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SPACEWARDS

Official Organ of the Combined British Astronautical Societies

ONE SHILLING—NON-MEMBERS

Edited by: K. W. GATLAND and E. BURGESS

EDITORIAL COMMENT

One advantage to emerge out of war is the great practical advancement made possible by an enforced struggle, nation against nation, for technical superiority in the weapons of conflict; this being undertaken in complete freedom from the 'drouge' of peace-time development, commercialisation and vested interests.

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Contributions are invited for Publication in this Journal, but the committee wish to state that they do not necessarily agree with opinions expressed in such contributions when published.

Communications should be addressed, c/o Hon. General Secretary, C.B.A.S., Southern Headquarters, 17, Southcote Avenue, Tolworth, Surbiton, Surrey.

Rockets—from War to Peace.

The past two years have seen the realisation of many ideals common to our science; the period 1943-44 will ever be remembered as the practical beginning of what we may term the 're-action power' era.

It is a difficult matter to classify directly what war-time development in the field of reaction propulsion may have bearing on post-war research. War-time development demands *effectiveness* above all else, *efficiency* more often than not becoming an extremely bad second. When it is considered that at very best, the German P. A/c. operated at barely a 3% efficiency, this point can be better understood. Yet though the P. A/c. did the job for which it was intended, with such a low thermal efficiency, its system of propulsion would not meet the keen demands of post-war commercialisation. The needs of peace are more exacting; speed with economy of operation are the prime factors.

Despite the low thermal efficiency of the P. A/c., however, the extreme simplicity of the compressor-less type, "impulse duct" reaction motor, is a no mean technical achievement. In passing, it is a credit to the Society that in the C.B.A.S. Supplement to the June Bulletin, Vol. 6, No. 4, we succeeded in beating every technical journal and paper in publishing details and diagrams of the working principle of the "impulse duct" motor —*Practical Mechanics* was the first of the technical press to print complete details of the compressor-less principle employed, and Mr. F. J. Camm, the Editor of that Journal, has expressed appreciation of the Society for the use of data as supplied, and published in his interesting article "Pilotless Aircraft," August issue.

The compressor-less thermal jet propulsion system is, of course, no new development. Power schemes based on this principle were conceived by Lorin, as early as 1913, and also by Luduc in 1933. Those wishing to pursue the development of compressorless systems in jet-propulsion are referred to the *Flight* publication, *Gas Turbines and Jet Propulsion for Aircraft.*

Compressor-less thermal-jet propulsion has never been considered capable of economic function, and thus, the system of thermal jet propulsion has been developed which exploits to a far greater degree the potentialities of the propulsive elements, efficiency being raised by employing a large mass flow, principally by means of *mechanical* compression, and also, by careful attention to 'stage phrasing,' in the compression/expansion sequence and by exploiting the expanding gasses by means of the emmission duct and efflux controlling components.

What effect then will this war-time development provide in the post-war era? What, for instance, out of that already produced is of real progressive value? We can immediately preclude the thermal-jet propelled aircraft, as the use of this principle is certain; a number of commercial, as well as service 'jet' aircraft, are now under development both in the United States and Britain.

We can rule out directly such weapons as the rocket "flak" shell, the "field" rocket projectile, and the rocket accelerated bomb; the firing duration required of these weapons is extremely brief, merely a few seconds and the propulsion systems are nothing but simple developments of the "firework" display rocket, employing cordite, or similar "solid" propellant.

Rocket power has, of course, been employed for assisted take-off purposes and for augmenting the speed of aircraft while in the air. In the main, the rocket system employed for this purpose has been the powder charge, (or " fuel store " rocket), but more recently liquid propellant and the constant volume combustion chamber has come into prominence.

The He. 293 and 294 " glide bombs," the Me. 163 tail-less rocket propelled fighter, and the " V-2 " long range rocket weapon may show originality in reaction motor design.

Unfortunately, extreme secrecy surrounds most of this recent work; we know little of the performances of these recent military developments.

That a considerable amount of research is required before the rocket becomes a truly practical propulsion means is beyond question. Undoubtedly, for many years after the war, progress will be slow. Proving stand tests will play a prominent part in trials of motors, fuels and their methods of combustion. Ours is a new science, a science whose immediate need is *experiment;* there is much yet to be learnt in the cold light of routine test experience.

Post-war Research problems.

In Britain prior to the war, the development of the rocket can hardly be said to have received encouragement—officially, the use of liquid oxygen for purposes of rocket research is prohibited. Solely " approved composition " may be employed as propellant; yet this is not all, the firing of any rocket employing as fuel " approved composition," under the obsolete Explosive Act, 1875, if the experimenter desires to " keep within the law," may be put to test only if the following conditions are satisfied :—(a) The firing range must be sanctioned by the local police authorities concerned. (b) The design of the rocket must be approved by the Secretary of State, or rather his advisors. (c) The filling of the rocket must take place on premises licensed under the Exposives Act, 1875.

It is stated that approval could not under any circumstances be given for the use of the liquid oxygen-petrol propellant.

If these conditions are fulfilled, any person of British nationality may legally carry out rocket experimentation in these Isles; small wonder that to-day, apart from the developments of our Amberican associates, we find the enemy alone using technically progressive rocket weapons.

Thus, before any worth-while post-war programme of practical experimentation can be got under way, this legal question must be faced. As our members will be aware, the German rocket Societies were fortunate in having for experiment, a tract of land, known as the " Raketflugplatz," or rocket flying field. There the construction and test of the "Mirak" and "Repulsors" rocket took place.

Is it too much to hope for a similar service to astronautics in Great Britain?

In the Combined Society Bulletin, July, 1942, (Vol. 4, No. 5) we published an article by R. A. Smith, (formerly organising Secretary, B.I.S.), in which he put forward the following suggestion for the establishment of a rocket research station in this Country.

(a) Attempts should be made to secure a suitable lease on a tract of land so situated that Home Office permission could be obtained for experiments with rockets, and rocket propellants.

(b) A small joint committee (possibly a Limited Company), could be formed for the purpose, who would hold the lease, and undertake the construction work of such premises and permanent facilities as were required, and the various Society Branches could lease from the Joint Committee the various premises under suitable agreements. These agreements would be designed to protect the Joint Committee against loss by damage and would bind the Branches to observe the safety conditions required by the Home Secretary.

Arrangements would be made for exclusive test days in rotation for the various Branches, if desired, on which days the experimenting Branch would have sole control of the premises with rights of exclusion, or admission, and would have to assume responsibility for any damage done during the period.

(c) Machinery could be purchased that would be generally useful to each Branch for experimental work, the cost being met by subscription by the Branches, or payment for the use of facilities.

A worked-out quarry might possibly be an excellent site for an experimental station in view of the fact that it would most probably already possess an explosive licence and would provide good cover for blast protection and siting of observation posts, etc.

It should be possible to obtain huts for living quarters fairly cheap after the war from surplus stores and it should be fairly easy to equip a club-house where experimenters could stay for a few days, or over the week-end. At times when experiments were not in progress, the premises could be used as a sort of general centre of rocket experiment where "Rocketeers" could meet for week-end or annual holiday conferences. A small charge for accommodation and food could be adjusted as circumstances provided, so that opportunities would be afforded for the members of the Branches to meet socially.

It should not be difficult to find a suitable site within fairly easy reach of London. The value of a worked-out quarry is very low as it is unsuitable for cultivation and of no further industrial value. Furthermore, the present "scrap" collection scheme would ensure the removal of valueless machinery which might otherwise constitute a fictitious capital value.

The Present and the Future.

Meanwhile, we are approaching another year, a year in which we have every right to assume will at least see the end of the conflict in the European war theatre. Let us hope that the time is not far distant when those technicians of the Society who are now serving with the H.M. Forces will, once more, be free to take an active part in the work of the Society. Our membership now numbers some 200—the highest enrolment figure so far achieved by any British rocket Society. During the present year, despite adverse conditions imposed by the enemy, we have succeeded in maintaining regular issues of both the Journal and Bulletin. Increasing interest in our subject is being shown by the Press. The article "Where will the rocket take us,' published in the *Sunday Express* on June 25th, written on behalf of the Society by Harry Harper, the well-known aeronautical writer, has undoubtedly done much for us in the way of publicity. References to our work have this year appeared in the influential U.S. Journal *Time*, and in this country, in the technical Journals *Flight* and *Practical Mechanics*, amongst others.

In view of the very limited personnel available for the work, it would have been highly creditable if we had only succeeded in keeping the Society "alive." Yet we have done more than merely this; we are continually enrolling new members, our theoretical research programme has been maintained, our publicity has increased. When it is possible to inform members of the true extent of our work, it will be seen that we have accomplished a great deal during these war years.

Those who feature prominently in our current work are the following members, without whose aid, the continuance of astronautics in Britain during this difficult period of history would be virtually impossible:—
Our President:—E. Burgess; Miss D. H. Burgess, Miss V. Kusack, A. Kunesch, J. Humphries, R. Ainsly, G. Richardson, H. Harper, A. C. Clarke, R. A. Smith, and the B.I.S. Nuclear Committee, R. J. Bremner, and P. R. Carter.

We would also like to take this opportunity of expressing our appreciation for the very warm co-operation shown by the U.S. rocket groups, the American Rocket Society, Inc., the United States Rocket Society, Inc., and the M.I.T. Rocket Research Society.

If so much has been accomplished under war-time impositions, high hopes for progress in the post-war era can be well sustained.

K.W.G.

REPORT OF ORDINARY GENERAL MEETING of the C.B.A.S. (Northern Branch) held at 7.0 p.m. on Thursday, 21st September, 1944, in Room 8a of the Manchester Adult Educational Institute, Lower Mosley Street, Manchester, 2.

An extremely good attendance of 25 members and friends marked the opening of a new meeting program for the Manchester area. The Secretary, Miss Y. Cusack opened the meeting by calling upon the President, (Mr. E. Burgess), who took the chair, to read the names of various members whose election had to be confirmed by the society. The President then gave a very brief account of the past, present and future work of the organisation and stated that the immediate object was to establish a strong and efficient body of enthusiasts and workers so that active work may be commenced as soon as possible after the war. He mentioned that several articles and books were soon to become available and the communication had been established between ourselves and the American Rocket Society.

The President mentioned also that Mr. Gatland, the General Secretary of the C.B.A.S. was rather busy with a great deal of enquiries, and that Miss Cusack had volunteered to deal with all enquiries relating to the election of members in both the Northern and Southern Branches. This should relieve the Southern Headquarters of a great deal of routine work.

A vote of thanks was then proposed and carried for Mr. Burney, the Secretary of the Social Club, who had made it possible for the C.B.A.S. to obtain the meeting room and lantern, and to Mr. Bossun, the Caretaker, who had very kindly arranged the room and attended to the lantern and other accessories.

The Northern Secretary, then proposed the new Northern Committee and this was elected, being the same as the last year. She then called upon the President to deliver his main address of the evening.

The President again took the floor and proceeded to state that his address was rather a 'picture show' than a lecture in the fact that he had about 60 lantern slides of German, American and British experiments and had not time to describe each in detail. The slides covered the early German workers such as Opel, Tilling, and the Mirak series of models, followed by photographs of the early American rockets of 1930's and later proving stand tests and motors. Photographs of Dr. Goddard's Rockets were shown, and also the Proving Stand of the GALCIT Group. From America, the President's slides brought the meeting home to Manchester, and showed the present members how the Research Committee of 1936 and 37 spent their time making, discussing and firing rockets. Photographs of the two-step rocket were included together with one slide of the M.A.A. rocket plane model.

From amateur work, the talk proceeded to military rockets, and slides were shown of Katusha, the Bazooka, Nebelwerfer, and British Z-guns and 'Snare-Rockets.'

As to the future, slides were shown illustrating the expected performance of sounding rockets for different load ratios, together with illustrations of proposed designs for sounding rockets both by the A.R.S. and the C.B.A.S. The ultimate object of an interplanetary voyage was represented by slides of the Moon and of the Ufa film *Girl in the Moon* finally showing a drawing of the B.I.S. Lunar Spaceship Design.

In the lively discussions which followed the lecture, the President explained several points regarding rocket efficiency in vacuo, interplanetary orbits, calculation of theoretical jet velocities, and several other points.

A vote of thanks to the President and to the Treasurer, Miss D. H. Burgess, who acted a lanternist, was proposed by Miss Cusack and carried. In reply to this Mr. Burgess stated that he enjoyed delivering the lecture, and that he sincerely hoped that in his absence on National Service, meetings would continue in the district as there was now sufficient local members to warrant the holding of regular meetings. Mr. Markall remarked that lecturers would be necessary, and Mr. Burgess answered that he would try to arrange for this. In reply to a query from Sgt. Palfreyman (R.A.F.) the President stated that enquiries would be made regarding the possibilities of obtaining a distinguished metal lapel badge, but that this may be impossible during wartime.

The meeting officially terminated at 9.30 p.m., but small discussion groups continued until well after ten o'clock when the remaining members had to leave the meeting room in order to be in time for their trams and buses. It was an excellent gathering and there should be no reason why a repeat performance cannot take place in the near future and throughout the coming winter months.

ABSOLUTE MOTION AND THE SPACE-SHIP COMPASS

by

J. J. Smith, D.Sc. and J. Dennis, M.P.S.

When navigating on the sea or in similar circumstances, crossing a trackless plain, a normal compass, which shows direction on that plane, is used.

In an aircraft, when flying in clouds, an artificial horizon is used to take the place of the true horizon, and all automatic pilot devies must employ some sort of artificial horizon in conjunction with a compass, to control the aircraft through a linking mechanism of some kind. This is true of every development of aircraft that guides itself for more than a few miles.

The compass normally used in aircraft is magnetic and the artificial horizon gyroscopic. We, that is, G. Alfred, P. Blair, and the writers, found it easiest to combine the gyroscopic compass with an artificial horizon and use the composite instrument as a guide. This system obtains a result comparable with the Sperry Gyro-pilot, by a different means that looks simpler. Had the device we made been used thus for hours instead of minutes, we should have added a clockwork compensator, which is necessary to correct for the motion of the earth. To explain this more fully—the reader will know that if a gyroscope is set at the angle to the stars at which it will not precess (i.e. approximately parallel to the axis of the Earth), and left free to maintain its axis in that "absolute line," it will act as a compass which is more accurate than the magnetic instruments. This is the principle of the developed gyroscopic compass. Now if, on this first gyroscope frame, a second gyroscope is mounted with its axis at right angles to that of the other, and the frame is completely free, it will turn on its axis in a sidereal day, because the frame maintains one angle to the space in the universe.

A telescope set on this frame and pointed at say, Sirius, will continue to point at that star in spite of the movements of the aerth and the sun. This assumes, of course, that Sirius has such a small angular motion in space as observable from the general direction of the Solar System, that it can be considered as 'fixed.'

Now we have a method of constructing an instrument that will appear like a marked ball in a glass case, which will enable us to point out wherever we are. Not only will it indicate North or South and East or West, but also the directions, Up or Down, and it can, therefore, direct an automatic pilot in three dimensions.

These six points are the basis of the complete compass of the space-navigator, but as they cannot be measured relative to the Earth, astronomical work is needed to calibrate the instrument. This can be accomplished by measuring the motion of the obvious stars compared with space which does not move. This is not the Space of Einstein's Theory, which is now commonly termed 'Space II.' The exact meanings of the terms 'Space,' 'Space II,' and the Ether, need to be, and can be defined.

J. W. Sullivan in his *Limitations of Science* (Penguin Edition) takes up the subject of motion in Chapter III and we can assume that what is said there about present-day theories is correct, i.e. 'Every motion that we can detect is a relative motion. We have to ask, compared with what is it moving? . . . . However far we go, we find nothing but a relative motion; the notion of absolute motion is in truth, unmeaning.' Now two of the observations cut right across this theory.

The one related to absolute linear motion would demand most careful work to even prove it was well founded. The other is easy to prove and well-known, but the significance of its effect on the relativity theory is not realised, nor is the fact that recent developments of air navigation instruments should make a determination of our Earth's motion, relative to the other, reasonably easy.

Foucoult's Pendulum Experiment, carried out in the dome of the Pantheon at Paris, about a century ago, showed that the Earth rotated on its axis relative to a heavy object swinging. Someone who knows about this and the related phenomena used in the gyroscopic compass, can work out a way to make a small object remain in a state of absolute *angular* rest. By that means we should be able to estimate the rate of the angular motion—if any—of the Solar System.

This is, of course, not a thing we want to do until we can be sure that *it has not been done before,* and that no one who is better equipped will do it for us. Now it appears that some one can find out these things from an astronomer.

The following questions should be put to an astronomer, as they are important in space navigation.

1. Has anyone carried out Foucoult's Pendulum Experiment with sufficient accuracy to measure the angular motion of the Earth in space, accurate to one in one thousand, or about 1/3rd of a degree per day?
2. If this is not possible with a pendulum, has a gyroscopic system been made that will give the same results?
3. If either of these has been done, is the motion known?

As has been mentioned earlier, it is obvious that if a big gyroscope 'G' is set up with its axis parallel to the Earth's axis of rotation, and on the same frame, another 'G2' is set at right angles, and the proper freedom of motion relative to the earth is provided, G.2, with a beam of light and a mirror, indicate the rate of the earth's rotation relative to the gyroscope.

It seems probable that this experiment has been done, as pneumatic and electric gyroscopes are so easy to obtain in these days—but if, on the other hand, we can be sure that it has not, then one of the writers will set up the apparatus.

. . . . .

The address to which information on this matter should be sent is :—

C.B.A.S. HEADQUARTERS,
ASTRONOMICAL SECTION.

A CONTRIBUTION TO THE FUEL PROBLEM.

By Arthur Janser.

The possibility of overcoming the gravitational attraction of earth and freely navigating through space has been proved and demonstrated by quite a number of investigators in the course of the last fifteen years, notably by Goddard, Oberth, Esnault-Pelterie and many others. This is rendered possible by the principle of reaction as demonstrated in a rocket and it has been shown that by means of a suitable arrangement—such as the well-known step rocket system—the available chemical energy of kknown exothermic reactions would be sufficient to impart the velocity of escape (11.3km/sec) to a suitable body (space ship). But even when the most powerful reaction mixture is used as a fuel and we manage to convert the bulk of its chemical energy into thrust, without incuring the losses, the problem remains formidable enough, involving the combustion of hundreds of tons of fuels within the space of a few minutes and the ejection of immense masses of hot exhaust gas to produce the thrust. If we would be forced by technical reasons to use low powered fuels or if we would sustain substantial losses when using a powerful one, this problem would assume phantastic dimensions and become unpracticable. The following example shows this clearly: Assuming we impart escape velocity to our craft, accelerating with 2g, the exhaust-velocity of the fuel being 2km/sec.; the load ratio $M\ /M_1$ would be then 1600; if the exhaust velocity be raised to 4km/sec., the load ratio comes down to 40. While the first rate is utterly beyond practical realization, the second offers a serious chance. It is noteworthy, that while there are quite a number of compounds known, whose reaction heat at their formation would produce exhaust velocities exceeding 4km/sec (calculated on the mechanical heat equivalent), practical tests carried out so far yielded exhaust velocities but little exceeding 2km/sec. It appears therefore, to be the key problem of astronautics, to determine all conditions which influence these exothermic reactions and based on this knowledge, to devise practical means, which permit a close approach to the theoretical value of v.

Firstly: The more powerful a fuel is, and the more we try to utilize its power, the higher t and p will be in the combustion chamber; with increasing t the loss caused by the specific heat of the combustion gases becomes appreciable. The combustion heat at a given temperature t, L will be given by L =L +/ (s—S) dt, whereby s is the specific heat of the substances in combustion and S the specific heat of the combustion products, both at the temterature t. Thus, for instance, when t rises from 1800°c to 2600°C, the thermic yield of the combustion of one gram mol. of H_2 drops from 55 to 48 calories, and with CO even from 6.0 to 1.9 cal.

High temperatures produce another adverse effect, that of thermic dissociation, which also increases with the temperature; it has been suggested, that it may reach such a value with the H_2+O reaction, that the theoretical value of its exhaust velocity of 5.2km/sec might be halved. A remedy in this particular case is offered by using a surplus H_2 over the stoichiometric amount: by the presence of free, uncombined H_2 the equilibrium of reaction will be shifted towards lesser dissociation; besides, free Hydrogen, at the t of reaction of around 4000°C will assume a v of its own exceeding 4.5 km/sec. In this way a mixture of $3\ H_2+2\ O$ will have a theoretical v of 5km/sec and an efficient v (v^1) exceeding in practice by far that of H_2 and O. The same objection applies in an increased measure to C, or C containing fuels (hydorcarbons); in this case the dissociation will reach considerable values at t over 2500°C and here the given remedy would be either to increase the amount of oxygen over the amount necessary for quantative combustion to CO_2, or cut it down to the amount just sufficient for the formation of CO. Again, the theoretical value of v will drop from 4.3 to 2.9 but v^1 will be appreciably higher. If we use for instance a liquified fuel consisting of 6 H_2 and 3CH we would cut down the oxygen from the theoretically required $5O_2$ by one third.

Increased pressure in the combustion chamber increases of course v^1, chiefly owing to decreased dissociation. Esnault-Pelterie shows in an example v^1 (of H_2+O) to be 4.15km/sec at 10atm. pressure, to rise to 4.45km/sec, when the pressure is raised to 100 atm. (These figures make allowance for inevitable losses in the expansion chamber, a practically adiabatic expansion being assumed). The increase of pressure on the other hand entails such difficulties regarding weight of the jet motor, fuel supply and so forth, that we will have to reckon with pressure not exceeding 40atm. as our practical limit.

The supply of the fuel into the combustion chamber overcoming the constant pressure of combustion in it, is a problem, which is by no means settled yet, especially, when the huge amount of fuel to be burnt in the short space of a few minutes, is to be considered. Oberth has made a big advance towards its solution, by discovering the principle of "self-disruption," by means of which it becomes possible to inject liquid fuel and oxygen into the chamber without the previous use of a carburettor. But even so, we are faced with losses due to insufficient contact and activation and consequently the fast removal of hot, partly unburnt gas from the chamber. Unburnt fuel leaves the chamber and some energy is lost; part of it is recovered by continued combustion in the expansion chamber the rest burns away in the open, producing the fiercely burning tail, so often observed on experimental rockets.

An intimate knowledge of the physico-chemical mechanism of the combustion in each individual case will help to avoid these losses and provide conditions approaching optimum. A typical example of this is the so often quoted case of the reaction between hydrogen and oxygen; this is not a simple combination of the two elements after the formula $H_2+O=H_2O$, but a very complicated chain reaction and it has been found, that its rate increases, up to a point, with the square of the diameter of the combustion chamber and also in the presence of an inert gas such as Nitrogen.

In this way optimum size and shape of the combustion chamber, etc., for each fuel will have to be developed individually, providing the necessary "inner streamlining" of furnace, throat and jet which the gas stream moving at high (over sound) velocities requires. Thus a jet engine for hydrogen may be constructed along somewhat different lines to a benzol rocket, very much the same way, as petrol and diesel engines are differentiated.

We come now to consider which type of fuel might be the most promising on account of the general principles outlined above. Surveying the available literature, the remarkable fact is revealed, that all fuels hitherto considered are either explosives, or usual motor fuels (including hydrogen, which is used in gas engines). Furthermore the opinion appears unanimously in favour of liquids, rejecting solid explosives entirely. This state of affairs is truly astounding. In the first place, the jet motor is neither a gun, nor a petrol engine, but in certain respects something in between. Consequently, neither gun cotton, nor gasoline would be the ideal fuel, but a energy carrier which takes up an intermediate position between the two. In fact, certain colloidal suspensions of high caloric value, containing oxygen carriers, considerably less brisant and erratic than an explosive, appear to be an ideal approach to this condition. A few tests, carried out recently, seem to bear great promise. It is not possible, to say much more on this matter at this early stage, except, that the energy carrier is a light metal in colloidial dispersion and that the obtained values of efficiency approach the theoretical value closer than any of the previously tested fuels.

There are a number of metals and metalloids which produce very high energy values on oxydation (some even exceeding that of hydrogen) which are still awaiting investigation. In the followin table the caloric values and relative exhaust velocities are given of the tested fuels, as well as of the ones which are here suggested, for easy comparison.

FUEL	Caloric	v	FUEL	Caloric	v
C to CO_2	2,220	4,3	Gun-Cotton	1,240	3,2
C to CO	1,050	2,9	Metal-Sol	2,300	4,4
H_2......O	3,240	5,2	Mg......O	3'590	5,6
CH_4...O	2,400	4,5	Al......O	3,850	5,7
C_2H_2...O	2,880	4,9	P.........O	2,580	4,6
C_2H_4...O	2,580	4,6	Ca......O	2,720	4,7
C_6H_6...O	2,430	4.5	Si......O	3,000	5,1
C_2H^5OH...O	1,970	4,0	B.........O	3,980	5,8
H_2S......O	1,380	3,4	$C_{14}H_{10}$...O	2,500	4,6

Notwithstanding these new and promising lines of progress the solid and liquid fuels in the usual sense still remain in the picture and are well worth our serious consideration. Some of them, suitably applied, even if not good enough for crossing space may lead up to interesting side lines, such as mail rockets, meteorological sounding rockets, take-off rockets for fully loaded planes, and other similar purposes. In this context it is worth noting that the solid fuels have an even chance with the liquids in producing practical results. This statement is made in spite of the generally accepted opinion to the contrary. Without wishing to refute any of the arguments for the liquid and against the solid fuels, which are fully accepted, it is necessary to point out, that the liquid fuel motor has still to overcome a number of difficulties, as has the combustion turbine (with which it has much in common). These are mainly of constructional nature, to which may be added the problem of adequate cooling and fuel supply. Against this the solid fuel rocket offers simplicity and cheapness of design, a more advantageous propagation of the reaction and less strain on the lining of the chamber. These advantages are sufficient to warrant further investigation to the solidly fuelled rocket.

Finally, mention should be made of two theoretically possible fuel components, which have the only drawback, that they cannot be produced in a sufficiently stable and safe form—yet. These substances are mono atomic hydrogen on the one, and tri atomic oxygen (ozone) on the other hand. To burn them together to water would give a theoretical v of near 30km/sec which may sound utterly phantastic. With this fuel at hand the conquest of the solar system would become the task of tomorrow. As things stand, the chances for this fuel are very small and the serious investigators will do better to concentrate his efforts to available fuels, which offer all the same an undoubted chance to produce practicable results.

—*Reprinted from the "Journal of the British Interplanetary Society," Vol.* 4, *No.* 2, *December,* 1937; *by courtesy of the Nuclear Committee.*

NOTE.

It may prove possible to compress or liquify, in safety, mono atomic hydrogen and tri atomic oxygen, with the use of suitable catalysts.

A noteworthy example of this is acetylene gas; in the early days of its development attempts were made to store it in a liquid, or compressed form, but under pressure the gas proved too dangerous. In 1896 Claude and Hess suggested making use of the solubility of acetylene in acetone, it was found that a simple solution of acetylene in acetone although safer, was not sufficiently free from danger to be generally used. Then it was found that when acetylene in acetone, was absorbed by porous material of the right kind, i.e. charcoal, asbestos and earth mixtures, etc., under a pressure of 10 atmospheres, it proved impossible to produce an explosion. Thus a cylinder of 1 cubic foot capacity, filled with porous material (porosity 80%) would contain 0.4 cubic feet of acetone, with 100 cubic feet of acetylene, of which 94% would be given off when the pressure is released.

A. KUNESCH.

CALCULATION OF HIGH ALTITUDE ROCKET TRAJECTORIES.

By E. Burgess.

A zenithal trajectory, which is the normal type of sounding rocket trajectory, can be resolved into four definite sections for the purpose of calculations.

(a) A period of constant propulsive force, giving continuous acceleration until either the fuel is exhausted or the value of drag equals the propulsive force.

(b) A period of constant propulsive force which is opposed by a high value of drag. The rocket ascends almost at constant velocity but experiences a slight acceleration due to reduction of the mass of the rocket and the density of the atmosphere.

(c) A period after the fuel is exhausted and the rocket travels as a projectile under the influence of the momentum it had at the time the last of the fuel was ejected. It is retarded by drag and the action of gravity and thus experiences a negative acceleration.

(d) A final period when the rocket reaches a height where the atmosphere is so thin as to be neglected. The equations of motion of a projectile in space can be employed.

1. Period of Acceleration.

So many variables occur during this period of propulsion that it is the most difficult to calculate. To obtain maximum propulsive efficiency, the fuel must be rapidly burned, and it is thus possible to regard the gravitational attraction as constant. Similarly, the specific mass of the air which is needed to calculate the value of drag can be regarded as constant over certain arcs.

Proceeding, therefore, from the simple expression $F = m \times a$,

$$\frac{dv}{dt} = \frac{F}{M} \qquad (1)$$

and allowing for the effects of gravity (g) and air resistance (D), the equation of motion of the rocket moving vertically upwards can be expressed as :—

$$\frac{dv}{dt} = \frac{F - D}{M} - g \qquad (2)$$

when :—

F = jet reaction = m.v.
M = mass in general.
M_o = original mass of rocket.
M_t = $(M - m.t)$ = mass of rocket at time t.
m = jet flow.
t = time.
v = jet velocity.
a = acceleration.
D = $K.k.p.S.V^2$.
K & k = coefficients.
p = specific mass of air.
S = maximum cross-sectional area of rocket.
V = velocity of the rocket.
B = $M_t/M_o = \dfrac{Mo - m.t}{Mo}$

Therefore :—

$$\frac{dt}{dB} = -\frac{Mo}{m} \qquad (3)$$

and (2) will become :—

$$-\frac{dv}{dB} = \frac{Mo}{m}\left(\frac{v.m - D}{B.Mo} - g\right).$$

giving, when simplified :—

$$= \frac{v - D/m}{B} \quad \frac{Mo.g}{m} \qquad (5)$$

The value of D is a function of the velocity, and also a function of the density of the atmosphere, which is, itself, a function of the height reached. It is possible to obtain a mean value of D over a certain arc and obtain a value of V for this arc, finally calculating the trajectory arithmetically.

$$\int dv = \int_{B_2}^{B^1} \frac{v - D/m.}{B} dB - \int_{B_1}^{B^1} \frac{v.g.dB}{a}$$

$$V = \left[(v - D/m)\log_e B_1 - (v - D/m)\log_e B_2\right] - \frac{v.g.}{a}(B_1 - B_2)$$

$$= (v - D/m)\log_e \frac{B_1}{B_2} - \frac{v.g.}{a}(B_1 - B_2) \qquad (6)$$

The distance travelled during this interval can be calculated from the mean velocity during the period multiplied by the time. The time has, of course, already been decided upon, when ascertaining a convenient value for B_1 and B_2. The mean value of drag is used in the calculations.

2. Period of Almost Constant Velocity.

As has been stated, the conditions necessary for almost constant velocity may result if the value of the jet-reaction is not large compared with values of drag that are likely to be experienced. At such an instant, the equation of motion will be equation two equated to zero :—

$$\frac{dv}{dt} = O = \frac{F - D}{M} - g \qquad (7)$$

and the velocity will be constant when :—

$$g(M_0 - m.t) + D = v.m \qquad (8)$$

If this velocity is much less than that of the efflux stream, the propulsive efficiency will be low. This must be allowed for in the design of a high altitude rocket.

3. Ascending Flight as a Projectile.

In this section the equations of exterior ballistics can be employed, because when the rocket has consumed and ejected all its fuel, it becomes similar to a normal projectile. V_f will represent the velocity of the rocket at the time the fuel is exhausted.

Neglecting variations in atmospheric density, the equation of motion is :—

$$\frac{dv}{dt} = -g - k.V^2 \qquad (9)$$

where k sums all the coefficients of the equation of drag. Therefore :—

$$dt = \frac{-dv}{g + k.V^2} = \frac{1.}{k} \frac{dv}{\frac{g}{k} + V^2} \qquad (10)$$

Integrating to find the time at which the rocket reaches the peak of the trajectory :—

$$T = -\frac{I}{k}\sqrt{\frac{k}{g}}.\tan^{-I}\sqrt{\frac{k.v^2}{g}} + C \qquad (11)$$

To find C remember that when T is zero then $v = V_f$, so :—

$$C = \frac{1}{\sqrt{k.g.}} \tan^{-1}\sqrt{\frac{k.\ V_f^2}{g}} \qquad (12)$$

and substituting :—

$$T = \frac{1}{\sqrt{k.g.}} . \left\{ \tan^{-1}\sqrt{\frac{k.V_f^2}{g}} - \tan^{-1}\sqrt{\frac{k.v.^2}{g}} \right\} \qquad (13)$$

At the peak, however, v is zero, so that the last term is zero and therefore :—

$$T = \frac{1}{\sqrt{k.g.}} . \tan^{-1}\sqrt{\frac{k.\ V_f^2}{g}} \qquad (14)$$

To calculate the height reached when t = T, consider :—

$$\frac{d^2 S}{dt^2} = \frac{dv}{dt} = \frac{dv}{dS} \cdot \frac{dS}{dt} = v \cdot \frac{dv}{dS} \qquad (15)$$

and re-writing expression (9) :—

$$\frac{dv}{dt} = \frac{d^2S}{dt^2} = v \cdot \frac{dv}{dS} = - g - k.v^2 \qquad (16)$$

so that :—

$$dS = - \frac{v \cdot dv}{g + k.v^2} \qquad (17)$$

To obtain the value of S, expression (17) must be integrated between the limits when $v = V_f$ and $v = v_1$ giving :—

$$S = -\frac{1}{2k} \log_e (g + k.v_1^2) + \frac{1}{2k} \log_e (g + k.V_f^2) \qquad (18)$$

which simplifies to :—

$$S = \frac{1}{2k} \log_e \frac{g + k.V^2}{g + k.v_1} \qquad (19)$$

If v_1 is not zero, then the equation can be employed to give intermediate values of S, for calculation by successive arcs, when k varies greatly. The maximum height will be when the limits of the equation are V_f and zero, giving :—

$$S = \frac{1}{2k} \log_e \frac{g + k.V_f^2}{g} \qquad (20)$$

It must be remembered that k is not only dependent upon the density of the atmosphere, but also upon the ratio between the velocity of the rocket and that of sound.

4. Ascending Flight Beyond the Atmosphere.

If the rocket has only a low velocity when it enters into this zone, it will not be expected to rise to any great height, so that the value of the gravitational attraction can be regarded as constant.

The equation of motion is simply :—

$$\frac{dv}{dt} = -g \qquad (21)$$

thus :—

$$V_t = V_f - g.t \qquad (22)$$

and :—

$$S = V_f \,.\, t - \frac{g.t^2}{2} \qquad (23)$$

and :—

$$T = V_f / g \qquad (24)$$

so that :—

$$S_{max} = V_f^2/2g \qquad (25)$$

Rocket projectiles and sounding rockets will ultimately be designed to enter this final zone with a high velocity, perhaps even for interplanetary purposes. In such cases, the value of g cannot be regarded as being constant but does, in fact, vary as :—

$$gs = g \frac{R^2}{(R + s)^2} \qquad (26)$$

where gs is the value of g at height S and R is the radius of the Earth. This is the well-known inverse-square law of gravitation.

To facilitate the approach to the calculations, (R + S) will be equated to r so that the equation of motion in this zone is :—

$$\frac{dv}{dt} = -g.\frac{R^2}{r^2} \qquad (27)$$

Multiplying both sides by dr :—

$$dv. \frac{dr}{dt} = - g \,.\, R^2 \,.\, r^{-2} \,.\, dr \qquad (28)$$

but dr/dt is a velocity, so that :—

$$v.\, dv = - g \,.\, R^2 \,.\, r^{-2} \,.\, dr \qquad (29)$$

Integrating this between the limits when r = R and r = r gives :—

$$\int_{V_r}^{V_R} v.dv = \int_{r}^{R} -g.R^2.\,r^{-2}.\,dr \qquad (30)$$

which is :—

$$\frac{V_R^2 - V_r^2}{2} = g \cdot R \left(\frac{1}{R} - \frac{1}{r}\right) \qquad (31)$$

If the projectile should reach an infinite height, that is, escape completely from the attraction of gravity, equation (30) can be rearranged, so that, when r is infinite Vr will be zero, therefore :—

$$V_R = V_{lib} = \sqrt{2 \cdot g \cdot R} \qquad (32)$$

With high altitude rockets this value of V_R may not be equal to escape velocity, and it will travel upwards until Vr becomes zero, giving :—

$$\frac{V_R^2}{2} = g \cdot R - \frac{g.R^2}{r} \qquad (33)$$

Rearranging to find r for a known value of initial velocity V it is found that :—

$$r = \frac{2gR^2}{2gR - V_R^2} \qquad (34)$$

and as 2g.R is equal to the square of the escape velocity, then :—

$$r = R \frac{V_{lib}^2}{V_{lib}^2 - V_R^2} \qquad (35)$$

and as r = (S + R), then :—

$$S = R \left\{ \frac{V_{lib}^2}{V_{lib}^2 - V_R^2} - 1 \right\} \qquad (36)$$

In the case of a rocket in the fourth period of the calculations V_R will be equal to V which is the initial velocity when the rocket enters the final stage.

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