knowledge, only a determined effort and the money to back it up are required. And if we don't do it, another nation—possibly less peace-minded—will. If we were to begin in immediately, and could keep going at top speed, the whole program would take about 10 years. The estimated cost would be $4,000,000,000—about twice the cost of developing the atomic bomb, but less then one quarter the price of military materials ordered by the Defense Department during the last half of 1951.

Our first need would be a huge rocket capable of carrying a crew and some 30 or 40 tons of cargo into the "two-hour" orbit. This can be built. To understand how, we again use the modern gun as an example.

A shell swiftly attains a certain speed within the gun barrel, then merely coasts through a curved path toward its target. A long-range rocket also requires its initial speed during a comparatively short time, then is carried by momentum.

For example, the V-2 rocket in a 200-mile flight is under power for only 65 seconds, during which it travels 20 miles. At the end of this 65-second period of propulsion it reaches a cut-off speed of 3,600 miles per hour; it coasts the remaining 180 miles. Logically, therefore, if we want to step up the range of the rocket, we must increase its speed during the period of powered flight. If we could step up its cut-off speed to 8,280 miles per hour, it would travel 1,000 miles.

To make a shell hit its target, the gun barrel has to be elevated and pointed in the proper direction. If the barrel were pointed straight up into the sky the shell would climb to a certain altitude and simply fall back, landing quite close to the gun. Exactly the same thing happens when a rocket is fired vertically. But to make the rocket reach a distant target after its vertical take-off, it must be tilted after it reaches a certain height above the ground. In rockets capable of carrying a crew and cargo, the tilting would be done by swivel-mounded rocket motors, which by blasting sideways, would cause the rocket to veer.

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Employing this method, at a cutoff speed of 17,460 miles per hour, a rocket would coast halfway around the globe before striking ground. And by boosting to just a little higher cut-off speed—4.86 miles per second or 17,500 miles per hour—its coasting path, after the power had been cut off would match the curvature of the earth. The rocket would actually be "falling around the earth," because its speed and the earth's gravitational pull would balance exactly.

It would never fall back to the ground, for it would now be an artificial satellite, circling according to the same laws that govern the moon's path about the earth.

Making it do this would require delicate timing—but when you think of the split-second predictions of the eclipses, you will grant that there can hardly be any branch of natural science more accurate than the one dealing with the motion of heavenly bodies.

Will it be possible to attain this fantastic speed of 17,500 miles per hour necessary to reach our chosen two-hour orbit? This is almost five times as fast as the V-2. Of course, we can replace the V-2's alcohol and liquid oxygen by a more powerful propellants, and even, by improving the design, reduce the rocket's dead weight and thereby boost the speed by some 40 or 50 per cent; but we would still have a long way to go.

The WAC Corporal, starting from the nose of a V-2 and climbing to 250 miles, has shown us what we must do if we want to step up drastically the speed of a rocket. The WAC started its own rocket motor the moment the V-2 carrying it had reached it maximum speed. It thereby added its own speed to that already achieved by the first stage. As mentioned earlier, such a piggyback arrangement is called "two-stage rocket;" and by putting a two-stage rocket on [28] another still larger booster we get a three-stage rocket. A three-stage rocket then, could treble the speed attainable by one rocket stage alone (which would give it enough speed to become a satellite).

In fact, it could do even better. The three-stage rocket may be considered as a rocket with three sets of motors; after the first set has given its utmost and has expired, it is jettisoned—and so is the second set in its turn. The third stage or nose of the rocket continues on its way, relieved of all that excess weight.

* * *

Besides the loss of the first two stages, other factors make the rocket's journey easier the higher it goes. First, the atmosphere is dense, and tends to hinder the passage of the rocket; once past it, the going is faster. Second, the rocket motors operate more efficiently in the rarefied upper layers of the atmosphere. Third, after passing through the densest portion of the atmosphere, the rocket no longer need climb vertically.

Imagine the size of this huge three-stage rocket ship: it stands 265 feet tall approximately the height of a 24-story office building. Its base measures 65 feet in diameter. And the over-all weight of this monster rocket ship is 14,000,000 pounds, or 4,000 tons—about the same weight as a light destroyer.

Its three huge power plants are driven by a combination of nitric acid and hydrazine, the latter being a liquid compound of nitrogen and hydrogen somewhat resembling its better-known cousin ammonia. These propellants are fed into the rocket motors by means of turbopumps.

Fifty-one rocket motors, pushing with a combined thrust of 14,000 tons, power the first stage (tail section). These motors consume a total of 5,250 tons of propellants in the incredibly short time of 84 seconds. Thus, in less than a minute and a half, the rocket loses 75 percent of its total original weight.

The second stage (middle section), mounted on top of the first, has 34 rocket motors with a total thrust of 1,750 tons and burns 700 tons of propellants. It operates for only 124 seconds.

The third and final stage (nose section)—carrying the crew, equipment and payload—has five rocket motors with a combined thrust of 200 tons. This "Body" or cabin stage of the rocket ship carries 90 tons of propellants, including ample reserves for the return trip to earth. In addition, it is capable of carrying a cargo or payload of about 36 tons into our two-hour orbit 1,075 miles above sea level. (Also, in expectation of the turn trip, the nose section will have wings something like an airplane's. They will be used only during the decent, after re-entry the earth's atmosphere.)

Years before the actual take-off, smaller rocket ships, called instrument carriers, will have been sent up to the two-hour orbit. They will circle there, sending back information by the same electronic method already in use with current rockets. Based on the data thus obtained, scientists, astronomers and engineers, along with experts from the armed forces, will plan the complete development of the huge cargo-carrying rocket ship.

The choice of the take-off site poses another problem, because of the vast amount of auxiliary equipment—such as fuel storage tanks and machine shops, and other items like radio, radar, astronomical and meteorological stations—an extensive area is required. Furthermore, it is essential, for reasons which will be explained later that the rocket ship fly over the ocean during the early part of the flight. The tiny U.S. possession known as Johnston Island, in the Pacific, or the Air Force Proving Ground at Cocoa, Florida, are presently considered by the experts to be suitable sites.

At the launching area, the heavy rocket ship is assembled on a great platform. Then the platform is wheeled into place over a tunnel-like "jet deflector" which drains off the fiery gases of the first stage's rocket motors. Finally, with a mighty roar which is heard many miles away, the rocket ship slowly takes off—so slowly, in fact that in the first second is travels less then 15 feet. Gradually, however, it begins to pickup speed, and 20 seconds later it has disappeared into the clouds.

Because of the terrific acceleration which will be experienced one minute later, the crew—located of course, in the nose—will be lying flat in "contour" chairs at take-off, facing up. Throughout the whole of its flight to the two-hour orbit, the rocket is under the control of an automatic gyropilot. The timing of its flight and the various maneuvers which take place have to be so precise that only a machine can be trusted to do the job.

After a short interval, the automatic pilot tilts the rocket into a shallow path, by 84 seconds after take-off when, the fuels of the first stage (tail section) are nearly exhausted, the rocket ship is climbing at a gentle angle of 20.5 degrees.

When it reaches an altitude of 24.9 miles it will have a speed of 1.46 miles per second or 5,256 miles per hour. To enable the upper stages to break away from the tail or first stage the tail's power has to be throttled down to almost zero. The motors of the second stage now begin to operate, and the connection between the now-useless first stage and the rest of the rocket ship is severed. The tail section drops behind, while the two upper stages of the rocket ship forge ahead.

After the separation, a ring-shaped ribbon parachute, made of fine steal wire mesh, is automatically released by the first stage. This chute has a diameter of 27 feet and gradually it slows down the tail section. But under its own momentum, this empty hull continues to climb, reaching a height of 40 miles before slowly descending. It is because the tail section could be irreparably damaged if it struck solid ground (and might be dangerous, besides) that the initial part of the trip must be over sea. After the first stage lands in the water, it is collected and brought back to the launching site.

The same procedure is repeated 124 seconds later. The second stage (middle section) is dropped into the ocean. The rocket ship by this time has attained an altitude of 40 miles and 332 miles from the take-off site. It also has reached a tremendous speed—14,364 miles per hour.

Now the third and last stage—the nose section or cabin equipped space ship proper—proceeds under the power of its own rocket motors. Just 84 seconds after the dropping of the second stage, the rocket ship, now moving at 18,468 miles per hour reaches a height of 63.3 miles above the earth.

At this point we must recall the comparison between the rocket and the coasting rifle shell to understand what occurs. The moment the rocket reaches a speed of 18,468 miles per hour at an altitude of 63.3 miles, the motors are cut off even though the fuel supply is by no means exhausted. The rocket ship continues on an unpowered trajectory until it reaches 1,075 miles above the earth. This is the high point, or "apogee"; in this case it is exactly halfway around the globe from the cut-off place. The rocket ship is now in the two-hour orbit where we intend to build the space station.

* * *

Just one more maneuver has to be performed however. In coasting up from 63.3 miles to 1,075 miles, the rocket ship has been slowed by the earth's gravitational pull to 14,770 miles per hour. This is not sufficient to keep the ship in our chosen orbit. If we do not increase the speed the craft will swing back halfway around the earth to the 63.3 mile altitude. Then it would continue on past the earth until as it curves around to the other side of the globe, it would be back at the same apogee at the 1,075-mile altitude.

The rocket ship would already be a satellite and behave like a second moon in the heavens, swinging on its elliptical path over and over for a long time. One might ask: Why not be satisfied with this? The reason is that part of this particular orbit is in the atmosphere at only 63.3 miles. And while the air resistance there is very low, in time it would cause the rocket ship to fall back to earth.

Our chosen two-hour orbit is one which, at *all* points, is exactly 1,075 miles above the earth. The last maneuver which stabilizes the rocket ship in this orbit, is accomplished by turning on the rocket motors for about 15 seconds. The velocity is thus increased by 1,030 miles per hour bringing the total speed to 15,800 miles per hour. This is the speed necessary for remaining in the orbit permanently. We have reached our goal.

[29] An extraordinary fact about the flight from the earth is this: it has taken only

56 minutes, during which the rocket ship was powered for only five minutes.

From our vantage point, 1,075 miles up, the earth to the rocket ship's crew appears to be rotating once every two hours. This apparent fast spin of the globe is the only indication of the tremendous speed at which the rocket ship is moving. The earth, of course, still requires a full 24 hours to complete one revolution on its axis, but the rocket ship is making 12 revolutions around the earth during the time the earth makes one.

We now begin to unload the 36 tons of cargo which we have carried up with us. But how and where shall we unload the material? There is nothing but the blackness of empty space all around us.

We simply dump it out of the ship. For the cargo, too has become a satellite! So have the crew members. Wearing grotesque-looking pressurized suits and carrying oxygen for breathing they can now leave the rocket ship and float about unsupported.

Just as a man on the ground is not conscious of the fact that he is moving with the earth around the sun at the rate of 66,600 miles per hour, so the men in the space ship are not aware of the fantastic speed with which they are going around the earth. Unlike men on the ground, however, the men in space do not experience any gravitational pull. If one of them, while working, should drift off into space, it will be far less serious than slipping off a scaffold. Drifting off merely means that the man has acquired a very slight speed in an unforeseen direction.

He can stop himself in the same manner in which any speed is increased or stopped in space—by reaction. He must do this, theoretically, by firing a revolver in the direction of his inadvertent movement. But in actual practice the suit will be equipped with small rocket motor. He could also propel himself by squirting some compressed oxygen from a tank on his back. It is highly probable, however, that each crew member will have a safety line securing him to the rocket as he works. The tools he uses will also be secured to him by lines; otherwise they might float away into space.

* * *

The spacemen—for that is what the crew members now are—will begin sorting the equipment brought up. Floating in strange positions among structural units and machinery, their work will proceed in absolute silence, for there is no air to carry sound. Only when two people are working on the same piece of material, both actually touching it, will one be able to hear the noises made by another, because sound is conducted by most materials. They will, however, be able to converse with built-in "walkie-talkie" radio equipment. The cargo moves easily; there is no weight, and no friction. To push it, our crew member need only turn on his rocket motor (if he shoved a heavy piece of equipment without rocket power, he might fly backward!).

Obviously the pay load of our rocket ship—though equivalent to that of two huge Super Constellations—will not be sufficient to begin construction of the huge, three-deck, 250-foot-wide space station. Many more loads will be required. Other rocket ships, all timed to arrive at the same point in a continuous procession as the work progresses, will carry up the reminder of the prefabricated satellite. This will be an expensive proposition. Each rocket trip will cost more than half a million dollars *for propellants alone.* Thus, weight and shipping space limitations will greatly affect the specifications of a space station.

In at least one design, the station consists of 20 sections made of flexible nylon-and-plastic fabric. Each of these sections is an independent unit which later, after assembly into a closed ring, will provide compartmentation similar to that found in submarines. To save shipping space, these sections will be carried to the orbit in a collapsed condition. After the "wheel" has been put together and sealed, it will then be inflated like an automobile tire to slightly less than normal atmospheric pressure. This pressure will not only provide a breathable atmosphere within the ring but will give the whole structure its necessary rigidity. The atmosphere will, of course, have to be renewed as the men inside exhaust it.

On solid earth, most of our daily activities are conditioned by gravity. We put something on a table and it stays there because the earth attracts it, pulling it against the table. When we pour a glass of milk, gravity draws it out of the bottle and we catch falling liquid in a glass. In space, however, everything is weightless. And this includes man.

This odd condition in no way spells danger, at least for a limited period of time. We experience weightlessness for short periods when we jump from a diving board into a pool. To be sure, there are some medical men who are concerned at the prospect of permanent weightlessness—not because of any known danger, but because of the unknown possibilities. Most experts discount these nameless fears.

However, there can be no doubt that permanent weightlessness might often prove inconvenient. What we require, therefore, is a "synthetic" gravity within the space station. And we can produce centrifugal force—which acts as a substitute for gravity—by making the "wheel" slowly spin about its hub (a part of which can be made stationary).

To the space station proper, we attach a tiny rocket motor which can produce enough power to rotate the satellite. Since [72] there is no resistance which would slow the "wheel" down, the rocket motor does not have to function continuously. It will operate only long enough to give the desired rotation. Then it is shut off.

Now, how fast would we like our station to spin? That depends on how much "synthetic gravity" we want. If your 250-foot ring performed one full revolution every 12.3 seconds we would get a synthetic gravity equal to that which we normally experience on the ground. This is known as "one gravity" or, abbreviated, "1 g." For a number of reasons, it may be advantageous not to produce one full "g." Consequently, the ring can spin more slowly: for example, it might make one full revolution every 22 seconds, which would result in a "synthetic gravity" of about one third of normal surface gravity.

The centrifugal force created by the slow spin of the space station forces everything out from the hub. No matter where the crew members sit, stand or walk inside, their heads will always point toward the hub. In other words, the inside wall of the "wheel's" outer rim serves as the floor.

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How about the temperature within the space station? Maybe you, too have heard the old fairy tale that outer space is extremely cold—absolute zero. It's cold, all right but not that cold—and not in the satellite. The ironical fact is that the engineering problem in this respect will be to keep the space station comfortably cool, rather than to heat it up. In outer space, the temperature of any structure depends entirely on its absorption and dissipation of the sun's rays. The space station happens to be in the unfortunate position of receiving not only direct heat from the sun but also reflected heat from the earth.

If we paint the space station white, it will then absorb a minimum of solar heat. Being surrounded by a perfect vacuum, it will be, except for its shape, a sort of thermos bottle which keeps hot what is hot and cold what is cold.

In addition, we can scatter over the surface of the space station a number of black patches which, in turn, can be covered by shutters closely resembling white Venetian blinds. When these blinds are open on the sunny side, the black patches will absorb more heat and warm up the station. When the blinds are open on the shaded side, black patches will absorb more heat and warm up the station. When the blinds are open on the shaded side, the black patches will radiate more heat into space, thereby cooling the station. Operate all these blinds with little electric motors, hook them to a thermostat, and tie the whole system in with the station's air conditioning plant—and there's your temperature control system.

Inflating the space station with air will, as we have indicated, provide a breathable atmosphere for a limited time only. The crew will consume oxygen at a rate of approximately three pounds per man per day. At intervals, therefore, this life-giving oxygen will have to be replenished by supply ships from earth. At the same time, carbon dioxide and toxic or odorous products must be constantly removed from the air-circulation system.

The air must also be dehumidified inasmuch as through breathing and perspiration each crew member will loose more than three pounds of water per day to the air system (just as men do on earth).

This water can be collected in a dehumidifier, from which it can economically be salvaged, purified and reused.

Both the air-conditioning and water recovery units need power. So do the radar systems, radio transmitters, astronomical equipment, electronic cookers and other machinery. As a source for this power we have the sun. On the earth, solar power is reliable in only a few places where clouds rarely obscure the sky, but in space there are no clouds, and the sun is the simplest answer to the station's power needs.

Our power plant will consist of a condensing mirror and boiler. The condensing mirror will be a highly polished sheet metal trough running around the "wheel." The position of the space station can be arranged so that the side to which the mirror is attached will always point toward the sun. The mirror then focuses the sun's rays on a steel pipe which runs the length of the mirrored trough. Liquid mercury is fed under pressure into one end of this pipe and hot mercury vapor is taken out at the other end. This vapor drives a turbogenerator which produces about 500 kilowatts of electricity.

Of course, the mercury vapor has to be used over and over again so after it has done its work in the turbine it is returned to the "boiler" pipe in the mirror. Before this can be done, the vapor has to be condensed back into liquid mercury by cooling. This is achieved by passing the vapor through pipes located behind the mirror in the shade. These pipes dissipate the heat of the vapor into space.

Thus we have within the space station a complete synthetic environment capable of sustaining man in space. Of course, man will face hazards—some of them, like cosmic radiation and possible collision with meteorites, potentially severe. These problems are being studied, however, and they are considered far from insurmountable.

Our "wheel" will not be alone in the two-hour orbit. There will nearly always be one or two rocket ships unloading supplies. They will be parked some distance away to avoid the possibility of damaging the space station by collision or by the blast from the vehicle's rocket motors. To ferry men and materials from rocket ship to space station, small rocket-powered metal craft of limited range, shaped very much like overgrown watermelons, will be used. These "space taxis" will be pressurized and, after boarding them, passengers can remove their space suits.

On approaching the space station, the tiny shuttle-craft will drive directly into an air lock at the top or bottom of the stationary hub. The space taxi will be built to fit exactly into the airlock, sealing the opening like a plug. The occupants can then enter the space station proper without having been exposed to the airlessness of space at any time since leaving the air lock of the rocket ship.

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There will also be a space observatory, a small structure some distance away from the main satellite, housing telescopic cameras for taking long exposure photographs. (The space station itself will carry extremely powerful cameras but its spin, though slow, will permit only slow exposures.) The space observatory will not be manned, for if it were, the movements of an operator would disturb the alignment. Floating outside the structure in space suits, technicians will load a camera with special plates or film, and then withdraw. The camera will be aimed and the shutter snapped by remote radio control from the space station.

Most of the pictures taken of the earth, however, will be by the space station's cameras. The observatory will be used manly to record the outer reaches of the universe, from the neighboring planets to the distant galaxies of stars. This mapping of the heavens will produce results which no observatory on earth could possibly duplicate. And, while the scientists are probing the secrets of the universe with their cameras, they will also be planning another trip through space—this time to examine the moon.

Suppose we take the power plant out of our rocket ship's last stage and attach it to a lightweight skeleton frame of aluminum girders. Then we suspend some large collapsible fuel containers in this structure and fill them with propellants. Finally, we connect some plumbing and wiring and top the whole structure with a cabin for the crew, completely equipped with air and water regeneration systems, and navigation and guidance equipment.

The result will be an oddly shaped vehicle [73] not much larger than the rocket ship's third stage, but capable of carrying a crew of several people to a point beyond the rear side of the moon, then back to the space station. This vehicle will bear little resemblance to the moon rockets depicted in science fiction. There is a very simple reason: conventional streamlining is not necessary in space.

The space station, as mentioned previously has a speed of 15,840 miles per hour. Our round-the-moon ship, to leave the two hour orbit, has to have a speed of 22,100 miles per hour to cover the 238,000 mile distance to the moon. This additional speed is acquired by means of a short rocket blast lasting barely two minutes. This throws the round-the-moon ship into a long arch or ellipse, with its remotest point beyond the moon. The space ship will then coast out this distance, unpowered, like a thrown stone. It will lose speed along the way, due to the steady action of the earth's gravitational pull—which, though weakening with distance extends far out into space.

Roughly five days after departure, the space ship will come almost to a standstill and if we have timed our departure correctly the moon will now pass some 200 miles below us with the earth on its far side. On this one trip we can photograph most of the unknown half of the moon, the half which has never been seen from the earth. Furthermore, we now have an excellent opportunity to view the earth from the farthest point yet, at this distance it appears not unlike a miniature reproduction of itself (from the vicinity of the moon the earth will look about four times as large as the full moon does to earth-bound man).

It is not necessary to turn on the space ship's motors for the return trip. The moon's gravity is too slightly to affect us substantially; like the shell which was fired vertically we simply "fall back" to the space station's orbit. The long five day "fall" causes the space ship to regain its initial speed of 22,100 miles per hour. This is 6,340 miles faster than the speed of the space station, but, as we have fallen back tail first, we simply turn on the motors for just two minutes, which reduces our speed to the correct rate which permits us to re-enter the two-hour orbit.

* * *

Besides its use as a springboard for the exploration of the solar system, and as a watchdog of the peace, the space station will have many other functions. Meteorologists, by observing cloud patterns over large areas of the earth, will be able to predict the resultant weather more easily more accurately and further into the future. Navigators on the seas and in the air will utilize the space station as a "fix" for it will always be recognizable.

But there will also be another possible use for the space station—and a most terrifying one. It can be converted into a terribly effective atomic bomb carrier.

Small winged rocket missiles with atomic war heads could be launched from the station in such a manner that they would strike their targets at supersonic speeds. By simultaneous radar tracking from both missile and target, these atomic-headed rockers could be accurately guided to any spot on the earth.

In view of the station's ability to pass over all inhabited regions on earth, such atom bombing techniques would offer the satellite's builders the most important tactical and strategic advance in military history. Furthermore its observers probably could spot in plenty of time any attempt by an enemy to launch a rocket aimed at colliding with the giant "wheel" and intercept it.

We have discussed how to get from the ground to the two-hour orbit, how to build the space station and how to get a look at the unknown half of the moon by way of a round trip from our station in space. But how do we return to earth?

Unlike the ascent to the orbit, which was controlled by an automatic pilot, the decent is in the hands of an experienced "space pilot."

To leave the two-hour orbit in the third stage, or nose section, of the rocket ship, the pilot slows down the vehicle in the same manner in which the returning around-the-moon ship slowed down. He reduces the speed by 1,070 miles per hour. Unpowered, the rocket ship the swings back toward the earth. After 51 minutes, during which we half circumnavigate the globe, the rocket ship enters the upper layers of the atmosphere. Again, it has fallen tail first; now the pilot turns it so that it enters the atmosphere nose first.

* * *

About 50 miles above the earth, due to our downward gravity powered swing from the space station's orbit our speed had increased to 18,500 miles per hour. At his altitude there is already considerable resistance.

With its wings and control surfaces, the rocket closely resembles an airplane. At first however, the wings do not have to carry the rocket ship. On the contrary, they must prevent it from soaring out of the atmosphere and back into the space station's orbit again.

His eyes glued to the altimeter, the pilot will push his control stick forward and force the ship to stay at an altitude of exactly 50 miles. At this height, the air resistance gradually slows the rocket ship down. Only then can the descent into the denser atmosphere begin, from there on the wings bear more and more of the ship's weight. After covering a distance of about 10,000 miles in the atmosphere, the rocket's speed will still be as high as 13,300 miles per hour. After another 3,000 miles the speed will be down to 5,760 miles per hour. The rocket ship will by now have descended to a height of 29 miles.

The progress of the ship through the upper atmosphere has been so fast that air friction has heated the outer metal skin of body and wings to a temperature of about 1,300 degrees Fahrenheit. The rocket ship has actually turned color, from steel blue to cherry red! This should not cause undo concern however inasmuch as we have heat resistant steels which can easily endure such temperatures. The canopy and windows will be built of double paned glass with a liquid coolant flowing between the panes. And the crew and cargo spaces will be properly heat-insulated and cooled by means of a refrigerator-type air conditioning system. Similar problems have already been solved on a somewhat smaller scale in present-day supersonic airplanes.

At a point 15 miles above the earth the rocket ship finally slows down to the speed of sound—roughly 750 miles per hour. From here on, it spirals down to the ground like a normal airplane. It can land on conventional landing gear, on a runway adjacent to the launching site. The touch-down speed will be approximately 65 miles per hour, which is less than that of today's air liners. And if the pilot should miss the runway a small rocket motor will enable him to circle once more and make a second approach.

After a thorough checkup, the third stage will be ready for another ascent into the orbit. The first and second stages (or tail and middle sections), which were parachuted down to the ocean, have been collected in specially made seagoing dry docks. They were calculated to fall at 189 miles and 906 miles respectively from the launching site. They will be found relatively undamaged, because at a point 150 feet above the water their parachute fall was broken by a set of cordite rockets which were automatically set off by a proximity fuse.

They, too, undergo a through inspection with some replacement of parts damaged by the ditching. Then all three stages are put together again in a towerlike hanger, right on the launching platform, and, after refueling and final check, platform and ship are wheeled out to the launching site—ready for another journey into man's oldest and last frontier: the heavens themselves.

THE END

Document I-14

[52] Man on the Moon: The Journey

By Dr. Wernher von Braun

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For five days, the expectation speeds through space on its historic voyage—50 men on three ungainly craft, bound for the great unknown

HERE is how we shall go to the moon. The pioneer expedition, 50 scientists and technicians, will take off from the space station's orbit in three clumsy-looking but highly efficient rocket ships. They won't be streamlined: all travel will be in space, where there is no air to impede motion. Two will be loaded with propellant for the five day, 239,000-mile trip and the return journey. The third, which will not return will carry only enough propellant for a one-way trip; the extra room will be filled with supplies and equipment for the scientists' six-week stay.

On the outward voyage, the rocket ships will hit a top speed of 19,500 miles per hour about 33 minutes after departure. Then the motors will be stopped and the ships will fall the rest of the way to the moon.

[53] Such a trip takes a great deal of planning. For a beginning we must decide what flight path to follow, how to construct the ships and where to land. But the project could be completed within the next 25 years. There are no problems involved to which we don't have the answers—or the ability to find them—right now.

First, where shall we land? We may have a wide choice, once we have had a close look at the moon. We'll get that look on a preliminary survey flight. A small rocket ship taking off from the space station will take us to within 50 miles of the moon to get pictures of its meteor-pitted surface—including the "back" part never visible from the earth.

We'll study the photographs for a suitable site. Several considerations limit our selection. Because the Moon's surface has 14,600,000 square miles—about one thirteenth that of the earth—we won't be able to explore more than a small area in detail, perhaps part of a section 500 miles in diameter. Our scientists want to see as many kinds of lunar features as possible, so we'll pick a spot of particular interest to them. We want radio contact with the earth so that means we'll have to stick to the moon's "face" for radio waves won't reach across space to any point the eye won't reach.

We can't land at the moon's equator because its noonday temperatures reach an unbearable 220-degrees Fahrenheit, more than hot enough to boil water. We can't land where the surface is too rugged because we need a flat place to set down. Yet the site can't be too flat either—grain sized meteors constantly bombard the moon at speeds of several miles a second; we have to set camp in a crevice where we have protection from these bullets.

There's one section of the moon that meets all our requirements, and unless something better turns up on closer inspection that's where we land. It's an area called *Sinus Rolis* or Dewy Bay on the northern branch of a plain known as *Oceanus Procellarum* or Stormy Ocean (so called by early astronomers who thought the moon's plains were great seas). Dr. Fred L. Whipple chairman of Harvard University astronomy department, says *Sinus Rolis* is ideal for our purposes—about 650 miles from the lunar north pole where the daylight temperature averages a reasonably pleasant 40 degrees and the terrain is flat enough to land on, yet irregular enough to hide [54] in. With a satisfactory site located we start detailed planning.

To save fuel and time, we want to take the shortest practical course. The moon moves around the earth in an elliptical path once every 27 $^1/_3$ days. The space station, our point of departure, circles the earth once every two hours. Every two weeks their paths are such that a rocket ship from the space station will intercept the moon in just five days. The best conditions for the return trip will occur two weeks later, and again two weeks after that with their stay limited to multiples of two weeks our scientists have set themselves a six week limit for the first exploration of the moon—long enough to accomplish some constructive research, but not long enough to require a prohibitive supply of essentials like liquid oxygen, water and food.

Six months before our scheduled take-off, we begin piling up construction materials, supplies and equipment at the space station. This operation is a massive, impressive one, involving huge shuttling cargo rocket ships, scores of hard working handlers, and tremendous amounts of equipment. Twice a day pairs of sleek rocket transports from the earth sweep into the satellite's orbit and swarms of workers unload the 36 tons of cargo each carries. With the arrival of the first shipment of material, work on the first of the three moon-going space craft gets underway picking up intensity as more and more equipment arrives.

The supplies are not stacked inside the space station; they're just left floating in space. They don't have to be secured and here's why: the satellite is traveling around the earth at 15,840 miles an hour; at that speed, it can't be affected by the earth's gravity, so it doesn't fall, and it never slows down because there's no air resistance. The same applies to any other object brought into the orbit at the same speed: to park beside the space station a rocket ship merely adjusts its speed to 15,840 miles per hour: and it, too, becomes a satellite. Crates moved out of its hold are traveling at the same speed in relation to the earth, so they also are weightless satellites.

As the weeks pass and the unloading of cargo ships continues, the construction area covers several littered square miles. Tons of equipment lie about—aluminum girders, collapsed nylon-and-plastic fuel tanks, rocket motor units, turbopumps, bundles of thin aluminum plates are a great many nylon bags containing smaller parts. It's a bewildering scene, but not to the moon-ship builders. All construction parts are color-coded—with blue tipped cross braces fitting into blue sockets red joining members keyed to others of the same color and so forth. Work proceeds swiftly.

In fact, the workers accomplish wonders, considering the obstacles confronting a man forced to struggle with unwieldy objects in space. The men move clumsily, hampered by bulky pressurized suits equipped with such necessities of space-life as air conditioning, oxygen tanks, walkie-talkie radios, and tiny rocket motors for propulsion. The work is laborious, for although objects are weightless they still have inertia. A man who shoves a one-ton girder makes it move all right but he makes himself move too. As his inertia is less than the girder's he shoots backward much farther than he pushes the big piece of metal forward.

The small personal rocket motors help the workers move some of the construction parts; the big stuff is hitched to space taxis, tiny pressurized rocket vehicles used for short trips outside the space station.

As the framework of the new rocket ships takes form; big, folded nylon-and plastic bundles are brought over. They're the personnel cabins; pumped full of air, they become spherical, and plastic astrodomes are fitted to the top of sides of each. Other sacks are pumped full of propellant and balloon into the shapes of globes and cylinders. Soon the three moon-going space ships begin to emerge in their final form. The two round-trip ships resemble and arrangement of hourglasses inside a metal framework; the one-way cargo carrier has much the same framework, but instead of hourglasses it has a central structure which looks like a great silo.

Dimensions of the Rocket Ship

Each ship is 160 feet long (nine feet more than the height of the Statue of Liberty) and about 110 feet wide. Each has at its base a battery of 30 rocket motors, and each is topped by the sphere which houses the crew members, scientists and technicians on five floors. Under the sphere are two long arms set on a circular track which enables them to rotate almost a full 360 degrees. These light booms which fold against the vehicles during take-off and landing to avoid damage, carry two vital pieces of equipment: a radio antenna dish for short-wave communication and a solar mirror generating power.

The solar mirror is a curved sheet of highly polished metal which concentrates the sun's rays on a mercury-filled pipe. The intense heat vaporizes the mercury, and the vapor drives a turbo-generator, producing 35 kilowatts of electric power—enough to run a small factory. Its work done, the vapor cools, returns to its liquid state and starts the cycle all over again.

Under the radio and mirror booms of the passenger ships hang 18 propellant tanks carrying nearly 800,000 gallons of ammonialike hydrazine (our fuel) and oxygen-rich nitric acid (the combustion agent). Four of the 18 tanks are outsized spheres, more than 33 feet in diameter. They are attached to light frames on the outside of the rocket ship's structure. More than half our propellant supply—580,000 gallons—is in these large balls: that's the amount needed for take-off. As soon as it's exhausted, the big tanks will be jetisoned. Four other large tanks carry propellant for the landing; they will be left on the moon.

We also carry a supply of hydrogen peroxide [56] to run the turbopumps which force the propellant into the rocket motors. Besides the 14 cylindrical propellant tanks and the four spherical ones, eight small helium containers are strung throughout the framework. The lighter-than-air helium will be pumped into partly emptied fuel tanks to keep their shape under acceleration and to create pressure for the turbopumps.

The cost of the propellant required for this first trip to the moon, the bulk of it used for the supply ships during the build-up period, is enormous—about $300,000,000, roughly 60 percent of the half-billion-dollar cost of the entire operation. (That doesn't count the $4,000,000,000 cost of erecting the space station, whose main purpose is strategic rather then scientific.)

The cargo ship carries only enough fuel for a one-way trip so it has fewer tanks; four discardable spheres like those on the passenger craft, and four cylindrical containers with 162,000 gallons of propellant for the moon landing.

In one respect, the cargo carrier is the most interesting of the three space vehicles. Its big silo-like storage cabin, 75 feet long and 36 feet wide, was built to serve a double purpose. Once we reach the moon and the big cranes folded against the framework have swung out and unloaded the 285 tons of supplies in a cylinder, the silo will be detached from the rest of the rocket ship. The winch-driven cables slung from the cranes will then raise half of the cylinder, in sections, which it will deposit on trailers drawn by tractors. The tractors will take them to a protective crevice on the moon's surface at the place chosen for our camp. Then the other lengthwise half will be similarly moved—giving us two ready-to-use Quonset huts.

Now that we have our space ships built and have provided ourselves with living quarters for our stay on the moon. A couple of important items remain; we must protect ourselves against two of the principal hazards of space travel, flying meteors and extreme temperatures.

For Protection Against Meteors

To guard against meteors, all vital parts of the three craft—propellant tanks, personnel spheres, cargo cabin—are given a thin covering of sheet metal, set on studs which leave at least one inch space between this outer shield and inside wall. The covering, called meter bumper, will take the full impact of the flying particles (we don't expect to be struck by any meteors much larger than a grain of sand) and will cause them to disintegrate before they can do damage.

For protection against excessive heat, all parts of the three rocket ships are painted white because white absorbs little of the sun's radiation. Then, to guard against cold, small black patches are scattered over the tanks and personnel spheres. The patches are covered by white blinds, automatically controlled by thermostats. When the blinds on the sunny side are open, the spots absorb heat and warm the cabins and tanks when the blinds are closed and all white surface is exposed to the sun permitting little heat to enter. When the blinds on the shaded side are open, the black spots radiate heat and the temperature drops.

Now we're ready to take off from the space station's orbit to the moon.

The bustle of our departure—hurrying space taxis, the nervous last-minute checks by engineers, the loading of late cargo and finally the take-off itself—will be watched by millions. Television cameras on the space station will transmit the scene to receivers all over the world. And people on the earth's dark side will be able to turn from their screens to catch a fleeting glimpse of light—high in the heavens—the combined flash of 90 rocket motors, looking from the earth like the sudden birth of a new short lived star.

Our departure is slow. The big rocket ships rise ponderously, one after the other, green flames streaming from their batteries of rockets, and then they pick up speed. Actually we don't need to gain much speed. The velocity required to get us to our destination is 19,500 miles an hour but we've had a running start, while "resting" in the space station's orbit, we are really streaking through space at 15,840 miles an hour. We need an additional 3,660 miles an hour.

Thirty-three minutes from take-off we have it. Now we cut off our motors; momentum and the moon's gravity will do the rest.

The moon itself is visible to us as we coast through space, but it's so far off one side that it's hard to believe we won't miss it. In the five days of our journey, though, it will travel a great distance and so will we; at the end of that time we shall reach the farthest point, or apogee, of our elliptical course, and the moon shall be right in front of us.

The earth is visible, too—an enormous ball most of it bulking pale black against the deeper black of space but with a wide crescent of day light where the sun strikes it. Within the crescent, the continents enjoying summer stand out as vast green terrain maps surrounded by the brilliant [58] blue of the oceans. Patches of white cloud obscure some of the detail; other white blobs are snow and ice on mountains ranges and polar areas.

Against the blackness of the earth's night side is a gleaming spot—the space station, reflecting the light of the sun.

Two hours and 54 minutes after departure we are 17,750 miles from the earth's surface. Our speed has dropped sharply to 10,500 miles and hour. Five hours and eight minutes en route, the earth is 32,950 miles away, and our speed is 8,000 miles an hour; after 20 hours, we're 132,000 miles from the earth traveling at 4,300 miles an hour.

On this first day, we discard the empty departure tanks. Engineers in protective suits step outside the cabin, stand for a moment in space, then make their way down the girders to the big spheres. They pump any remaining propellant into reserve tanks, disconnect the useless containers, and give them a gentle shove. For a while the tanks drift along beside us; soon they float out of sight. Eventually they will crash on the moon.

There is no hazard for the engineers in this operation. As a precaution they are secured to the ship by safety lines. But they could probably have done as well without them. There is no air in space to blow them away.

That's just one of the peculiarities of space to which we must adapt ourselves. Lacking a natural sequence of night and day, we live by an arbitrary time schedule. Because nothing has weight; cooking and eating are special problems. Kitchen utensils have magnetic strips or clamps so they won't float away. The heating of food is done on electronic ranges. They have many advantages: they're clean, easy to operate, and their short-wave rays don't burn up precious oxygen.

Difficulties of Dining in Space

We have no knives, spoons or forks. All solid food is precut; all liquids are served in plastic bottles and forced directly into the mouth by squeezing. Our mess kits had spring operated covers; our only eating utensils are tonglike devices; if we open the covers carefully, we can grab a mouthful of food without getting it all over the cabin.

From the start of the trip, the ship's crew has been maintaining a round-the-clock schedule, standing eight hour watches. Captains, navigators and radio men spend most of their time checking and rechecking our flight track, ready to start up the rockets for a change in course if an error turns up. Technicians back up this operation with reports from the complex and delicate "electronic brains"—computers, gyroscopes, switchboards and other instruments—on the control deck. Other specialists keep watch over the air-conditioning, temperature, pressure and oxygen systems.

But the busiest crew members are the maintenance engineers and their assistants, tireless men who been bustling back and forth between ships since shortly after the voyage started, anxiously checking propellant tanks, tubing, rocket motors, turbopumps and all other vital equipment. Excessive heat could cause dangerous hairline cracks in the rocket motors; unexpectedly large meteors could smash through the thin bumpers surrounding the propellant tanks; fittings could come loose. The engineers have to be careful.

We are still slowing down. At the start of the fourth day, our speed has dropped to 800 [59] miles an hour, only slightly more than the speed of a conventional jet fighter. Ahead, the harsh surface features of the moon are clearly outlined. Behind, the blue-green ball of the earth appears to be barely a yard in diameter.

Our fleet of unpowered rocket ships is now passing the neutral point between the gravitational fields of the earth and the moon. Our momentum has dropped off to almost nothing—yet we're about to pick up speed. For now we begin falling toward the moon, about 23,600 miles away. With no atmosphere to slow us we'll smash into the moon at 6,000 miles an hour unless we do something about it.

Rotating the Moon Ship

This is what we do: aboard each ship, near its center of gravity is a positioning device consisting of three fly-wheels set at right angles to one another and operated by electric motors. One of the wheels heads in the same direction as our flight path—in other words; along the longitudinal axis of the vehicle, like the rear wheels of a car. Another parallels the latitudinal axis, like steering wheel of an ocean vessel. The third lies along the horizontal axis like the rear steering wheel of a hook and ladder truck. If we start anyone of the wheels spinning it causes our rocket ship to turn slowly in the other direction (pilots know this "torque" effect as increased power causes a plane's propeller to spin more rapidly in one direction, the pilot has to fight his controls to keep the plane from rolling in the other direction).

The captain of our space ship orders the longitudinal flywheel set in motion. Slowly our craft begins to cartwheel; when it has turned a revolution, it stops. We are going toward the moon tail-end-first, a position which will enable us to brake our fall with our rocket motors when the right time comes.

Tension increases aboard the three ships. The landing is tricky—so tricky that it will be done entirely by automatic pilot, to diminish the possibility of human error. Our scientists compute our rate of descent, the spot at which we expect to strike; the speed and direction of the moon (it's traveling at 2,280 miles an hour at right angles to our path). These and other essential statistics are fed into a tape. The tape, based on the same principle as the player-piano roll and the automatic business-machine card, will control the automatic pilot. (Actually, a number of tapes intended to provide for all eventualities will be fixed up long before the flight, but last minute-checks are necessary to see which tape to use and to see whether a manual correction of our course is required before the autopilot takes over.)

Now we lower part of our landing gear—four spiderlike legs, hinged to the square rocket assembly, which have been folded against the framework.

As we near the end of our trip, the gravity of the moon which is still to one side of us, begins to pull us off our elliptical course, and we turn the ship to conform to this change of direction. At an altitude of 550 miles the rocket motors begin firing; we feel the shock of their blasts inside the personnel sphere and suddenly our weight returns. Objects which have been not secured before hand tumble to the floor. The force of the rocket motors is such that we have about one third our normal earth weight.

The final 10 minutes are especially tense. The tape-guided automatic pilots are now in full control. We fall more and more slowly, floating over the landing area like descending helicopters as we approach, the fifth leg of our landing gear—a big telescoping shock absorber which has been housed in the center of the rocket assembly is lowered through the fiery blast of the motors. The long green rocket flames being to slash against the baked lunar surface. Swirling clouds of brown-gray dust are thrown out sideways; they settle immediately instead of hanging in air, as they would on the earth.

The broad round shoe of the telescopic landing leg digs into the soft volcanic ground. If it strikes too hard an electronic mechanism inside it immediately calls on the rocket motors for more power to cushion the blow. For a few seconds, we balance on the single leg then the four outrigger legs slide out to help support the weight of the ship, and are locked into position. The whirring of machinery dies away. There is absolute silence. We have reached the moon.

Now we shall explore it.

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[21]

Is There Life on Mars?

By Dr. Fred L. Whipple

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Astronomers—planning to give the great red planet its closest scrutiny in history this summer—are nearer than ever before to answering the most fascinating question of all.

On July 2nd, the planet Mars, swinging through its lopsided orbit around the sun, will be closer to the earth than any time since 1941. All over the world scientists will train batteries of telescopes and cameras on the big red sphere in history's greatest effort to unravel some of the mystery surrounding this most intriguing of the planets.

Next to Venus, Mars is our closet planetary neighbor. Even so, it will be 40,000,000 miles away as it passes by this summer (compared to 250,000,000 miles at its farthest point from the earth); on the most powerful of telescopes it will look no larger than a coffee saucer. Still it will be close enough to provide astronomers important facts about its size, atmosphere and surface conditions—and the possibility that some kind of life exists there.

We already know a great deal.

Mars's diameter is roughly half the size of the earth, the Martian day is 24 hours, 37 minutes long, but its year is nearly twice as long as ours—67 Martian days. During daylight hours the temperature on Mars shoots into the eighties, but at night a numbing cold grips the planet; the temperature drops suddenly to 95 below zero, Fahrenheit.

There is no evidence of oxygen on Mars's thin blue atmosphere. Moreover, its atmospheric pressure is so low that an earth man couldn't survive without a pressurized suit. If life of any kind does exist on Mars it must be extremely rugged.

Through the telescope, astronomers can clearly see Mars's great reddish deserts, blue-tinted cloud formations and—especially conspicuous—its distinctive polar caps.

The Martian polar caps cover about 4,000,000 square miles in the wintertime—an area roughly half the size of the North American continent. But as they melt in spring strange blue-green areas develop near their retreating edges. Some months later these color patches, now covering great areas of the planet's surface turn brownish, finally in the deep of Martin Winter they're dark chocolate color. Do the seasonal color variations indicate some sort of planet vegetable life? That's one of the riddles we'd like to solve.

There's another big question mark: Mars's so-called canals. Although most modern astronomers have long since discounted the once popular theory that the faint tracings seen by some on Mars are actually a network of waterways (and, therefore perhaps constructed by intelligent beings), we still don't know what they are—or if they exist at all.

The "canals" have had a controversial history. They were first reported in 1877 by an Italian astronomer named Giovanni Schiaparelli who said he had seen delicate lines tracing a gridlike pattern over vast areas of the planet. He called them *canali*—"canals" or "channels."

Since Schaparelli, many astronomers (especially Dr. Percival Lowell, who established an observatory for the primary purpose of studying Mars) have reported observing the delicate vein-like lines. Others, just as keensighted, have spent years studying the Martian face without once seeing the disputed markings.

This year we may get an opportunity to clear up the canal confusion once and for all. An American team sponsored jointly by the National Geographic Society and Lowell Observatory, will photograph Mars from Bloemfontein, South Africa, where Mars will appear almost directly over head nightly during early July. The U.S. team, using new photographic techniques and the latest in fast film emulsions, expects to get the most detailed photographs of the planet yet obtained.

But great as the 1954 Mars observation program promises to be, it's only the curtain raiser for 1956, when Mars will approach to within 35,000,000 miles of the earth. Not for another 15 years, in 1971, will it be so close again.

When all the finding have been evaluated we may be able to make some intelligent guesses as to the possibilities of life on Mars. Chances are that bacteria are the only type of animal life which could exist in a planet's oxygenless atmosphere. There also may be some sort of tough primitive plant life—perhaps lichens or mosses which produce their own oxygen and water. Such plants might explain the changing colors of the Martian seasons.

There's one other possibility.

How can we say with absolute certainty that there isn't a different form of life existing on Mars—a kind of life that we know nothing about? We can't. There's only one way to find out for sure what is on Mars—and that's to go there.

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[22]

Can We Get to Mars?

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[23]

Man's trial-blazing journey to Mars will be a breath-taking experience —with problems to match

The first man who set out for Mars had better make sure they leave everything at home in apple-pie order. They won't get back to earth for more than two and a half years.

The difficulties of a trip to Mars are formidable. The outbound journey, following a huge arc 255,000,000 miles long, will take eight months—even with rocket ships that travel many thousands of miles an hour. For more than a year, the explorers will have to live on the great red planet, waiting for it to swing into a favorable position for the return trip. Another eight months will pass before the 70 members of the pioneer expedition set foot on earth again. All during that time, they will be exposed to a multitude of dangers and strains, some of them impossible to foresee on the basis of today's knowledge.

Will man ever go to Mars? I am sure he will—but it will be a century or more before he's ready. In that time scientists and engineers will learn more about the physical and mental rigors of interplanetary flight—and about the known dangers of life on another planet. Some of that information may become available within the next 25 years or so, through the erection of a space station above the earth (where telescope viewings will not be blurred by the earth's atmosphere) and through the subsequent exploration of the moon, as described in previous issues of Collier's.

Even now science can detail the technical requirements of a Mars expedition down to the last ton of fuel. Our knowledge of the laws governing the solar system—so accurate that astronomers can predict an eclipse of the sun to within a fraction of a second—enables scientists to determine exactly the speed a space ship must have to reach Mars, the course that will intercept the planet's orbit at exactly the right moment, the methods to be used for the landing, take-off and other maneuvering. [24] We know, from these calculations, that we already have chemical rocket fuels adequate for the trip.

Better propellants are almost certain to emerge during the next 100 years. In fact, scientific advances will undoubtedly make obsolete many of the engineering concepts on which this article, and the accompanying illustrations, are based. Nevertheless, it's possible to discuss the problems of a flight to Mars in terms of what is known today. We can assume, for example, that such an expedition will involve about 70 scientists and crew members. A force that size would require a flotilla of 10 massive space ships, each weighing more than 4,000 tons—not only because there's safety in numbers, but because of the tons of fuel, scientific equipment, rations, oxygen, water and the like necessary for the trip and for a stay of about 31 months away from earth.

All that information can be computed scientifically. But science can't apply a slide rule to man; he's the unknown quantity, the weak spot that makes a Mars expedition a project for the far distant, rather than the immediate, future. The 70 explorers will endure hazards and stresses the like of which no men before them have ever known. Some of these hardships must be eased—or at least better understood—before the long voyage becomes practical.

For months at a time, during the actual period of travel, the expedition members will be weightless. Can the human body stand prolonged weightlessness? The crews of rocket ships plying between the ground and earth's space station about 1,000 miles away will soon grow accustomed to the absence of gravity—but they will experience this odd sensation for no more than a few hours at a time. Prolonged weightlessness will be a different story.

Over a period of months in outer space, muscles accustomed to fighting the pull of gravity could shrink from disuse—just as do the muscles of people who are bedridden or encased in plaster casts for a long time. The members of a Mars expedition might be seriously handicapped by such a disability. Faced with a rigorous work schedule on the unexplored planet, they will have to be strong and fit upon arrival.

The problem will have to be solved aboard the space vehicles. Some sort of elaborate spring exercisers may be the answer. Or perhaps synthetic gravity could be produced aboard the rocket ships by designing them to rotate as they coast through space, creating enough centrifugal force to act as a substitute for gravity.

Far worse than the risk of atrophied muscles is the hazard of cosmic rays. An overdose of these deep-penetrating atomic particles, which act like the invisible radiation of an atomic-bomb burst, can cause blindness, cell damage and possibly cancer.

Scientists have measured the intensity of cosmic radiation close to the earth. They have learned that the rays dissipate harmlessly in our atmosphere. They also have deduced that man can safely venture as far as the moon without risking an overdose of radiation. But that's a comparatively brief trip. What will happen to men who are exposed to rays for months on end? There is no material that offers practical protection against cosmic rays—practical, that is for space travel. Space engineers could provide a barrier by making the cabin walls of lead several feet thick—but that would add hundreds of tons to the weight of the space vehicle. A more realistic plan might be to surround the cabin with the fuel tanks, thus providing the added safeguard of a two- or three- foot thickness of liquid.

The best bet would seem to be a reliance on man's ingenuity; by the time an expedition from the earth is ready to take off for Mars, perhaps in the mid-2000s, it is quite likely that researchers will have perfected a drug which will enable men to endure radiation for comparatively long periods. Unmanned rockets, equipped with instruments which send information back to earth, probably will blaze the first trail to our sister planet, helping to clear up many mysteries of the journey.

Small Meteors Could Do Little Damage

Meteors, for example. Many billions of these tiny bullets, most of them about the size of a grain of sand, speed wildly through space at speeds of more than 150,000 miles an hour. For short trips, we can protect space ships from these lightning fast pellets by covering all vital areas—fuel tanks, rocket motors, cargo bins, cabins and the like—with light metal outer shields called meteor bumpers. The tiny meteors will explode against this outer shell, leaving the inner skin of the ship—and the occupants—unharmed.

But in the 16 months of space travel required for a visit to mars, much larger projectiles might be encountered. Scientists know that the density of large meteors is greater near the red planet than it is around the earth. If, by some chance, a rock the size of a baseball should plow through the thin shell of one of the rocketships it could do terrible damage—especially if it struck a large solid object inside. A meteor that size, traveling at terrific speed, could explode with the force of 100 pounds of TNT. In the cabin of a space vehicle, such an explosion would cause tremendous destruction.

Fortunately, meteors that size will be extremely rare, even near Mars.

Dime-sized chunks are more likely to be encountered. They will be a danger, too, although not so bad as the larger rocks. They'll rip through the bumper and skin like machine-gun bullets. If they strike anything solid, they'll explode with some force. If not, they'll leave through the other side of the ship—but even then they may cause trouble. Holes will have to be plugged to maintain cabin pressure. The shock wave created by the meteors' extreme speed may hurt the ship's occupants: there will be a deafening report and a blinding flash; the friction created by their passage through the cabin atmosphere will create enough heat to singe the [25] eyebrows of a man standing close by. And, of course, a person in the direct path of a pebble-sized meteor could be severely injured. A fragile piece of machinery could be destroyed, and it's even possible that the entire rocket ship would have to be abandoned after sustaining one or more hits by space projectiles that size (astronomers estimate that one out of 10 ships on a 16-month voyage might be damaged badly, although even that is unlikely).

If one of the Mars-bound vehicles does suffer serious damage, the incident needn't be disastrous. In a pinch, a disabled space vehicle can be abandoned easily. All of the ships will carry small self propelled craft—space taxis—which are easily built and easily maneuvered. They will be fully pressurized, and will be used for routine trips between the ships of the convoy, as well as for emergencies. If for some reason the space taxis aren't available to the occupants of a damaged ship, they will be able to don pressurized suits and step calmly out into space. Individual rocket guns, manually operated, will enable each of them to make his way to the nearest spaceship in the convoy. Space suited explorers will have no difficulty traveling between ships. There's no air to impede motion, no gravitational pull and no sense of speed. When they leave their ship the men will have to overcome only their own inertia. They'll be traveling through the solar system at more than 70,000 miles an hour, but they will be no more aware of it then we on earth are aware that every molecule of our bodies is moving at a speed of 66,600 miles an hour around the sun.

Science ultimately will solve the problems posed by cosmic rays, meteors and other natural phenomena of space. But man will still face one great hazard: himself.

Man must breathe. He must guard himself against a great variety of illnesses and ailments. He must be entertained. And he must be protected from many psychological hazards, some of them still obscure.

How will science provide a synthetic atmosphere within the space-ship cabins and Martian dwellings for two and a half years? When men are locked into a confined, airtight area for only a few days or weeks oxygen can be replenished, and exhaled carbon dioxide and other impurities extracted, without difficulty. Submarine engineers solved the problem long ago. But a conventional submarine surfaces after a brief submersion and blows out its stale air. High-altitude pressurized aircraft have mechanisms which automatically introduce fresh air and expel contaminated air.

There's no breathable air in space or on Mars; the men who visit the red planet will have to carry with them enough oxygen to last many months.

When Men Live Too Close Together

During that time they will live, work and perform all bodily functions within the cramped confines of a rocket-ship cabin or a pressurized—and probably mobile—Martian dwelling. (I believe the first men to visit Mars will take along inflatable, spherical cabins, perhaps 30 feet across, which can be mounted atop tractor chassis.) Even with plenty of oxygen, the atmosphere in those living quarters is sure to pose a problem.

Within the small cabins, the expedition members will wash, perform personal functions, sweat, cough, cook, create garbage. Every one of those activities will feed poisons into the synthetic air—just as they do within the earth's atmosphere.

No less than 29 toxic agents are generated during the daily routine of the average American household. Some of them are body wastes, others come from cooking. When you fry an egg, the burned fat releases a potent irritant called acrolein. Its effect is negligible on earth because the amount is so small that it's almost instantly dissipated in the air. But that microscopic quantity of acrolein in the personnel quarters of a Mars expedition could prove dangerous; unless there was some way to remove it from the atmosphere it would be circulated again and again through the air-conditioning system.

Besides the poisons resulting from cooking and the like, the engineering equipment—lubricants, hydraulic fluids, plastics, the metals in the vehicles—will give off vapors which could contaminate the atmosphere.

What can be done about this problem? No one has all the answers right now, but there's little doubt that by using chemical filters, and by cooling and washing the air as it passes through the air-conditioning apparatus, the synthetic atmosphere can be made safe to live in.

Besides removing the impurities from the man-made air, it may be necessary to add a few. Man has lived so long with the impurities in the earth's atmosphere that no one knows whether he can exist without them. By the time of the Mars expedition, the scientists may decide to add traces of dust, smoke and oil to the synthetic air—and possibly iodine and salt as well.

I am convinced that we have, or will acquire, the basic knowledge to solve all the physical problems of a flight to Mars. But how about the psychological problem? Can a man retain his sanity while cooped up with many other men in a crowded area, perhaps twice the length of your living room, for more then thirty months?

Share a small room with a dozen people completely cut off from the outside world. In a few weeks the irritations begin to pile up. At the end of [26] a few months, particularly if the occupants of the room are chosen haphazardly, someone is likely to go berserk. Little mannerisms—the way a man cracks his knuckles, blows his nose, the way he grins, talks or gestures—create tension and hatred which could lead to murder.

Imagine yourself in a space ship millions of miles from earth. You see the same people every day. The earth, with all it means to you, is just another bright star in the heavens; you aren't sure you'll ever get back to it. Every noise about the rocket ship suggests a breakdown, every crash a meteor collision. If somebody does crack, you can't call off the expedition and return to earth. You'll have to take him with you.

The psychological problem probably will be at its worst during the two eight-month travel periods. On Mars, there will be plenty to do, plenty to see. To be sure, there will be certain problems on the planet, too. There will be considerable confinement. The scenery is likely to be grindingly monotonous. The threat of danger from some unknown source will hang over the explorers constantly. So will the knowledge that an extremely complicated process, subject to possible breakdown, will be required to get them started on their way back home. Still, Columbus's crew at sea faced much the same problems the explorers will face on Mars: the fifteenth-century sailors felt the psychological tension, but no one went mad.

But Columbus traveled only ten weeks to reach America; certainly his men would never have stood an eight-month voyage. The travelers to Mars will [27] have to, and psychologists undoubtedly will make careful plans to keep up the morale of the voyagers.

The fleet will be in constant radio communication with the earth (there probably will be no television transmission, owing to the great distance). Radio programs will help relieve the boredom, but it's possible that the broadcasts will be censored before transmission; there's no way of telling how a man might react, say, to the news that his home town was the center of a flood disaster. Knowing would do him no good—and it might cause him to crack.

Besides radio broadcasts, each ship will be able to receive (and send) radio pictures. There also will be films which can be circulated among the space ships. Reading matter will probably be carried in the form of microfilms to save space. These activities—plus frequent intership visiting, lectures and crew rotations—will help to relieve the monotony.

There is another possibility, seemingly fantastic but worth mentioning briefly because experimentation already has indicated it may be practical. The nonworking members of a Mars expedition may actually hibernate during part of the long voyage. French doctors have induced a kind of artificial hibernation in certain patients for short periods in connection with operations for which they will need all their strength (Collier's December 11, 1953—Medicine's New Offensive Against Shock, by J.D. Ratcliff). The process involves a lowering of the body temperature, and the subsequent slowing down of all normal physical processes. On a Mars expedition, such a procedure, over a longer [28] period, would solve much of the psychological problem, would cut sharply into the amount of food required for the trip, and would, if successful, leave the expedition members in superb physical condition for the ordeal of exploring the planet.

Certainly if a Mars expedition were planned for the next 10 or 15 years, no one would seriously consider hibernation as a solution for any of the problems of the trip. But we're talking of a voyage to be made 100 years from now; I believe that if the French experiments bear fruit, hibernation may actually be considered at that time.

Finally, there has been one engineering development which may also simplify both the psychological and physical problems of a Mars voyage. Scientists are on the track of a new fuel, useful only in the vacuum of space, which would be so economical that it would make possible far greater speeds for space journeys. It could be used to shorten the travel time, or to lighten the load of each space ship, or both. Obviously, a four- or six-month Mars flight would create far fewer psychological hazards than a trip lasting eight months.

In any case, it seems certain that members of an expedition to Mars will have to be selected with great care. Scientists estimate that only one person in every 6,000 will be qualified, physically, mentally and emotionally, for routine space flight. But can 70 men be found who will have those qualities—and also the scientific background necessary to explore Mars? I'm sure of it.

One day a century or so from now, a fleet of rocket ships will take off for Mars. The trip could be made with 10 ships launched from an orbit 1,000 miles out in space, that girdles our globe at its equator. (It would take tremendous power and vast quantities of fuel to leave directly from the earth. Launching a Mars voyage from an orbit about 1,000 miles out, far from the earth's gravitational pull, will require relatively little fuel.) The Mars-bound vehicles, assembled in the orbit, will look like bulky bundles of girders, with propellant tanks hung on the outside and great passenger cabins perched on top. Three of them will have torpedo-shaped noses and massive wings—dismantled, but strapped to their sides for future use. Those bullet noses will be detached and will serve as landing craft, the only vehicles that will actually land on the neighbor planet. When the 10 ships are 5,700 miles from the earth, they will cut off their rocket motors; from there on, they will coast unpowered toward Mars.

After eight months they will swing into an orbit around Mars, about 600 miles up, and adjust speed to keep from hurtling into space again. The expedition will take this intermediate step, instead of preceding directly to Mars, for two main reasons: first, the ships (except for the three detachable torpedo-shaped noses) will lack the streamlining required for flight in the Martian atmosphere; second, it will be more economical to avoid carrying all the fuel needed for the return to earth (which now comprises the bulk of the cargo) all the way down to Mars and then back up again.

Upon reaching the 600-mile orbit—and after some exploratory probings of Mars's atmosphere with unmanned rockets—the first of the three landing craft will be assembled. The torpedo nose will be unhooked, to become the fuselage of a rocket plane. The wings and set of landing skis will be attached, and the plane launched toward the surface of Mars.

The landing of the first plane will be made on the planet's snow covered polar cap—the only spot where there is any reasonable certainty of finding a smooth surface. Once down, the pioneer landing party will unload its tractors and supplies, inflate its balloon-like living quarters, and start on a 4,000 mile overland journey to the Martian equator, where the expedition's Main base will be set up (it is the most livable part of the planet—well within the area that scientists want most to investigate). At the equator, the advance party will construct a landing strip for the other two rocket planes. (The first landing craft will be abandoned at the pole.)

In all, the expedition will remain on the planet 15 months. That's a long time—but it still will be too short to learn all that science would like to know about Mars.

When, at last, Mars and the earth begin to swing toward each other in the heavens, and it's time to go back, the two ships that landed on the equator will be stripped of their wings and landing gear, set on their tails and, at the proper moment, rocketed back to the 600-mile orbit on the flat leg of the return journey.

What curious information will these first explorers carry back from Mars? Nobody knows—and its extremely doubtful that anyone now living will ever know. All that can be said with certainty today is this: the trip can be made, and will be made...someday.

Document I-17

Document title: Statement by James C. Hagerty, The White House, July 29, 1955.

Source: NASA Historical Reference Collection, NASA History Office, NASA Headquarters, Washington, D.C.

NSC 5520, "Draft Statement of Policy on U.S. Scientific Satellite Program," recommended the creation of a scientific satellite program as part of the International Geophysical Year (IGY) as well as the development of satellites for reconnaissance purposes. Based upon this report, the National Security Council approved the IGY satellite on May 26, 1955. However, it was not until July 28 that a public announcement was made during an oral briefing at the White House. The formal statement was dated July 29. This statement emphasized that the satellite program was intended to be the U.S. contribution to the IGY and that the scientific data was to benefit scientists of all nations.

July 29, 1955

The White House

Statement by James C. Hagerty

On behalf of the President, I am now announcing that the President has approved plans by this country for going ahead with launching of small unmanned earth-circling satellites as part of the United States participation in the International Geophysical Year which takes place between July 1957 and December 1958. This program will for the first time in history enable scientists throughout the world to make sustained observations in the regions beyond the earth's atmosphere.

The President expressed personal gratification that the American program will provide scientists of all nations this important and unique opportunity for the advancement of science.

Documents I-18 and I-19

Document title: F.C. Durant, "Report of Meetings of Scientific Advisory Panel on Unidentified Flying Objects Covered by Office of Scientific Intelligence, CIA, January 14-18, 1953," February 16, 1953.

Document title: "Air Force's 10 Year Study of Unidentified Flying Objects," Department of Defense, Office of Public Information, News Release No. 1083-58, November 5, 1957.

Sources: NASA Historical Reference Collection, NASA History Office, NASA Headquarters, Washington, D.C.

This CIA report on Unidentified Flying Objects (UFOs), which was declassified in December 1974, is frequently cited by UFO conspiracy theorists who claim that the government is covering up knowledge of extraterrestrial visits. Several studies of UFOs were conducted by the U.S. military throughout the 1950s and 1960s, partly out of Cold War concern that UFOs were actually Soviet spycraft, and partly in response to public outcry.

Document I-18

Report of Meetings of the Office of Scientific Intelligence Scientific Advisory Panel on Unidentified Flying Objects

Covered by Office of Scientific Intelligence, CIA

January 14–18, 1953

[1] MEMORANDUM FOR: Assistant Director for Scientific Intelligence

FROM: F. C. Durant

SUBJECT: Report of Meetings of the Office of Scientific Intelligence Scientific Advisory Panel on Unidentified Flying Objects, January 14 - 18, 1953

PURPOSE:

The purpose of this memorandum is to present:

a. A brief history of the meetings of the O/SI Advisory Panel On Unidentified Flying Objects (Part I),

b. An unofficial supplement to the official Panel Report to AD/SI setting forth comments and suggestions of the Panel Members which they believed were inappropriate for inclusion in the formal report (Part II).

Part I: History of Meetings

General

After consideration of the subject of "unidentified flying objects" at the 4 December meeting of the Intelligence Advisory Committee, the following action was agreed:

"The Director of Central Intelligence will:
a. Enlist the services of selected scientists to review and appraise the available evidence in the light of pertinent scientific theories...."

Following the delegation of this action to the Assistant Director for Scientific Intelligence and preliminary investigation, [2] an Advisory Panel of selected scientists was assembled. In cooperation with the Air Technical Intelligence Center, case histories of reported sightings and related material were made available for their study and consideration.

Present at the initial meeting (0930 Wednesday, 14 January) were: Dr. H P. Robertson, Dr. Luis W. Alvares, Dr. Thornton Page, Dr. Samuel A. Goudsmit, Mr. Philip G. Strong, Lt. Col. Frederick C. E. Oder (P&E Division), Mr. David B. Stevenson (W&E Division), and the writer. Panel Member, Dr. Lloyd V. Berkner, was absent until Friday afternoon. Messrs. Oder and Stevenson were present throughout the sessions to familiarize themselves with the subject, represent the substantive interest of their Divisions, and assist in administrative support of the meetings. (A list of personnel concerned with the meetings is given in Tab A.)

Wednesday Morning

The AD/SI opened the meeting, reviewing CIA interest in the subject and action taken. This review included the mention of the O/SI Study Group of August 1952 (Strong, Eng, and Durant) culminating in the briefing of the DCI, the ATIC November 21 briefing, 4 December IAC consideration, visit to ATIC (Chadwell, Robertson and Durant), and O/SI concern over potential dangers to national security indirectly related to these sightings. Mr. Strong enumerated these potential dangers. Following this introduction, Mr. Chadwell turned the meeting over to Dr. Robertson as Chairman of the Panel. Dr. Robertson enumerated the evidence available and requested consideration of specific reports and letters be taken by certain individuals present (Tab B). For example, case histories involving radar or radar and visual sightings were selected for Dr. Alvares while reports of Green Fireball phenomena, nocturnal lights, and suggested programs of investigations were routed to Dr. Page. Following these remarks, the motion pictures of the sightings at Tremonton, Utah (2 July 1952) and Great Falls, Montana (15 August 1950) were shown. The meeting adjourned at 1200.

Wednesday Afternoon

The second meeting of the Panel opened at 1400. Lt. R. S. Neasham, USN, and Mr. Harry Woo of the USN Photo Interpretation Laboratory, Anacostia, presented the results of their analyses of the films mentioned above. This analysis evolved considerable discussion as elaborated upon below. Besides Panel members and CIA personnel, Capt. E. J. Ruppelt, Dr. J. Allen Nyack, Mr. Dewey J. Fournet, Capt. Harry B. Smith (2-e-2), and Dr. Stephen Possony were present.

Following the Photo Interpretation Lab presentation, Mr. E. J. Ruppelt spoke for about 40 minutes on ATIC methods of handling and evaluating reports of sighting and their efforts to improve the quality of reports. The meeting was adjourned at 1715.

Thursday Morning

The third and fourth meetings of the Panel were held Thursday, 15 January, commencing at 0900 with a two-hour break for luncheon. Besides Panel members and CIA personnel, Mr. Ruppelt and Dr. Hynak were present for both sessions. In the morning, Mr. Ruppelt continued his briefing on ATIC collection and analysis procedures. The Project STORK support at Battelle Memorial Institute, Columbus, was described by Dr. Hynek. A number of case histories were discussed in detail and a motion picture film of seagulls was shown. A two hour break for lunch was taken at 1200.

Thursday Afternoon

At 1400 hours Lt. Col. Oder gave a 40-minute briefing of Project TWINKLE the investigatory project conducted by the Air Force Meteorological Research Center at Cambridge, Mass. In this briefing he pointed out the many problems of setting up and manning 24-hour instrumentation watches of patrol cameras searching for sightings of U.F.O.'s.

At 1615 Brig. Gen. William N. Garland joined the meeting with AD/SI. General Garland expressed his support of the Panel's efforts and stated three personal opinions:

a. That greater use of Air Force intelligence officers in the field (for follow-up investigation) appeared desirable, but that they required thorough briefing.

b. That vigorous effort should be made to declassify as many of the reports as possible.

c. That some increase in the ATIC section devoted to U.F.O. analysis was indicated.

This meeting was adjourned at 1700.

Friday Morning

The fifth session of the Panel convened at 0900 with the same personnel present as enumerated for Thursday (with the exception of Brig. Gen. Garland).

From 0900–100 [6] there was general discussion and study of reference material. Also, Dr. Hynek read a prepared paper making certain observations and conclusions. At 1000 Mr. Fournet gave a briefing on his fifteen months experience in Washington as Project Office for U.F.O.'s and his personal conclusions. There was considerable discussion of individual case histories of sightings to which he referred. Following Mr. Fournet's presentation, a number of additional case histories were examined and discussed with Messrs. Fournet, Ruppelt, and Hynek. The meeting adjourned at 1200 for luncheon.

Friday Afternoon

This session opened at 1400. Besides Panel members and CIA personnel, Dr. Hynek was present. Dr. Lloyd V. Berkner, as Panel Member, was present at this meeting for the first time. Progress of the meetings was reviewed by the Panel Chairman and tentative [6] conclusions reached. A general discussion followed and tentative recommendations considered. It was agreed that the Chairman should draft a report of the Panel to AD/SI that evening for review by the Panel the next morning. The meeting adjourned at 1715.

Saturday Morning

At 0945 the Chairman opened the seventh session and submitted a rough draft of the Panel Report to the members. This draft had been reviewed and approved earlier by Dr. Berkner. The next two and one-half hours were consumed in discussion and revision of the draft. At 1100 the AD/SI joined the meeting and reported that he had shown and discussed a copy of the initial rough draft to the Director of Intelligence, USAF, whose reaction was favorable. At 1200 the meeting was adjourned.

Saturday Afternoon

At 1400 the eighth and final meeting of the Panel was opened. Discussions and rewording of certain sentences of the Report occupied the first hour. (A copy of the final report is appended as Tab C.) This was followed by a review of work accomplished by the Panel, and restatement of individual Panel Member's opinions and suggestions on details that were felt inappropriate for inclusion in the formal report. It was agreed that the writer would incorporate these comments in an internal report to the AD/SI. The material below represents this information.

Part VI: Comments and Suggestions of Panel

General

The Panel Members were impressed (as have been others, including O/SI personnel) in the lack of sound data in the great majority of case histories; also, in the lack of speedy follow-up due primarily to the modest size and limited facilities of the ATIC section concerned. Among the case histories of significant sightings discussed in detail were the following:

Bellefontaine, Ohio (1 August 1952); Tremonton, Utah (2 July 1952); Great Falls, Montana (15 August 1950); Yaak, Montana (1 September 1952); Washington, D.C. area (19 July 1952); and Haneda A.F.B., Japan (5 August 1952), Port Huran, Michigan (29 July 1952); and Presque Isle, Maine (10 October 1952).

After review and discussion of these cases (and about 15 others, in less detail), the Panel concluded that reasonable explanations could be suggested for most sightings and "by deduction and scientific method it could be induced (given additional data) that other cases might be explained in a similar manner." The Panel pointed out that because of the brevity of some sightings (e.g. 2-5 seconds) and the inability of the witnesses to express themselves clearly (sometimes) that conclusive explanations could not be expected for every case reported. Furthermore, it was considered that, normally, it would be a great waste of effort to try to solve most of the sightings, unless such action would benefit a training and educational program (see below). The writings of Charles Fort were referenced [8] to show that "strange things in the sky" had been recorded for hundreds of years. It appeared obvious that there was no single explanation for a majority of the things seen. The presence of radar and astronomical specialists on the Panel proved of value at once in their confident recognition of phenomena related to their fields. It was apparent that specialists in such additional fields as psychology, meteorology, aerodynamics, ornithology and military air operations would extend the ability of the Panel to recognize many more categories of little-known phenomena.

On Lack of Danger

The Panel concluded unanimously that there was no evidence of a direct threat to national security in the objects sighted. Instances of "Foo Fighters" were cited. These were unexplained phenomena sighted by aircraft pilots during World War II in both European and Far East theaters of operation wherein "balls of light" would fly near or with the aircraft and maneuver rapidly. They were believed to be electrostatic (similar to St. Elmo's fire) or electromagnetic phenomena or possibly light reflections from ice crystals in the air, but their exact cause or nature was never defined. Both Robertson and Alvarez had been concerned in the investigation of these phenomena, but David T. Griggs (Professor of Geophysics at the University of California at Los Angeles) is believed to have been the most knowledgeable person on this subject. If the term "flying saucers" had been popular in 1943–1945, these objects would [9] have been so labeled. It was interesting that in at least two cases reviewed that the object sighted was categorized by Robertson and Alvarez as probably "Foo Fighters" to date unexplained but not dangerous; they were not happy thus to dismiss the sightings by calling them names. It was their feeling that these phenomena are not beyond the domain of present knowledge of physical science, however.

Air Force Reporting System

It was the Panel's opinion that some of the Air Force concern over U.F.O.'s (notwithstanding Air Defense Command anxiety over fast radar tracks) was probably caused by public pressure. The result today is that the Air Force has instituted a fine channel for receiving reports of nearly anything anyone sees in the sky and fails to understand. This has been particularly encouraged in popular articles on this and other subjects, such as space travel and science fiction. The result is the mass receipt of low-grade reports which tend to overload channels of communication with material quite irrelevant to hostile objects that might some day appear. The Panel agreed generally that this mass of poor-quality reports containing little, if any, scientific data was of no value. Quite the opposite, it was possibly dangerous in having a military service foster public concern in "nocturnal meandering lights." The implication being, since the interested agency was military, that these objects were or might be potential direct threats to national security. Accordingly, the need for deemphasisation made itself apparent. Comments on a possible educational program are enumerated below.

Tab C

SCIENTIFIC ADVISORY PANEL ON UNIDENTIFIED FLYING OBJECTS

14 - 17 January 1953

Members	**Field of Competence**	**Organization**
Dr. H. P. Robertson (Chairman)	California Institute of Technology	Physics, weapons systems
Dr. Louis W. Alvares	University of California	Physics, radar
Dr. Lloyd V. Berkner	Associated Universities, Inc.	Geophysics
Dr. Samuel Goudsmit	Brookhaven National Laboratories	Atomic structure, statistical problems
Dr. Thornton Page	Office of Research Operations, Johns Hopkins University	Astronomy, Astrophysics
Associate Members		
Dr. J. Allan Hynek	Ohio State University	Astronomy
Mr. Frederick C. Durant	Arthur D. Little, Inc.	Rockets, guided missiles
Interviewees		
Brig. Gen. William M. Garland	Commanding General, ATIC	Scientific and technical intelligence
Dr. E. Marshall Chadwell	Assistant Director, O/SI, CIA	Scientific and technical intelligence
Mr. Ralph L. Clark	Deputy Assistant Director, O/SI, CIA	Scientific and technical intelligence

Document I-19

[1]

Air Force's 10 Year Study of Unidentified Flying Objects

November 5, 1957

In response to queries as to results of previous investigation of Unidentified Flying Object reports, the Air Force said today that after 10 years of investigation and evaluation of UFO's, no evidence has been discovered to confirm the existence of so-called "Flying Saucers."

Reporting, investigation, analysis and evaluation procedures have improved considerably since the first sighting of a "flying saucer" was made on 27 June 1947. The study and analysis of reported sightings of UFO's is conducted by a selected scientific group under the supervision of the Air Force.

Dr. J. Allen Hynek, Professor of Astrophysics and Astronomy at Ohio State University, is the Chief Scientific Consultant to the Air Force on the subject of Unidentified Flying Objects.

The selected, qualified scientists, engineers, and other personnel involved in these analyses are completely objective and open minded on the subject of "flying saucers." They apply scientific methods of examination to all cases in reaching their conclusions. The attempted identification of the phenomenon observed is generally derived from human impressions and interpretations and not from scientific devices or measurements. The data in the sightings reported are almost invariably subjective in nature. However, no report is considered unsuitable for study and categorization and no lack of valid evidence of physical matter in the case studies is assumed to be "prima facie" evidence that so-called "flying saucers" or interplanetary vehicles do not exist.

General categories of identification are balloons, aircraft, astronomical, other, insufficient data and unknowns.

Approximately 4,000 balloons are released in the U. S. every day. There are two general types of balloons: weather balloons and upper-air research balloons. Balloons will vary from small types 4 feet in diameter to large types 200 feet in diameter. The majority released at night carry running lights which often contribute to weird or unusual appearances when observed at night. This also holds true when observed near dawn or sunset because of the effect of the slant rays of the sun upon the balloon surfaces. The large balloons, if caught in jet streams, may assume a near horizontal position when partially inflated, and move with speeds of over 200 MPH. Large types may be [2] observed flattened on top. The effect of the latter two conditions can be startling even to experienced pilots.

Many modern aircraft, particularly swept and delta wing types, under adverse weather and sighting conditions are reported as unusual objects and "flying saucers." When observed at high altitudes, reflecting sunlight off their surfaces, or when only their jet exhausts are visible at night, aircraft can have appearances ranging from disc to rocket in shape. Single jet bombers having multi-jet pods under their swept-back wings have been reported as UFOs or "saucers" in "V" formation. Vapor trails will often appear to glow with fiery red or orange streaks when reflecting sunlight. Afterburners are frequently reported as UFOs.

The astronomical category includes bright stars, planets, meteors, comets, and other celestial bodies. When observed through haze, light fog, or moving clouds, the planets Venus, Mars, and Jupiter have often been reported as unconventional, moving objects. Attempts to observe astronomical bodies through hand-held binoculars under adverse sky conditions has been a source of many UFO reports.

The "other" category includes reflections, searchlights, birds, kites, blimps, clouds, sun-dogs, spurious radar indications, hoaxes, firework displays, flares, fireballs, ice crystals, bolides, etc., as examples: Large Canadian geese flying low over a city at night, with street lights reflecting off their bodies; searchlights playing on scattered clouds, appearing as moving disc-like shapes.

The insufficient data category include all sightings where essential or pertinent items of information are missing, making it impossible to form a valid conclusion. These include description of the size, shape or color of the object; direction and altitude; exact time and location; wind weather conditions, etc. This category is not used as a convenient way to get rid of what might be referred to as "unknowns." However, if the data received is insufficient or unrelated, the analysts must then place that particular report in this category. The Air Force needs complete information to reach a valid conclusion. Air Force officials stressed the fact that an observer should send a complete report of a bona fide sighting to the nearest Air Force activity. There the report will be promptly forwarded to the proper office for analysis and evaluation.

A sighting is considered an "unknown" when a report contains all pertinent data necessary to normally suggest at least one valid hypothesis on the cause or explanation of the sighting but when the description of the object and its maneuvers cannot be correlated with any known object or phenomenon. In its Project Blue Book Special Report #14, released in October, 1955, the Air Force showed that evaluated sightings in the "unknown" category had been reduced to 3 percent at that time.

Previously "unknown" sightings had been 9% in 1953 and 1954 and in the previous years "flying saucer" sightings had run as high as 20% "unknowns." Project Blue Book Special Report #14, covered "flying saucer" investigations from June 1947 to May 1955. Latest Air Force statistics show the number of unknowns has since been reduced to less than 2%.

[3] The following table presents the results of the evaluation of all reports received by the Air Force from the time that Project Blue Book, Special Report #14, was completed through June 1957. The table gives the percentage of all the reports received by the Air Force during each time period.

	1955 June thru December	1956	1957 January thru June
Balloons	27.4%	26.0%	26.4%
Aircraft	29.3%	24.6%	28.8%
Astronomical	20.1%	26.3%	24.4%
Other (Hoax, searchlight, birds, etc.)	12.3%	6.8%	6.4%
Insufficient Information	8.8%	14.1%	12.1%
Unknown	2.1%	2.2%	1.9%
TOTAL NUMBER OF SIGHTINGS	273	778	250

Air Force conclusions for the ten years of UFO sightings involving approximately 5,700 reports were: first, there is no evidence that the "unknowns" were inimical or hostile; second, there is no evidence that these "unknowns" were interplanetary space ships; third, there is no evidence that these unknowns represented technological developments or principles outside the range of our present day scientific knowledge; fourth, there is no evidence that these "unknowns" were a threat to the security of the country; and finally there was no physical or material evidence, not even a minute fragment, of a so-called "flying saucer" was ever found.

The Air Force emphasized the belief that if more immediate detailed objective observational data could have been obtained on the "unknowns" these too would have been satisfactorily explained.

A critical examination of the reports revealed that a high percentage of them were submitted by serious people, mystified by what they had seen and motivated by patriotic responsibility.

Reports of UFOs have aroused much interest on this subject throughout the country and a number of civilian clubs, committees and organizations have been formed to study or investigate air phenomena. These private organizations are not governmental agencies and do not reflect official opinion with respect to their theories or beliefs based upon observed phenomena or illusions.

No books, motion pictures, pamphlets, or other informational material on the subject of unidentified flying objects have been cleared, sponsored, or otherwise coordinated by the U. S. Air Force, with the exception of the official press releases issued by Headquarters, USAF, in Washington.

The Air Force, assigned the responsibility for the Air Defense of the United States, will continue to investigate, through the Air Defense Command, all reports of unusual aerial objects over the U.S., including objects that may become labeled Unidentified Flying Objects. The services of qualified scientists and technicians will continue to be utilized to investigate and analyze these reports, and periodic public statements will be made as warranted.

END

[1]

Summary

(Analysis of Reports of Unidentified Aerial Objects)

Reports of unidentified aerial objects (popularly termed "Flying saucers" or "flying discs") have been received by the U.S. Air Force since mid-1947 from many and diverse sources. Although there was no evidence that the unexplained reports of unidentified objects constituted a threat to the security of the United States, the Air Force determined that all reports of unidentified aerial objects should be investigated and evaluated to determine if "flying saucers" represented technological developments not known to this country.

In order to discover any pertinent trend or pattern inherent in the data, and to evaluate or explain any trend or pattern found, appropriate methods of reducing these data from reports of unidentified aerial objects to a form amenable to scientific appraisal were employed. In general, the original data upon which this study was bases consisted of impressions and interpretations of apparently unexplainable events, and seldom contained reliable measurements of physical attributes. This subjectivity of the data presented a major limitation to the drawing of significant conclusions, but did not invalidate the application of scientific methods of study.

The reports received by the U.S. Air Force on unidentified aerial objects were reduced to IBM punched-card abstracts of data by means of logically developed forms and standardized evaluation procedures. Evaluation of sighting reports, a crucial step in the preparation of the data for statistical treatment, consisted of an appraisal of the reports and the subsequent categorization of the object or objects described in each report. A detailed description of this phase of the study stresses the careful attempt to maintain complete objectivity and consistency.

Analysis of the refined and evaluated data derived from the original reports of sightings consisted of (1) a systematic attempt to ferret out any distinguishing characteristics inherent in the data of any of their segments, (2) a concentrated study of any trend or pattern found, and (3) an attempt to determine the probability that any of the UNKNOWNS represent observations of technological developments not known to this country.

The first step in the analysis of the data revealed the existence of certain apparent similarities between cases of objects definitely identified and those not identified. Statistical methods of testing when applied indicated a low probability that these apparent similarities were significant. An attempt to determine the probability that any of the

UNKNOWNS represented observations of technological developments not known to this country necessitated a thorough re-examination and re-evaluation of the cases of objects not originally identified; this led to the conclusion that this probability was very small.

[2] The special study which resulted in this report (Analysis of Reports of Unidentified Aerial Objects, 5 May 1955) started in 1953. To provide the study group with a complete set of files, the information cut-off date was established as of the end of 1952. It will accordingly be noted that the statistics contained in all charts and tables in this report are terminated with the year 1952. In these charts, 3201 cases have been used.

As the study progressed, a constant program was maintained for the purpose of making comparisons between the current cases received after 1 January 1953, and those being used for the report. This was done in order that any change or significant trend which might arise from current developments could be incorporated in the summary of this report.

The 1953 and 1954 cases show a general and expected trend of increasing percentages in the finally identified categories. They also show decreasing percentages in categories where there was insufficient information and those where the phenomena could not be explained. This trend had been anticipated in the light of improved reporting and investigating procedures.

Official reports on hand at the end of 1954 totaled 4834. Of these, 425 were produced in 1953 and 429 in 1954. These 1953 and 1954 individual reports (a total of 854), were evaluated on the same basis as were those received before the end of 1952. The results are as follows:

Balloons	16 per cent
Aircraft	20 per cent
Astronomical	25 per cent
Other	13 per cent
Insufficient Information	17 per cent
Unknown	9 per cent

As the study of the current cases progressed, it became increasingly obvious that if reporting and investigating procedures could be further improved, the percentages of those cases which contained insufficient information and those remaining unexplained would be greatly reduced. The key to a higher percentage of solutions appeared to be in rapid "on the spot" investigations by trained personnel. On the basis of this, a revised program was established by Air Force Regulation 200-2, Subject: "Unidentified Flying Objects Reporting" (Short Title: UFOB), dated 12 August 1954.

This new program, which had begun to show marked results before January 1955, provided primarily that the 4602d Air Intelligence Service Squadron (Air Defense Command) would carry out all field investigations. This squadron has sufficient units and is so deployed as to be able to arrive "on the spot" within a very short time after a report is received. After treatment by the 4602d Air Intelligence Service Squadron, all information is supplied to the Air Technical Intelligence Center for final evaluation. This cooperative program has resulted, since 1 January 1955, in reducing the insufficient information cases to seven percent and the unknown cases to three percent of the totals.

[3] The period 1 January 1955 to 5 May 1955 accounted for 131 unidentified aerial object reports received. Evaluation percentages of these are as follows:

Balloons	26 per cent
Aircraft	21 per cent
Astronomical	23 per cent
Other	20 per cent
Insufficient Information	7 per cent
Unknown	3 per cent

All available data were included in this study which was prepared by a panel of scientists both in an out of the Air Force. On the basis of this study it is believed that all the unidentified aerial objects could have been explained if more complete observational data had been available. Insofar as the reported aerial objects which still remain unexplained are concerned, there exists little information other than the impressions and interpretations of their observers. As these impressions and interpretations have been replaced by the use of improved methods of investigation and reporting, and by scientific analysis, the number of unexplained cases has decreased rapidly towards the vanishing point.

Therefore, on the basis of this evaluation of the information, it is considered to be highly improbably that reports of unidentified aerial objects examined in this study represent observations of technological developments outside of the range of present-day scientific knowledge. It is emphasized that there has been a complete lack of any valid evidence of physical matter in any case of a reported unidentified aerial object.