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RADIOLINE BETWEEN AIRCRAFT IN THE ATMOSPHERE OF JUPITER AND STATION ON EARTH

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Abstract

With the development of space technologies and their reaching farther places in the Solar system, man’s desire to study in more detail the structures of the planets near Earth is increasing. This is where the idea of Flyer is born. Flyer is unmanned aerial vehicle for other planets atmosphere. He has the ability to collect much more data than a regular satellite, which is thousands of miles above the planet’s atmosphere. The most suitable planet for such a study is Jupiter, because of its location, the thin atmosphere and the lack of hard surface. An important part of designing such a mission is the way Flyer and Earth communicate. This article describes a common idea for a radioline between Flyer’s probes, Flyer, satellite around Jupiter and station on Earth.

Key words: radioline, probes, Flyer, aircraft, satellite, station, Jupiter, Earth

Introduction. In studying the planets of the solar system, the main focus of the scientific community is on Mars and Venus, probably because of their proximity and Earth-like structure. Since the beginning of the space age, more than 100 missions have been sent to them, but only nine to Jupiter, four to Saturn, and even one – *Voyager 2* to Uranus (1986) and Neptune (1989). At the same time, knowledge of the structure, composition and dynamics of the processes taking place in the gas and ice giants is very limited. Even the mechanisms that cause

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their familiar structure are not yet fully known [1]. Given the fact that most of the discovered exoplanets are giants, the study of such in the solar system can provide extremely important information to find its application [2]. In addition, many issues concerning the formation of the processes accompanying their formation and life remain to be resolved [3]. Given the huge reserves of useful resources such as hydrogen, methane, ammonia and even helium-3, it is obvious that gas and ice giants are virtually inexhaustible sources of energy, which makes their study particularly important. For now, this is still done with the help of artificial satellites that perform remote measurements of their atmospheres [4]. Landing probes are expected to be sent in the coming decades to clarify their physical and chemical characteristics [5].

On December 7, 1995, the Galileo lander entered Jupiter's atmosphere, sending valuable data about its atmosphere to Earth [6]. The data from such missions are extremely valuable, but they also have significant shortcomings – they make a vertical incision in a small area of the planet and cannot make long-term observations in different locations, their movement cannot be controlled, and their probes have very limited volume for the deployment of diverse and bulky scientific equipment.

To compensate for these shortcomings, it is reasonable, although technically more difficult, to create an unmanned aerial vehicle (Flyer) with a nuclear power plant that has the ability to perform long-term flight in the atmosphere of the target planet. A flyer could collect much more data than a satellite thousands of kilometers above a planet's atmosphere. This can be done not only by using its on-board measuring equipment, but also by launching numerous probes to send the collected information back to the Flyer, and from there to the Earth. An important part of designing such a mission is the way the probes, Flyer and Earth communicate. It can be done through several radiolines that connect the various components of the mission.

The purpose of the present work is to calculate the main characteristics of a radio link between the Flyer probes and a station on Earth through which to transmit the data collected by the probes. For this purpose, the necessary transceivers, antennas and their operating parameters must be selected, as well as the losses in the atmospheric conditions of the planet must be calculated. The height and speed of the satellite, as well as the windows of direct visibility between it and the Earth, must also be determined.

The most suitable planet for this type of study is Jupiter, for several reasons:

- Its atmosphere is better studied than other gas and ice giants thanks to the Galileo lander, which sent information about its basic physical characteristics.
- Although in the first approximation the possibility of conducting a flight in its atmosphere, where it is possible, has been studied [7].

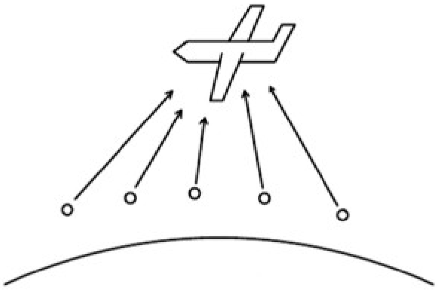

Fig. 1. Scheme of the radioline – probes to aircraft

- In the next 10 years, there are at least five planned missions next to it that can interact with Flyer and the satellite.

Radioline probes – aircraft. The first section of the global interplanetary radioline is between the data collection probes ejected by Flyer and itself (Fig. 1).

The probes fall into the atmosphere of Jupiter, and their task is to send as much information as possible to the Flyer until the moment of its destruction. Each of the probes has a spherical shape and a diameter of 20 cm.

The altitude chosen for the Flyer is 60 km above sea level and it weighs 1000 kg. It flies with the help of a rectilinear jet engine with a nuclear thermal installation and a speed of 3 Mach.

In this case, the most suitable for the probes are four monopole antennas, just like the telemetry connections of small satellites in orbit. They are also very similar to the antennas of Sputnik-1, and in addition to communicating with the device, they also serve for aerodynamic stabilization (Fig. 2).

An antenna array with the widest possible directional diagram is attached to the underside of the Flyer's body. It should point down and back from the device.

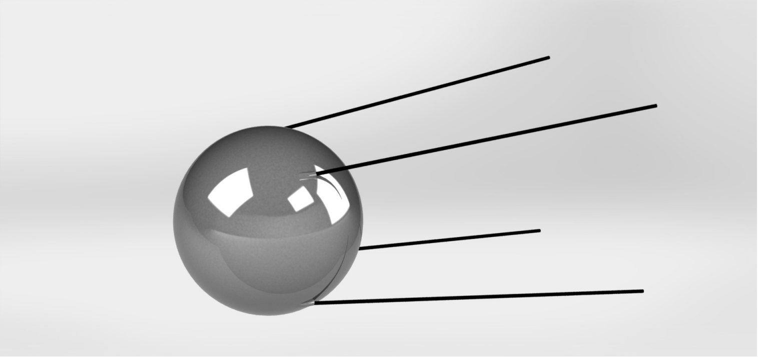

Fig. 2. Schematic representation of the probe and its monopole antennas. The probe has a similar outer appearance to Sputnik 1 (1957)

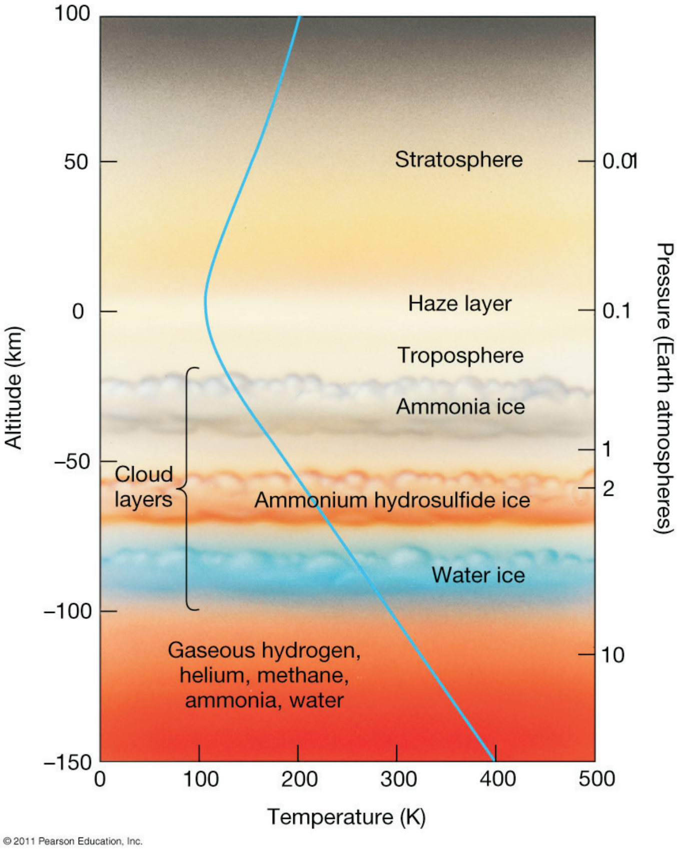

Fig. 3. The structure of Jupiter's haze and cloud layers. The blue curve represents the temperature distribution with the pressure and altitude. Source: Pearson Education, Inc.

Thus, the connection with the probes is for a longer period after they begin to lag behind in the atmosphere. In this case, this type of antenna is suitable for others, mainly due to its aerodynamic stability of the body of the device.

To prove the theory so far, however, it is necessary to calculate the budget of the connection. It is a determination of the losses, speed and signal-to-noise ratio for a given route, and is a basic equation in each space connection, showing the necessary parameters for it to work normally.

Jupiter is a gas giant composed mainly of hydrogen and helium. It has several layers of ice, which are the main obstacle to the first section of the radioline (Fig. 3) [8]. The probes that fall out of the Flyer pass through all the cloud layers, and their purpose is to transmit data for as long as possible.

An example of operating frequency in these conditions can be taken from one of the first missions to Jupiter, namely Galileo [9]. Galileo's probe had the same path in the atmosphere as the current probes. It operated in the L band of the frequency 1387 MHz, which turned out to be the most suitable for these conditions.

The following is a step-by-step calculation of the connection budget. The formulas are taken from [10].

Wavelength for the above frequency:

$$\lambda = \frac{c}{f} = 21.63 \ \ \text{cm}, \tag{1}$$

where $c = 3.10^8$ m/s is the speed of light in vacuum, and $f = 1387$ MHz is the abovementioned work frequency.

Transmitting antenna amplification:

$$G = 10 \log \left(\eta \frac{4\pi S}{\lambda^2} \right) = 17.3 \text{ dB}, \tag{2}$$

where $\eta = 0.5$ is the efficiency of the radiating surface, and $S = 40$ cm is the length of the antennas.

Equivalent isotropic radiated power of transmitting antennas:

$$EIRP = G + P = 20.3 \text{ dBW}, \tag{3}$$

where $P = 3$ dBW is the power of the transmitter.

Receiving antenna gain:

$$G = 10 \log \left(\eta \frac{4\pi S^2}{\lambda^2} \right) = 7.3 \text{ dB}, \tag{4}$$

where $S = 20$ cm is the length of one side of the antenna.

Relation of the gain to the noise temperature of the receiving antenna:

$$\frac{G}{T} = G - 10 \log T = -6.68 \text{ dB/K}, \tag{5}$$

where $T = 25°$K is the system noise temperature of the receiver.

Losses from the distance between the probes and the aircraft:

$$L_R = 20 \log \frac{4\pi R}{\lambda} = 143.24 \text{ dB}, \tag{6}$$

where R is the distance between the two apparatuses if it is assumed that in the boundary case data of 250 km between them are obtained.

Signal to noise ratio:

$$\frac{C}{N} = EIRP + \frac{G}{T} + 228.6 - L_R - L_A = 58.98 \text{ dB/Hz}, \tag{7}$$

where L_A are the losses due to hydrometeors if it is assumed to be about 40 dB.

When using a modem that complies with the DVB-S2 standard and operates with the lowest degree of modulation QPSK 1/4, operation is possible at $C/N = -2.4$ dB.

Modem activation threshold in the receiver:

$$\frac{E}{N} = \frac{C}{N} - 10 \log \Gamma = -4.7 \ \text{dB/Hz}, \tag{8}$$

where $\Gamma = 1.7$ is the reflection coefficient of the receiving antenna.

Character flow rate:

$$R_S = antlog \left(\frac{\frac{C}{N} - \frac{E}{N}}{10} \right) = 2.33 \frac{\text{Mb}}{\text{s}}. \tag{9}$$

Data transfer rate:

$$R = R_S . \frac{1}{4} = 582.5 \text{ Kb/s}. \tag{10}$$

Radioline aircraft – satellite. There are many factors on which the smooth operation of the Flyer depends – the proper operation of the engine and on-board equipment, weather conditions, structural stability and more. These factors hide the risk of unexpected problems, which in turn leads to increased requirements for the reliability of the connection with the station, and especially for the need for it to be constant. A non-permanent connection would lead to a risk of data loss in the event of an accident, and the nature of the accident would remain unclear. For this reason, it is necessary for the satellite to be in a stationary orbit relative to the Flyer, and the angular velocity of the two devices should ideally be equal (Angular Velocity Equality Orbit – AVEO) (Fig. 4).

In real flight, adjustments can be made by both the Flyer and the satellite. This allows the Flyer to send data to the satellite at any time, and no antenna targeting is required.

Altitude for AVEO is:

$$R = \sqrt[3]{GM \frac{r^2}{v^2}} = 142\ 083 \text{ km}, \tag{11}$$

where $G = 6.67 \times 10^{-11}$ N.m^2/kg^2 is the universal gravitational constant, $M = 1.9 \times 1027$ kg is the mass of Jupiter, $r = 71\ 552$ km is the radius of flight of the aircraft relative to the centre of the planet at an altitude of 60 km, and $v = 15.04$ km/s is the linear velocity of the aircraft plus the speed of rotation of the planet.

The data transmission is again via an antenna array, this time located on the top of the Flyer. Their reception by the satellite is through a mirror-parabolic antenna.

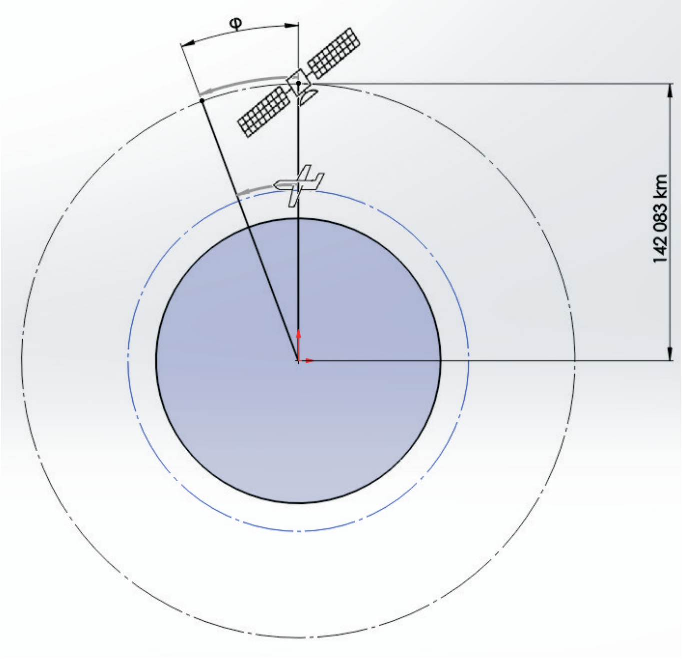

Fig. 4. Schematic representation of Angular Velocity Equality Orbit – AVEO

The calculation of the connection budget is again done first by selecting the correct frequency. In this case, the connection is again partly through the planet's atmosphere, although it does not pass through the cloud layers. This means that a frequency close to the previous one can be used. However, in order to avoid interference, this time it is in the S band of 2.4 GHz.

The following is a step-by-step calculation of the connection budget.

Wavelength for the above frequency:

$$\lambda = \frac{c}{f} = 12.5 \text{ cm}, \tag{12}$$

where $c = 3.10^8$ m/s is the speed of light in vacuum, and $f = 2.4$ GHz is the above frequency.

The gain of the transmitting antenna has the same value as in expression (4).

Equivalent isotropic radiated power of the transmitting antenna:

$$EIRP = G + P = 17.3 \text{ dBW}, \tag{13}$$

where $P = 10$ dBW is the power of the transmitter.

Receiving antenna gain:

$$G = 10 \log \left(\eta \frac{4\pi\pi S^2}{\lambda^2} \right) = 24.99 \text{ dB}, \tag{14}$$

where $S = 50$ cm is the radius of the antenna.

Relation of the gain to the noise temperature of the receiving antenna:

$$\frac{G}{T} = G - 10\log T = 11.01 \text{ dB/K}, \tag{15}$$

where $T = 25^{\circ}$K is the system noise temperature of the receiver.

Losses from the distance between the plane and the satellite:

$$L_R = 20\log\frac{4\pi R}{\lambda} = 197.01 \text{ dB}, \tag{16}$$

where $R = 70\ 531$ km is the distance between the two devices.

Signal to noise ratio:

$$\frac{C}{N} = EIRP + \frac{G}{T} + 228.6 - L_R - L_A = 39.9 \text{ dB/Hz}, \tag{17}$$

where L_A are the losses due to hydrometeors if they are assumed to be about 20 dB.

The activation threshold of the modem in the receiver has the same value as in expression (8).

Character flow rate:

$$R_S = antlog\left(\frac{\frac{C}{N} - \frac{E}{N}}{10}\right) = 28.84 \text{ Kb/s}. \tag{18}$$

Data transfer rate:

$$R = R_S.\frac{1}{4} = 7.21 \text{ Kb/s}. \tag{19}$$

Radioline satellite – station. Due to the fact that the Flyer and the satellite are static in relation to each other, it turns out that the satellite does not have a permanent connection with the station, and this happens only in certain windows of direct visibility between them.

These windows can be determined depending on the position of the satellite around Jupiter and the station on Earth. If the Earth uses the world's deep space communication system, which has three stations 120 degrees apart (Madrid, Goldstone and Canberra), then there will be no limit to the visibility of the stations to Jupiter. However, the problem comes with the location of the satellite, and especially from the fact that it is only one. One day on Jupiter is equal to 0.4 times Earth's, which is about 10 hours. This means that the satellite has visibility to earth stations every 10 hours.

The connection budget for such a line is quite unpredictable, mainly due to the fact that the distance between the two planets is not constant. Therefore, the equations for the nearest and farthest point of the connection must be calculated and compared.

Most often, communications between spacecraft and Earth take place in the X band of 8.4 GHz.

The following is a step-by-step calculation of the connection budget.

Wavelength for the above frequency:

$$\lambda = \frac{c}{f} = 3.57 \text{ cm}. \tag{20}$$

The gain of the transmitting antenna has the same value as in expression (14).

Equivalent isotropic radiated power from the transmitting antenna:

$$EIRP = G + P = 34.99 \text{ dBW}, \tag{21}$$

where $P = 10$ dBW is the power of the transmitter.

Receiving antenna gain:

$$G = 10 \log \left(\eta \frac{4\pi\pi S^2}{\lambda^2} \right) = 72.78 \text{ dB}, \tag{22}$$

where $S = 35$ m is the radius of the receiving antenna.

Relation of the gain to the noise temperature of the receiving antenna:

$$\frac{G}{T} = G - 10 \log T = 58.8 \text{ dB/K}, \tag{23}$$

where $T = 25°$K is the system noise temperature of the receiver.

Losses from the distance between the satellite and the station:

$$L_R = 20 \log \frac{4\pi R}{\lambda} = 286.32 \text{ dB}, \tag{24}$$

where Jupiter and Earth at their nearest point are at a distance $R = 588\ 000\ 000$ km.

$$L_R = 20 \log \frac{4\pi R}{\lambda} = 290.65 \text{ dB}, \tag{25}$$

where Jupiter and Earth at their farthest point are at a distance $R = 968\ 000\ 000$ km.

Despite the large difference in distance, the difference in losses is not so drastic, so only the farthest point can be used for other calculations.

Signal to noise ratio:

$$\frac{C}{N} = EIRP + \frac{G}{T} + 228.6 - L_R = 31.74 \text{ dB/Hz}. \tag{26}$$

The activation threshold of the modem in the receiver has the same value as in expression (8).

Character flow rate:

$$R_S = antlog\left(\frac{\frac{C}{N} - \frac{E}{N}}{10}\right) = 4.41\ \text{Kb/s}. \tag{27}$$

Data transfer rate:

$$R = R_S.\frac{1}{4} = 1.1\ \text{Kb/s}. \tag{28}$$

Conclusions. Based on the results obtained, the following contributions can be drawn:

- Cloud layers in the atmosphere of Jupiter are often unpredictable and can negatively affect the communication between the probes and the Flyer.
- The parameters of the antennas and transceivers must comply with the targets for signal-to-noise ratio and connection speed.
- A new type of orbit has been introduced – Angular Velocity Equality Orbit (AVEO), in which the rotation of the satellite and the Flyer around Jupiter is synchronized and has approximately the same angular velocity. This is done to ensure a constant line of sight between the two devices.
- The radius of the satellite's orbit must be 142 083 km. This is due to the large angular velocity of Jupiter.
- The difference of 380 000 000 km in the distance from the closest to the farthest point between the two planets changes the attenuation by only 4 dB, which is relatively small.

A total of nine spacecraft have been launched on missions that involve visits to the outer planets; all nine missions involve encounters with Jupiter, with four spacecraft also visiting Saturn. One spacecraft, *Voyager 2*, also visited Uranus and Neptune. *Juno*, the most recent orbiter of Jupiter, arrived at this planet in 2016.

In this regard, the present work provides a new approach and contributes to the study of the physical processes of the terrestrial [11,12] and giant [13–18] planets in the solar system. This suggests the study of the structure of solar system [19,20] and especially of the outer planets and their moons: Jupiter [21], Saturn [22,23], Uranus [24,25] and Neptune [26].

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