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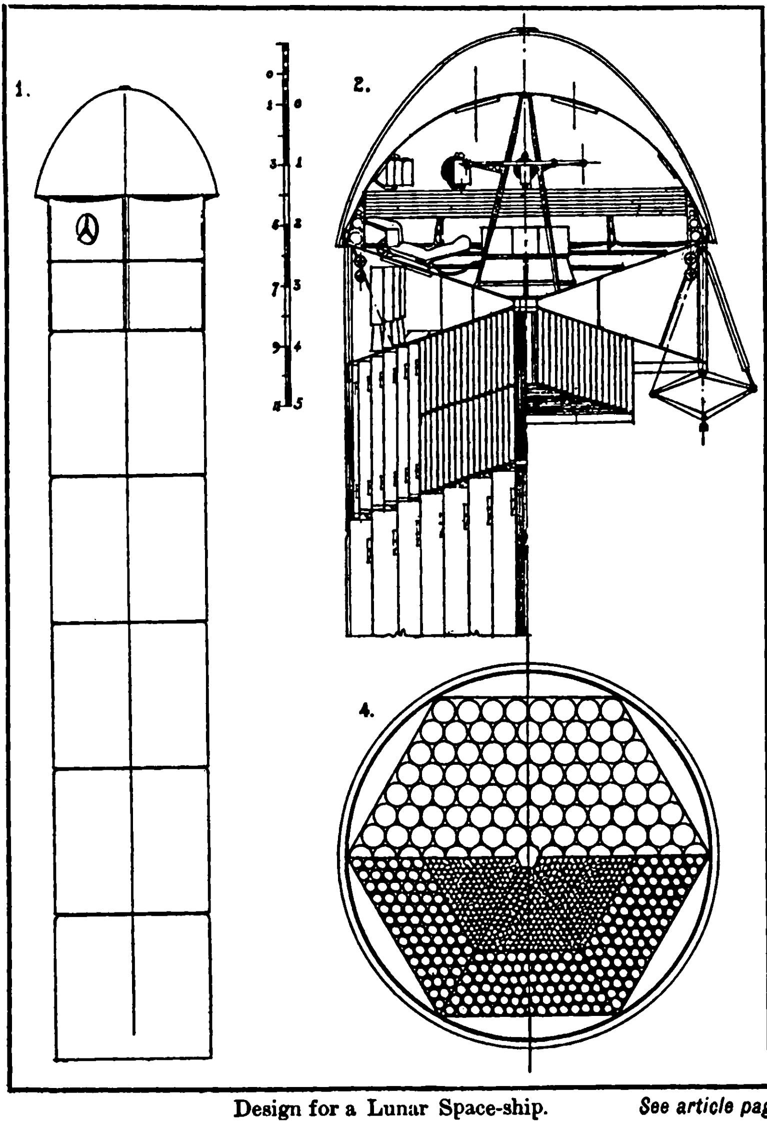

Design for a Lunar Space-ship. *See article page 4.*

THE BRITISH INTERPLANETARY SOCIETY

DEVOTED TO THE CONQUEST OF SPACE

"Founded for the stimulation of public interest in the possibility of interplanetary travel, the dissemination of knowledge concerning the problems which the epock-making achievement of an extra-terrestrial voyage involves, and the conducting of practical research in connection with such problems."

Constitution of the Society.

Headquarter's Address: 88 Grays Inn Road, London, W.C.1
Secretary: 13 Park Avenue, Wood Green, London, N.22

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All members receive free copies of the Society's publications, as well as such available literature obtainable from other Rocket Societies.

THE RESEARCH FUND

The Research Fund has been established for the purpose of financing rocket and other astronautical research in the British Isles. All contributions should be sent to the Treasurer, and requests for further particulars from the Hon. Secretary.

Neither the Society as a body nor the Editor hold themselves responsible for the statements made or the opinions expressed by contributors to the Journal.

ON THE COVER OF THIS ISSUE

is a drawing of the B.I.S. space-ship, further details of which are shown on page 7. The scale is in meters; diagrams 2 and 4 are on twice the scale of the others. For description see article on page 4.

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BRITISH INTERPLANETARY SOCIETY

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EDITORIAL

Let us stand back and take a detached view of the B.I.S. What is this miscellaneous group of people from all walks of life, from the hard-headed engineer and qualified architect to the enthusiastic schoolboy, from the City clerk to the sociological philosopher ? What do they want ?

There are the "technical" people, the mechanics and chemists, who believe in the future of the rocket motor as a means of swift transport. To them it is a new branch of engineering research, and accordingly must be developed as far as possible. So they join to keep in touch with the latest research, to keep track of the knotty problems as they are unravelled.

There are the idealists, the people who believe that one day man will cross outer space to the planets, and they join the B.I.S. to further that end. Whether or not a rocket will be the **Santa Maria** of Space they do not care, so long as a spaceship of some design is produced eventually. Generally their enthusiasm is equalled only by their ignorance of technical matters. They are the half-inarticulate lookers-on, eager to help, yet not quite knowing how, and constantly and unnecessarily fearful of a snub for their technical shortcomings.

But the most to be envied are those who are a combination of both : the idealistic practical men, the practical idealists. For they have enough technical knowledge to know that Space **can** be crossed, and enough idealism to believe it worth while. And it is this group of people who have evolved the space-ship design presented in this **Journal.**

Space travel is not a dream of the far future, you idealists ! And none of the practical problems is insoluble, you technicians ! A voyage to the Moon is possible at this moment. If the rest of the B.I.S. had worked as hard as certain members of it have, if but a fraction of the money thrown away on armaments had been devoted to this purpose, the lunar trip would be an historical fact by now. Man would be conquering new worlds instead of destroying his own.

All along, the B.I.S. has been hobbled by lack of finance, by the narrow conservatism of the specialized scientists, by ridicule, by misunderstanding, by lack of proper workshops and workmen, and largely by lack of time. There are members whose impatience with these obstacles has diverted their enthusiasm to things which give more immediate satisfaction. They have an excuse, for life is overcrowded and uncertain to-day, and people are inclined to gather the rosebuds while they may under the threat of an approaching storm of war.

But Mr. Olaf Stapledon, a member of the B.I.S., said of the hero of one of his novels : " He had already begun to feel an obscure impulse to devote himself to ends beyond private gratification . . . . ".

That instinct to serve some cause which will outlast us is part of the make-up of normal man, and he seeks to satisfy it in various ways, through religion, art, patriotism, or social reform. The B.I.S. has chosen exploration, to help in the work of pushing the boundaries of known territory as far as we can, sheer across the universe if possible.

This present civilization may collapse, as several have before it, and as more may after it. But sooner or later man will stand astride worlds, and the part, however small, the B.I.S. plays in achieving that end will have justified its existence.

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 cans, 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*) of fuel to take a 1 tonne

* A metric tonne is roughly equivalent to an English ton.

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 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, provided 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.

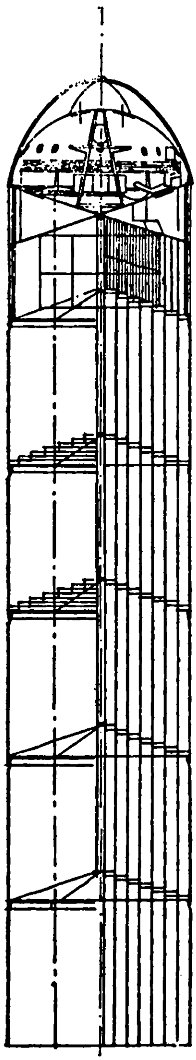
It will be seen that the streamlining is conspicuous by its absence. The form of the ship has been largely dictated by other considerations, and as compared to the terrific power needed to lift the vessel out of the earth's gravitational field the total air resistance is quite negligible (less than 1%), 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 minimise 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 minimised 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 centre. 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



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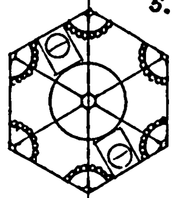

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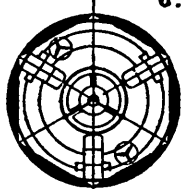

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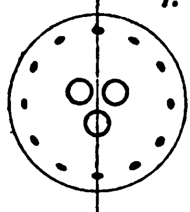

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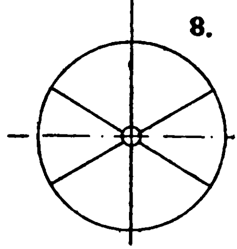

stacked in banks A to E ; these are used to obtain release from Earth. The lower half of diagram 4 shows the medium and small tubes used for deceleration at the moon (the ship, having been turned end to end, approaches stern first). Fine control for the actual landing is provided by the vertical liquid 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.

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 3½ seconds). The g value desired is therefore under control of the crew. Not only is this artificial gravitation considered a necessary precaution (the physical affect of long periods of no-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 manœuvred that its landing will be without shock. Hydraulic shock absorber arms are therefore 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 corect 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 contactor automatically controls stability. The main wiring cable to the tubes is led down a central column, provided at each bank level with a plug connection which breaks 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 needed for the ascent from Moon. The return into Earth's atmosphere will be done at low velocities, hence heating of this shell will not be excessive.

Owing to the small scale of the diagrams it has not been possible to show many of the fitments 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 round the life-compartment. The crew recline on these chairs with their heads towards the centre of the ship and a circular catwalk is provided for them round 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 to 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 a gyroscope ensures maintenance of direction. A suspended pendulum provides indication of " wobble " and modified 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 synchronised, 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 centre of the life-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-locks 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.

THE PAYLOAD ON THE LUNAR TRIP.

Being an account of the equipment, supplies, etc., taken on the first voyage to the moon as far as it is possible to detail them at the present stage of the Society's researches.

In order that the part played by each item of equipment be fully understood it is necessary to give a brief description of the voyage to the moon as it is visualized at the moment. Before it is launched the space-ship will be set rotating at a speed of about one revolution in three seconds and this rotation will be maintained throughout the voyage which will be of a duration of approximately four days. It will be necessary to take frequent observations when in space and means to enable this to be done from a rotating ship must be provided. To land on the moon it will be necessary to turn the ship round so that its base points in the direction of the lunar surface and to provide some form of landing device to minimize concussion. Once on the moon the astronauts (two or three will make the journey) will set about their work of scientific observation and mineral prospecting, sleeping and eating in the ship and using it as their general headquarters. They will remain on the moon for a fortnight before making the return trip from which the landing on earth will be made by means of atmospheric braking and probably the use of parachutes.

The term ' payload ' embraces the whole of the ship except the hull and rockets and includes the permanent equipment, supplies, fittings, instruments, and material necessary for the fortnight on the moon. The payload, however, forms only a small fraction of the weight of the whole ship and it will not exceed one ton whereas before the journey is commenced the ship will weigh something like 1,000 tons. The life-container of the space-ship, which will contain practically everything that the payload includes, and in which the crew will be confined during the journey, will consist of a hemisphere of about ten feet radius providing little more than 2,000 cubic feet of space. There are, therefore, severe limitations on both the weight and the bulk of the material that constitutes the payload, and the utmost economy in these respects will be necessary, especially with regard to weight.

It will not be possible, for instance, to carry water for washing purposes or razors. Smoking, also, will be most strictly probited, for every cubic inch of oxygen will be needed for human consumption. It can be seen that those who undertake the journey will in addition to a variety of hazards be subject to severe privations. Neither will it be necessary to take along any form of arms for in the unlikely event of there being inimical life on our satellite it is not probable that it would be of a type that would be seriously affected by them.

The material of which the payload is comprised may be roughly divided into four classes which it is convenient to deal with separately. First of all there is that consisting of general supplies and equipment which are needed for the maintenance of life during the lunar excursion. This includes food, air, water, heat, light, sanitary arrangements and so on.

Air and water will be taken in the combined form of hydrogen peroxide, one molecule of which can be very readily split up into one molecule of water and half a molecule of oxygen. This arrangement is convenient in that it enables weight to be saved by taking only one storage tank for the two commodities, and also gives a saving in space since the two substances could never be stored as compactly as when they are in chemical combination. Furthermore one set of controls which will be sufficient to regulate both air and water supplies while economising in weight and space occupied will be a feature of welcome unification amongst the numerous complex controls in the ship.

The pure hydrogen peroxide which would be employed is a syrupy viscous liquid that can be broken up into air and water either by the application of heat or by catalytic action. When fine particles of practically any metal are placed in contact with the liquid the reaction proceeds continuously at an easily-regulated rate so long as any hydrogen peroxide remains in the combined state, the metal itself not being consumed. Thus the hydrogen peroxide would be stored in a 2-foot tank of a light non-corrodible alloy and run as required into a reaction chamber from which oxygen would issue into the atmosphere and water flow into a small storage vessel. 34lbs. of hydrogen peroxide yield 16lbs. of oxygen and 18lbs. of water, and 1lb. of oxygen occupies 13 cubic feet at N.T.P. which is sufficient for one man who is normally active for a period of six hours. On this basis approximately 500 pounds of hydrogen peroxide will provide sufficient oxygen for three men for twenty days and allow a little to spare for emergency purposes. The same quantity of peroxide will provide about three pints of water per man per day as well as a small amount for chemical purposes or other uses. The three pints a day ration while not too rigorous will entail, nevertheless, a great deal of care and economy.

The excess carbon dioxide and water vapour that will accumulate in the atmosphere inside the space-ship from the exhaled breath of the astronauts will be removed by soda-lime or other suitable chemicals. In this connection it is pointed out that the unpleasantness of a stuffy atmosphere is due more to the excess water vapour than to the large amount of carbon dioxide in it and it will be a fairly easy matter to control the humidity of the atmosphere in the life-container of the space-ship. When preparing to leave the moon the astronauts will take care to leave behind the amount of soda-lime used up till then in purifying the air they breathed.

In addition to the hydrogen peroxide a small amount of liquid oxygen will also be taken for use in the case of an emergency such as a breakdown in the plant splitting up the hydrogen peroxide, and it will also be used as an air supply for space-suits.

The food taken will be chosen for its energy-yielding rather than any other properties. Prior to the journey the astronauts will undergo specialized exercises and training and will be fed on a diet which will supply their bodies with all the proteins necessary for their three weeks' trip, a fattening for the slaughter process, as it were. This will eliminate the need for taking protein-yielding foods on the journey leaving only the necessity for energy-yielding carbohydrates and fats. Lack of vitamins during a three week period will be rather unimportant but extremely small quantities of cod-liver oil and other extracts could be taken to counteract any possible ill-effects from this source.

The average manual labourer expends an amount of energy up to 3,000 gramme-calories a day. It is safe to take the same figure for the astronauts, since, although when on the moon they will probably work for a longer period than the average labourer, the gravitational forces will be much less than on earth. The energy that can be obtained by digesting a pound of butter is approximately 3,500 calories. Thus quantitatively one pound of butter per man per day would be sufficient food for the whole journey. Other foodstuffs of high energy content include sugar, chocolate, oatmeal, bread, cheese and brazil nuts varying from 1,000 to 3,400 calories per pound. It seems therefore that the astronaut might exist principally on bread and butter, cheese, porridge, chocolate and sweet cocoa. For variety he might take small amounts of raisins (1,190 cals. per lb.), ham (900 cals. per lb.), honey (1,300 cals. per lb.) and salmon (1,000 cals. per lb.). Such luxuries as pepper and mustard will be dispensed with though a small amount of salt will be necessary for perspiration processes.

Water will of course be the basis of all beverages, chief amongst which will be cocoa, though a small amount of coffee might be necessary as a stimulant for navigators falling asleep over their interminable calculations. It is debatable whether some alcoholic beverage should be permitted to celebrate the landing on the moon but there will in any case be a small amount in the medicine chest.

Culinary processes will be carried out in one electrically heated vessel of some light alloy which will serve as a saucepan for boiling water and frying pan for cooking any meat permitted. Each astronaut will be allowed one cup (but no saucer), one plate, and one spoon, and a knife and fork might also be taken to be passed from hand to hand. The cups will be of aluminium or bakelite or some other plastic. Unless it is decided to take food in sausage form contained in thin edible skins, it will be kept in ordinary light wrappings. When in space and on the moon it might be stored outside the ship in a hermetically-sealed container acting as refrigerator which could be hauled in as required.

The electric lighting system will be more or less of a normal type and will be run on power from a primary battery. It may be in frequent use during the journey since the life-container's windows are rather small and lighting will also be required when on the moon since the ship will land in the dark section illuminated only by stars and light reflected from the earth. Heat will be needed for the life-container when on the moon but not during the journey through space as the ship will be rotating and will be evenly heated by the sun. The electric heaters will be fed from the same battery that will supply all the rest of the power needed during the trip. The battery will represent the most concentrated form of energy available (except the rocket fuel itself which is too violent for general use) and will probably work on the principle of feeding magnesium sheets into a cell of which the magnesium is one pole, the chemical action ensuing releasing as much energy as in the combustion of the magnesium but not requiring oxygen as such.

A small steam boiler will be taken, light and not very elaborate, to furnish steam at high pressure for jets used in delicate manœuvres of the space-ship for which rocket fuel would be too vigorous.

Sanitation of the ship will be accomplished through the medium of an air-lock in which refuse will be deposited. Upon removing the outer cover the air remaining in the lock will drive the refuse away from the ship.

The second class of material comprising the payload is that including the various fittings of the life-container, stowages, etc., and miscellaneous items required during the course of the journey. Chief amongst this is the seating accommodation upon which the astronauts will spend most of their time during the voyage through space and which will act as their bed for the whole of the three weeks. Owing to the rotation of the ship and the various changes of direction when starting and stopping the seats will have to be fairly elaborate. They will be placed in the angle between what will seem to be the floor and wall when the ship is stationary on earth. Upon rotation and the commencement of the journey the direction that the travellers perceive as downwards will change and the part of the seat which was being sat on will become the back-rest and vice versa. The seats will be comfortably upholstered so that pressure on the body during the initial acceleration will be reduced to a minimum. They will be mounted on rails in order that they can be moved round the central control panel during the acceleration with only a small amount of exertion. This control panel will be situated somewhere in the centre of the life-container so that the seats can be grouped around it, will contain the controls for firing different groups of rocket cells and may resemble somewhat the console of an organ.

Some ingenuity will be necessary in stowing the numerous articles of the payload so that they will be securely held in spite of the acceleration, rotation and manœuvring of the ship, and especially during the landing on the moon, but provision of sufficiently light and convenient stowages will only be a matter of adroitness and patience.

A general repair kit and medicine chest will be included amongst the miscellaneous equipment taken. The former will be required to cope with any mishaps to instruments or apparatus and for general use on the moon. The medicine chest will contain a fairly comprehensive selection of medical supplies with perhaps some emphasis on aspirins and anodynes. The chief sources of injury to be expected will be bruises and concussion from sudden movements of the ship, and abrasions from the sharp rocks of the moon. Anything up to a broken limb could be dealt with satisfactorily but if one of the astronauts contracted appendicitis it seems that he would be extremely unfortunate.

A few reference books, almanacks, mathematical tables, etc., printed on specially light rice-paper, as well as geometrical instruments, will be taken for use in navigational calculations. An adequate store of similar paper will be required for calculations and keeping records of the journey. Indelible balsa wood pencils will be used, the necessity for ink thus being eliminated.

One pack of light weight cards will while away any tedious hours of the journey remaining after calculations have been completed. Finally in this group mention might be made of handkerchiefs which will obviously be required although every effort will be made to avoid colds. Handkerchiefs will, however, be used for miscellaneous purposes such as mopping up spilt liquids or carrying out rudimentary washing operations. Two large handkerchiefs for each member of the crew and several square feet of rag should be sufficient for these various duties.

Navigational and other instruments make up the next of the four groups of equipment. The coelostat is a rotating mirror device by means of which it will be possible to obtain a view outside the ship, both back and front. The rotation of the mirrors will be arranged so that they neutralise exactly the rotation of the ship and a stationary view of the heavens will be obtained from which observations of the planets necessary for navigational purposes will be taken. An altimeter and speedometer both working on inertia alone will be provided for use during the firing of rocket cellules in the initial acceleration. A small telescope for cursory observation of the moon and the earth during the journey may be taken but in any case space-sextants for observing the positions of heavenly bodies will also be required together with a reliable chronometer. An electrically-maintained gyroscope which will keep a fixed axis of rotation will be used to indicate any deviation of the ship from its proper direction. Lastly, a range-finder will be employed for landing on the moon for determining the height of the ship above its surface. After the landing this will also be of use in a certaining the distance of any particular landmarks.

The final of these arbitrary groups of equipment is that required for the work of the astronauts when on the moon. Outstanding amongst this equipment is the item of space-suits, four of which will be employed, one for each member of the crew and one spare in case of serious damage being sustained, the danger of tears on the sharp-edged rocks of the lunar landscape being by no means negligible. They will be constructed of thin but tough rubber or leather, will be provided with a roomy headpiece and will contain heating arrangements and a supply of oxygen, probably in liquid form. Surgeon's thin rubber gloves will enable fine objects to be handled easily and a small puncture repair outfit will always be carried. To enable the exploring astronauts to leave the ship for some considerable time rubber membranes might be provided which could be blown up ballon-wise over the head and arms and inside the atmosphere of which one might eat in comfort.

It is possible that there may be large tracts of quick-sand-like dust on the surface of the moon and a large pair of flat-bottomed shoes will be provided for negotiating such areas. Other requisites for journeys over the lunar surface will include signal rockets with which distant explorers could communicate with the ship. As an alternative it will be possible to arrange for signalling by light flashes from an electric light mounted on a pole near the spaceship. The explorers could blaze their trial very easily by marking the rocks on their route with chalk and determine their position by observations with the light miniature sextant that each will carry so that there will be small chance of them losing their way. They will also each carry a light but reliable watch. Dark goggles for each member of the crew will be necessary and a small amount of sunburn lotion in case the actinic rays prove harmful in the absence of an atmosphere.

To carry out a mineralogical examination of that portion of the moon that they explore the astronauts will need small dynamite charges for removing surface and outcropping rocks, and at least two spades for digging away rubble. They will also take geological hammers and an ample supply of thin glass specimen tubes. Rather than transport to the moon the numerous chemicals required for complete analysis on the spot samples will be sealed in specimen tubes for detailed examination on return to earth, though a small amount of a few salient reagents will be concluded in the payload.

Various scientific instruments taken for exclusive use on the moon will include a fairly powerful telescope for a commencement of the astronomical research for which the moon has always been considered an ideal observatory, a good microscope and accessories for examination of mineralogical specimens and possible spores, lichens or other forms of life that may conceivably be found on the moon and which would be adversely affected by terrestrial conditions. A light spring balance will be used for making fairly accurate measurements of weight in conjunction with a gravity pendulum by means of which the moon's gravitational attraction will be speedily and accurately determined at any particular point.

Amongst the general equipment in use on the moon will be a light canvas tent to be placed above the ship and so appreciably reduce the amount of heat lost by radiation since the ship will be in a vacuum on all sides except for its base which will rest on the ground.

One of the most important items of lunar equipment will be the earth-signalling apparatus. Powerful units on earth will be able easily to pick up and amplify flashes of light transmitted by travellers on the dark part of the moon. It may even be possible to transmit speech by modulating the intensity of the beam and a running commentary by one of the astronauts on the exploration of the moon broadcast by the B.B.C. is not beyond the bounds of possibility.

A light, compact cine-camera and an ordinary miniature camera together with an ample supply of films and a certain amount of reagents for developing specimens of the photographs taken will constitute the photographic equipment of the expedition.

On quitting the moon it will be possible to leave behind empty tins, surplus equipment, the flat-bottomed shoes, tent, etc., so that as much fuel as possible may be conserved. The return journey will be similar in most respects to the outward one except that the landing on earth will be accomplished by atmospheric braking and in the last stages by parachute. After the parachute the final item to be included in the payload will be an adequate supply of various kinds of paper money with which the intrepid explorers will pay for their return to civilization should they land in one of the more barbarous regions of the earth.

MAURICE K. HANSON.

THE B.I.S. TECHNICAL REPORT.

Following the result of the appeal for the Research Fund, a meeting was held at which a number of suggestions were put forward by the Technical Committee and were considered by the meeting, and an experimental programme was drawn up. In view of the fact that the majority of the members are unable to be present at meetings this article is principally for the purpose of making clear the reasons which led the meeting to its decisions and to explain, in fuller detail, the work with which the experimental section is occupied.

The Technical Committee has made, during the past two years, a very exhaustive survey of the problems involved in crossing space. They have latterly concentrated upon the consideration of the specific case of a return voyage from the Earth to the Moon with a gross pay load of one ton and a crew of three. By considering this case in full detail it is hoped that they have adequately determined all the factors concerned and are thus in the position to state exactly what is required in equipment, fuel, etc., and in technical knowledge. Of course, there is always the possibility that there will be problems to be dealt with which cannot be foreseen until the voyage is actually in progress, but we feel confident that no difficulty which it is at all possible to forsee has been overlooked. The result of this survey has led to the following conclusions :—

That the fuels already tested by the members of the Technical Committee have ample energy for such a voyage provided that means can be devised for the control of their combustion and the reasonably efficient utilisation of their energy.

That the methods of navigation which have been tentatively suggested in the past are not nearly sufficiently accurate to make a successful voyage even possible and that it is essential that swift and accurate methods should be devised for determining altitude and velocity.

That the only satisfactory means proposed up to the present for stabilising a driven spaceship is that of bodily rotation and that it is necessary to devise (1) means whereby the vessel may be set in rotation before the tubes are switched on and (2) means of taking visual observations during rotation.

That no method of landing proposed up to the present can be considered satisfactory (although some of them may be possible) and this problem may be considered as one yet to be solved.

That a considerable amount of electrical power will be required for operation of the equipment of the vessel and that in the event of a prolonged stay being made on the night side of the Moon it would be desirable to be able to increase this to as much as 10 KVA.

for heating purposes. Known battery systems are not capable of doing this without involving an excessive weight, and it is therefore necessary to design a battery of improved energy-weight ratio.

It is considered that if these problems can satisfactorily be solved it is only a question of obtaining the finance to pay for the fuel, etc., to enable the voyage to be carried out forthwith.

From the above list the following experimental syllabus has been devised.

1—The construction of a pressure tank to enable the combustion speeds of the various fuels at any given pressure to be determined.

2—The construction of a proving stand for the determination of the efficiencies of the resultant fuel motor combinations.

3—The design and construction of an altimeter operating by inertia alone and thus independent of an atmosphere and with a sufficient range and accuracy for the required purpose.

4—The design and construction of a speedometer, also as above.

5—The design and construction of a model of a launching gear suitable for the launching of a 1,000 ton spaceship in a condition of rotating.

6—The design and construction of a coeleostat, being the scanning device to enable a stationery view of the sky (relative to the observer) to be obtained from a rotating vessel.

7—The design and construction of a model of a primary battery having an energy weight ratio comparable with that of rocket fuel.

In the consideration of an actual programme it was decided that only such experiments would be started as might be finished with the funds available. Thus 1. would be left over and as a result of this, 2. would be pointless, although it would not be particularly expensive in itself, as it would not be possible to make up fuel-motor combinations which could safely be tested until the essential values of rate of combustion had been determined. At the time of the meeting it was also considered that it would not be possible to make up suitable motors until we were in the position to pay the cost of moulds for the ceramic nozzles ; there is a possibility however, that some investigations which are being carried out towards devising improved ceramics may lead us to a cheaper solution to this point. It was felt that 5. might best be left over until after 1. and 2. had been dealt with so that the test of the launching gear might be made more suitably, with a model powered by the resultant motor. This left us with 3, 4, 6, and 7, and a vote of the meeting led to the order being decided as follows, altimeter, speedometer, primary battery and coeleostat.

After prolonged consideration both by the Technical Committee and at the experimental meetings, it was decided to proceed with experiments on an altimeter and a speedometer to the design described under. An advantage of these particular designs was that a large amount of the experimental work and of the apparatus required would be identical for both instruments and thus effect considerable saving.

The principle of operation of the altimeter, is to record the double integral of acceleration by time, the measure of the acceleration being determined by balancing a weight against a spring. When the vessel accelerates there will be a change in the internal gravitation, so that the spring-weight combination is out of balance by an amount proportional to the acceleration. The double integral is performed by setting the out-of-balance force to operate a fly-wheel. The fly-wheel will be acted upon by a force which is proportional to the acceleration of the vessel, and thus the acceleration of the fly-wheel will itself be proportional to that of the vessel. It will be seen at once that if the accelerations are constantly proportional to one another, and both the fly-wheel and the vessel are at rest to commence with, their velocities will also be constantly in the same proportions, and hence, also, the distances through which they move. Recording dials, registering the number of revolutions of the fly-wheel, thus give a reading of the altitude reached by the vessel.

In the actual design which is being experimented with, the fly-wheel consists of a disc of aluminium 3 mm. thick and 40 cms. in diameter, mounted upon a small ball race. This is attached, through a chain of gears, to a sprocket wheel over which passes a closed loop of chain. The weight is attached to the top of one side of this chain. The spring might be attached directly to the sprocket shaft, but may be geared further for reasons given later. The heavier the weight used the greater will be the motion of the disc in proportion to the motion of the vessel, and since the instrument is required to read up to altitudes of the order of 2,000 Km. the weight must be quite small, as it can only move through half the length of the chain and consequently the revolutions of the disc must be limited to a corresponding amount, allowing for the gearing ratio. The higher the gearing ratio the more the revolutions that can be allowed to the wheel and the greater the weight that can be used. The most difficult source of error to be overcome is the friction, and since this becomes smaller in proportion the greater the driving force used, the gearing ratio and weight should both be as large as possible. These are, however, limited by the fact that the weight of equipment must be kept down to a minimum, and the main purpose of the present experiments is to determine whether an instrument of the required degree of accuracy can be constructed without running to an excessive weight. Other sources of error are the change in gravitation with altitude and the change in torque of the spring as it is wound up. These errors are both determined by the amount of height recorded, and it is hoped that it will be possible very largely to balance them out by having an auxiliary spring with a different law of change of torque to the main spring, so that it can provide a balancing force to the changes without balancing out the main force. It is however, desirable to keep the spring error as small as possible, and to do this a strong spring should be used and only a few turns on its shaft permitted. For this reason the spring is attached to the sprocket shaft, or even geared down still further, as the fast moving disc shaft does too many revolutions.

The speedometer is very similar to the altimeter, but in this case instead of the force of the weight being resisted by the inertia of the disc, a magnet is fixed close to the disc and eddy currents are induced which resist the motion. This system is already in use for electric light meters, and a rather different application is used in existing speedometers. The resisting force produced is proportional to the velocity of the disc, and since the driving force is proportional to the acceleration of the vessel, the two will balance when the disc revolves at a speed proportional to the vessel's acceleration, and thus the distance through which the disc has revolved will indicate the extent to which the vessel's velocity has altered. Since the force on the disc will be large as compared to that when inertia alone is resisting it, friction will not be so large in proportion, but fresh difficulties arise to take its place. Since the change in gravitation will be proportional to altitude and not to velocity, it cannot be directly compensated within the instrument. A compensating force might be applied from the altimeter to the speedometer, but it would be difficult to do this without risking upsetting the accuracy of the altimeter. Another difficulty arises through the inertia of the disc. The main controlling factor in the altimeter, it appears as an error in the speedometer. It does not alter the ultimate reading, but induces a lag of several seconds in the response of the instrument to changes of velocity. This does not sound serious, but the velocity is altering so rapidly as to make it important to have the right answer quickly. For this reason it is important to keep the inertia as low as possible in proportion to the eddy losses. Unluckily it is very difficult to reduce one without the other.

Let M = Mass of disc.
,, R = Radius of inertia of disc.
,, t = Thickness of disc.
,, s = Radius of disc shaft.
,, f = Coefficient of friction of disc bearings.
,, W = Mass of weight.
,, r = Radius of sprocket wheel.

,, L = Half length of chain.
,, n = Gearing ratio.
,, k = Specific electrical resistance of disc.
,, F = Effective flux through disc.
,, h = Recorded (full scale) altitude.
,, V = Recorded (full scale) velocity.
,, N = Mean g ratio.
,, q = Relative error due to friction.
,, D = Lag.

(k in ohms per cm. cube, remainder C.G.S.)

Then for Altimeter :—

$y = nsMf/rW$
$h = n^2R^2ML/r^2W$
$n = hfsr/LR^2y$
$W = hs^2Mf^2/LR^2y^2$

And for Speedometer :—

$y = nsMf/rW$
$V = Ln^2R^2F^2t/1\frac{1}{2} \cdot 10^{10}r^2Wk$
$n = 1\frac{1}{2}.10^{10}sMfrkV/LR^2F^2ty$
$W = 1\frac{1}{2}.10^{10}s^2M^2f^2kV/LR^2F^2ty$
$D = 1\frac{1}{2}.10^{10}Mk/F^2t$

where y is a proportional of q lying between (N—1)q and (N—1)q/N according to the proportion of friction which is inherent in the bearing and the proportion which is dependent upon the load. Tests indicate that a value close to (N—1)q may be expected.

F, the effective flux, may differ slightly from the total flux, depending upon the distribution, a radical distribution reducing F and a circumferential distribution increasing it.

REPORT OF EXPERIMENTAL MEETINGS.

Owing to the fact that there have only been a few experimental meetings prior to going to press there is not a great deal to report as yet.

Attention has been concentrated upon the mounting of the disc on its bearings and reducing the friction to a minimum. At first considerable difficulty was found in obtaining a consistent friction—a difficulty resultant from the fact that, whereas it is essential to use ball races so as to minimise the friction, the ordinary purpose of even the very smallest ball races we are able to obtain was for use in conjunction with appreciable loads to minimise the friction resultant and not, as in our case, to obtain a friction of instrument-like accuracy. By adjusting the ball races extremely carefully and washing them out and replacing the oil with a very thin variety, a fair degree of consistancy was obtained, when the co-efficient of friction was .019 plus or minus .001. This value is considerably higher than that estimated by the makers of the ball races, but from our point of view consistency is more important than the actual amount of friction. The value obtained means that an accuracy of plus or minus 1% would be obtained with a gearing ratio of 60 to 1 between the sprocket shaft and the disc shaft. For the altimeter this is a quite sufficient degree of accuracy, as this instrument is required principally for the purpose of determining the reduction in release velocity due to the altitude attained and, since this is only of the order of 20% of the release velocity, this accuracy corresponds to an accuracy of determination of release of .2%. For demonstration purposes it is proposed to make up an altimeter with a full scale deflection at a comparatively small altitude. As this instrument will probably have to demonstrate under conditions of mixed rising and falling, the problem is somewhat more difficult than that of the actual case for which it is required, since in the case of a persistent rise the friction appears as an error, but where both rising and falling have to be taken into consideration the effect due to friction reverses, consequently it cannot be compensated and the entire friction becomes an error, which is thus ten times as great. It will be noted that it is essential to know the laws governing the operation of these instruments extremely accurately since the altitude which it is required to measure is about 2,000 Km. whereas the maximum distance over which it could be tested against measurement would be about 2 Km. which is of course, quite useless. Consequently it is necessary to calculate the performance of the instrument, to an extremely high degree of accuracy, beforehand.

Very rough tests have been carried out of the principle of the speedometer but it is too early yet to give any definite report. It is felt however that the speedometer may actually be a more difficult proposition than the altimeter, not so much from its inherent difficulties of construction as from the considerably higher degree of accuracy required of it.

As there was one meeting at which nothing could be done on the above (owing to delay in delivery of parts that had been ordered) some preliminary experiments in connection with the battery were carried out. These experiments were limited to voltage tests only of the proposed combinations, but it is of considerable interest that, at least in this respect, marked success was obtained, a combination being tried which gave a voltage of 2.5 per cell without depolariser and 2.9 per cell with depolariser. So far as we know these results are very considerably higher than any previously obtained. This work has, of course, been put aside for the time being until the first two jobs are complete or again held up.

Rough designs have been prepared for a coelostat and those who have been able to follow the rough drawings are convinced that the system proposed will work. As however, the design is very difficult to follow from rough sketches, the conviction is by no means unanimous as yet.

We hope that by the time the next Journal is due to be issued it will be possible to report definite and satisfactory results in most of the matters under experiment. J.H.E.

FUELS AND MOTORS

by Arthur Janser.

My article in the last "Journal" had a large response. Several letters arrived, offering criticisms and suggestions, the prevailing note being a very strong bias in favour of liquid fuels.

Since the fuel question is of fundamental importance to space navigation, I feel justified in dealing with its different aspects more fully and also to report about my latest findings and conclusions.

The subdivision between liquid and solid fuels is not a sufficient one ; we must also distinguish between oxygen carrying fuels and comburants to which oxygen must be added to produce combustion. Usually solids are of the first and liquids of the second type. But there are many examples of liquid aliphatic hydroaromatic nitrates, such as nitrogycerine, which carry all the necessary oxygen for combustion, and magnesium metal is a good example of a solid fuel which requires the addition of oxygen.

Even this distinction is not quite sharp for we may get all kinds of intermediate materials, e.g., a fuel in paste form—which incidentally proved very promising in initial tests—and fuels containing only part of the necessary oxygen, the balance being supplied for recombustion.

This latter type of propellant requires a specially designed motor with a larger second combustion chamber in tandem arrangement and fitted with air injectors. While unsuitable for spaceships, it bears great promise for the development of rocket planes, but might all the same be very useful for starting the spaceship which has to cross many miles of atmosphere until it reaches the near vacuum of space.

This diversion into the theme of rocket motor construction shows that propellants cannot be considered for themselves alone, without at the same time bearing in mind the type of motor in which they are going to be used. Each separate fuel requires a motor of individual design to obtain optimum conditions of combustion. Two main types can be distinguished, the usual rocket type where the combustion chamber serves at the same time as a fuel store, and rocket motors where the fuel or its two components are supplied into the chamber. The latter type has the great advantages that the volume of the chamber remains constant, the rate of supply can be regulated and its action continued over a longer stretch of time than is possible in the usual type of rocket,

Against this stand difficulties of construction and vastly increased costs. A new and very ingenious model of a ' pulsating ' propulsion engine is now under consideration, which solves this difficulty by an intermittent two pulse action : in a sense the surge of the ejected exhaust gas is used to suck in a supply of fresh fuel at every second pulse-beat. If this model holds its promise in actual practical tests, a very great progress towards the realization of the liquid fuel motor will be accomplished.

These advances are accompanied by equally promising findings in the thermo-chemistry of fuels. The principle of mutual activation was found, showing how two fuels of very different character when mixed influence each other beneficially on combustion. A great advance is the use of liquid hydrocarbon fuels, in which a certain amount of hydro-aromatic nitrates have been dissolved. Improved results with liquid oxygen were obtained, when it contained a small amount of liquid nitrogen. The reason for this effect is by no means obvious and it may be assumed that small traces of nitric oxi des, are formed while the reaction takes place, which have some kind of catalytic action.

Experiments are greatly hampered by lack of funds and lack of time. Allowing for these handicaps the progress made must be considered very satisfactory. The next step of importance would be to carry out research work on ozone. This is tri-atomic oxygen and carries an extra charge of energy against ordinary (two atomic) oxygen, but it cannot be used for fuels owing to its dangerous instability. Willy Ley in a letter has put forward the suggestion that this is in all likelihood due to small amounts of impurities contained in the Ozone. This view finds much support in the general evidence provided by chemical science and it would well be worth while to try producing pure ozone. Up to 50% increase of exhaust velocity may be thus obtained.

More attention is paid lately to solid fuels of the non oxygen carrying variety ; they consist chiefly of metals and metalloids and require oxygen (or ozone if possible) for their combustion. Some difficulty is expected in cases where the combustion temperature is not high enough to produce the oxides formed in gaseous condition. The ejection of solids would not produce the same thrust as the expansion and ejection of hot gas of the same caloric value. The use of ozone may in such cases help to overcome the trouble by raising the combustion temperature sufficiently to convert the oxides into gas. Such rockets may show a smoky tail consisting of finely dispersed solid oxides, but this would not matter as long as these oxides were in the gaseous state before leaving the nozzle.

For the combustion of solid, not self combustible fuels, solid oxygen will have to be used. This is not available as a commodity, but its manufacture on a commercial scale should not offer any difficulty. Solid oxygen looks like bluish snow and melts at -219° C to liquid oxygen, which in its turn boils at -183° C at ordinary atmospheric pressure. The mixture of solid oxygen with a solid combustible element, such as carbon black or magnesium powder is a terrific explosive and the slightest impurity can produce spontaneous self-detonation. Thus they must be injected separately into the combustion chamber where they meet at the moment at which they are reacting together. The simultaneous supply of the two solid fuel components offers a number of constructional problems which are not too easily overcome. But considering the extremely high caloric values and indicated exhaust velocities obtainable by these mixtures, which exceed by far those of hydrogen-oxygen, the " most powerful fuel," it will be worth taking the trouble to find a feasible constructional solution for the motor. Liquid oxygen and hydrogen yield 3.100 calories on combustion of 1 gram of the re-action mixture, solid oxygen and aluminium yield 3.700. The weight volume ratio is considerably more favourable and the cost is lower.

Several suggestions for the supply of solid propellants into the furnace are found in literature, such as the revolving supply wheel which delivers equal portions of solid fuel in equal time intervals. This suggestion has received many criticisms, and only a practical model could give us an idea of its workability.

Further research into the chemical side of the problem may produce stabilizing agents for the solid metal oxygen mixture which we may visualize as a stiff paste, squeezed into the oven by suitable means. Thus advances on the chemical side can definitely contribute to the solution of the constructional problem.

In conclusion it can be stated, that the modern view is to consider fuels and motor jointly and no longer as different problems detached from each other. The investigator must beware of prejudice against the one or other type of propellant and consider them solely on their merits.

A great deal of work is yet to be done but we feel confident, that consistent and sustained research work along the indicated lines will eventually yield results which will bring the realization of our object, the conquest of space, within our reach.

AN ELEMENTARY MATHEMATICAL APPROACH TO ASTRONAUTICS.

by ARTHUR C. CLARKE

The fundamental equation of rocket flight, as derived from the ordinary $P = Mf$ law is

$$(M-wt)\, dV/dt = vw$$

where M is the original mass of the rocket, w is the rate of combustion of fuel, v is the exhaust velocity, V is the final velocity and t is the time.

Integration between the limits $t = o$ and $t = t$ gives:-

$$V = v \log M/(M-wt).$$

Since M-wt is the mass of the rocket at time t, we may write this equation: $V = v \log R$, where R is the ratio between the original mass of the rocket and the final mass after combustion. If all the fuel is burnt, R will equal the load ratio.

In the case of a rocket leaving a planet and requiring merely the escape velocity E, we have

$$E = v \log R$$

and we can thus calculate the load ratio required for any given exhaust velocity. For instance, taking the theoretical exhaust velocity of oxy-hydrogen mixture as 5Km./sec. and the escape velocity from the earth as 11Km./sec., the necessary R is found to be about 9.5.

For actual voyages the same formula can be used but V becomes more complicated, since the planets are moving in different orbits and their orbital velocities must be considered besides the velocities of escape from them. After the initial acceleration, a spaceship travels in some type of astronomical orbit, either an ellipse, a parabola or a hyperbola. The path requiring minimum power is the ellipse touching the orbits of the two planets, and this curve would normally be used if the time factor were not considered.

To obtain the velocities needed on a voyage between two planets, take the energy of release from the body of origin and add the energy of transfer from the planet's orbit to the voyage orbit (i.e., half the square on the difference in velocity). The velocity corresponding to this total energy is V for the start of the voyage. If the start is made from a satellite, add the energy of release from its orbit to the other two energies. Since the release velocity from an orbit is $\sqrt{2}$ times the orbital velocity, the extra energy in the case of a satellite is proportional to $(\sqrt{2} - 1)^2$ times the orbital energy.

The same treatment is used at the destination and the resulting velocities are added arithmetically. For a return journey V is doubled. This of course ignores errors due to air resistance and also an error due to the fact that on larger bodies the acceleration has to be reduced to avoid damage to vessel or crew. These corrections are rather indefinite and their values would depend largely on the skill and practice of the pilot. A small margin for errors in calculation should also be allowed.

The table, for which I am indebted to Mr. Edwards, shows values of V in Km./sec. for a one way trip between the more important bodies in the Solar System, excluding the outer planets. Deimos and Yapetus are shown as possible fueling stations, but as fuel materials could hardly be found " in situ " on such small bodies, they cannot be considered for the first voyage. The figures for Saturn would have to be increased in practice to avoid the rings. It will be seen that Saturn is about at the limit for jet-propelled

	Mercury	Ven.	Ear	Moo.	Dei.	Mar.	Cal.	Gan.	Eur	Io	Jup.	Yap.	Tit.	Rhe.	Mi.
Venus	19.7														
Earth	23.9	22.2													
Moon	18.3	14.3	13.6												
Deimos	22.3	16.3	14.4	6.5											
Mars	23.6	17.9	17.3	9.4	6.0										
Callisto	26.6	23.1	21.0	15.8	11.5	13.4									
Ganymede	27.2	23.8	21.8	16.6	12.4	14.4	5.6								
Europa	27.6	24.3	22.4	17.2	13.0	15.0	6.8	5.5							
Io	28.7	25.4	23.6	18.4	14.4	10.3	9.3	8.2	5.8						
Jupiter	78	75	74	69	65	67	67	69	70	72					
Yapetus	25.6	21.6	20.8	16.2	12.4	13.9	6.4	7.5	8.3	9.8	60				
Titan	26.4	22.4	21.6	17.0	13.3	14.8	8.0	9.2	10.0	11.5	62	3.6			
Rhea	26.8	22.8	22.2	17.5	13.8	15.3	8.9	10.1	10.8	12.4	63	5.3	6.2		
Mimas	27.8	23.9	23.4	18.6	15.1	16.6	10.5	11.7	12.4	14.0	64	7.7	8.2	6.5	
Saturn	55	52	51	47	43	45	40	41	42	43	94	38	40	42	43

vessels, as the present designs would just about allow landing but not taking off again.

In practice the planetary orbits are elliptical, and the planets travel fastest when nearest the sun. Consequently corrections in velocity and direction are needed according to the configurations at the time of the voyage. Moreover, the planes of the orbits do not exactly correspond. The allowance for this is best made by taking the distances of the points of arrival and departure north or south of the mean plane and dividing the difference by the time which is expected to be taken. A corresponding N.—S. velocity component can then be given to the vessel.

Although the path of the ship has so far been taken as the co-tangent ellipse, this is only approximately the case. It is true for the central portion of the voyage, though even here it may be necessary to allow for the perturbations of the nearer planets. At the beginning and end of the journey the path is actually that of a satellite round the respective primary, perturbed by the sun.

The main orbit is first determined to give the correct appointment, ignoring the attractions of the planets involved. The relative velocities at start and finish thus obtained are used as the velocities of approach from infinity for the calculation of the circumplanetary orbits at the beginning and end of the voyage. Since the main field does not leave off when the destination field commences, there will be a small error produced by considering them separately. This error is small enough to be ignored except when the destination planet is in the Saturnian or Jovian systems, or for voyages between Moon and Earth.

Voyages between satellites of the same system can be treated in a precisely similar manner to the above. Voyages between a planet or satellite and a satellite of another system are more complicated. In the immediate vicinity of the satellite an orbit must be calculated about the satellite ; at moderate distances an orbit must be caculated about the primary, and at long distances an orbit must be calculated about the sun. The corrections for perturbations may become extremely involved. This is particularly true of the Earth—Moon system, owing to the large size and mass of the moon as compared with the earth. Consequently in this case no satisfactory approximate algebraic solutions can be used and it is necessary to arithmetically integrate the orbit.