Centaur is to achieve its performance from the 360,000lb-thrust Atlas by using liquid hydrogen and liquid oxygen for specific impulse of some 420sec in the second stage. Can it give us a useful indication of the size of the Lunik launcher—which we are assuming did not use propellants comparable with liquid hydrogen and liquid oxygen? A rocket relying on conventional propellants would have to be substantially heavier. Let us tentatively suggest first-stage thrust of 600,000 to 700,000lb, and a liftoff weight of 350,000 to 450,000lb.

By comparison with Centaur, much greater first-stage thrust is easier to accept than considerably increased weight. Centaur is reported to have a liftoff weight of about 290,000lb, giving a thrust/weight ratio of about 1.24. The initial acceleration which this implies of 0.24g, compared with the usual optimum of about 0.3, would not in general argue efficient use of the first-stage propellants; but Centaur is yet another American compromise, in which the greatly superior specific impulse of the upper-stage propellants means that some first-stage efficiency can be advantageously sacrificed for a larger upper stage.

A figure of 700,000lb for Lunik thrust has been widely quoted, with the authority of Dr Keith Glennan, former Administrator of NASA, who said: "Soviet scientists have had at their command a rocket which our scientists and engineers estimate is in the 600,000 to 800,000lb-thrust range. They have spoken of multi-stage launch vehicles, and some of their mission accomplishments would indicate that they have used upper stages with these very powerful first-stage rockets." Dr Glennan's remarks relate to Phase I of the Russian programme.

How could this increase of first-stage thrust have been obtained, assuming basic first-stage design did not vary throughout Phase I? It might have been within the development potential of the engines, or it might have been obtained by the attachment of booster units. Judging from alleged photographs of Russian rockets the latter is a frequent technique; many of their rockets must be expressly designed to accommodate these boosters.

This picture coincides broadly with a description in a Czech journal, which suggested that the first-stage thrust of Lunik 1 was 600,000lb—440,000lb main engine plus two auxiliary motors each producing 80,000lb. The two auxiliaries were ignited at about 2,000m (6,560ft).

It is of interest that these figures for the Phase I launching vehicle—about 500,000lb first-stage thrust in the initial two-stage form, 700,000lb in the final three-stage form—agree with unofficial reports of the so-called T-3 and T-3A Russian ICBMs. The inference is apparently that these two related missiles have been accepted by Western intelligence sources as the launchers of the first three Sputniks and the three Luniks respectively, and that their main characteristics have been decided on the basis of their performances in these space experiments.

Much more information about the precise achievements of contemporary rocket technology would be available to Western intelligence bureaux than to the public. Here we have been making estimates on a rough order of magnitude basis, but we may not be very much less accurate, for Russian rocket technology is in an almost unknown state of development. We can only see its results.

The Phase II vehicle

We turn now to the Phase II launching vehicle. Many general considerations have a bearing on our ideas of the size of this rocket. We have already seen that there is a strong case for believing that it was designed to send the 10,500lb spaceship-satellite on a variety of missions. Almost certainly, therefore, it would need to be able to accelerate it to near-escape velocity. Much comment in the Soviet Press lends support to this thesis. For example, Maj Gagarin is reported to have said that the rocket could orbit payloads several times greater than the spaceship-satellite. We are also told officially that the quantity of propellants for the manned orbital launch was more than 100 times the payload weight. So we have here a rocket of comfortably over 1,000,000lb take-off weight, even for a mission which is not assumed to represent its ultimate capability. The apparently large ratio of fuel to payload may be a further indication that the rocket was designed for bigger jobs, and not at its most efficient with this relatively small payload.

So far the picture is of a rocket fully comparable in size and capabilities with the US Saturn. In its initial C-1 form Saturn is estimated to have a close-orbit payload capability of 20,000lb, and in the later C-2 form 45,000lb. To pursue the comparison, the minimum liftoff thrust of the Russian rocket must be about 1,300,000lb, in view of the weight of at least 1,000,000lb of the version which put Gagarin into orbit; and in later applications the rocket will probably weigh substantially more. But Saturn's performance depends on the use of high-energy propellants in the upper stages. If the Russians are relying on conventional propellants their rocket will need to be appreciably heavier to produce equivalent performance. In this case 2m to 2.5m pounds is a conservative estimate for the first-stage thrust.

What information can we extract from the figures the Russians gave the Fédération Aéronautique Internationale in support of their record claim? A precise translation of part of their submission states: "at launching, the rocket had six engines with total power of 20,000,000 h.p." It is difficult to make much of the horsepower figure. It is ambiguous. In determining the significance of the six engines, the configuration is the first problem—how many stages were there, in series or parallel? It is not necessarily implied that all six engines were clustered for first-stage propulsion. In fact it clearly seems that there were six engines all-told, and for all six to be operating at liftoff a completely parallel stage-configuration would be required. Gagarin's own accounts have told of the stages falling away "one after the other," suggesting a three- or four-stage rocket. One would not easily accept the possible maximum of six or even five stages. A two-stage vehicle would probably be adequate for the given close-orbit mission; but what the Russians have created is a space rocket for other and more ambitious projects, for which it is logical to suppose three or four stages in optimum relationship.

Photographs from the film of Gagarin's flight show the *Vostok* with what is apparently the final stage of the carrier-rocket, closely resembling the final stage of Lunik 2. If we accept that this resemblance implies a single engine, as on Lunik 2, then for the two or three lower stages of the vehicle we have five engines. Many configurations are possible. Particularly interesting is a parallel combination of the five engines for first-stage propulsion, with transition to subsequent stages by discarding engines with or without corresponding sections of tankage. Advantages of this configuration are the theoretically higher efficiency of parallel staging, and the elimination of the need for in-flight ignition of multi-engined upper stages. It may also account for the appendages looking like boosters or accessory tanks which, as previously noted, frequently appear in photographs of Russian rockets.

One further conjecture. A reference has been reported in a Czechoslovak journal to a Soviet rocket engine developing 1,000 metric tonnes thrust, i.e., 2,204,900lb. Such an engine might be at the centre of the cluster of five, being discarded to leave four engines sustaining the second stage of operation. A reasonable estimate for the total thrust of these four engines is somewhere in the region of 500,000lb, which gives a total first-stage thrust of roughly 2,700,000lb. Mr Val Cleaver of Rolls-Royce has pointed out that the most technically meaningful interpretation of the quoted 20,000,000 h.p. is on the basis of dissipation of kinetic energy in the exhaust, in which interpretation it corresponds to a thrust of some 2,730,000lb. (Strictly this applies to all six engines, but the final-stage engine makes a relatively negligible contribution to the sum of the thrusts.) These figures are all approximate, the horsepower quoted by the Russians probably being much rounded-off.

To sum up, in the Phase II launching vehicle we have a rocket of three, and possibly four, stages. These provide it with considerably greater potential than necessary for the close-orbit *Vostok* mission. If based on conventional propellants, its liftoff thrust is likely to be at least 2,000,000lb.

How does this rocket match up to the future needs of the Russian space programme? It certainly looks as though the Russians intend to put a man on the Moon by 1967, and possibly before. They intend to have men on Venus and Mars in the early 1970s.

MAIN EVENTS OF RUSSIAN SPACE PROGRAMME

	Phase I	
Sputnik 1	Oct. 1957	First Earth satellite
Sputnik 2	Nov. 1957	Dog-carrying satellite
Sputnik 3	May 1958	Physical experiments satellite
Lunik 1	Jan. 1959	Lunar near-miss
Lunik 2	Sept. 1959	Lunar impact
Lunik 3	Oct. 1959	Photographed back of moon
	Phase II	
Space-rocket tests	Jan. 1960	Two ballistic firings into Pacific
Sputnik 4	May 1960	First spaceship-satellite
Space-rocket tests	July 1960	Two further firings into Pacific
Sputnik 5	Aug. 1960	Spaceship carrying dogs. Recovered
Sputnik 6	Dec. 1960	Spaceship carrying dogs. Not recovered
Sputnik 7	Feb. 1961	14,295lb satellite, function undisclosed
Sputnik 8	Feb. 1961	Parking-orbit satellite for Venus probe
Sputnik 9	Mar. 1961	Spaceship with dog. Recovered
Sputnik 10	Mar. 1961	Spaceship with dog. Recovered
Vostok 1	Apr. 1961	First manned orbital flight
Vostok 2	Aug. 1961	Seventeen manned orbits

If the lunar mission is to be fulfilled by a chemical rocket with conventional propellants and direct transfer, a vehicle weighing tens of thousands of tons—of the order of 50,000—at launching seems inevitable. Propellants of higher energy would bring this figure down very considerably, but not below about 4,000 tons.

This is not an impossible perspective, but it is most improbable. What we are looking for is a reasonable "next step" which would carry us from the present state to the realization of manned lunar landing. The time-scale we have in mind does not permit more than one major "next step" in rocket technology. In this sense the all-chemical, direct-transfer method does not seem to be a logical "next step."

The alternatives are orbital rendezvous—flight refuelling on a parking orbit—rendezvous on the lunar surface, or the use of a direct-transfer vehicle based on the present Phase II vehicle with one or more nuclear intermediate stages.

Each of these is a conceivable next step. The existing Phase II vehicle should be big enough to make orbital rendezvous a relatively simple technique, in that not more than five vehicles would have to rendezvous. Rendezvous on the lunar surface looks less likely.

It will not be long before the course of events reveals whether orbital rendezvous is the method selected. If it is, experiments must begin soon. That we have reached the present date without any orbital-rendezvous experiments by the Russians may be taken as favouring the nuclear hypothesis, for a nuclear stage could be thoroughly tested and developed without recourse to orbital experiments. On previous form the Russians prefer this type of progress, and their rockets have been very reliable by the time of operational employment. The first orbital-rendezvous experiments might reveal unanticipated difficulties.

Current development of either orbital-rendezvous techniques or a nuclear rocket would go far to justify confidence in the achievement of manned lunar exploration before the 1960s are out. Unless experiments in orbital rendezvous are made before long, it would seem that nuclear stages combined with the existing giant chemical rockets constitute the selected option—if we are not tantalizing ourselves with unreal hopes.