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PENETRATORS (PENETRATING SONDES) AND NEW POSSIBILITIES FOR STUDY OF THE PLANETS

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16. Abstract The fields of possible use of penetrators in space research are considered. A short survey of the condition of development and plans for use of penetrators abroad is presented (according to published material) and an analysis is given of the significance of scientific problems when probing planets.

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PENETRATORS (PENETRATING SONDES) AND NEW POSSIBILITIES FOR STUDY OF THE PLANETS

V. D. Davydov and G. A. Skuridin

I. Introduction and Posing the Problem. /3*

In the third decade of the space era, such problems as the study of the physical characteristics of the planets of the Solar system including the internal structure of the planets of the Earth group are some of the most important problems to be solved using space equipment; the largest satellites, Jupiter... and Saturn stand out.

The development of modern cosmonautics showed that at the present time practically all of the planets of the Solar system have become attainable for direct study.

The possibility of delivering an automated craft to the surface of celestial bodies makes it possible to use traditional methods of geophysics for studying them. Such automatic equipment as landing stations with devices for soil sampling including drilling and also lunokhods have been created.

In spite of the technically unique character of automatic units developed at the present time, the possibility of studying planets right now is limited by a whole series of specific conditions:

a) the complexity of designing systems for a soft landing on the surface of planets;

b) the rigidity of requirements for selecting landing regions;

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* Numbers in the margin indicate pagination in the foreign text.

c) the complexity of controlling the landing station in the descent area and during operation on a planet;

d) the possibility of locating centers and studying soil samples within the limits of very shallow depths; /4

e) the effect of ambient conditions on the planet on operation of instruments (high and low temperatures, high and low pressures, mechanical effect of the wind).

Improvement of the existing and the creation of new equipment for delivering scientific instruments to the surfaces of planets in order to expand the study regions is extremely important; this involves decreasing the requirement for the landing region, decreasing the weight of the landing craft, simplifying control systems, decreasing the requirement for landing speed of the craft, increasing the depth of probing for the planet.

The purpose of our method survey is to attract attention of specialists to one of the most important methods of probing planets which has recently become widely considered in the scientific and technical press of foreign countries.

Later on we will discuss a system of so-called penetrators.

2. A System of Shell-Penetrators.

At the end of the 1950's, in the USA, a system of shell-penetrators was proposed for development which could withstand impact on the surface of Earth after being ejected from low flying and possibly supersonic craft [1].

The shell-penetrators with low weight have the capability of penetrating into the soil to a considerable depth thanks to their specific design characteristics: needle shape, high strength of the nose section, center of gravity set forward, stabilized point of orientation of the aerodynamic tail unit at the impact moment (figure 1).

of solid steel. Under the layer of ablated entry covering (see figure 2) the nose section has the characteristic shape of a leading section optimum for movement in the soil.

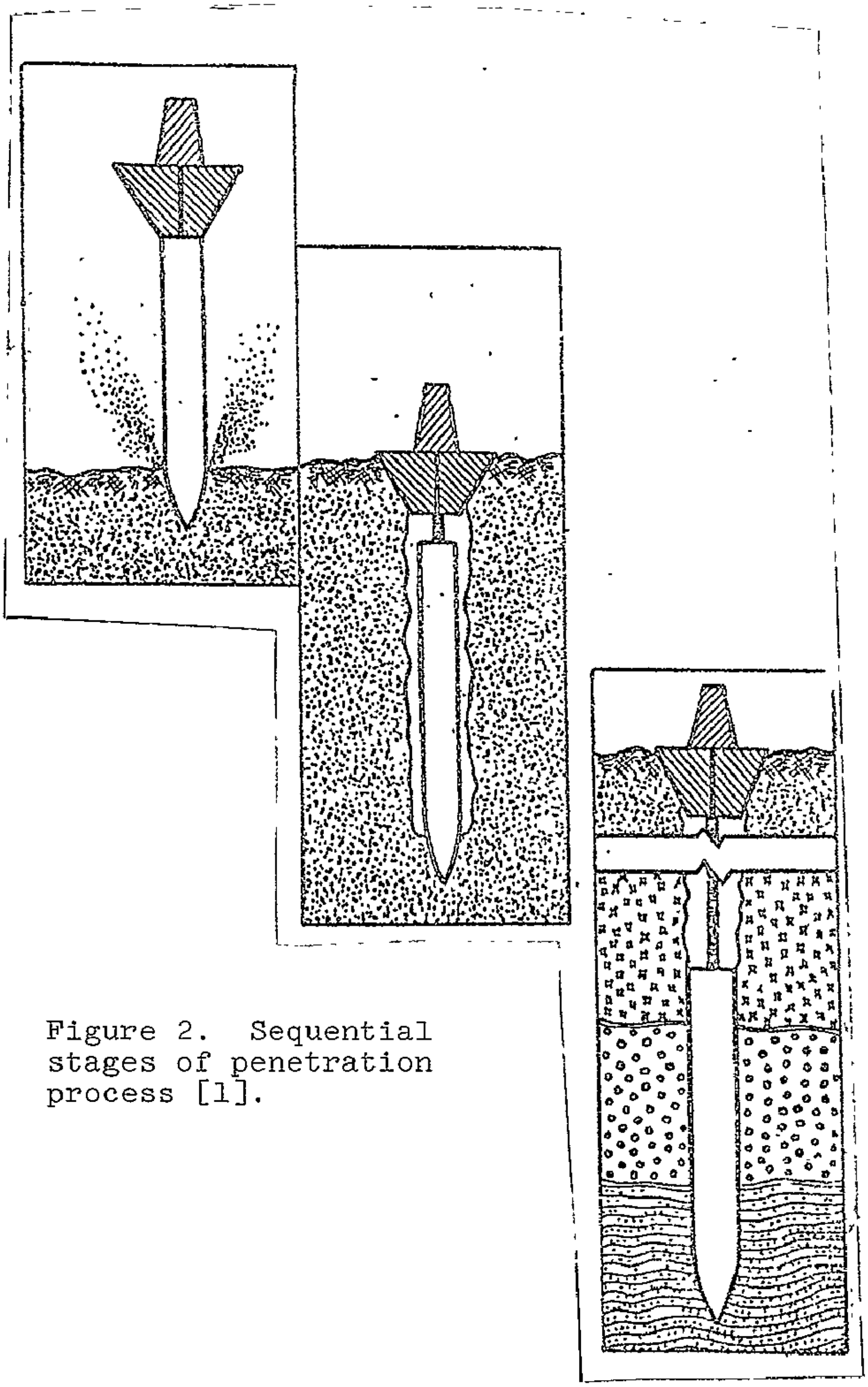

Figure 2. Sequential stages of penetration process [1].

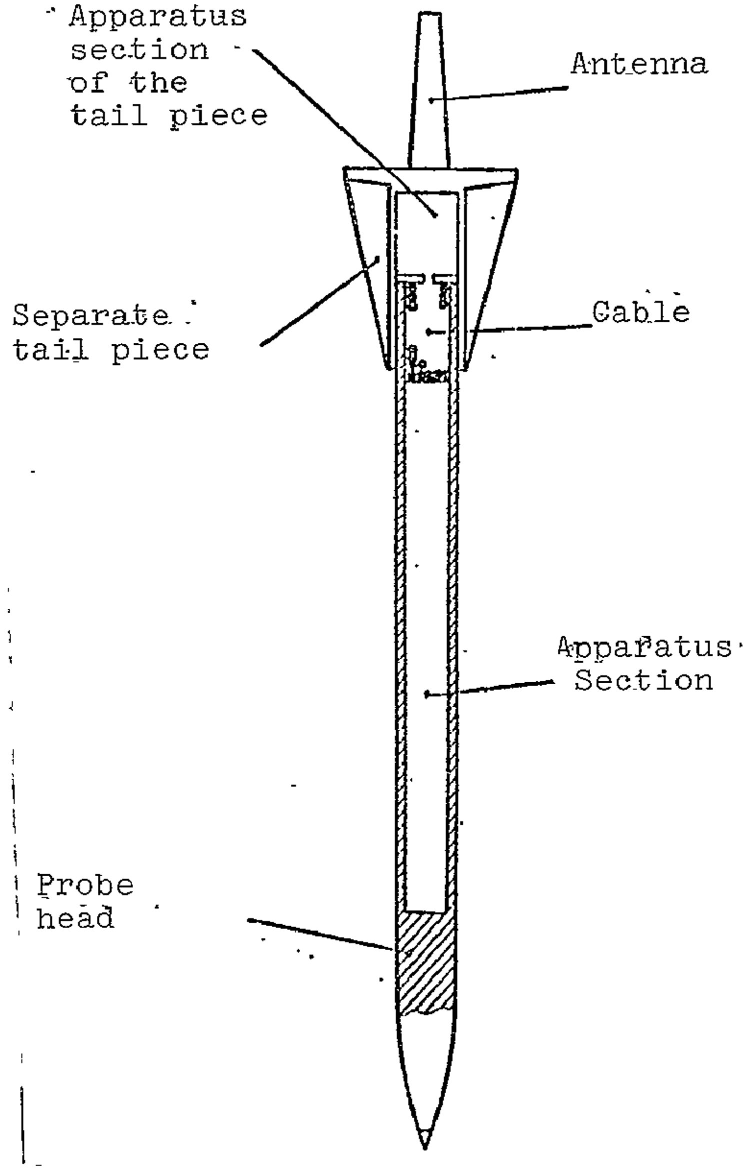

Figure 1. Penetrator (general diagram) [1]

The shell-penetrator is made up of the probe nose (forebody) and the tail piece (afterbody) which separate at the landing moment from the aerodynamic stabilizer. The afterbody is made of light aluminum alloy. The aerodynamic stabilizer with additional braking surface placed far back of the center of gravity of the penetrator provides the necessary stable orientation of the apparatus during its fall in the atmosphere. The forebody, designed for penetration into the soil is made /5

A significant part of the volume of the nose probe is taken up internally for the accelerometer and scientific equipment with electronic supply, telemetry system and electrical energy source. The entire design is subject to the requirement of shifting the center of gravity of the apparatus as far forward as possible.

Preliminary decrease in velocity of the penetrator to the velocity calculated for the landing moment is accomplished by aerodynamic braking in the atmosphere of the planet using parachutes or a two stage system of inflatable balloons.

When colliding with the solid surface of a planet, the afterbody separates from the forebody; in certain systems, separation occurs only due to design characteristics and in others by firing. The main purpose of this procedure is to leave the receiver center on the surface of the antenna mounted in the afterbody and also the meteorological complex and device for obtaining images of the landing area. Entrance of the forebody into the soil involves the multistrand cable of the afterbody's placement in its original location as shown in figure 1. A detailed record of braking of the penetrator in all movement /6
in the soil is done with the accelerometer according to telemetry directly in the penetration process or is recorded in the onboard ZU [zondiruyushcheye ustroistvo, probe device] for subsequent removal.

3. Preliminary Results of Testing the Shell-Penetrators.

When a spacecraft encounters the surface of a planet without taking special measures for a soft landing, the peak load reaches a considerable magnitude as a result of which damping of the velocity occurs on a very small section of the brake path of the apparatus; it is limited usually to the depth of the impact crater.

Thanks to the design characteristics of the shell-penetrators, instead of a sharp stop on the surface, braking occurs extended for a considerable time interval on a comparatively long movement path for the shell (approximately several meters) in the soil up to a full stop.

According to the published test results, the depth of penetration of the shell-penetrator with impact velocity of about 160 m/s amounts to from 1 to 15 meters depending on the hardness of the soil (basalt -- loose sand) [1].

Going from this, one can determine the magnitude of the acceleration factor when braking the shell.

As is well known, impact velocity v_o, the braking path x_o, braking acceleration -- $a(x_o)$ and braking time t have a simple relationship.

Assuming movement of the shell-penetrator in the soil slows down evenly, we find: $t = \frac{2x_o}{v_o}$; -- $a(x_o, t) = 2\frac{x_o}{t^2}$. From this, the braking time of the shell-penetrator when penetrating 1 m /7
into the soil (monolithic soil) amounts to $\sim$ 0.012 s, and with 15-meter (loose soil) penetration $\sim$ 0.188 s. In these cases, negative acceleration in units of earth "g" amount to about 1300 and 90, respectively, for monolithic and loose soil.

The first penetrator tests showed that the actual process of movement of the solid body in the soil with a velocity in a 10^2-10^3 m/s range differs sharply from the preliminary concepts of this process. The depth of penetration of the shell-penetrator into solid earth was considerably greater than that predicted on the basis of resistance of materials and peak acceleration g which the onboard systems underwent was considerably smaller than that predicted.

In the final section on the graph recorded for acceleration g, a relatively short term peak was noted with large amplitude after which there were attenuated vibration waves. On the painted lateral surface of the apparatus, after passing through the soil and then being removed for study, one detected unlikely weak signs of abrasion or a complete absence of it.

In the last ten years Sandia Laboratories has tested approximately 15,000 shell-penetrators weighing from a kilogram to almost three tons with impact velocity from 70 m/s to 1 km/s; the depth of penetration varied in a range of incomplete penetration of the apparatus under the surface to more than 70 meters [1].

On the basis of the entire accumulation of tests made, a preliminary interpretation of results and their characteristics was obtained [1].

The main stages of the process of penetration is shown diagrammatically in figure 2. Figure 3 shows the smooth (a) and actual (b) recordings of readings from the onboard accel- /8
erometer.

At the initial moment of impact of the apparatus on the surface, the nose section of the penetrator cuts into the soil forming a crater with a small volume of ejected material.

G. J. Simmons indicates [1] that in the process of formation of this crater, braking of the penetrator usually is high (point W in figure 3a).

As the housing of the apparatus continues to penetrate into the soil, the stop of the afterbody reaches the surface and impact occurs separating the afterbody from the forebody

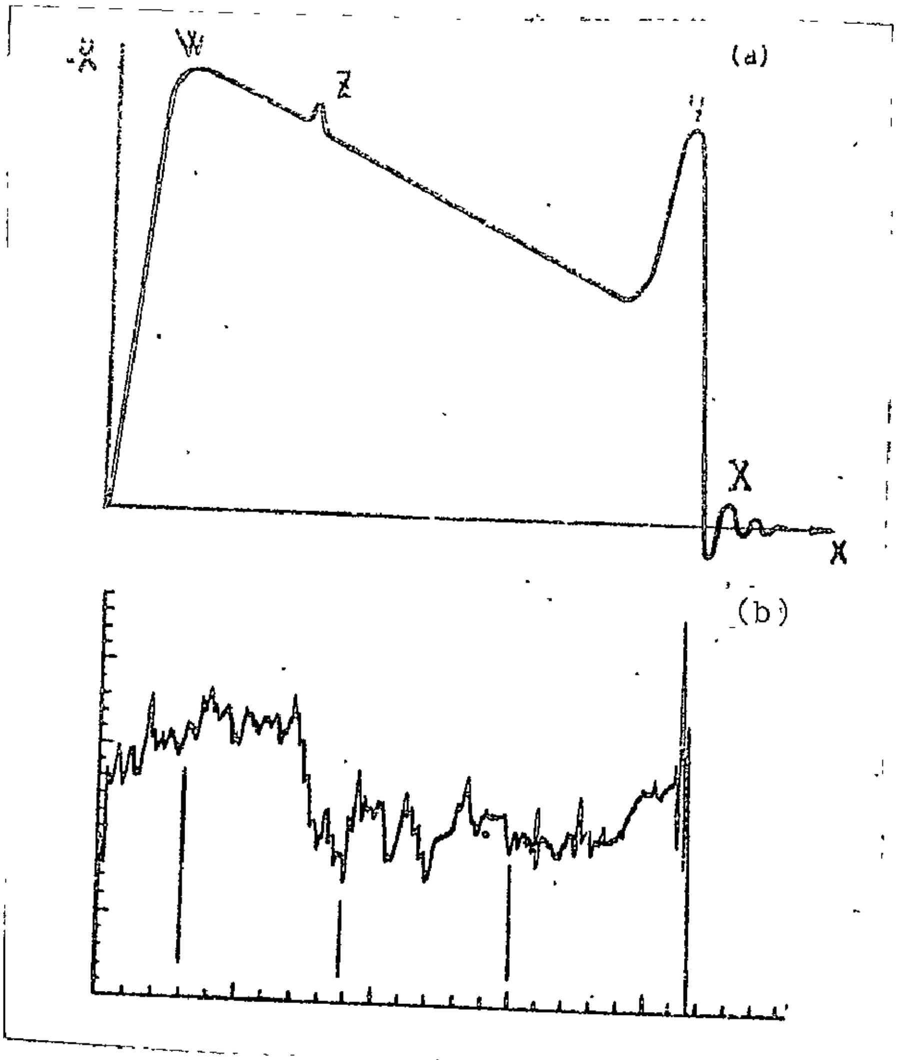

Figure 3. Data on the accelerometer [1]
a) idealized diagram of braking of the penetrator;
b) a sample of the actual recording of penetration.

which continues its motion inward. The process of separation of the afterbody is shown on the recording of braking the forebody as a small flash of acceleration g (point Z on the graph in figure 3a).

While the shell-penetrator moves into the soil at high velocity, the nose section cuts into the solid substance moving and compressing it. The particles encountered by the nose section acquire only a significant speed in a lateral direction which continues its motion even after the force on them stops and has a pressure on the wall of the hole through which they move. Around the housing of the penetrator there is a cavity.

In a considerable part of the path of penetration, in contact with rock, only the nose part of the housing of the penetrator has an effect and the center section of it passes through the hole formed hardly touching the walls. And therefore the lateral surface of the penetrator and even the color on it is only slightly scratched.

After the shell-penetrator passes through, the particles of soil ricochet due to the elasticity of the substance and the diameter of the hole decreases. Behind the penetrator the hole remains with a diameter after its passage always smaller than the diameter of the penetrator.

After a considerable decrease in the velocity of the forebody, a strong compaction occurs of its housing by the ricocheting soil and on the recording of the braking one sees a strong final flash (point Y in figure 3a) corresponding to a sharp increase in acceleration g with the sudden stop. At the stopping moment, one observes significant vertical vibration of the penetrator in the surrounding material contacting it elastically. /9

We note that in the work done [1] the smoothed characteristic recording of braking in the process of penetration (figure 3a) is clearly traced according to the decrease in velocity of the penetrator in the soil and negative acceleration gradually disappears. However, this is far from obvious if one looks at the single example of nonsmoothed recording published in this work (figure 3b).

The forebody of the penetrator must have a large ratio of length to diameter (~ 8-10) for a stable trajectory of deep penetration. For this purpose, one can add a small non-separating stabilizer.

4. The Possibility of Using Shell-Penetrators for Probing Planets.

In recent years in the USA, the possibility of using penetrators for probing celestial bodies has been considered. For this purpose, NASA turned to the Sandia Laboratories with a proposal for developing a small penetrator with an accelerometer which could be used on the Moon for obtaining data on braking in the first few centimeters of introducing the apparatus into the soil; this would make it possible to evaluate the load bearing capability of the lunar surface material.

Later on, the necessity for this development lost its sig- /10 nificance. At the presnt time, G. J. Simmons (USA) had the idea of the possibility of using penetrators as landing apparatuses for delivering scientific apparatuses to Mars [1]. Since 1969, Sandia Laboratories has developed a design of a penetrator for landing on Mars from the Viking orbital craft in 1976.

The experiment was deemed incompatible with the Viking program by the experts at NASA and was not realized.

Later on, a variation was considered in which from one spacecraft, 4-6 sterilized penetrators would be ejected for scientific measurements simultaneously at several points on the surface of Mars. Possible systems for landing the penetrators on the surface of the planet are shown in figures 4 and 5.

Tables 1 and 2 show the nominal characteristics of a shell-penetrator for probing the planet Mars and also indicate the scientific problem [1].

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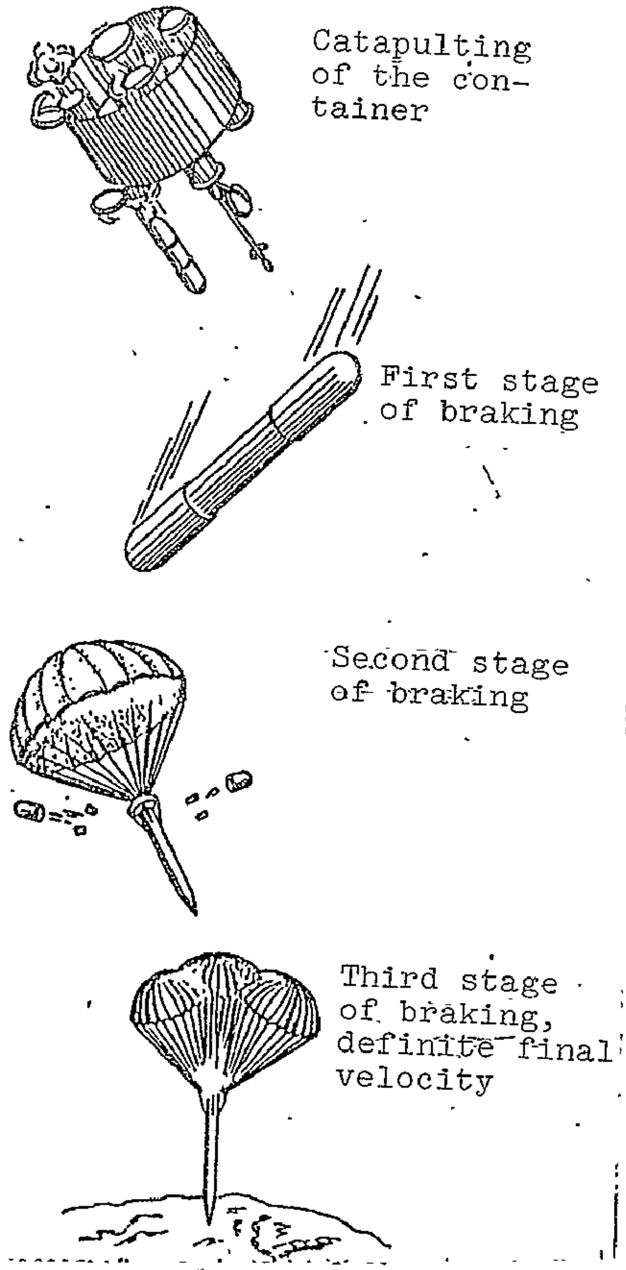

Figure 4. Proposed landing of a penetrator on the surface of Mars according to the Sandia Laboratories system [1].

It is not adequately clear why in the description of the characteristics of Martian penetrators there is mention of the absence of depth control. This, to a significant degree, would decrease the value of the scientific results of the experiments and sharply limit their capabilities. Moreover, the recording /10

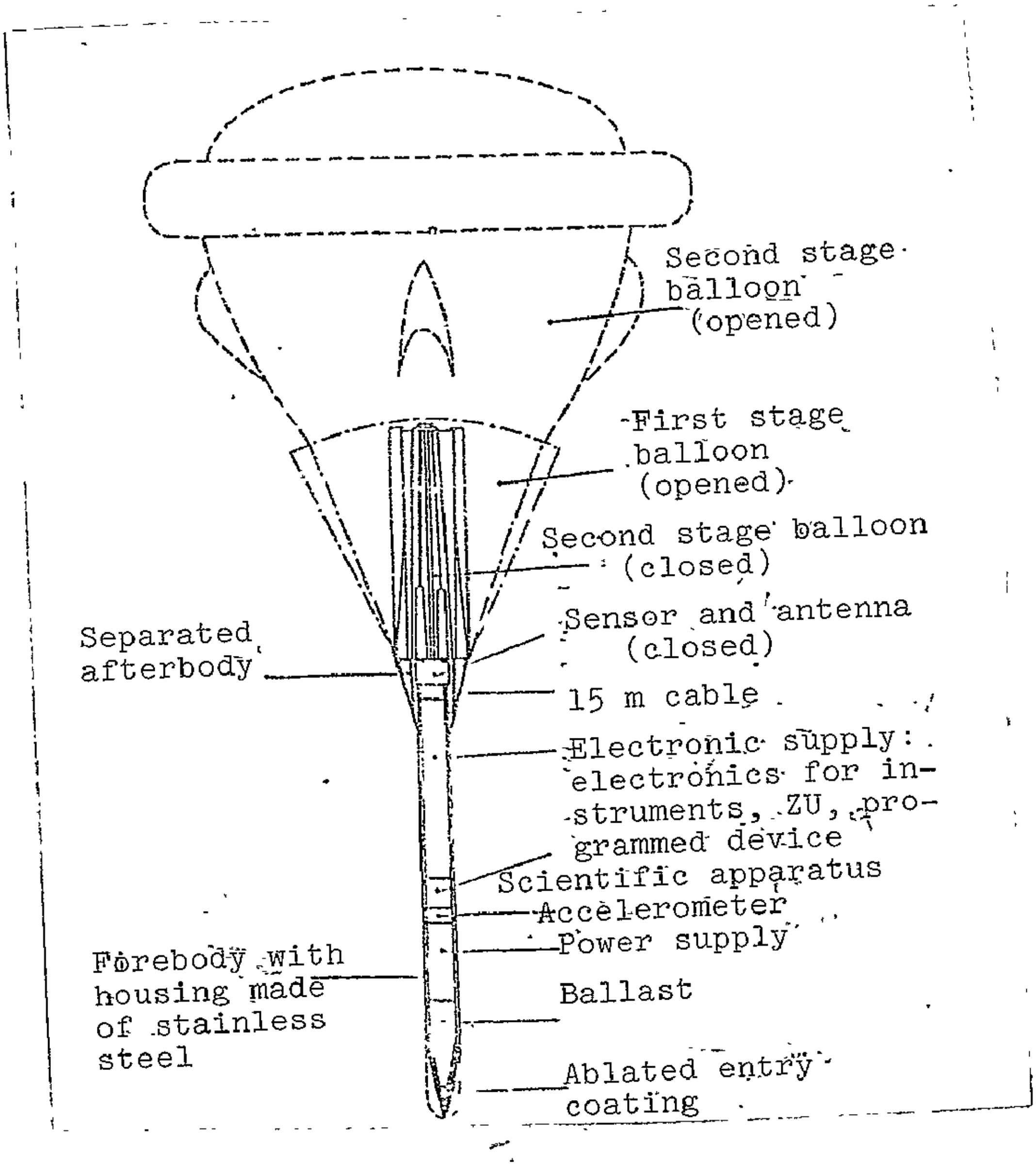

Figure 5. Penetrator with two-stage system of inflatable balloons for preliminary aerodynamic braking according to the Hughes Aircraft Company system.

of readings from the accelerometer contains information on the mechanical properties of the soil at different depths. Calibration of the recordings by depth penetrated (for depth referencing of interesting features) results obviously in a dual integration in time of the indices of the accelerometers. /10

Table 1

Nominal Characteristics of the Martian Penetrator from the Sandia Laboratories

	Weight of the Penetrator	Block of Scientific Equipment and Electronics	
Mass	31 kg		7.3 kg
Diameter	9 cm		7.6 cm
Length	140 cm		102 cm
Depth of penetration into the soil	Noncontrolled, from 1 to 15 m	Average power of the supply source	0.3 watts
Landing speed	140-170 m/s	Capacity of the ZU	250 thousand bits
		Transmission speed	Maximum 200-500 bits/s
Impact acceleration factors	Average, not more than		Peak, not more than
Block of scientific equipment	1200 *g* for 15-20 ms		1800 *g* for 15 ms
Antenna			18,000 *g* for 2-3 ms

This same method in principle makes it possible to conduct remote measurements of the full length of the path covered by the forebody until it stops and then this operation could be carried out using a computer located onboard the penetrator. Inasmuch as the hole usually is not vertical, for locating the depth of stopping of the forebody one has to know also the angle of deviation of the axis of the hole from the vertical. /10

Table 2 /12

System of Scientific Problems of Penetrators

Study	Instruments
Earth's Interior	
Tectonic	Seismometer, tilt indicator
Thermal flow	Thermocouples
Magnetism	3-component magnetometer
Soil	
Element composition	Apparatus for X-ray flourescent analysis Gamma-spectrometer
Chemical composition	Apparatus for neutron-activated analysis. Hygrometer. Pyrolytic chamber. Ion chamber
Mineral composition	Proton/gamma-spectrometer
Physical properties	Accelerometer Ion chamber
Surface	
General and geological characteristics of the landing area	Device for receiving images (IM).
Meteorological observations	Anemometer, barometer, thermometer, IM
Aeolian activity	IM
Transfer of volatile substances	IM

Let us discuss in more detail the scientific problems which /13 can be solved using penetrators.

In the recommendations of the American committee on scientific use of penetrators [4] there is a conclusion that the program-minimum must include simultaneous landing on Mars of four penetrators and that each of the penetrators must carry a seismometer and in the afterbody there must be a device for obtaining optical images of the landing area. Moreover, on each penetrator there must be equipment for carrying out at least one of the following additional experiments:

-- determining the chemical composition of rock,
-- measuring the content of water,
-- measuring heat flow,
-- meteorological observations on the surface.

In the opinion of the committee, the appropriate forces would make it possible to realize all of these experiments plus others.

For an experiment on seismic listening on Mars in the USA, it was proposed that one use either a 3-component seismometer or a 2-component, sensitive only to the horizontal plane in combination with an accelerometer sensitive in a vertical direction.

G. Simmons, presenting conclusions from considering the scientific problem, includes the seismic experiment, and also obtaining information on mechanical and thermal and physical properties of the soil among problems of the second category of importance putting in first place the quantitative evaluation of thermal flow from the Earth's interior and geological analysis of the vertical profile of the bore hole. /14

In our opinion, the primary task in using penetrating soil probes for studying Mars must be obtaining information on questions involving the depth of the structural body of the planet. For solving connected questions in the problem of thermal evolution of planets of the Earth group, studies are required primarily on two main approaches:

1. measurements of thermal flow from the Earth's interior in different regions of the surface;

2. deep seismic "fluoroscopy" of the planet using a global network made up of several instruments with high sensitivity.

Information of this type will have a decisive importance for clarifying a number of questions of planetary physics and when selecting the most important approaches to the study in the future.

Evaluations of regional values of thermal flow from the interior of planets according to measurements of the vertical gradient of temperature and temperature conductivity of substances in the subsoil layers of the Earth can be used as the most important criteria when making models of the internal structure and thermal evolution more precise for Mars. For carrying out measurements, it is necessary to place the sensor at a depth of at least several meters under the surface of the soil. The penetrator makes this possible without using drilling equipment. However, in view of the negligible effect of the apparatus on temperature distribution in the soil, the method of these precise measurements must be developed with participation of specialists in geophysics.

Seismic "fluoroscopy" of the interior is an effective method of obtaining information on the physical properties and state of substances in the deep zones of the planet. In the experiments on active seismics for disturbance and oscillation /15
of the soil, a charge of explosives is used. An advantage is the absence of requirements of long duration of operation of the instruments, but the radius of effect is limited. A long term passive seismic listening would be much more valuable; the advantage of this is the following additional possibilities.

a) The probability of recording natural seismic phenomena on Mars. Simultaneous work of several 3-component seismometers at different points on Mars would permit unambiguously finding the coordinates and depth of epicenters of Mars tremors, as has been done on the Moon with instruments left after the Apollo expedition. If the seismic reports are caused by tectonic movement, one can discover the seismic zones and obtain an idea of the characteristics of tectonics on Mars and compare it with tectonics on Earth.

b) The probability of recording impact-explosive processes when meteorites fall; thus, an increase in the duration of seismic observations even on a tectonically quiet planet would eliminate the necessity for causing an explosion on the planet in order to conduct active seismic probing.

c) It is probable to expect the appearance of natural processes of excitation of oscillations significantly more powerful than during active seismics. This makes it possible to observe seismic events without limitation of the length of time and to study the structure of the internal structure on a global scale.

For reliable operation of the seismometer it is extremely desirable to isolate it from the effect of wind disturbances and sharp variations in temperature; good mechanical contact of the housing of the instrument with the soil is necessary. These conditions are provided by placing a seismometer in the forebody of the penetrator.

Other scientific problems from the field of study of /16 planets in the Earth group, in principle solvable by penetrators, are undoubtedly important and must be carried out without detriment to the two primary problems if the main problem in carrying out the program of research on Mars considers its scientific value.

The possibility of using penetrators for probing other celestial bodies is considered in the following section.

5. The Advantages and Limitations of the Use of Penetrators.

The delivery of scientific equipment in penetrators naturally requires a radical reconsideration of the design of precise instruments but has significant advantages in comparison with a soft landing. In the first place, the requirement for control of landing speed is lower than with soft landings and, in the second place, it is possible to land in regions which, due to the complexity of the terrain or the low load bearing capability of the soil, are not suitable for a soft landing of spacecraft. It is just this property of penetrators which is their important advantage; in certain cases no other method of landing can be selected, that is, it makes the penetrators irreplaceable for example, for studies of many interesting regions on Mars. Moreover, the penetrating probes make it possible to make observations which require:

a) making measurements at a depth of several or more meters (measurements of regional geometric gradients and thermal flows from the interior, stratigraphy);

b) isolation of instruments from meteorological conditions (seismometry);

c) reliable contact of the instrument with the soil (geochemical study, seismometry).

The advantages of the penetrators are most clearly apparent /17 only in certain conditions which limit the possibility of using the method.

On which celestial bodies would the use of penetrators be most advantageous? First of all, on those which have an atmosphere and at the same time which do not have very high or extremely low temperatures of the underlying surface. Of these bodies in the solar system there is the planet Mars and, with a certain extension, the largest satellite of the giant planets, primarily, the closest to the Sun. That is, it is possible to talk about landing penetrators on the satellites of Jupiter and Saturn but these same planets are not included as prospective sites inasmuch as generally they have an absence of a "surface," at least under the external layer of atmosphere to a depth corresponding to a temperature value unsuitable for any equipment.

In high temperature conditions, for example, on the surface of Venus, the use of penetrators is unsuitable due to the high ratio of length of the housing to its diameter. With this type of apparatus, its surface is large for the unit of volume and the problem of thermal insulation of scientific instruments becomes too difficult to solve; the time of actual existence is extremely short.

In the case of celestial bodies without atmosphere (the Moon, Mercury, the asteroids, the satellites of Mars, small satellites of other planets) the use of penetrators is considerably complicated by the absence of the possibility for using aerodynamic equipment for preliminary braking and for providing the necessary orientation of the penetrator at the moment of impact. As is well known, modern technical equipment makes it possible to overcome these difficulties but requires considerable increase in the mass of the descent craft involving necessities for using retrorockets with a system for orientation of loadbearing platforms and radio altimeters. Here, the modulus /18
of the vector of velocity corresponding to the braking pulse in almost all cases exceeds landing velocity of the penetrator by a magnitude of 10 or more. Besides the oriented direction of the brake pulse, one needs a definite orientation of the penetrator itself; the direction of the main axis of the

penetrator at the moment of impact must coincide with the vector of velocity of motion relative to the physical surface of the "target" and, as a rule, differ from the direction of the braking pulse. Thus, in a case of celestial bodies without atmospheres, the use of penetrators has considerably less advantage because at the level of technical complexity and the magnitude of the braking pulse necessary for preliminary decrease in velocity, it differs very little from carrying out a program with a soft landing. Nevertheless, for certain aspects of research which require probing of subsurface layers of soil, the use of penetrators can be more useful than using landing craft with drilling equipment even with the absence of atmosphere.

In conclusion let us note that the development of equipment for probing celestial bodies using shell-penetrators requires design development both of the penetrators themselves and a corresponding complex of scientific apparatuses, and also the creation of a theory of motion of the shells in an elastic medium -- a new field of mechanics which at the present time is in the initial stages of its development.

Obviously, the successful development of a hydrodynamic theory of cumulative streams and the creation of a method of a cumulative charge for probing elastic media can have unexpected promise for the development of a theory of motion of shell-penetrators in order to probe planets [5,6].

On the other hand, one must not exclude the possibility /19 that for studying processes of penetration one can use jet powder charges (RS type) [7].

REFERENCES

1. Simmons, G. J., "Surface penetrator - a promising new type of planetary lander", J. Brit. Interplanetary Soc., 30/7, 243-256 (1977).

2. "Space research 'down under'", Spaceflight (Engl.), 19/6, 205-206 (1977).

3. Niehoff, J. C. and A. L. Friedlander, "Pioneer Mars 1979 mission options", J. Spacecraft and Rockets, 12/8, 451-452 (1975).

4. "A new concept in planetary probes - the Mars penetrator," Spaceflight, 18/12, 432-434 (1976).

5. Lavrent'yev, M. A., "Cumulative charge and the principle of its operation," Uspekhi matematicheskikh nauk, 12/4, 41-56 (1957).

6. Lavrent'yev, M. A. and B. V. Shabat, Problemy gidordinamiki i ikh matematicheskiye modeli [Problems of hydrodynamics and their mathematical models], Nauka Press, Moscow, 1973.

7. Zel'dovich, Ya. B, M. A. Rivin and D. A. Frank-Kalonetskiy, Impul'sy reaktivnoy sily norokhovykh [Pulses of reactive forces of powder rockets], Oborongiz Publishers, Moscow, 1963.