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SPACECRAFT FOR FLIGHT IN THE ATMOSPHERE OF VENUS

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SPACECRAFT FOR FLIGHT IN THE ATMOSPHERE OF VENUS

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[Article by candidate of technical sciences G. M. Moskalenko]

[Text] Vehicles able to fly in the atmosphere of Venus will be required in the further exploration of that planet. What will they look like?

Direct spacecraft exploration of Venus was begun in October, 1967, by the Soviet Venera-4 automatic station. After reaching the planet, it made the first-ever smooth descent into the planet's atmosphere down to an altitude of 26 km above its surface; the station transmitted for 1.5 hours data on the physical, chemical, and structural parameters of the atmosphere. In May, 1969, Veneras-5 and -6 penetrated to 20 km above the surface. Then a qualitatively new level in the exploration of Venus was achieved in December, 1970. The descent vehicle of the Venera-7 station landed and transmitted information from the planet's surface. On 22 July 1972, the descent vehicle of the Venera-8 achieved soft landing on the planet's surface. The exploration of Venus continued, and in October, 1975, the orbiting sections of the Veneras-9 and -10 stations were injected into near-planetary orbits; thus, for the first time, artificial satellites of the planet were created and television images of the surface obtained from the descent vehicles. The study of Venus was continued by the Soviet Venera-11 and Venera-12 stations and by the American Pioneer Venus-1 and Pioneer Venus-2.

We already know much about Venus, yet there is even more to be learned. Nobody doubts the advisability of further explorations of the atmosphere and of conditions on the planet itself. But how best to achieve that? In order to answer this, serious development of possible vehicles is necessary. Such vehicles would be delivered to the planet by rocket systems; they would then autonomously carry out exploratory flights in an automatic (and possibly even piloted) mode.

Flight Conditions

And so, what could be used for flight in the Venusian atmosphere? The question is complicated. The problem is that the density of the Venusian atmosphere is about 55 times greater than Earth's, and its pressure corresponds to the pressure in an earthly sea at a depth of about 1 km. Therefore, a Venusian flight vehicle has to incorporate a system of complex flight-mechanical properties appropriate simultaneously to aviation, lighter-than-air flight, and deep submergence equipment and yet capable of withstanding high temperatures at the same time.

Difficulties occur also in creating a powerplant, as no atmospheric oxygen is available for its operation as it is on earth. The atmosphere of Venus consists of 96 percent carbon dioxide, 4 percent nitrogen, and practically no oxygen. The usefulness of solar batteries under the conditions of high density and low light transmissibility in the Venusian atmosphere is also dubious.

Aerodynamic loads, aerostatic forces, heating of the structure, type of propulsion, and other characteristics of the flight vehicle depend substantially on the properties of the atmosphere. The value of all aerodynamic characteristics and the type of flow about bodies are determined by the Reynolds number. This number indicates the role played by the forces of viscosity in the motion of a vehicle through a resisting medium. If it is large, viscosity can be neglected; when small, it has to be considered. The following question arises: Is it possible to use "earthly" aerodynamic coefficients for the computation of flight conditions in the Venusian atmosphere without introducing appropriate corrections for the value of the Reynolds number? Special studies made by the author indicate that the Reynolds number for terrestrial and Venusian atmospheres for similar flight profiles is relatively close and therefore it is possible to make studies using terrestrial aerodynamic characteristics of flight vehicles.

Venus Flight Vehicles

Depending on mission and altitude of flight, it is possible to group the Venus flight vehicles into two categories: Base (high altitude) and deep [low altitude] vehicles.

The high-altitude vehicles are intended for long-duration exploration in the atmosphere using the drift mode (free-floating aerostat type) and for controlled flight (dirigible type) at altitudes between 50 and 70 km. In this region, pressure, density, and temperature approximately correspond to those on earth at sea level. The vehicles possess little maneuverability and serve as carriers for equipment, scientific devices, and other cargo. High-altitude vehicles can become the means for studying the atmosphere of Venus (its gas composition) from above. In this group, we can include free-floating aerostats, drifting platforms (single and coupled), highly maneuverable vehicles with aerodynamic features, aerostatic wings of variable volume (length),

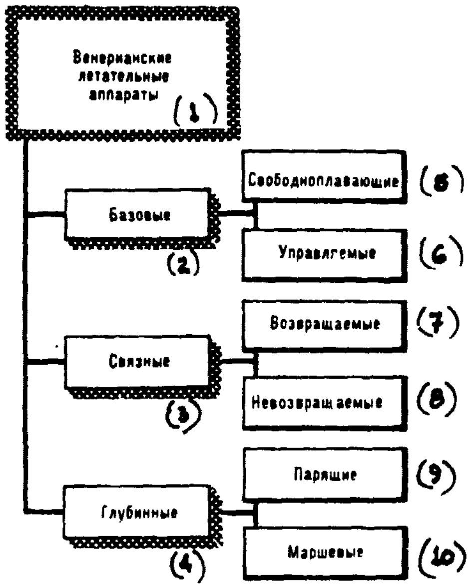
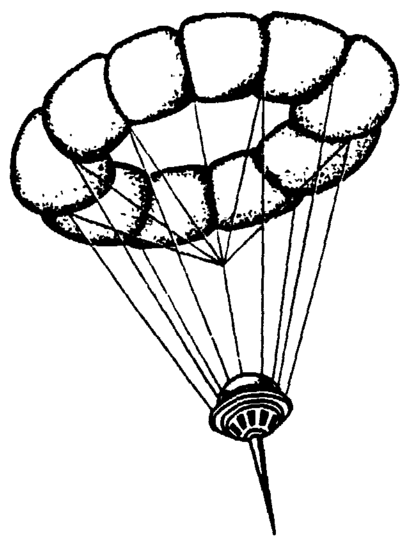


Figure 1. Classification of Venus Flight Vehicles

Key:

1. Venus flight vehicles
2. Base [high altitude]
3. Communication
4. Deep [low altitude]
5. Free-floating
6. Controlled
7. Returnable
8. Nonreturnable
9. Soaring
10. Cruising

Figure 2. Aerostat



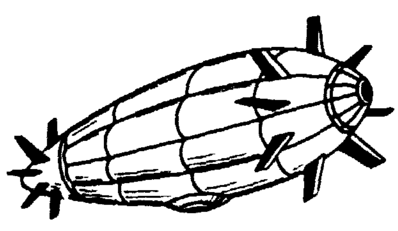


Figure 3. Vehicle With Aerodynamic Features

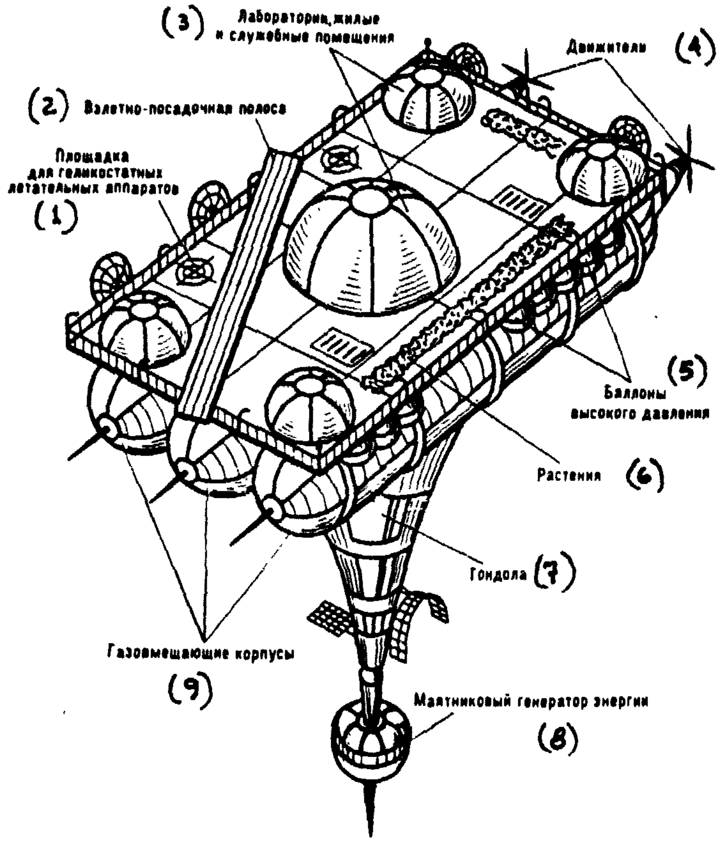


Figure 4. Aerostatic Base Station

Key:

1. Helipad
2. Runway [flight deck]
3. Laboratory, living, and service spaces
4. Propulsion units
5. High-pressure tanks
6. Plants
7. Gondola
8. Pendulum power generator
9. Gas containers

and vehicles of toroidal configuration. The latter can serve as carriers for rocket systems that deliver Venusian containers to Earth with scientific information, surface samples, and ampules of atmospheric gas.

Drifting flight vehicles of sufficiently large dimensions can be used as carriers of small exploratory devices intended for sounding those layers of the atmosphere unreachable for the high- and low-altitude vehicles.

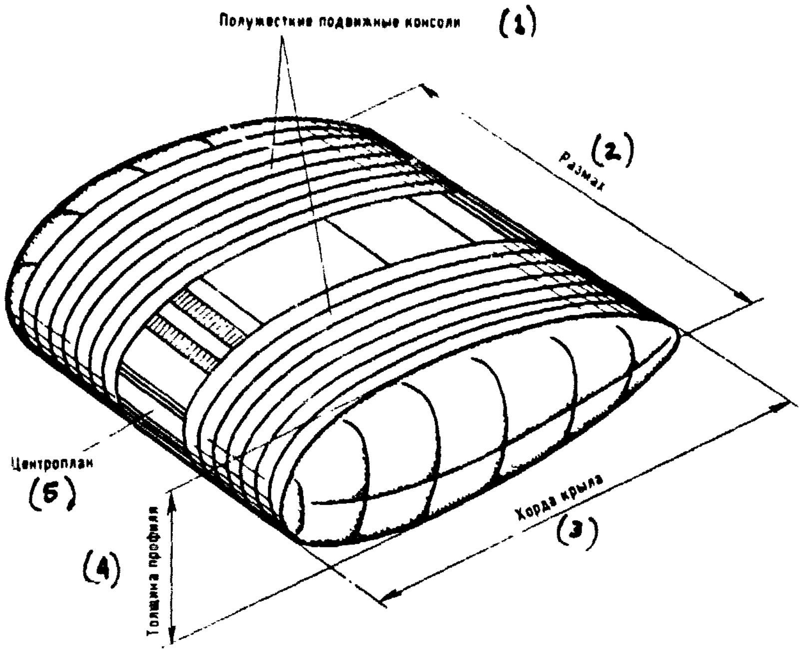


Figure 5. Vehicle in the Form of a Variable-Length Aerostatic Wing

Key:

1. Semirigid, movable outboard wing panels
2. Span
3. Wing chord
4. Section thickness
5. Wing center section

The mission of the low-altitude vehicles is the exploration of the planet from flight altitudes in the vicinity of the surface of Venus, as well as to land on it. Analogous to deep submergence vehicles of the type such as the bathyscaph and bathyplane, they can have a certain amount of maneuverability and become the means for studying the atmosphere of Venus (its boundary layer) from below. Among the low-altitude vehicles are bathyscaphs, bathyplanes, vehicles of variable geometry, aerostatic convertiplanes, and others.

The largest class (in terms of design, aerodynamic form, and dynamics of flight) of Venus vehicles are the communication flight vehicles. Similar to terrestrial ones, they can be equipped with a propulsion unit (returnable) or be without one (nonreturnable). Communication vehicles can sound various layers of the Venusian atmosphere, reach the surface of the planet, effect communication between high-altitude and low-altitude vehicles, maneuver, and return (if it is a reusable system) to the base flight vehicle.

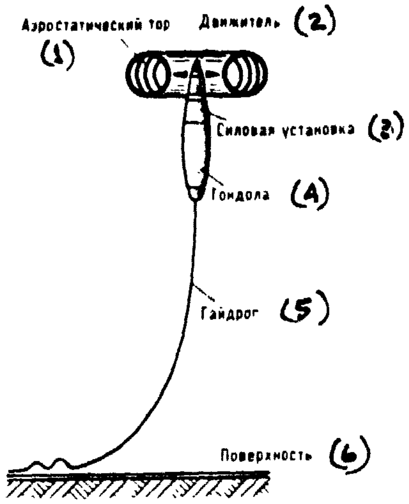


Figure 6. Vehicle With Toroidal Configuration

Key:

1. Aerostatic torus
2. Propulsion unit
3. Powerplant
4. Gondola
5. Trail rope
6. Surface

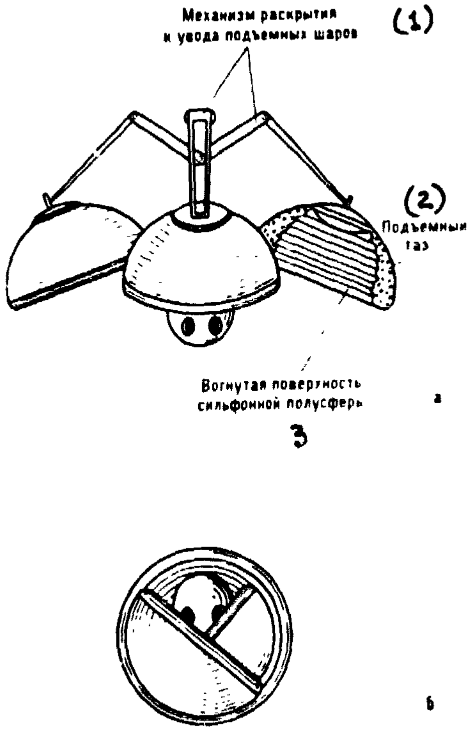


Figure 7. Low-High Altitude Aeroscaph a) At the moment of deployment, b) Stowed configuration

Key:

1. Mechanism for deploying and retracting the buoyance spheres
2. Buoyancy gas
3. Concave surface of the bellows-type hemisphere

What Vehicle Is Best?

It turns out that aerostats carry the largest payload. While drifting, they require neither a powerful onboard powerplant installation nor large fuel supplies. They are capable of long-duration exploration and are relatively simple in construction. Such vehicles can be equipped with a trailing cable from which are suspended instruments for vertical sounding of the atmosphere as well as devices for obtaining surface samples. The length of the cable is easily increased, and compensation is made for cable loading by attaching lifting spheres at intervals along the cable. By proper choice of dimension for the lifting spheres, the cable can be raised above the aerostat carrying it.

From the viewpoint of flight mechanics, there are no objections to the idea of such a vehicle, and its construction can be completed entirely under terrestrial conditions. However, serious questions arise connected with the control of such a system, its stability in flight, and its reliability.

A combination of dirigible and aircraft is of particular interest. The lifting surfaces (wings) are advisable should it be possible to achieve speeds at which aerodynamic lifting force compensates, with some margin, for the weight of the lifting surfaces. Under terrestrial conditions, such a combination is usually not advantageous, but on Venus the vehicle can have some advantages such as a large payload capability and the ability to maneuver in space, resulting in a decrease in the mass of the gas-containing system.

Obviously, use can be made of aerostatic disk-shaped planes. The form of this vehicle will depend on the pressure of the medium and can change from a disk shape to spherical or cylindrical. For a deep descent into the atmosphere, such a vehicle will be disk-shaped and, therefore, besides aerostatic, will also have aerodynamic lift due to the flow about its shape, which gives it maneuverability. With such a rigid-body vehicle, it is possible to achieve long-range flight without need for a propulsive unit, by using gliding and lift (such as in an aerostat) along a sawtooth trajectory.

It is, of course, desirable to use returnable flight vehicles. These are vehicles such as aircraft, helicopters, helistats, and devices for vertical ascent and landing, and many other hybrid devices. But high maneuverability, flight in different regimes, and zones of operation require the blending of contradictory conditions of flight mechanics and a host of complex flight-mechanical parameters. The main difficulty is the creation of power (propulsion) installations capable of working without oxygen for a long time under conditions of high temperature and pressure.

But, on the other hand, nonreturnable flight vehicles do not present such problems in implementation, and they can be used, along with aerological ballons (to be dropped into the Venusian atmosphere) as small-scale, onboard means of flight.

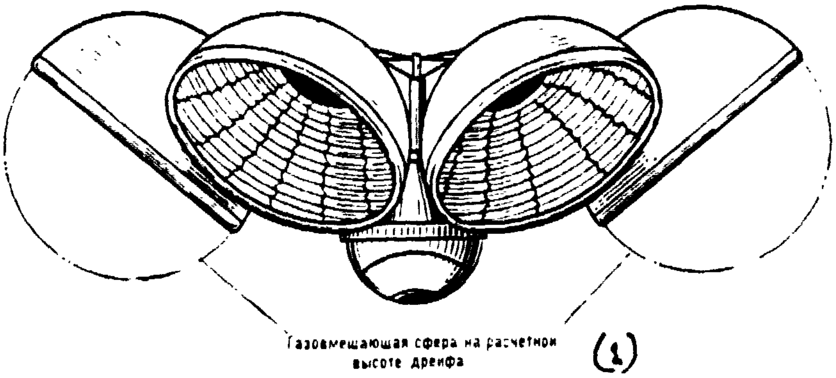


Figure 8. Floating Bathyscaph

Key:

1. Gas-containing sphere at the design altitude of drift

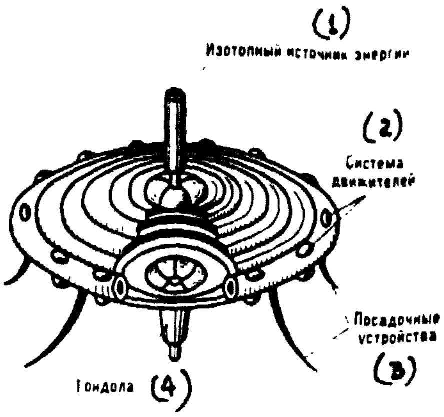
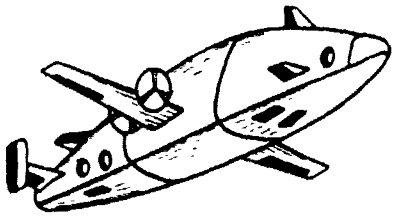


Figure 9. Communication (Multipurpose) Flight Vehicle

Key:

1. Isotope power source
2. Propulsion system
3. Landing devices
4. Gondola

Figure 10. Hybrid Aerostatic Vehicle With Attached Wing



But how should these flight vehicles be delivered from Earth to the atmosphere of Venus?

Problem of Transportation

Obviously the greatest difficulties arise in delivering vehicles of rigid construction. The prime item that determines the dimension of payloads at the present time is the maximum allowable diameter of the last stage of the rocket launcher. Calculations show that a rocket launcher of about 6-meter diameter can deliver to Venus a rigid aerostatic envelope vehicle, which, at the surface of the planet, has a lifting capability of about 6 tons. At an altitude of 15 km, its weight-lifting ability decreases to 3 tons, but this is already quite small, if we keep in mind that the envelope of such a vehicle with its service module requires a lion's share of that mass. For this reason, rocket launchers at this time are able to deliver to Venus only vehicles with a soft envelope such as slightly maneuverable ones such as low-altitude bathyscaphs.

One can attempt to use improved stages of launcher rockets (those that achieve escape velocity) in the role of aerostatic means at the low-altitude layers of the Venusian atmosphere. Such stages, once the spent motors and their support systems have been jettisoned and once they have passed through the dense layers of the atmosphere, will become suspended in its lower layers at altitudes where the force of buoyancy equals the force of gravity.

Analysis of the entry trajectory into the dense layer of the atmosphere shows that the hot and dense atmosphere of Venus is more favorable (from a heating point of view) to the entry of space vehicles than is the atmosphere of Earth. This is because: (1) The density of the atmosphere of Venus at the altitude of entry is less than the density of the Earth's atmosphere; (2) The speed at which a spacecraft enters the Venusian atmosphere from satellite orbit (7.32 km/s) is less than the speed with which a spacecraft enters the atmosphere of the Earth (7.95 km/s). Therefore, for a sufficiently low loading per unit of lifting surface (wing), the temperature of heating does not exceed the temperature in the vicinity of the surface of Venus.

Hypersonic aerostatic flight vehicles are of interest in this connection, as they can enter the Venusian atmosphere without a descent mechanism when they are filled with gas (either partially or fully). Such Venus vehicles are particularly advantageous, because the bulky, gaseous balloon system can be jettisoned during the approach to Venus and does not represent a ballast for further movements.

Peculiarities of Flight in the Venusian Atmosphere

Studies of flight mechanics carried out by the author of this article show that aerostatic force significantly influences the characteristics of Venus flight vehicles. It increases the altitude of flight for steady speed, it increases the rate of ascent but decreases the rate of descent for flight in

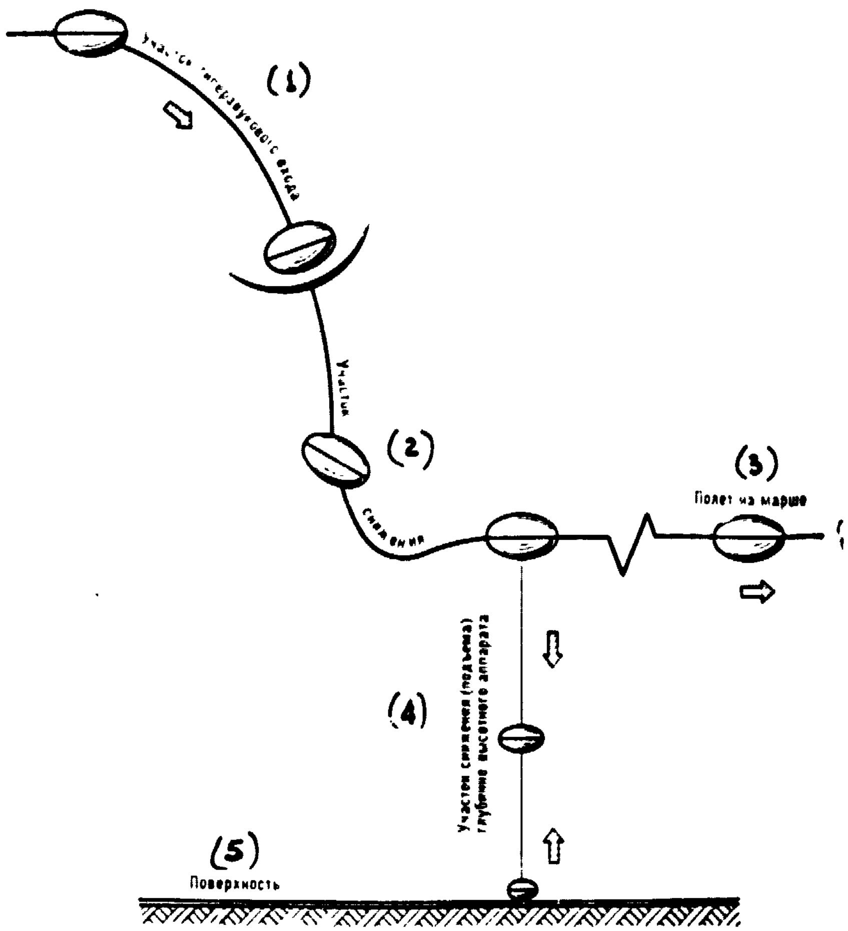


Figure 11. Diagram of Entry Into the Planetary Atmosphere of Both a High-Altitude and a Low-High Altitude Aerostatic Vehicle

Key:

1. Hypersonic entry region
2. Descent region
3. Cruising flight
4. Descent (ascent) region of the low-high altitude vehicle
5. Surface

ascending or descending flows. The aerostatic force affects the angle and distance of glide. During maneuvering, the aerostatic force increases the angular speed and decreases the turn radius, but during leveling off, besides decreasing the radius of curvature, it also reduces the speed along the trajectory.

The speed of horizontal flight remains constant independent of the altitude of ascent or depth of descent, if the area of the body changes in correspondence with the changes of the density of the medium and the aerostatic force remains constant during this change.

The speed, range of flight, and lift capability of a Venus flight vehicle at low altitude amount to 18.5, 40, and 14 percent, respectively, of the analogous parameters of terrestrial flight vehicles. In this fashion, the presence of the aerostatic force opens up new possibilities for the perfection and formation of varied forms of movement, even new and yet unknown ones, which is especially important for Venus flight vehicles.

Density and barometric pressure decrease during ascent. For this reason, the mass of the gas envelope has to be increased and the mass of the hermetically sealed gondola decreased. During descent, on the other hand, the mass of the envelope has to decrease and the mass of the gondola increase. These factors, which act opposite to each other, determine the optimum altitude for cruising flight, at which the mass of the Venus vehicle becomes a minimum. Presence of an onboard cooling system with a increased life will make possible flights in the region of decreased temperatures. Thus, for drift times not exceeding 10 hours, the optimum altitude of flight is approximately 40 km (temperature at this altitude is 140°C).

In view of the high temperatures on Venus, the most likely vehicle designs are those that will use ammonia and its solutions as a working fluid (for producing the aerostatic force). Such tropospheric vehicles must have a larger lift capability than systems that use a light gas (hydrogen or helium), with their attendant heavy and bulky high-pressure balloons.

In spite of apparent contradictions, there exists a certain analogy between aerostatic flight vehicles and spacecraft. In motion, the character (but not the magnitude) of speed, loading, and distance traveled remains similar. We can compare vehicles that enter the dense layers of the atmosphere at high velocities to aerostatic vehicles that fly in the descent regime with absence of active forces; vehicles that enter the dense layers of the atmosphere at low velocities and aerostatic vehicles flying in the descent regime under action of active forces; the rocket lifting off vertically through a resisting medium and the aerostatic flight vehicle flying in the ascent regime under the action of forces aligned with the vector of velocity.

Analysis of flight vehicles shows that, in spite of the complex aerothermodynamic conditions, flight in the atmosphere of Venus is possible. This result is important for the reason that it opens up the opportunity to study the planet with the aid of special flight equipment.