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6 February 1980

USSR Report

SPACE

(FOUO 2/80)

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[redacted]

I. MANNED MISSION HIGHLIGHTS

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SUBMILLIMETER-BAND TELESCOPE FOR THE "SALYUT-6" MANNED ORBITAL STATION

Moscow RADIOTEKHNIKA in Russian No 5, 1979 pp 33-40

[Article by A. Ye. Salomonovich, V. N. Bakun, V. S. Kovalev, T. M. Sidyakina, A. S. Khaykin, B. O. Iskhakov, L. Z. Dul'kin, V. A. Kovkov, V. I. Kostyukevich, B. K. Chemodanov, L. A. Sen'ko, V. A. Mol'kov, V. S. Ovchinnikov, E. I. Grigorov, A. D. Magdesyan, A. A. Nikonov, V. P. Poluektov, A. V. Puchinin, I. A. Gerasimov and A. V. Serov, submitted for publication 28 December 1978]

[Text] An enormous number of celestial sources emit primarily in the far-IR (submillimeter) wavelength range (50-1000 μm). With a sufficiently high spatial and spectral resolution it is of great interest to make observations of atmospheres of planets in the solar system, and also stars of early, intermediate and late types, revealing IR excesses in continuous emission spectra.

Also of special interest are measurements in individual lines and in the continuous spectrum of submillimeter radiation of molecular and gas-dust clouds, associated with regions of ionized and neutral hydrogen, because precisely in these objects it is necessary to expect the development of processes of active star formation. However, many of these objects are inaccessible for observation in visible light.

Observations in the submillimeter range of the center of our Galaxy and the outer galaxies are also exceptionally important for a clarification of their physical nature and evolution, chemical composition and structure. However, submillimeter astronomy began to develop vigorously only during recent years. At least two factors make progress in this field difficult.

1. The earth's atmosphere, to be more precise, atmospheric water vapor, oxygen, ozone and some other components virtually completely (except for individual windows of relative transparency) make it impossible to receive cosmic submillimeter radiation from the earth's surface. This has necessitated the lifting of submillimeter telescopes to great altitudes -- into the upper layers and even beyond the limits of the earth's atmosphere, that is, these instruments have been transformed into on-board instruments.

2. Sensitive reception of submillimeter radiation requires deep (to helium temperatures) cooling of both wide-band bolometers and photoresistors, and also detectors used in apparatus similar to that used in superhigh-frequency

technology; in a number of cases it is also necessary to cool the optical systems of the telescopes. Thus, the creation of on-board submillimeter telescopes required the development of on-board cryogenic apparatus. The problem was especially complicated in the creation of telescopes intended for long-term orbital stations.

In the course of implementation of the program for creating telescopes for such stations, at the Physics Institute imeni P. N. Lebedev USSR Academy of Sciences in the early 1970's specialists developed, and in 1974 aboard the "Cosmos-669" artificial earth satellite tested the "Obzor" submillimeter radiometer [1], whose detectors were cooled to the temperature of liquid helium in a special nitrogen-free space cryostat [2] over a period of a week. Computations and experiments indicated that an increase in the dimensions of the cryostat can increase the time of its functioning under flight conditions to several months. However, the more prolonged operation of a submillimeter telescope aboard an orbital station required the development of a cryogenic system of a closed type -- a microcryogenic helium refrigerator.

The solution of most of the mentioned astrophysical problems requires telescopes with a quite large collecting surface, with a main mirror not less than 1 m [3]. Until recently telescopes of such a size were used only aboard an aircraft and a high-altitude balloon [4, 5]. Therefore, it was important to accumulate experience in the construction and operation of large instruments.

It was also of interest to clarify to what degree it was feasible for the crew to take an active part in the servicing of astronomical instruments of such a scale (and not only submillimeter instruments), what could be the functions of the operators, and what could be the degree of their intervention in the operation of the instruments.

At the same time, it was obviously desirable for full-scale tests in the above-mentioned directions to construct instruments with record optical characteristics, whose cost would not be justified in the first experiments. In this work it was necessary to take into account the relatively limited dimensions of the compartment for scientific instruments aboard the orbital station and the necessity for placement of a telescope of extremely short length.

In choosing the design, construction and work program for the submillimeter telescope, in addition to the methodological problems, it was desirable to obtain simultaneously useful scientific information. Such a principle was realized in the experiment aboard the "Cosmos-669" artificial earth satellite: the "Obzor" radiometer was used in obtaining unique information on the earth's submillimeter radiation as a planet [6]. The water vapor in the earth's atmosphere, impeding the penetration of cosmic radiation, is itself a source of radiation in this range. Therefore, one of the important tasks assigned to the submillimeter telescope was measurement of the characteristic radiation of the earth's atmosphere during orbital orientation of the station.

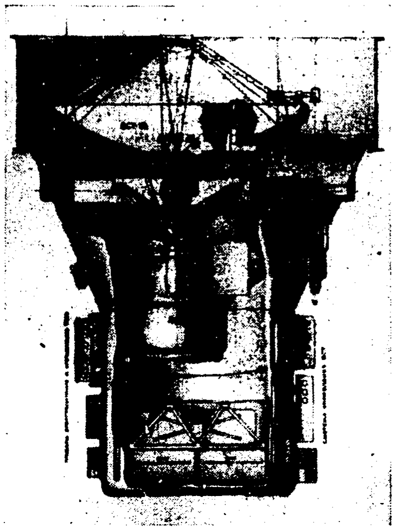


Fig. 1.

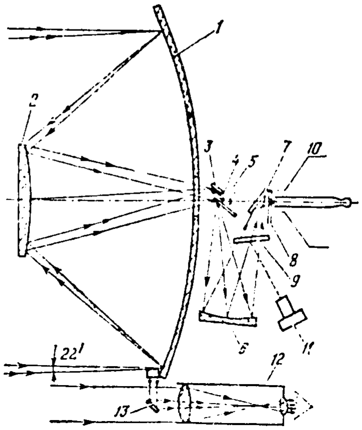


Fig. 2.

It was also deemed desirable for the telescope to have an additional channel not requiring cooling. After examining different possibilities we decided on the ultraviolet range, to be more precise, on the band near a wavelength 2500 A, coinciding with the absorption band of ozone. It was proposed, observing the setting of stars bright in this spectral region, to carry out investigations of atmospheric ozone on the basis of attenuation of the received radiation of the setting source.

Now we will proceed to a concise description of the design and characteristics of the BST-1M submillimeter telescope installed aboard the "Salyut-6" manned orbital station [7].

Design of the BST-1M telescope. The telescope (Fig. 1), consisting of the following basic systems: optical system (OS), active cooling system (ACS), ACS support system, amplification-recording system (ARS) and control system (CS), was placed in the scientific instrumentation compartment (SIC) in the "Salyut-6" station.

For more precise autonomous guidance of the telescope axis its optical system and the ACS container rigidly coupled to it were attached on a supporting-rotating base on the inner side of the SIC. The biaxial Cardan joint of the supporting-rotating base permits rotations by angles of ±5° from the mean position of the optical axis of the objective, coinciding with the axis of symmetry of the SIC housing. This part is connected to the remaining parts of the telescope, situated in the working compartment, by means of flexible cables and lines passing through sealed plates. The optical sight-refracting telescope was installed on the wall of the SIC housing in the direction of the working compartment, opposite a special window. In a nonworking regime the shafts of the Cardan joint of the supporting-rotating base are rigidly locked by means of electromechanical remotely controlled locking devices. In the necessary cases, when autonomous guidance is used, the telescope is unlocked. Now we will examine the telescope systems in greater detail.

Optical system (OS). Figure 2 shows the telescope optical system. The objective is of the two-mirror type, of the Cassegrainian system, with a main parabolic mirror 1 with an inner diameter of 1,500 mm (F/0.5) and a secondary hyperbolic mirror 2 with a diameter of 250 mm.

The radiation of the source situated on the objective axis is focused in the plane of the modulator 5. The projection system of the optical unit 6, 7 transmits the source "image" into the plane of the light conductor entrance window, situated in the cooling system ACS 10. An additional rotating mirror 9 transmits the "image" given by the projection system onto the photocathode of the uncooled detector (photomultiplier) of UV radiation.

In the telescope provision is made for modulation of received radiation of two types: "diagram" (by oscillation of the field of view) and "amplitude" (by comparison with a standard emitter). In the first case use is made of a rotating bisector mirror of the modulator 5 (Fig. 2) and the fixed mirror of the comparison channel 3. The latter is in the focal plane of the objective, but is displaced 32 mm relative to its axis and is tilted somewhat relative to the modulator mirror. With rotation of the modulator, the radiation passing through the objective and reflected from the modulator mirror 5 or from the mirror 3 alternately enters into the projection system and then into the light conductor with a modulation frequency of 185 Hz. In the first case radiation is received from the region with its center on the main axis; in the second case -- from the region displaced by 22' from the main axis. With an equality of the radiation fluxes from all the telescope units the output signal is proportional to the difference in radiation intensities of the two regions. Thus, when the investigated source is on the main axis, its radiation is compared with the radiation of the adjacent region, whereby there should be exclusion of the cosmic background ("diagram" modulation regime).

In the second case -- with "amplitude" modulation -- on the path of the radiation reaching the mirror 3 there has been introduction of a calibrator 4, constituting a blackened plate, being the source of calibrated radiation. In an "amplitude" modulation regime during rotation of the modulator the radiation from the region with its center on the main axis of the telescope is compared with the radiation from the calibrator. Modulation of this type is used in measurements of background radiation.

A disk with interchangeable interference filters 8 is placed in front of the entrance window of the light conductor with the cooled detectors 10 for discriminating different sectors of the submillimeter spectrum, as well as neutral signal attenuators and a shutter for cutting off the radiation flux to the cooled detectors when the additional rotating mirror 9 transmits an image to the uncooled detector (photomultiplier) situated in the UV block of the channel 11. Figure 2 also shows the optical sight 12 and the collimator 13, intended for pointing the telescope at the visible sources (see below).

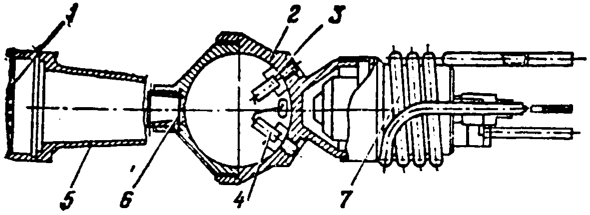


Fig. 3.

The submillimeter radiation enters through the conical light conductor (Fig. 3), whose entrance window is designed in the form of a lens of crystalline quartz 1, into the integrating chamber 2, on whose walls are mounted radiation sensors -- cooled photoresistors based on germanium, alloyed with boron 3, and n-type indium antimonide 4. The detector based on germanium is sensitive to radiation in the region 60-130μm (arbitrarily called the "IR channel"); the detector based on indium antimonide is sensitive to the region of wavelengths exceeding 300μm (arbitrarily called the "SM channel"). In the conical part of the light conductor 5, necessary for matching, together with the quartz lens 1, the apertures of the detectors with the field of view of the telescope detector, there are cooled filters 6, cutting off the short-wave radiation [8].

Amplification-recording system (ARS), whose structural diagram is shown in Figure 4, is for amplification at the modulation frequency and conversion of signals received from the photoresistors.

First the signals are amplified by preamplifiers mounted in the immediate neighborhood of the light conductor. The amplified signals are fed along coaxial cables to the blocks of the measuring apparatus BIA-1 and BIA-2, where they are again amplified (at two scales -- precise and approximate) and are synchronously transformed into a constant voltage. Control of the synchronous detectors of all channels is accomplished with the modulation frequency from the sensor on the modulator. In each of the channels the constant voltage by means of d-c amplifiers is reduced to the telemetered range 0-6 V. For visual indication of the observed signals provision is also made for an external signal indicator which the operator attaches in a place convenient for observation. The reference voltage phase, and also amplification of the channels, is regulated by potentiometers whose slits open on the BIA-1 and BIA-2 panels. The ARS units also hold secondary stabilized current sources and a command-programming device controlling the logic of telescope operation. This command-programming device can issue commands for calibration, replacement of filters, closing the amplifier inputs for monitoring level, deflecting the telescope axis for measuring the background level and for cutting off the current at the end of the session in the case of automatic operation.

Active cooling system (ACS). This is used for low-temperature thermostating of the radiation detectors for the IR and SM channels. It is an on-board helium refrigerator of the closed type with a three-stage throttling cycle, based on two-stage cooling by means of gas refrigerators operating in a Stirling reverse cycle. Gaseous helium of a high degree of purity is used as the working cooling agent in the refrigerator.

Gaseous helium in a throttling circuit is compressed by a compressor to 20-25 bar. The heat of compression is carried off through the construction elements of the compressor and in gas-fluid heat exchangers. In the first stage of the cycle the flow of compressed helium is first cooled to 80 K by a single stage GKhM-2 refrigerating unit. In the second stage of this cycle the temperature of the compressed gas is reduced to 16-18 K by a two-stage GKhM-1 refrigerating unit. In the final stage the compressed helium is cooled to a temperature of about 6 K and is throttled into the cooling chamber of the throttling circuit with a temperature decrease to 4.2-4.8 K. The pressure in the cooling chamber is in the range 0.9-1.2 kg/cm^2. The two-phase helium flow cools the walls of the integrating chamber in the light conductor in which the radiation detectors of the IR and SM channels of the telescope are placed. The low-pressure gas flow (return flow) passes through the group of heat exchangers and enters into the pneumatic supply unit. The cycle is closed.

With an expenditure of gaseous helium not less than 1.0 m^3/hour and a thermal load at the level 4.5 K not more than 0.1 W the active cooling system ACS ensures a refrigerating capacity of about 0.5 W with a power consumption of not more than 1.5 KW.

In contrast to the light conductor scheme used in the cryostat variant [9], the photoresistors in the IR and SM channels are attached by means of crystal holders directly on the well-heat conducting body of the light conductor integrating chamber (Fig. 3). The two-phase flow of helium, circulating through the throttling circuit and heat exchanger 7 of the active cooling system ACS, washes the walls of the integrating chamber 2. The good thermal contact of the photoresistors with the body of the chamber ensures their effective thermostating at the necessary temperature level ~ 4.5 K. In order to decrease the heat influx the light conductor itself, made of thin-walled stainless steel, has a narrow annular cut. The throttling circuit and the heat exchanger 7 with the integrating chamber 2 and the conical part of the light conductor 3 are protected by two cooled heat-reflecting shields; the remaining part of the light conductor is protected by one cooled shield. The heat influx into the zone where the radiation detectors are placed does not exceed 0.1 W.

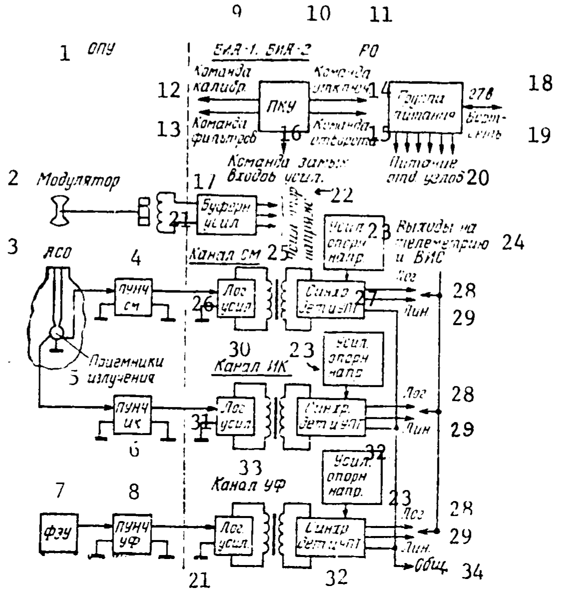
The system for ACS support is necessary for supplying the ACS assemblies with a three-phase alternating current with a frequency of 400 Hz and a voltage of 208±8 V. The starting-up of the relatively powerful GKhM-1 refrigerating apparatus is accomplished gradually with a frequency range from 13 to 400 Hz. In order to decrease the voltage fluctuations in the d-c current network during operation of the ACS filter units are mounted in front of the compressor supply unit and the motor supply unit.

The automation unit is responsible for automatic control of the ACS. The unit for measuring temperature, in addition to measuring the ultralow temperatures of the ACS and monitoring its parameters, issues a command for closing the valve in the start-up line when a definite temperature value is attained in the light conductor chamber.

The control system (CS), being of the astrotracking system type [10], is intended for pointing the telescope optical axis on a stipulated sector of the celestial sphere and tracking it, and also for scanning with the telescope axis in the limits of a square 2.5 x 2.5 degrees.

In the control system (Fig. 5) there is also a control panel (CP) from which the operator controls the operation of the measuring apparatus. The control lever (CL), control panel (CP) and the optical sight (OS) are mounted on the body of the SIC in such a way that the operator can conveniently work with them, carrying out observations through the sight.

The control system can be used in one of the following regimes:
an automatic tracking of visible sources not weaker than $+2^m$ star magnitude using the mismatch signals received from the photoguides (PG) mounted on the teleobjective parallel to its optical axis. The initial interception of the sources is accomplished by the operator in a combined or semiautomatic regime: the operator, in the field of view of the sight (OS), matches the collimator mark (Fig. 2), simulating the position of the telescope axis, with the source image. The mark is the image of the luminescent circle of the collimation tube, attached to the objective in such a way that the collimator axis is parallel to the optical axis of the telescope;
semiautomatic pointing and holding of the mark in the field of view of the optical sight on a visible source using the control lever (CL). Using this it is possible to introduce voltages activating the actuating motors (AM) for both axes;
combined tracking, under optical interference conditions, of a visible source not weaker than $+2^m$ star magnitude using the photoguides (PG) with visual monitoring of the position of the mark in the field of view of the optical sight (OS). The operator, using the control lever (CL), corrects the errors in automatic tracking;
scanning -- the registry of visible and invisible sources with transit of the telescope field of view through them, scanning without fail along the two axes within the limits of a square in the plane of the figure measuring 2.5 x 2.5 degrees of angle.



KEY:

1. General control panel
2. Modulator
3. ACS
4. SM LF preamplifiers
5. Radiation detectors
6. IR LF preamplifiers
7. Photomultiplier
8. UV LF preamplifiers
9. BIA-1
10. BIA-2
11. Operational regime
12. Calibration command
13. Command to filters
14. Command for cutoff
15. Command for deflection
16. Command for closing amplifier inputs
17. Reference voltage amplifier
18. Power group
19. On-board network
20. Power for individual units
21. Buffer amplifier
22. Reference voltage amplifier
23. Reference voltage amplifier
24. Outputs to telemetric system and visual display
25. SM channel
26. Logarithmic amplifier
27. Synchronous rectification and intermediate amplification
28. Logarithmic
29. Linear
30. IR channel
31. Logarithmic amplifier
32. Synchronous rectification and intermediate amplification
33. UV channel
34. Cumulative

Principal Characteristics of BST-1M Telescope

Optical System

Diameter of primary parabolic mirror (F-0.5)	1500 mm
Diameter of secondary hyperbolic mirror	250 mm
Focal length of objective	5013 mm
Angular field of view	18'
Amplitude of oscillation of field of view with diagram modulation	22'
Diameter of entrance window of light conductor	30 mm
Diameter of photomultiplier photocathode	20 mm
Region of response of UV channel	0.2-0.26 μm
Region of response of IR channel (Ge:B detector with filters)	60-130 μm
Region of response of SM channel (n-InSb detector with filters)	300-1000 μm
Maximum response of detectors:	
IR channel	$2 \cdot 10^{-12}$ W/Hz$^{1/2}$
SM channel	$1 \cdot 10^{-12}$ W/Hz$^{1/2}$

Active Cooling System

Thermostating temperature	4.2-4.8 K
Cooling capacity at level 4.2 K	≯ 0.5 W
Working temperature of GKhM-1	20 K
Cooling capacity of GKhM-1 at level 20 K	≯ 3 W
Working temperature of GKhM-2	80-100 K
Cooling capacity of GKhM-2 at level 80 K	≯ 5 W
Time for ACS to establish operating regime	< 90 min
Time capable of operation	> 350 hours

Amplification-Recording System

Number of amplification channels	3
Modulation frequency	185 Hz
Limits of change in output voltage	0-6 V
Required power with supply voltage 27 V	95 W

Control System

Angular field of view of sight	5 or 18°
Corresponding magnification	12*, 3*
Field of view of photoguides	3°
Maximum angles of oscillation along two axes	±5°
Mean square error in autotracking	2'
Angles of scanning in plane of figure along two axes	±75'
Oscillation time during scanning	
along X-axis	32 sec
along Y-axis	650 sec

ACS Support System

D-c current power voltage	27 V
Required power of d-c current	≤ 2510 W
Power voltage of ACS assemblies	3-phase, 208 V
Frequency of a-c current	400 Hz
Required power of a-c current	≤ 1400 W

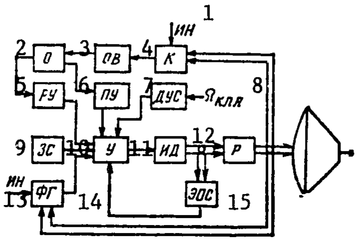


Fig. 5.

KEY:

1. Radiation source
2. Operator -- O
3. Optical sight -- OS
4. Collimator -- C
5. Control lever -- CL
6. Control panel -- CP
7. Angular velocities sensor -- AVS
8. Spacecraft
9. Scanning control -- SC
10. Amplification-conversion unit
11. Actuating motors -- AM
12. Reducer -- R
13. Radiation source
14. Photoguides -- PG
15. Feedback unit

In a scanning regime the control signal, determined by the scanning control, is fed to an amplification-conversion unit where it is compared with a signal from a feedback element. In order to ensure the required pointing accuracy the amplification-conversion unit is also fed a signal from the angular velocities sensor mounted on the station. The converted and amplified control signal is fed to an actuating motor which brings the supporting-rotating unit of the telescope into rotation through the reducer in the control system.

In addition, provision is made for the joint operation of components of the telescope control system and the station astroorientation systems used for preliminary pointing and holding the axis of the latter in the direction to the source. A special method for determining and taking mismatch errors into account has been developed for the most precise possible matching of the axes of the station astroorientation systems and the axes of the submillimeter telescope, as well as the mentioned axis and the axis of the BST-1M optical sight.

The control system panel makes it possible to select the control regime, control the measurement instruments in the amplification-recording system, change the types of modulation, have visual indication of the position of the filters, etc.

Principal specifications of the BST-1M telescope. The maximum diameter of the main mirror of the telescope is determined by its compatability with the construction of the scientific instruments compartment and the focal length of the telescope is determined by the depth of the compartment. These restrictions led to an objective with an unusual relative aperture. It appeared feasible to use a relatively inexpensive parabolic mirror with external aluminization, correcting its zonal errors by appropriate retouching of the secondary hyperbolic mirror using a method similar to that described in [11]. The objective errors determined the size of the focal spot (~ 20 mm), and accordingly, the diameter of the entrance window of the light conductor (~30 mm), and the latter -- the telescope field of view (18'). The accuracy of pointing (2-3 minutes of angle) agreed with this parameter. The principal specifications of the optical, cryogenic and amplification-recording systems, and also the telescope control system, are given in the table.

Summary. The BST-1M submillimeter-band telescope was developed, fabricated and underwent ground tests, during which confirmation was obtained for the specifications given in the table. The telescope carried on the "Salyut-6" orbital scientific station was activated by the cosmonauts Yu. V. Romanenko and G. M. Grechko for adjustments and tests in February 1978, in the course of which measurements of submillimeter radiation of the earth's atmosphere were initiated. The cosmonauts V. V. Kovalenok and A. S. Ivanchenkov continued experiments with the telescope in June-September 1978.

In the course of the experiments there was testing of all the telescope systems under flight conditions and their operability was confirmed. The active cooling system ACS ensured cooling of the submillimeter radiation detectors to the required temperature, close to 4.2 K. The electromechanical units and electronic components of the amplification-recording system functioned normally. The system for telescope control ensured its pointing in all the proposed regimes. Important experimental data were accumulated on the thermal regimes of the large telescope under orbital flight conditions and on the optimum method for work of the operators with the telescope.

In the course of the experiments with the BST-1M measurements were made of submillimeter radiation of the earth's atmosphere. "Sections" of the radiating layers were made in both parts of the submillimeter range.

Using the UV channel of the telescope there were relative photometric measurements of a number of stars, which is of interest for astrophysics, and there was registry of the settings of bright stars below the earth's horizon for the purpose of studying the behavior of the ozone layer at nighttime. The results are being processed.

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II. SPACE ENGINEERING

SOVIET COMMAND-MEASUREMENT COMPLEX DESCRIBED

Moscow NOVOYE V ZHIZNI, NAUKE, TEKHNIKE, SERIYA "KOSMONAVTIKA, ASTRONOMIYA" No 6, 1979 pp 3-17, 50-61

[Excerpts from monograph by P. A. Agadzhanov, "Command-Measurement Complex," Izdatel'stvo "Znaniye," 32,250 copies, 64 pages]

[Text] Introduction. The conquest of space to all intents and purposes began with the launching of the earth's first artificial earth satellite in the Soviet Union on 4 October 1957. During the last 20 or more years the vigorous development of space technology has now made it possible to attain considerable successes in the field of investigation and conquest of space and carry out a number of outstanding experiments. However, none of these attainments would have been possible without solving such an important problem as space vehicle flight control.

Already in the mid-1950's, while only preparations were being made for the launching of the first satellite, Soviet scientists and engineers already clearly visualized the present-day complex of technical facilities intended for support of flight and control of the on-board space vehicle systems.

What are the basic functions of this complex which in accordance with the proposal of S. P. Korolev and M. V. Keldysh has been given the name "command-measurement complex?"

For this we will first examine those problems which must be solved by the command-measurement complex during the flights of the first artificial earth satellites.

First, using a complex of a number of ground points, it was necessary to measure, with the required accuracy, the parameters of satellite motion, and as a result of processing of these trajectory measurements, determine the actual orbital parameters and compute their evolution. The collected data were then used in predicting the motion of satellites relative to the earth's surface, which made it possible to determine the zones of visibility and precise time of transit over the corresponding ground points, and also to formulate instructions for observations. For all these purposes specialists developed different kinds of ground and on-board apparatus -- radiotechnical and optical equipment intended for observations of satellites and measurements of their trajectory parameters. It should be noted that the results of the trajectory measurements were first processed at ground stations, after which they were transmitted through different communication channels to the processing center, later called the coordination center.

Second, the command-measurement complex was used in monitoring (both during the time of prelaunching preparations and during the course of the flight) the state and correctness of operation of the on-board systems and assemblies of satellites. Radiotelemetric systems were created for this purpose. These included ground receiving stations and on-board instrumentation for measurements made using sensors furnishing data on the nature of the processes which transpired aboard the satellite and in the space surrounding it.

Finally, third, the complex made it possible, during the time of the flights, to control the satellite on-board systems. For this purpose radio transmitters were installed at the corresponding ground points, sending to the satellite different radio commands. Upon receiving these radio commands various kinds of equipment aboard the satellites was switched on or off. In particular, this equipment included scientific apparatus which during the flight of the first satellites made it possible to obtain interesting data on radio wave propagation in circumterrestrial space and a number of other phenomena.

Monitoring, control, observation and measurements were carried out in a uniform time system, which was achieved using on-board and ground highly stable generators producing standard frequency and time signals. The results of measurements and observations were transmitted to the coordination-computation center along communication lines with an extent of several thousand kilometers.

All of this large, territorially scattered measurement-control system, consisting of several hundreds of kinds of technical facilities, in whose operation thousands of specialists participated, functioned as a unified well-functioning mechanism. For this it was necessary to have adequate personnel for the command-measurement complex and coordination center and also workers for all the ground observation and flight support systems and all the centers for processing measurement information.

How great has been the change in the functioning of the modern command-measurement complex in comparison with that described above and what more than anything else characterizes the present-day command-programming control of space flights?

First of all we should note the three principal peculiarities of use of now-existing space vehicles: artificial earth satellites (AES), spaceships (SS) and automatic interplanetary stations (AIS). The first is that several AES, AIS or SS, executing different space programs, can be present in space simultaneously. The second peculiarity is that separately launched SS (including freighters) can form a unified orbital complex in space -- during docking with one another or with an orbital scientific station (OS). Third, several AES or SS can execute a unified program.

These peculiarities required the creation of ground and on-board multichannel radioelectronic facilities by means of which it is possible, simultaneously, to carry out different kinds of observations, measurements, issuance of radio commands to space vehicles, and also accomplish simultaneous reception at earth of different kinds of information from space.

The mentioned facilities, in interaction with on-board and ground computers, form a complex information-computation network functioning at a real time scale. It includes coordination centers (including major computers with a handling capacity up to several millions of operations per second), computation centers for stationary (situated on the land), floating (shipboard) and aircraft command-measurement points, and also on-board computers. Among these elements of the computation network there is a continuous exchange of data and the exchange system includes diverse technical facilities and radio communication systems, including satellite space communication systems.

The extensive use of small on-board computers, having a small mass and low energy requirements, but constructed using large integrating circuits and having considerable computation capacity, affords the possibility of autonomous actions for the crew of a SS or OS, and also makes it possible to create automatic space vehicles having the properties of universal robots. There is automation of solution of many problems in flight control: space navigation and orientation in space or on the surface of another celestial body, rendezvous and docking in space, adoption of decisions under unexpected (nonstandard) situations, etc.

Thus, based on the principles of command-programming telecontrol, the command-measurement complex now ensures reliable flight control for manned and automatic flight vehicles in circumterrestrial and interplanetary space. An increase in the general level of the automation of control processes and an increase in the number of space vehicles simultaneously present in space and carrying out diverse tasks dictate the special role of this complex at the present level of development of cosmonautics.

General Information on Operation of Command-Measurement Complex

Space vehicles and the command-measurement complex (which is usually abbreviated CMC) constitute a unified continuous system, whose effectiveness to a considerable degree is dependent on the rational linking together and optimum distribution of functions between the on-board systems and the ground facilities of the command-measurement complex. This is determined by the fact that the flight control of space vehicles is accomplished by means of the combined command-programming method of telecontrol in which the on-board systems, controllable by the SS crew or working automatically (in accordance with a stipulated program) interact with the command-measurement complex and are monitored by its technical facilities.

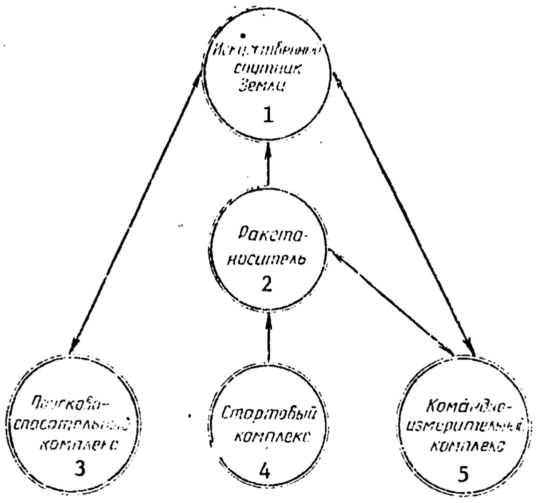

Fig. 1. Simplified diagram of rocket-technical complex intended for launching, flight control and descent of returnable artificial earth satellite.

KEY:

1. Artificial earth satellite	4. Launching complex
2. Carrier-rocket	5. Command-measurement complex
3. Search-rescue complex	

Thus, the space-measurement complex is an indispensable part of any rocket-space complex. Any modern rocket-technical complex intended for putting a space vehicle into a stipulated orbit, and also for flight control and descent to the earth, consists of several systems or complexes, including the control-measurement complex (Fig. 1). Each of them is a complex system consisting of a number of subsystems and for the most part is characterized by properties inherent in so-called large systems, which will be discussed somewhat below.

Even if the flight is accomplished in a manned regime or if automatic control by means of an autonomous on-board system is used for these purposes, in either case the control processes and the results of implementation of the flight program are usually monitored by the command-measurement complex. Sometimes it is desirable to use the command-measurement complex to duplicate implementation of individual operations of the crew or the on-board system for the autonomous control of a space vehicle. In the first case the command-measurement complex is a large automated control system performing measurement and monitoring functions and in the second case -- performing control, measurement and monitoring functions.

Depending on the type and purpose of the space vehicle, the command-measurement complex intended for its control is outfitted with different types of on-board and surface means making trajectory measurements corresponding to command radio links, different kinds of radiotelemetric facilities for diagnosis of the state and monitoring of processes transpiring aboard the space vehicle and in surrounding space, and also means for tele- and radio communication and data transmission. In many cases use is made of technical means operating in so-called "matched" regimes, when control, trajectory and telemetric measurements, communication and transmission of television images are accomplished simultaneously.

In order to ensure flight control, in addition to the mentioned means it is necessary to have on-board and surface computer complexes, using high-speed electronic computers with different capacities and with different volumes of the operational and long-term memory, and also means for monitoring, transmission and automatic input of the results of trajectory and telemetric measurements into the mentioned electronic computers.

The facilities at the command-measurement complex are characterized by reliability, readiness for operation at the strictly planned time, virtual fault-free operation. For the simultaneous control of several spacecraft the facilities at the command-measurement complex must operate at frequencies differing from one another and in different regimes, that is, at the command-measurement complex there is a quite broad range of frequencies and codes which can be used, taking into account the maneuverability of the vehicle (the necessary speed of readjustment to new frequencies).

In addition, the increasing duration of active existence of spacecraft in orbit (that is, the period during which their instrumentation still continues to function), now attaining several years for some types of AES, and the associated increase in the number of communication contacts, require that the means used at the command-measurement complex be characterized by an adequate duration of continuous operation, a great energy reserve and long operational life.

Principal functions and structure of command-measurement complex. In controlling the flight of space vehicles the command-measurement complex ensures solution of the following problems:
1) maintenance of stable two-directional communication with the spacecraft in all stipulated flight trajectory segments;
2) measurement of the parameters of motion of the space vehicle for the purpose of determining its actual trajectory and preparation of data for carrying out the necessary operations associated with carrying out control of motion (for example, orbital correction, descent of a space vehicle from orbit, etc.);
3) diagnosis of the condition of the crew and operation of the spacecraft assemblies and systems, measurement of the characteristics of the processes transpiring aboard it and in surrounding space, and also the collection

and processing of information on implementation of the stipulated flight program;
4) adoption and implementation of decisions on flight control.

Measurements of the parameters of motion of a space vehicle are made periodically, and after computation of the orbital parameters and the nature of orbital evolution instructions are formulated which are transmitted to all ground tracking facilities, measurement and control installations.

Telemetric monitoring of the crew's condition and diagnosis (analysis, evaluation and prediction of state) are carried out constantly, as is monitoring of the operating regimes and diagnosis of the state of assemblies and the principal systems aboard the space vehicle (including determination of the expenditure of energy and other resources of on-board systems) so that in time it is possible to detect deviations from the norm which may appear. At the same time there is monitoring of the entry of on-board systems, instruments and assemblies into the stipulated regime and also monitoring of the cutoff of malfunctioning instruments or those being tested or switching to reserve instruments and systems.

In addition to its direct functions (trajectory measurements, monitoring and control), the command-measurement complex ensures the reception and primary processing of basic information, that is, the purpose for which the particular space vehicle was launched (in particular, scientific -- for AES of the "Kosmos" series or meteorological -- for the "Meteor" AES).

Figure 2 shows the principal elements of the command-measurement complex which are intended for carrying out all the operations enumerated above. The figure shows how different types of on-board instrumentation aboard the space vehicle interact with the ground facilities, in particular with those established at stationary (situated on land) and moving (floating and aircraft) command-measurement points (Fig. 3).

It must be emphasized that the number and position of the stationary command-measurement points are dependent on the specific problems involved in ensuring continuous control of the corresponding type of space vehicle and also to what extent the command-measurement complex must duplicate the output of commands of on-board systems. In addition, the makeup and distribution of stationary and moving facilities of the command-measurement complex, intended for control of a specific type of space vehicle, are determined by the orbit of the latter and also by the makeup of its on-board instrumentation and flight program.

A distinguishing characteristic of any command-measurement complex is a spacing of its ground command-measurement points many hundreds and thousands of kilometers from one another, and as a result, these points are distributed in the most different regions of the country and even the earth. The fact is that most AES move in so-called low orbits (with an altitude of several hundred kilometers) and the presence of such an AES in the zone of radiovisibility of one ground station is a matter of only 5-10 minutes. However, usually it is necessary that flight control of an AES be carried out over a longer time and frequently there must be continuous communication with an AES over the course of an entire orbital revolution.

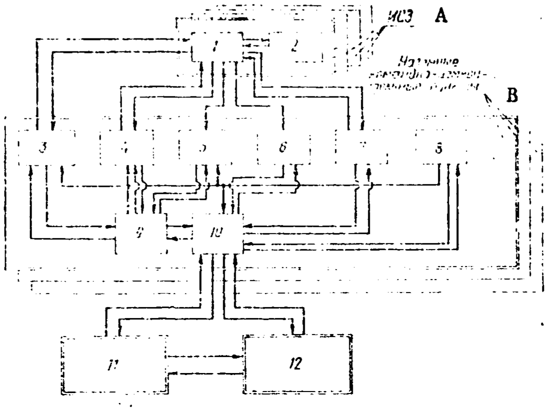

Fig. 2. Structure of command-measurement complex for several (four) AES: 1) on-board instrumentation (command-programming, trajectory and telemetric measurements, television, communication and uniform time systems); 2) on-board computers; 3-8) different facilities of ground command-measurement points (3 -- command-programming radio links, 4 -- trajectory measurements, 5 -- telemetric measurements, 6 -- transmission of television images, 7 -- communication, 8 -- uniform time system), 9 -- computation center of command-measurement point; 10 -- communications unit; 11 -- flight control center; 12 -- coordination center

KEY:

A) Artificial earth satellites
B) Ground command-measurement points

Thus, the flight control of an AES requires such a distribution of ground command-measurement points that with passage through the effective zone (zone of radiovisibility) of one station the space vehicle is in the effective zone of another ground command-measurement station (Fig. 4). It must be taken into account that since the orbital planes of AES can be characterized by the most different inclination to the plane of the ecliptic, the command-measurement points must be situated in regions which are distant from one in both latitude and longitude.

[Note: In the original test there is a diagram of interactions among the principal elements of the command-measurement complex. It is not reproduced here because of its poor reproduction quality.]

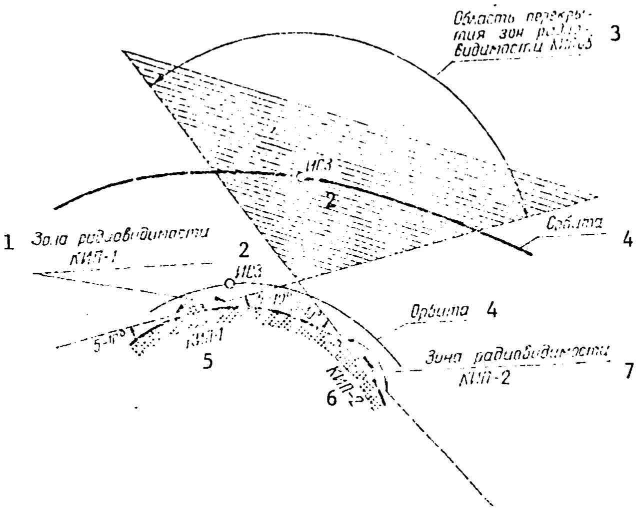

Fig. 4. Positioning of two command-measurement points with which there is flight control coverage for an AES situated in a lower orbit.

KEY:

1. Zone of radiovisibility of command-measurement point 1
2. AES
3. Region of coverage of zones of radiovisibility of command-measurement points
4. Orbit
5. Command-measurement point 1
6. Command-measurement point 2
7. Zone of radiovisibility of command-measurement point 2

As a rule, a large number of AES or other space vehicles can be present in space simultaneously and therefore only a correct combination of ground and on-board facilities and also an optimum distribution among them of the corresponding functions ensure successful and thorough use of both the space vehicles themselves and the facilities used at the command-measurement complex. The rational distribution of functions, optimum planning of use of measurement, radio command and telemetric facilities of the command-measurement complex, and also possible flexible restructuring of operation of the services and facilities of the command-measurement complex and exclusion of "conflicting situations" (in the use of radio frequencies, etc.) -- all this is related to the principal tasks which are solved by the coordination center of the command-measurement complex, working in interaction with the main computation center of the command-measurement complex.

The coordination center carries out the coordination of the work of ground command-measurement points and the planning of interaction between systems of the command-measurement complex and the flight control center. There are several flight control centers, depending on the specific type of spacecraft. For example, at the present time there are flight control centers for manned space vehicles (manned ships or orbital stations), flight control centers for meteorological, communication, geodetic and other types of AES, and also centers for deep space communication (for flight control of automatic interplanetary stations).

The principal functions for the flight control centers are: diagnosis and prediction of the condition of the crew and the operating regime of space vehicle systems, evaluation of the completeness of implementation of work under the flight program, adoption of decisions on the on-board performance of various operations in standard and nonstandard (emergency) flight regimes. One of the important peculiarities of the numerous technical facilities and services of the command-measurement complex is that their operation is synchronized. The trajectory measurements, processing of data, issuance and implementation of radio commands (individual and under a program), operation of on-board scientific instrumentation and other operations performed aboard the space vehicle and on the earth, must be strictly coordinated and governed by a strict schedule, corrected in dependence on implementation of the flight program.

The nonimplementation of some operations, and also delays, lags and other impairments in interaction between the on-board automatic systems and ground facilities can lead to complications and interruptions in flight control. If unforeseen and emergency situations arise aboard the space vehicle, for detecting their causes and determining the influence on implementation of the flight program they are simulated and modeled at the flight control center.

Thus, flight control of space vehicles provides for the comprehensive, interrelated use of a great number of on-board and ground command-measurement, computation and other facilities spaced over enormous distances and joined into a unified global control system.

The standard facilities entering into the makeup of command-measurement complexes also form systems, among which the following systems are typical for any command-measurement complex:

1) for command-programming radio links;
2) for trajectory measurements;
3) for telemetric measurements;
4) for television observations;
5) for communication (oral and telegraphic);
6) standard time;
7) processing and display of information.

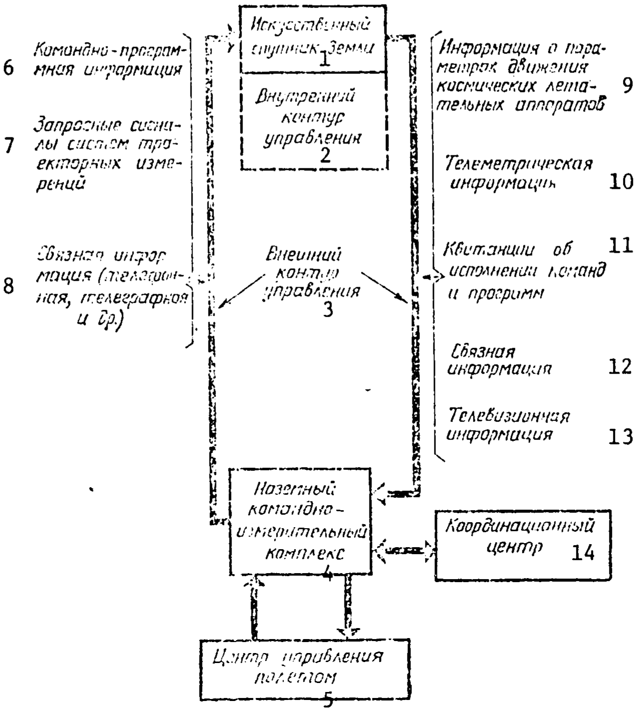

Fig. 5. Diagram of space vehicle control.

KEY:

1. Artificial earth satellite
2. Internal control circuit
3. External control circuit
4. Ground command-measurement complex
5. Flight control center
6. Command-programming information
7. Interrogation signals of trajectory measurement systems
8. Communication information (telephonic, telegraphic, etc.)
9. Information on parameters of motion of space vehicles
10. Telemetric information
11. Acknowledgments of implementation of commands and programs
12. Communication information
13. Television information
14. Coordination center

The interaction of these systems is accomplished in accordance with a program determined by the coordination center of the command-measurement complex on the basis of the corresponding statements arriving from the flight control centers. These requests include the issuance of command-programming information, the carrying out of different kinds of measurements and entry into communication with a space vehicle and are determined by the specific flight program.

The command-measurement complex -- a major system. If a space vehicle is regarded as some controlled object, then the diagram for such control, including the facilities of the command-measurement complex and the on-board instrumentation, will have the form shown in Fig. 5. This diagram shows that the flows of data will circulate in the external control circuit, including the space vehicle itself and the ground facilities of the command-measurement complex, and in the internal circuit, which includes the autonomous on-board orientation, stabilization and other systems. The external control circuit consists of a large number of special circuits differing from one another in structure, flows of information and dynamic characteristics of the links making them up.

As already mentioned above, command-measurement complexes belong to the class of so-called large control systems which accomplish the solution of complex engineering and economic problems with the broadest use of automation and telemechanics, radio engineering and electronics, computer complexes, mathematical, programming and information support. These include, for example, systems for the control of air transport, hydraulic engineering and power systems, major production complexes, etc.

In general, a large system is a large-scale controllable system considered as the totality of the interrelated controlled subsystems combined by the overall functioning purpose. The characteristic criteria of a large system include the presence of controllable subsystems, the material, energy and information relationships among them, the relationship between the considered system and other systems, participation of man, machines and the environment in the system. As a rule the control of a large system is organized on the hierarchical principle, in which a higher organ controls several subdivisions (subsystems) at a lower level, each of which controls subsystems of a still lower rank.

The diversity of equipment and the complexity of the functions characteristic of large systems require a special approach to their study and planning. In this connection the need arises for using a systemic (complex) approach for such purposes. In particular, a systemic approach is also necessary for formulating the general conditions ensuring successful operation of a number of independent parts of a large system when they are joined into an integrated whole.

The use of the systemic approach to so-called complex systems, to which large systems also belong, led to the appearance of a special scientific-technical discipline -- systems analysis. It takes in the matters of designing, creating, testing and operation of all complex systems, in particular, a study of problems relating not only to the properties of component parts of a complex system (its principal elements, subsystems), but also to the laws of functioning of the system as a whole (overall system problems). Sy tems analysis makes extensive use of the methods of mathematical logic and statistics, the theory of algorithms, combinational analysis, the theory of games, situation theory, mass servicing theory, information theory, etc.

The systemic approach assumes an examination of more than one variant of possible solutions and therefore systems analysis must include an all-inclusive consideration of different methods for achieving the desired result. According to the definition of the American scientist J. Morton, the systemic approach means that each system is an integrated whole even when it consists of individual separated functional systems and subsystems. Each of them has a number of purposeful indices and the balance between them can vary from system to system in a broad range.

The effective functioning of the whole is the fundamental problem facing the command-measurement complex. The individual components and installations making up the command-measurement complex in certain time intervals may or may not operate in an optimum regime, but in the general balance of all the indices of this system their effect in the stipulated time interval ensures satisfaction of all the requirements for the entire period of operation of the command-measurement complex.

The methods of systems analysis are directed to the finding of the optimum choice of the purpose functions of the system with respect to individual parameters and the attainment of a maximum interchangeability of the component parts of the complex system. Applicable to a command-measurement complex this choice is made relative to the following parameters:
1) optimum range of used radio frequencies;
2) best energy characteristics of the employed radio links;
3) optimum information characteristics of the command-measurement complex as a whole and its principal elements.

The choice is made taking into account such factors as the peculiarities of propagation and absorption of radio waves, the level of interference and noise at the reception point, and the possibility of technical realization of search for the optimum parameters both for the command-measurement complex as a whole and for the systems making it up.

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Principal Elements of Operation of Command-Measurement Complex

Two-directional communication. The solution of this problem ensures implementation of all the principal functions of the command-measurement complex: the carrying out of observations and measurements, the transmission and reception of command-programming, measurement and other information by the facilities of the command-measurement complex and aboard a space vehicle. For this purpose at the present time the command-measurement systems are using surface pencil-beam large-dimensional antennas with a diameter of 18-180 m, having effective areas 500-5,000 m^2, and also directional antennas installed aboard space vehicles, these having a diameter of 3-10 m and capable of being spatially oriented.

In the surface receiving-amplifying systems of the command-measurement complex extensive use has been made of parametric (cooled) and quantum amplifiers, whereas in on-board receivers it is most common to use amplifiers with travelling-wave tubes, but also parametric amplifiers. The surface transmitters usually have a signal power of 150 KW at the output (in a continuous radiation regime); the on-board transmitters have a signal power of several KW (in a pulsed regime) and several tens of watts (in a continuous radiation regime).

Processing and coding are carried out using such methods as code-pulse modulation and phase modulation. Use is made of wide-band noiselike signals, the method of compression and adaptation of information, accomplished using surface and on-board computers, etc. For synchronizing the operation of the command-measurement complex use is made of on-board and surface frequency standards with a relative instability of 10^{-10}-10^{-12}.

Trajectory measurements. These are carried out systematically from a number of surface points and after processing with the use of high-speed electronic computers are employed for determining the actual trajectory parameters and the precise time of transit of an AES in the zone of radiovisibility of ground stations, for predicting evolution of the trajectory and producing data for its correction, as well as for preparing instructions.

As already noted above, these measurements are made using surface and on-board radio and also (in some cases) optical apparatus; after preliminary processing at ground stations in the command-measurement complex the results of the trajectory measurements are fed to a joint processing center.

But what are the results of the trajectory measurements? What trajectory parameters are determined in this case?

Now we will examine the simplest example: the motion of an AES around the earth. In this case during the trajectory measurements computations are made of the parameters of motion of the AES around the earth or its orbital elements, that is, the values characterizing the dimensions, form and position of the orbit in space, and also the position of the AES in orbit. The Keplerian elements are usually used in this process.

According to Kepler's law, the plane of the elliptical orbit of an AES passes through the center of the earth, which is one of the foci of this orbit. The line of intersection of this plane with the earth's equatorial plane is called the line of nodes and is of fundamental importance for determining the Keplerian elements (Fig. 21). The orbit of an AES intersects the equatorial plane at two points called the ascending and descending nodes: the AES passes through the ascending node with passage from the southern into the northern hemisphere (if its motion coincides with the direction of the earth's rotation) and passes through the descending node with passage from the northern into the southern hemisphere.

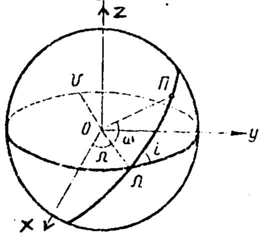

Fig. 21. Schematic representation of celestial sphere and coupled system of rectangular coordinates.

In order to determine the orbital elements use is made of a rectangular coordinate system (see Fig. 21) whose OZ-axis passes through the north pole and whose OX-axis is directed to the point of the vernal equinox: at the moment of the vernal equinox, that is, 21 March, the sun is situated at this point in the celestial sphere; the OY-axis supplements this coordinate system to the right.

The position of the AES orbital plane is determined by two Keplerian elements -- inclination i and the longitude of the ascending node Ω, which constitute the angle of inclination of the orbital plane to the equatorial plane (reckoned from the latter plane) and the angle between the OX-axis and the direction to the point of the ascending node $O\Omega$ (reckoned from the OX-axis). The orbits of an AES are called equatorial if $i = 0°$, polar if $i = 90°$, and inclined in all the remaining cases. The orbital motion of the AES is direct if it coincides with the direction of the earth's rotation ($0 < i < 90°$) and retrograde if it is opposite to this direction ($90 < i < 180°$).

The orbital plane of the AES, intersecting the celestial sphere, forms a great circle, that is, a circle which is seemingly the "trace" of the orbit (or its projection) in the celestial sphere. In order to determine the orientation of the elliptical orbit in the coordinate system XYZ use is made of the projection of the perigee point onto the celestial sphere, that is, the point of the AES orbit closest to the center of the earth. The angle ω, reckoned from the line of nodes to the direction to the perigee point $O\Pi$, is the third Keplerian element.

Two other Keplerian elements -- the semimajor axis a and eccentricity e -- determine the form and dimension of the elliptical orbit. Still another Keplerian element is used for computing the orbital position of the AES; this is τ -- the time of AES transit through the perigee (since on the basis of the Keplerian laws it is possible to carry out easy computations of the orbital position of an AES at any moment in time if the τ value is known). All six Keplerian elements (i, Ω, ω, a, e, τ) make it possible to determine the position of the AES in the celestial sphere at any moment in time using the so-called ephemerides.

The projection of the AES orbit onto the earth's surface determines its position over the corresponding points on this surface. Such a projection in the first approximation is a sine curve intersecting the equator at an angle equal to the inclination i and having an amplitude which attains a geographical latitude equal also to i. As a result of the earth's rotation this sine curve with each successive AES orbital revolution moves along the earth's surface with a velocity > 1,000 km/hour in a westerly direction. The distance on the earth's surface between two projections of adjacent AES orbital revolutions is dependent on the period of its revolution around the earth, which, in turn, is dependent on orbital altitude above the earth's surface.

The orbital elements of the AES, for example, such as inclination i and the semimajor axis a, play a major role in determining the possible range of communication with a space vehicle and in selecting the earth-AES and AES-earth communication channels. Therefore, flight control requires computation of AES orbital position at different moments in time. The total motion of the AES is determined on the basis of solution of the differential equations of AES motion. As the initial data use is made of the parameters of AES motion and the earth's gravitational parameters, which makes possible an unambiguous determination of the AES orbital parameters.

However, as a result of the earth's asphericity, the presence of gravity anomalies and the effect of different factors perturbing the orbit (atmospheric drag, attraction from the direction of the moon, sun, planets, etc.) the real AES orbit is never an ideal ellipse. Therefore, in computing the real AES trajectory it is customary to use numerical methods for solving the system of differential equations of AES motion using an electronic computer.

In addition, as a result of trajectory measurements it is not the parameters of motion themselves (orbital elements) which are obtained, but values functionally related to the latter. In addition, the trajectory measurements process is influenced by different kinds of systematic errors. All this, and also the presence of a considerable excess of measurements in comparison with their minimum number necessary for solving this system of equations, require a statistical approach to solution of the problem of determining the total motion of an AES.

Earlier we examined only motion of an AES in an orbit around the earth, but all the conclusions drawn above also relate to determination of the parameters of motion of manned spaceships, orbital stations and also automatic interplanetary stations, although in the latter case it is not the Keplerian orbital elements which are determined, but some other parameters of motion of these space vehicles.

In all cases the determinations of the parameters of motion of space vehicles seemingly pass through two stages: initial determination of the parameters of motion and refinement of the initial values of these parameters as a result of search for the corresponding corrections. The totality of these corrections is obtained as a result of statistical processing of the results of trajectory measurements. In this process use is made of the greatest possible number of measurements (considerably exceeding the minimum necessary number) because this will make it possible to increase the accuracy in determining the motion of the space vehicle.

The type of trajectory, the number of used parameters of motion of the space vehicle, and also the necessary accuracy of their determination govern solution of the problem of the distribution of the command-measurement complex measurement facilities. The number of employed parameters of motion of the space vehicle will be extremely different in dependence on the nature of the trajectory.

Due to the requirements on routineness of space vehicle computations and the need for using high-speed computers for these computations, at the present time there is total automation of the processes of registry, collection and processing of the results of trajectory measurements with the use of different specialized and universal electronic computers at the command-measurement complex.

Telemetric measurements. Various kinds of ground and on-board telemetric facilities and corresponding systems of sensors are used for monitoring the state and correctness of operation of the principal space vehicle systems and assemblies (during the flight and in the course of prelaunching preparations) and also for determining the characteristics of the processes transpiring aboard a space vehicle and in the space surrounding it.

The arriving telemetric data make it possible to carry out a diagnosis of operation of the systems and assemblies aboard the space vehicle, the collection of scientific and other information, preparation and monitoring of operations for flight control. In order for the results of the measurements for each group of parameters (see Fig. 21) to be used in evaluating the operation of the on-board apparatus as a whole (identification problem) it is necessary to carry out joint mathematical processing of all the measurement results.

For this purpose algorithms are being developed for evaluating the reliability .f the telemetric information and determinations are made of the mathematical expectation and other parameters of the probability density functions, determined by such factors as the volume of arriving information, the periodicity of output of processed results and and the capability (speed) of the processing system. The methods of the theory of probability and mathematical statistics, the theory of random functions, etc. are used extensively in such cases.

The results of processing of telemetric information are presented on displays and on cathode-ray tube screens, are registered by curve plotters and alphabetical-digital printout apparatus and are then fed to secondary data carriers (punch cards, punch tapes); these results remain in storage units of the processing system or are transmitted through communication channels.

The automation of all these measurement and processing procedures is acquiring the greatest importance in the case of analysis (monitoring) of the operation of extremely complex on-board instrumentation of modern space vehicles, whose flight program is very saturated, and the arriving information, due to its considerable volume, becomes difficult to assimilate.

The correctness of diagnosis and prediction, governed by the reliability of monitoring, controls the outcome of functioning of all the on-board instrumentation, and therefore, for solution of the problems involved in technical diagnosis use is made of the most powerful computers and extremely correct methods and algorithms for the processing of telemetric information are being developed. In addition, for the accomplishment of successful monitoring of the operation of systems aboard a space vehicle it is necessary to accumulate considerable masses of data obtained as a result of processing of telemetric information.

Flight control. By "flight control" is meant the implementation of a complex of measures for the implementation of a stipulated flight program. This essentially involves the carrying out of operations for controlling the position of a space vehicle relative to its center of mass, for control of motion of the center of mass in the required trajectory, for control of the operation of on-board systems, for directing the actions of the crew, etc. The implementation of control is accomplished using different radio commands transmitted (separately or in a program) to the space vehicle and whose implementation is monitored at the flight control center.

It is obvious that for the adoption of decisions for flight control of a space vehicle it is necessary to carry out an analysis of data on the parameters of the actual trajectory of motion of the space vehicle, on the state of its systems, assemblies and energy resources. In addition, with the appearance of nonstandard situations during the time of space vehicle flight, which can lead to deviations from the stipulated flight program, there must be a thorough analysis of these situations and their consequences.

All this is accomplished at the flight control center, which receives all the necessary information. This same center monitors the operational and long-term flight control of the space vehicle, including the adoption of decisions on continuation of the planned flight program and on the introduction of the necessary changes into it.

The prospective, long-term and operational planning of optimum loading of the command-measurement complex facilities and systems for space vehicle flight control (one or in a system) is carried out by the coordination center of the command-measurement complex, which from the flight control center receives corresponding requests for the servicing of a particular type of space vehicle.

Coordination center. The planning and coordination of the operation of command-measurement complex facilities, carried out at the coordination center, is of great importance for the flight control of a great number of space vehicles (for example, systems of artificial earth satellites). Indeed, only the proper combination of ground and on-board facilities and the optimum distribution of the corresponding functions among them can bring about the successful and thorough use of a particular system of space vehicles.

The coordination center at the command-measurement complex carries out this planning taking into account the maximum satisfaction of the requests arriving from the flight control centers with the use of the minimum number of ground and on-board facilities in the case of uniform loading of the latter. In addition, it ensures absence of significant time gaps in the operation of the employed facilities and exclusion of "conflicting situations" with respect to the use of working radio frequencies.

The basis for practical solution of the planning problem is modeling (using an electronic computer) of the development of an operational situation. The fact is that with an increase in the prediction period the initial data change, and this is reflected both in the individual planning results and in the mathematical methods employed. Extensive use is made of different mathematical theories -- the probability, sets, mass servicing and reliability theories.

The problem of operational planning of the loading of facilities at the command-measurement complex has much in common with the similar problems solved in the planning of loading of large-scale transportation systems. In particular, in this case as well use is made of the linear and nonlinear programming approaches, elements of dynamic programming, the theory of adoption of statistical solutions with the use of a great number ($\sim$10,000) of equations.

In an analysis of operation of the command-measurement complex it appears that it is also necessary to take into account the parameters characterizing the participation of a man-operator in its work, that is, take into account the psychic and physiological peculiarities of man. The quantitative evaluations of the parameters characterizing the man-operator make it possible, on the one hand, to ascertain the influence of his performance on the fundamental working characteristics of individual systems and the command-measurement complex as a whole, and on the other hand, to detect the influence of operating conditions of the serviced subsystems and the difficulties of the performed operations on performance of the man-operator (taking individual peculiarities into account). A factor of more than a little importance is the proper distribution of tasks between servicing personnel at the control center and the automatic systems aboard spacecraft during the course of the entire flight.

Accordingly, only a thoroughly analyzed, scientifically sound optimum distribution of functions between man (the operator) and machine (the automatic systems) and their mutual duplication make possible reliable assurance of implementation of the flight program and obtaining a high probability of solution of the problems to be solved by the "man-machine" system.

Status and Prospects

The further development of command-measurement complex systems and their improvement are directly related to an increase in the handling capacity of space-earth radio links and with the use of AES relay systems as elements of the command-measurement complex.

Handling capacity of radio links. During flights of space vehicles a great flow of information arrives at earth from them, in individual cases being reckoned in hundreds of thousands of bits per second. For example, during the transmission of telemetric information from aboard an orbital station this flow can attain 10^6 bits/sec. In order for there to be oral communication between the crew of an orbital station and the earth the information must be transmitted at a rate of several thousand bits per second. In order to obtain a television image with a resolution of about 300-400 lines the information must be transmitted at a rate of several million bits per second, and for transmitting television images with a resolution of about 550-600 lines -- several hundred million bits per second.

However, in a number of cases (for example, in the flight of automatic interplanetary stations to other planets) the handling capacity, that is, the rate of data transmission, of the space-earth radio link is far lower than the cited values for the orbital station-earth radio link. In particular, the handling capacity of the space-earth radio link, the maximum possible for the particular command-measurement complex, decreases sharply with an increase in the distance between the automatic interplanetary station and the earth. In addition, the handling capacity is dependent on different characteristics of the used radio link, the noise and interference level, and also on the method for transmission and reception of radio signals.

The computations show that the most acceptable handling capacity of the space-earth radio link in the case of flights of automatic interplanetary stations to other planets is attained only when the command-measurement complex systems use parabolic antennas with a diameter not less than 64 m. For the preamplification of the received high-frequency signal it is desirable to use a quantum amplifier.

The pulse (phase) modulation method employed in systems for radio communication with automatic interplanetary stations also exerts an appreciable influence on the maximum possible handling capacity for a particular space-earth radio link. In particular, the effectiveness of this method, as well as the handling capacity itself, is dependent on the signal-to-noise ratio at the receiver input.

Now we will compare the handling capacities of automatic interplanetary station-earth radio links with the rates of data transmission from aboard an orbital station to the earth. As indicated by computations, with the use of a surface (receiving) 64-m antenna (with an amplification of 61 db) and with an equivalent noise temperature of 30 K and a signal-to-noise ratio of 10 db, and also with on-board instrumentation including a 2.3-m antenna with an amplification of 32 db and a transmitter with a power of 50 W, the maximum handling capacity of the automatic interplanetary station-earth radio link is $(0.3-2)\cdot10^4$ bits/sec with operation of the on-board transmitter at a frequency of 2300 MHz in the neighborhood of the planet Mars and only 500 bits/sec in the neighborhood of the planet Jupiter. It is obvious that such a rate of data transmission is greatly inferior to the handling capacity of orbital station-earth radio links.

What are the prospects for increasing the handling capacity of automatic interplanetary station-earth radio links in the coming decade?

Already in modern command-measurement complex systems, using the method of coherent phase modulation of a high-frequency signal, the signal-to-noise ratio can attain values 7-10 db. In the near future still more improved command-measurement complex systems evidently will make it possible to obtain a signal-to-noise ratio of about 4 db. In addition, there are prerequisites for a changeover to a frequency range $(5-8)\cdot10^3$ MHz, corresponding to the minimum noise level of the Galaxy and atmospheric absorption, which also has a favorable influence on improvement in the handling capacity of automatic interplanetary station-earth radio links.

In the years immediately ahead the use of on-board parabolic antennas with a diameter of 3 m will make it possible to increase the rate of transmission of data at frequencies 3-3.75 GHz to 50,000 bits/sec. In addition, with the use of on-board transmitters with travelling-wave tubes their power can attain 100 W in the centimeter range of wavelengths. Existing designs of on-board antennas with a diameter of 6 m, taking into account this increase in the power of on-board transmitters, will ensure obtaining a handling capacity of space-earth radio links up to 300,000 bits/sec.

In turn, the further development of all possible methods for the logical processing of telemetric information aboard space vehicles should ensure such a "compression" which will eliminate excess information in the transmitted communications, decrease energy expenditures in the used radio links and increase the information handling capacity of the command-measurement complex systems as a whole.

Moving radio communication stations and AES relay systems. In order to ensure constant communication with manned spaceships and orbital stations the surface command-measurement points of the command-measurement complex must be distributed in such a way that most of the flight trajectory of these space vehicles will, insofar as possible, fall within the limits of radio-visibility of the surface tracking, communication and flight control stations.

A considerable part of the flight trajectories of orbital space vehicles pass over the surface of seas and oceans, and therefore it is not surprising that already at the dawn of cosmonautics, in the 1950's, there was wide discussion of the problem of creating floating (shipboard) complexes for tracking the flight of artificial earth satellites. At the present time the USSR has several scientific research ships which are well equipped with special radio facilities for control and communication with spacecraft: "Kosmonavt Yuriy Gagarin," "Akademik Sergey Korolev," "Kosmonavt Vladimir Komarov," "Kosmonavt Vladislav Volkov" and others.

The enormous antenna systems of these floating complexes are installed on gyroplatforms, as a result of which the influence of rolling is eliminated and the possibility of highly precise tracking in the angular coordinates of space vehicles during their motion in the celestial sphere is ensured. The telemetric, radiotelevision and other information received by the stations of the shipboard complexes is relayed to the "Molniya" communications artificial earth satellite, from which, in turn, it is transmitted to the corresponding surface satellite communication station ensuring the transmission of this information to the flight control center.

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ANALYSIS OF ONE CLASS OF LINEAR ESSENTIALLY NONSTATIONARY AUTOMATIC CONTROL SYSTEMS FOR SPACE FLIGHTCRAFT OF THE VKS (AIR-SPACE AIRCRAFT) TYPE IN THE FINAL DESCENT SEGMENT

Moscow NAVIGATSIYA NAVEDENIYE I OPTIMIZATSIYA UPRAVLENIYA in Russian 1978 pp 76-82

[Article by N. I. Sokolov and N. B. Sudzilovskiy]

[Text] An air-space aircraft (VKS) is controlled in the final descent segment by means of aerodynamic forces. In this segment the flight velocity changes by several times. Thus, for example, whereas at an altitude of 30-35 km it is 3.5 M, at the time of approach to the ground it is reduced to 0.27 M. In this process the effectiveness of the control surfaces, the characteristic frequency of the controlled object, damping forces and other parameters vary in an extremely wide range. In a general case the system for automatic control of such an object will be nonlinear and nonstationary.

In the case of a known (stipulated) descent trajectory it is possible to consider the variable parameters of the object as known functions of time.

It is possible to control such nonstationary objects by means of regulators with a rigorous structure and with constant parameters.

In a limited case such systems can frequently be represented by linear nonstationary models and it is possible to describe dynamic processes by linear nonstationary differential equations.

Next it is assumed that the forms of the transfer functions in the case of VKS acceleration control in longitudinal motion in different stages of the considered descent trajectory must remain approximately constant, the duration of the transfer function can vary in stipulated limits and in this case all the regulator links must satisfy the conditions of physical realization.

In symbolic form the differential equation for such a system can be written approximately in the form

$$[\varphi^n(t)\,p^m + \varphi^n(t)\,A_{m-1}p^{m-1} + \ldots + \varphi^n(t)\,A_n p^n + \varphi^{n-1}A_{n-1}p^{n-1} + \ldots + \\ + \varphi^2(t)\,A_2 p^2 + \varphi(t)\,A_1 p + A_0]\,X_{\text{вых}} = A_{01}X_{\text{вх}},$$

[BX = in(put); BЫX = out] where p = d/dt and the zero approximation of the confluent equation has the form

$$[\varphi^n(t)\,A_n p^n + \varphi^{n-1}(t)\,A_{n-1}p^{n-1} + \ldots + \varphi(t)\,A_1 p + A_0]\,X_{\text{вых}} = A_{01}X_{\text{вх}}. \tag{1}$$

[BX = in; BЫX = out]

The derived nonstationary differential equation is used as the initial equation and is regarded as belonging to equations of a special class, which, as will be demonstrated, can frequently be solved by employing the "frozen coefficients" method.

1. Reduction of the initial differential equation of the system to an equivalent equation. In a more general case the initial linear differential equation of the considered essentially nonstationary control system, formulated by the considered method [1], can have the form

$$\theta_n(t)\frac{d^nX}{dt^n} + A_{n-1}\,\theta_{n-1}(t)\frac{d^{n-1}X}{dt^{n-1}} + \ldots + A_1\theta_1(t)\frac{dX}{dt} + A_0X = A_{01}X_{\text{вх}}, \tag{2}$$

where $A_{01}, A_1, \ldots, A_{n-1}$ are constant coefficients; $\theta_n(t) = \varphi^n(t)$ is positive, not transforming to zero the function having "n" derivatives; $\theta_{n-1}(t), \ldots, \theta_1(t)$ are arbitrary continuous functions of time.

We will introduce the new independent variable χ in such a way that the coefficients on the highest and lowest (zero) derivatives in the new equation are constant.

We will take χ in such a way that $t = z(\chi)$. Then $dt = z(\chi)d\chi$, where $z\chi = dz/dt$.

We will write

$$\frac{dx}{dt} = \frac{dx}{z(\chi)d\chi}$$

and

$$\varphi(t)\frac{dx}{dt} = \frac{\varphi[z(\chi)]}{z'(\chi)}\cdot\frac{dx}{d\chi}.$$

We will require that

$$\frac{\varphi[z(\chi)]}{z'(\chi)} = 1.$$

Then

$$d\chi = \frac{dz(\chi)}{\varphi[z(\chi)]} \qquad \text{and} \qquad \chi = \int\frac{dz(\chi)}{\varphi[z(\chi)]} + c,$$

where c is the integration constant.

With a change to a new independent variable it is convenient to assume that $\chi = 0$ when $t = t_i$, where t_i is the moment of imparting of the effect. For these conditions it is easy to find the integration constant c.

We use the notation

$$\int \frac{dz(\chi)}{\varphi[z(\chi)]} = \Phi[z(\chi)]$$

or

$$\chi = \Phi[z(\chi)] + c,$$

where

$$c = -\Phi(t_i).$$

We will limit ourselves to such a class of functions $\varphi[z(\chi)]$ for which $\Phi[z(\chi)]$ will be a monotonic function. Then for the functions $\Phi[z(\chi)]$ it is possible to determine $z(\chi)$, $z'(\chi), \ldots, z^{(n)}(\chi)$.

After proceeding to the new independent variable, we obtain

$$\frac{d^n x}{d\chi} + \left\{ A_{n-1} \frac{\theta_{n-1}[z(\chi)]}{\varphi^{n-1}[z(\chi)]} - N_{n-1}[z'(\chi), z''(\chi)] \right\} \frac{d^{n-1}x}{d\chi} + \ldots +$$
$$+ \left\{ A_1 \frac{\theta_1[z(\chi)]}{\varphi[z(\chi)]} - N_1[z'(\chi), z''(\chi), z'''(\chi), \ldots, z^{(n)}(\chi)]\right\} \frac{dx}{d\chi} +$$
$$+ A_0 x = A_{01} x_{\text{BX}}.$$

[BX = in(put)]

In the derived differential equation, as a result of the special replacement of the independent variable of the initial equation the coefficients on the highest and lowest derivatives are constant values. Henceforth we will call such equations "equivalent equations."

With some $\varphi(t)$ and $\Phi(t)$ the coefficients also with other derivatives also will be constant values, that is, there is such a class of nonstationary differential equations which correspond to the equivalent stationary differential equations. We will assign these nonstationary equations to the first type of equations of a special class.

A solution of these nonstationary equations of the first type is obtained [6] from solution of the corresponding equivalent equation by means of replacement of the independent variable χ in the solution by the initial independent variable t

$$\chi = \int \frac{dt}{\varphi(t)} + c.$$

2. Conditions of quasistationarity of equivalent differential equation. Assume that the initial nonstationary differential equation has the form (1).

We will assign such equations to the second type of equations of a special class.

After replacing the independent variable we obtain an equivalent equation in the form

$$\frac{d^n x}{d\chi^n} + \left\{ A_{n-1} - N_{n-1} [z'(\chi), z''(\chi)] \right\} \frac{d^{n-1} x}{d\chi^{n-1}} + \dots + \\ + \{ A_1 - N_1 [z'(\chi), z''_1(\chi), \dots, z^{(n)}(\chi)] \} \frac{dx}{d\chi} + A_0 x = A_{01} x_{\text{BX}} [z(\chi)]. \quad (3)$$

[BX = in(put)]

Here $N_{n-1}, \dots, N_1$, in a general case are variable values of the function χ, $A_n = 1$.

The derived equivalent equation is nonstationary, but each of its coefficients consists of the sum of two components: variable and constant. This makes it possible for evaluations of its solution to employ the known theorems from [2, 3] and others.

Under real conditions it is frequently of interest to solve the equations in the stipulated time interval T, where $T > t_{comp}$ is the time of the impulse transfer function.

An evaluation of solution of the initial differential equation when $t \to \infty$ in this case may not be of interest. The change from the initial differential equation of the second type of a special class to an equivalent equation makes it possible to transform many essentially nonstationary differential equations of the second type of a special class into equations with slowly changing coefficients, that is, into quasistationary equivalent equations [4].

It is possible to apply the approximate methods for investigating stationary systems [4] to quasistationary systems.

One of the simplest approximate methods for such an investigation is the "frozen coefficients" method, which, however, is not always applicable to quasistationary systems. The replacement of the independent variable in equations of the second type leads to a decrease in the rate of change of the parameters in the equivalent equation by a factor of 10, and accordingly, to a decrease in the ranges of change in the coefficients of the derived equation during the time of the effective activity of the impulse transfer function by a factor of 10.

This means that with a change in the coefficients of the differential equation of the second type by an order of magnitude or even by two orders of magnitude during the time of the effective duration of the impulse transfer function the change in the coefficients of the corresponding equivalent equation may be in the limits of several percent of the mean value. Under these conditions there is a possibility of obtaining an approximate solution of the equivalent differential equation by the "frozen coefficients" method when this method is inapplicable directly to the initial nonstationary or quasistationary equations of a special class [4].

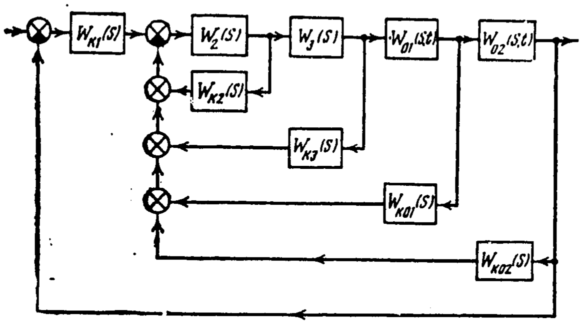

Fig. 1. Structural diagram of control system.

Table 1

Values of Coefficients $a_1(t)$, $a_2(t)$, $a_3(t)$, $a_4(t)$, $k_3(t)$ for Different Points on VKS Flight Trajectory

№ точек points	a_1	a_2	k_3a_2	$k_3a_2a_3$	$k_3a_2a_4$
1	0,3	0,80	2,0	0,6	0,5
2	0,32	0,84	3,0	0,62	0,8
3	0,34	0,865	5,1	0,70	1,6
4	0,37	0,91	7,35	2,34	3,0
5	0,40	0,97	8,95	3,10	5,0
6	0,42	1,02	10,3	5,16	7,0
7	0,46	1,18	13,4	9,9	14,0
8	0,51	1,30	15,2	12,6	20,0
9	0,60	1,44	17,3	16,2	30,0
10	0,70	1,76	18,5	18,5	40,0
11	0,80	2,00	20,0	21,0	50,0

Example. Assume that the requirements on the transfer function for acceleration control are stipulated: the duration of the transfer function must fall in the limits t_{comp} = 6-2 sec during motion of the VKS in the final descent segment from H = 35 km to landing (H = 0) with an admissible deviation from a steady value of the adjustable coordinate 5%; the admissible overregulation is 10%.

Figure 1 shows the constructed structural diagram of the VKS control system in the longitudinal acceleration channel. It is assumed that in the case of small deviations the control system ("circuit") can be considered linear.

The transfer functions of the control object have the form

$$W_{01}(s,t)=\frac{k_3(t)\,a_2(t)\,[s+a_3(t)]}{s^2+a_1(t)\,s+a_2(t)}; \tag{4}$$

$$W_{02}(s,t)=\frac{a_4(t)}{s+a_3(t)}. \tag{5}$$

The values of the coefficients $a_1(t)$, $a_2(t)$, $a_3(t)$, $a_4(t)$, $k_3(t)$ for different points on the VKS flight trajectory are given in Table 1.

The transfer functions of the correcting devices, amplifier and actuating apparatus have the form:

$$W_{k_1}(s)=\frac{1}{s^2+5s+1}$$

-- the measuring device and the subsequent correcting device;

$W_2(s) = 14.1$ -- the amplifier;

$W_3(s)=\dfrac{400}{s\,(s^2+25s+400)}$ -- the actuating device;

$$\left.\begin{aligned} W_{k_2}(s)&=\frac{0{,}71\,(s+1)}{s^2+5s+1};\\ W_{k_3}(s)&=\frac{0{,}6s}{s^2+5s+1};\\ W_{k_{o1}}(s)&=\frac{0{,}238s^2+0{,}62s}{s^2+5s+1};\\ W_{k_{o2}}(s)&=\frac{0{,}142s^2+0{,}865s}{s^2+5s+1}.\end{aligned}\right\}\ \text{parallel correcting devices.}$$

Under the condition that the considered system is quasistationary, its differential equation can be written in the form

$$\begin{aligned}\{p^7 &+ 40p^6 + 785p^5 + (6275 + 250a_1)p^4 + \\ &+ (7400 + 3400a_2 + 1340\ K_{\text{э}}a_2)p^3 + \\ &+ (9170a_2 + 1380\ K_{\text{э}}a_2a_3 + 3480\ K_{\text{э}}a_2 + 800\ K_{\text{э}}a_2a_4)p^2 + \\ &+ (7800\ a_2 + 3480\ K_{\text{э}}a_2a_3 + 4900\ K_{\text{э}}a_2a_4)\,p + \\ &+ 5640\ K_{\text{э}}a_2a_4\}x_{\text{вых}} = 5640\ K_{\text{э}}a_2a_4x_{\text{вх}}.\end{aligned} \tag{6}$$

[BX = in(put); BЫX = out(put); Э = e]

In the entire considered range the system remains stable and the transfer function satisfies the stipulated quality requirements (Fig. 2).

The coefficients of the differential equation vary quite rapidly. For example, during the time t_{comp} = 6 sec (for N = 1) the coefficient $K_e a_2 a_4$ changes by a factor of 25. It is impossible to use the "frozen coefficients" method directly for an investigation of the system.

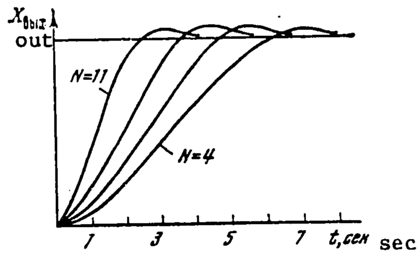

Fig. 2. System transfer functions.

However, if the considered nonstationary equation belongs to a special class of nonstationary equations of the variety [5], it can be transformed to a form making it possible to employ the "frozen coefficients" method for its investigation.

Approximating the curves of the variable coefficients (Table 1), we write equation (6) in the form

$$[p^7+40p^6+785p^5+6475p^4+12\,800\sigma(t)\,p^3+15\,500\sigma^2(t)\,p^2+ \\ +10\,700\sigma^3(t)\,p+2820\sigma^4(t)\,]\,x_{вых}=2820\sigma^4(t)\,x_{вх}, \qquad (6^*)$$

where

$$\sigma(t)=\sqrt[4]{2K_э(t)\,a_2(t)\,a_4(t)}.$$

The zero approximation of the confluent equation can be written in the form [7]

$$[p^4+1{,}98\sigma(t)\,p^3+2{,}4\sigma^2(t)\,p^2+1{,}65\sigma^3(t)\,p+0{,}435\sigma^4(t)]\,x_{вых}= \\ =0{,}435\sigma^4(t)\,x_{вх}. \qquad (7)$$

For the stipulated values of the variable coefficients (see Table 1) we have, approximately, $\sigma(t) = e^{0.134t}$. Replacing $\varphi(t) = 1/\sigma(t)$, equation (7) is written in the form

$$[\varphi^4(t)\,p^4+1{,}98\varphi^3(t)\,p^3+2{,}4\varphi^2(t)\,p^2+1{,}65\varphi(t)\,p+ \\ +0{,}435x_{вых}=0{,}435_{вх}. \qquad (8)$$

[BЫX = out; BX = in]

We introduce

$$\chi=\int\frac{dz(\chi)}{\varphi[z(\chi)]}+c=\int\frac{dz(\chi)}{e^{-0{,}134t}}+c=7{,}5e^{0{,}134t}-7{,}5.$$

Then

$$z(\chi)=7{,}5\ln(0{,}134\chi+1); \qquad z'(\chi)=\frac{1}{0{,}134\chi+1}; \qquad z''(\chi)=-\frac{0{,}134}{(0{,}134\chi+1)^2};$$

$$z'''(\chi)=\frac{0{,}036}{(0{,}134\chi+1)^3};\qquad z''''(\chi)=-\frac{0{,}014}{(0{,}134\chi+1)^4}.$$

In this case the equivalent equation will be

$$\begin{gathered}\frac{d^4x_{\text{вых}}}{dx^4}+\left[1{,}98+\frac{6\cdot 0{,}134}{0{,}134\chi+1}\right]\frac{d^3x_{\text{вых}}}{d\chi^3}+\left[2{,}4+\frac{2{,}6\cdot 0{,}134}{0{,}134\chi+1}+\right.\\ \left.+\frac{15\cdot 0{,}134^2}{(0{,}134\chi+1)^2}-\frac{4\cdot 0{,}136}{(0{,}134\chi+1)^3}\right]\frac{d^2x_{\text{вых}}}{d\chi^2}+\left[1{,}65+3{,}8\frac{0{,}134}{0{,}267\chi+1}+\right.\\ +2{,}6\frac{3\cdot 0{,}134^2}{(0{,}134\chi+1)^2}-2{,}6\frac{0{,}036}{(0{,}134\chi+1)^3}-10\frac{0{,}134\cdot 0{,}036}{(0{,}134\chi+1)^4}+\\ \left.+15\frac{0{,}134^3}{(0{,}134\chi+1)^3}+\frac{0{,}014}{(0{,}134\chi+1)}\right]\frac{dx_{\text{вых}}}{d\chi}+0{,}435x_{\text{вых}}=0{,}435x_{\text{вх}}.\end{gathered}\tag{9}$$

If the solution of the initial differential equation is considered in the interval t_{comp} = 6 sec, this corresponds to the interval

$$\Lambda=\int\limits_0^6\frac{dt}{e^{-0{,}134t}}-7{,}5=9{,}2 \text{ units.}$$

In this case the coefficients of the equivalent confluent equation will vary little. Their values when χ = 0 and χ= 9.2 are given in Table 2.

Table 2

	Значение 1	Коэффициент при 2				
		d^4/dx^4	$d^3/d\chi^3$	$d^2/d\chi^2$	$d/d\chi$	$d^0/d\chi^0$
3	При χ=0	1	2,78	2,88	2,16	0,435
3	При χ=9,2	1	2,34	2,60	1,88	0,435
4	Средн. знач. коэффициентов	1	2,56	2,74	2,02	0,435

KEY:

1. Value
2. Coefficient for
3. When
4. Mean values of coefficients

It can therefore be seen that the equivalent confluent equation will be quasistationary and accordingly it can be investigated using the "frozen coefficients" method.

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COMPUTATION OF "APPARENT" AND "GRAVITATIONAL" VELOCITIES IN GIMBALLESS INERTIAL SYSTEMS

Kiev KOSMICHESKIYE ISSLEDOVANIYA NA UKRAINE in Russian 1977 pp 55-58

[Article by A. I. Tkachenko and A. P. Panov, submitted for publication 10 September 1975]

[Text] In this article we introduce a replacement of variables making it possible to reduce the volume of computations when determining the parameters of motion of a space vehicle by means of integration of the fundamental equation for inertial navigation.

Examining a moving object (such as a space vehicle), which carries a gimballess inertial system (GIS), as a material point, incorporated in the mass of the object and matched with its center of mass, we write the equations of motion of this point in the form

$$\frac{dv}{dt} = a + g(r), \tag{1}$$

$$\frac{dr}{dt} = v. \tag{2}$$

Here v is the absolute velocity vector of the object relative to the inertial coordinate system; r is a radius-vector characterizing the position of the object in the inertial coordinate system; g(r) is the vector of strength of the gravitational field at the place where the object is situated. We use $\underline{a}$ to denote the apparent acceleration vector -- the difference between the acceleration of the object relative to the inertial coordinate system and the acceleration of gravity [1].

The essence of the inertial navigation system is a determination of the velocity and position of the object by means of integration of the equations (1), (2) [2]. The specific force sensors employed in inertial navigation systems -- newtonometers -- measure the projections of the $\underline{a}$ vector onto the directions of their sensitivity axes. The components of strength of the gravitational field are computed in advance as known functions of the coordinates of the object.

We will assume that the GIS newtonometers measure the projections of the a vector onto the axes of a right-hand orthogonal instrument trihedron xyz, related to the object. The GIS also includes devices for measuring angular velocity, supplying information on the projections of the vector ω of angular velocity of the object onto the x, y, z axes and a digital computer.

Assume that the g vector is determined by means of expressions for its projections onto the axes of the right-hand orthogonal trihedron -- the accompanying trihedron of the reference coordinate system rotating with a known angular velocity $\omega^0 = \omega^0(v, r)$ during movement of the object. We will assume that the purpose of the GIS is a determination of the projections of the v vector onto the axes of the trihedron $\xi\eta\zeta$ and the position of the object in the reference coordinate system. An indispensable part of the computation process in the GIS, together with the integration of equations (1), (2), is the integration of the kinematic equations of rotational motion of the object, whose solution determines the parameters of transformation of the coordinates of the vectors from the system of axes xyz into the system $\xi\eta\zeta$.

Introducing notations of the form p_{acc}, p_{inst} for the matrix columns, whose elements are the projections of some vector p onto the axes of the accompanying and instrument trihedrons respectively, we write the transformation of coordinates symbolically in the form

$$p_c = F(p_n), \quad p_n = F^{-1}(p_c). \tag{3}$$

For example, in the integration of the kinematic equations of rotational motion in the form of the generalized Poisson equations [3], we determine nine elements of the matrices of directional cosines stipulating the transformation F; the inverse transform F^{-1} is stipulated by a transposed matrix.

An important requirement on the organization of the process of integration of the GIS equations is assurance of the least possible volume of computations. For the purpose of decreasing the number of operations in integration of the kinematic equations of vertical motion it is preferable, instead of the matrix of directional cosines, to use four- or three-parameter representations of the transformation of coordinates (Rodrigues-Hamilton parameters [4], vector orientation parameters [5]). The Rodrigues-Hamilton parameters are especially interesting in this respect: they satisfy a system of linear differential equations, for whose solution it is possible to use simple and economical algorithms, and remain limited for any evolutions of the object; allowance for the transfer motion of the trihedron $\xi\eta\zeta$ in computation of the Rodrigues-Hamilton parameters is extremely simple. It should be noted that the use of three- or four-parameter transformations of coordinates in place of solution of the Poisson equations ensures a gain in the volume of computations under the condition that the frequency of the transformation of coordinates of the vectors is at least an order of magnitude less than the frequency of the iterations in the integration of the kinematic equations.

Usually the angular velocity of the object greatly exceeds the angular velocity of the accompanying trihedron (geocentric, orthodromic, orbital, etc.), whereas the computed projections of the g vector onto the ξ, η and ζ axes are smoother functions of the time of motion than the readings of the GIS newtonometers. Accordingly, it is desirable to separate the process of integration of the GIS equations into "high-frequency", realized with a relatively small h interval, and "low-frequency" computed with the interval H = nh, multiples of h. In the high-frequency part we must include the operations in the integration of equation (1) and the kinematic equations taking into account the absolute angular motion of the object and the processing of newtonometer readings. In the low-frequency part of the computation process it is possible to include allowance for movements of the accompanying trihedron, computation and allowance for the strength of the gravitational field, and also integration of equation (2) in a reference coordinate system with the use of the determined v_{acc} values. The optimum relationship of the h and H intervals is determined by the ratio of the values of the angular velocities ω and ω^0 and a number of other factors such as the required accuracy of computations, the handling capacity of the computer, discreteness of the input and output of information, etc. In actual practice the H value must exceed h by approximately an order of magnitude.

Taking into account what has been said, it was desirable to organize the computation process in the GIS in such a way that all the transformations of coordinates were included in the low-frequency part of the computations and the number of these transformations was as small as possible.

We will represent equation (1) in the system of axes $\xi\eta\zeta$:

$$\dot{v}+\omega^0\times v=a+g. \tag{4}$$

The asterisk denotes local differentiation of the vector in the axes $\xi\eta\zeta$. The numerical integration of equation (4) can be carried out with an interval H using formulas in the form

$$v_c(t_l+H)=v_c(t_l)+H[\Omega_c^0(t_l)v_c(t_l)+ \\ +g_c(t_l)]+h\sum_{k=0}^{n-1}F[a_c(t_l+kh)]. \tag{5}$$

[c = acc]

Here Ω^0_{acc} is a skew-symmetric matrix, whose elements are components of the column ω^0_{acc}, computed in each H interval:

$$\Omega_c^0(t_l)=\Omega^0[v_c(t_l),\ r_c(t_l)]. \tag{6}$$

Also known are algorithms which are more precise than (5) for the integration of equation (4), and also formulas for computing the columns v_{acc} which include the readings of the integrating newtonometers. A shortcoming characteristic of all these algorithms is the necessity for carrying out the transformation of coordinates of the $\underline{a}$ vector in each h interval employed.

Still less convenient for integration is the form of writing of equation (1) in the coordinate system xyz:

$$\dot{v}+\omega\times v=a+g. \tag{7}$$

The dot over the notations of the vector indicates local differentiation in the system of axes xyz. Integration of equation (7) must be carried out with the interval h using algorithms in the form

$$v_{\text{п}}(t_i+h)=v_{\text{п}}(t_i)+h\{\Omega_{\text{п}}(t_i)v_{\text{п}}(t_i)+a_{\text{п}}(t_i)+F^{-1}[g_{\text{с}}(t_i)]\}. \tag{8}$$

[π = inst; c = acc]

Here Ω_{acc} is a skew-symmetric matrix formed from elements of the column ω_{inst}. Each iteration of the computations using formula (8) or more precise formulas of such a type assumes the inverse transformation (3) of the coordinates of the g vector. This is already undesirable because the expressions for g_{acc} themselves are usually quite complex. In addition, in each H interval it is necessary to carry out transformation of coordinates of the v vector in order to obtain the column v_{acc}:

$$v_{\text{с}}(mH)=F[v_{\text{п}}(mh)],\qquad m=1,\,2,\,\ldots \tag{9}$$

[c = acc]

Thus, the integration of equation (1) in the form (4) or (7) limits the possibility of effective realization of the advantages of three- and four-parameter transformations of coordinates.

In order to obtain a method for computing the column v_{acc} free of the mentioned inadequacy we will represent the solution of equation (1) in the form of the vector sum

$$v=w+u. \tag{10}$$

The vector w, which we will call the apparent velocity of the object, is determined in such a way that its absolute derivative is equal to the apparent acceleration of the object:

$$\frac{dw}{dt}=a. \tag{11}$$

Equation (11) determines w with an accuracy to a constant vector term -- the w values at the initial moment in time t_0. For definiteness we will assume that $w(t_0) = 0$. The integration of newtonometer readings gives the increment in the projection of apparent velocity onto the axis of instrument sensitivity (response) only in the case when this axis is invariably oriented in inertial space [1].

Regarding equation (10) as the formula for the replacement of variables in equation (1), we obtain

$$\frac{du}{dt} = g, \quad u(t_0) = v(t_0). \tag{12}$$

It is natural to call the u vector the "gravitational" component of velocity of the object. In accordance with the principle of superposing of the solutions of linear inhomogeneous differential equations, the equations (11) and (12), together with expression (10), are equivalent to equation (1).

We will represent equation (11) in the form

$$\dot{w} + \omega \times w = a, \tag{13}$$

and write equation (12) as follows:

$$u + \omega^v \times u = g. \tag{14}$$

It is possible to integrate equation (13) with the interval h independently of equation (14) using formulas in the form

$$w_\text{п}(t_i + h) = w_\text{п}(t_i) + h\,[\Omega_\text{п}(t_i) w_\text{п}(t_i) + a_\text{п}(t_i)]. \tag{15}$$

[п = inst]

Extremely simple and precise algorithms are known for the integration of equation (13) with use of the readings of the ordinary or integrating measuring elements of the GIS [6]. It is feasible to solve equation (14) with the interval H using formulas of the type

[c = acc]

$$u_c(t_j + H) = u_c(t_j) + H\,[\Omega_c^0(t_j) u_c(t_j) + g_c(t_j)]. \tag{16}$$

Such a computation scheme does not contain transformations of coordinates in the high-frequency part; this transformation is carried out only in the low-frequency part when finding the column v_{acc}:

$$v_c(mH) = u_c(mH) + F\,[w_\text{п}(mH)], \qquad m = 1, 2, \ldots \tag{17}$$

The indicated stipulation of the initial values of the w and u vectors is not the only one possible; it is only important that the initial conditions satisfy equation (10). For example, we will assume that at some moment in time t_j corresponding to the beginning of the "large" interval, $w(t_j) = 0$, $u(t_j) = v(t_j)$.

We will integrate equation (13) with the interval h in the time $(t_j, t_j + H)$, after which we compute the value v_{acc} $(t_j + H)$ using the formula

$$v_c(t_j + H) = v_c(t_j) + H\,[\Omega_c^0(t_j)\,v_c(t_j) + g_c(t_j)] + F\,[w_\pi(t_j + H)]. \tag{18}$$

[c = acc; π = inst]

Then, assuming w_{inst} $(t_j + H) = 0$, we renew integration of equation (13) with the interval h. Such a computation method makes it possible not only to decrease the frequency of transformation of coordinates, but also to increase the accuracy in determining the velocity of the object [7].

We note in conclusion that if the gravitational field is assumed to be central, in some cases (especially when using the readings of integrating measuring elements of the GIS) it can be feasible to integrate equations (1), (2) in a system of coordinate axes parallel to the axes of the instrument trihedron and having an origin at the attracting center [8]. The values v_{inst} and r_{inst} are determined in each integration interval; in case of necessity they are transformed into v_{acc} and r_{acc} values.

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SYSTEM FOR ORBITAL CONTROL OF A STATIONARY ARTIFICIAL EARTH SATELLITE (SAES) WITH TRANSFER TO A STIPULATED LONGITUDE USING A LOW-THRUST CORRECTING ENGINE (CE)

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[Article by A. A. Lebedev, M. N. Krasil'shchikov, V. V. Malyshev, A. I. Zverev, A. I. Kibzun, V. N. Chekurishvili and A. V. Fedorov]

[Text] This report is devoted to the problem of synthesis of a command system for orbital control of a stabilized artificial earth satellite (SAES) in the stage of its transfer to the "hovering" point with use of the facilities of the ground command-measuring complex (CMC). We will examine the problem of optimizing the transfer process for the purpose of attaining the required final accuracy with the minimum number of corrections. Also discussed are the problems involved in the formulating of operational control algorithms and algorithms for the processing of measurement data, whose realization is possible with the use of existing electronic computers, and also the problems involved in organizing the operation of CMC facilities.

1. Formulation of problem. As is well known, a SAES is a satellite moving in an easterly direction in a circular 24-hour equatorial orbit and thus "hovering" over the corresponding point on the earth's surface. Due to this property, by means of a group of SAES it is possible to create a global communication system. However, for such use each SAES must be put into the computed orbit with a very high accuracy. Due to a number of technical reasons it is not immediately possible to launch a satellite to the required "hovering" longitude. The so-called wandering orbit method can be used for its transfer in longitude [1]. In accordance with this method, the launching of a satellite is accomplished into some intermediate orbit with a period of revolution less than (or greater than) 24 hours, as a result of which the satellite will drift in an easterly (or westerly) direction, thereby striving to eliminate the longitude "mismatch." In the course of such motion there is periodic correction of the orbital parameters (period and eccentricity) in such a way that when the satellite reaches the required longitude the orbit will become stationary. With the use of a low-thrust correcting engine as the actuating control apparatus, with this engine rigidly

coupled to the SAES and capable of developing at the nominal a constant controlling acceleration in the direction perpendicular to the SAES radius vector, this correction can be accomplished by means of a corresponding choice of the moments of firing and shutdown of the correcting engine.

The transfer of the SAES is considered completed when the final errors in longitude $\Delta\theta$, period ΔT and eccentricity e satisfy the following conditions:

$$|\Delta\theta| \leqslant \Delta\theta_m, \quad \left|\Delta\theta + t_m \frac{\Delta T}{T_0}\right| \leqslant \Delta\theta_m, \quad e \leqslant e_m, \tag{1}$$

where $\Delta\theta_m$, e_m are used in denoting the limiting admissible errors in longitude and eccentricity and t_m denotes the minimum admissible time of presence of the SAES in the region $|\Delta\theta| \leqslant \Delta\theta_m$ after ending of the transfer process.

The high requirements on final accuracy leads, on the one hand, to the necessity for constructing a control system using the feedback principle, which can be realized by means of measurement of the current position of the satellite (for example, slant range, azimuth angles or slant range and its rate of change), and on the other hand, to the necessity for taking into account random perturbations in formulation of the control algorithm. These perturbations, in particular, include the errors in launching a satellite by a carrier, measurement errors and errors in producing the correcting effect.

For the purpose of forming an optimum system for control of the process of transfer of the SAES we will formulate the following optimization problem: find such a control algorithm (on the basis of measurement data) for the moments of the firing and shutdown of the correcting engine which ensures transfer of the SAES into the stipulated position with the required accuracy with a minimum number of corrections (firings). Naturally, it is assumed that the transfer time and the fuel reserve are limited upward.

The mathematical formulation of this problem belongs to the class of so-called control problems with incomplete data. At the present time it is possible to obtain a practical acceptable solution only approximately if the separation procedure is used [1], in accordance with which the problem of synthesis of optimum control on the basis of incomplete data is broken down into two problems, solved first independently of one another and then (should this be necessary) "refinable" on the basis of one another. The first problem involves a determination of the control algorithm on the assumption that there is all the information necessary for this purpose. The second problem is obtaining such information by the optimum processing of measurement data.

In accordance with what has been stated above, the closed control system will include two units: a data processing unit (DPU) and an optimum control unit (OCU). The DPU input receives the measurements arriving from the ground measurement station; the output is estimates of parameters of the the current orbit and satellite position in it. These estimates in turn are sent to the OCU, whose output is the moment of the next firing (or shutdown) of the CE.

Below we will discuss some methods for forming the structure of these units. In contrast to [1], the emphasis now will be on the problem of formulating operational control algorithms and the processing of information, the realization of which is possible at a real time scale on the basis of existing digital computers.

2. Operational control algorithm. In the forming of operational control algorithms as the initial mathematical model we will employ the equations of plane motion of an SAES in deviations relative to the computed stationary orbit [1]

$$z_{i+1} = \Phi_i(t_{ni}, \tau_i) z_i + V_i(t_{ni}, \tau_i) u_i (1 + \mu_i), \qquad i = 0, 1, \ldots, N, \tag{2}$$

where z_i denotes the vector of state at the moment of ending (i - 1) of the correction with the components: z_{1i} is the deviation of the orbital radius from a stationary value, z_{2i} is the radial velocity of the SAES; z_{3i} is the angular deviation of the satellite from a stipulated position; z_{4i} is the deviation of angular velocity of the SAES from the velocity of the earth's own rotation; Φ_i, V_i are some matrices dependent both on the duration of the passive flight segment t_{ni} and on the CE operating time for the i-th correction τ_i; u_i is the controlling, characteristic velocity impulse; μ_i is a random value characterizing the error in performing the i-th correction.

We note that one of the methods for solving the considered problem was described in [1]. Its distinguishing characteristic was the finding of the durations of the passive flight segments in the form of a program; on the one hand this required enormous expenditures of computer time in seeking for this program, and on the other hand, in many cases (for example, in the case of great deviations from the worst computation conditions for the launching) led to a considerable increase in the required number of corrections. The latter circumstance is associated with the considerable influence of the moments of firing and shutdown of the CE on orbital eccentricity after the corresponding correction.

Taking into account what has been said, and making our way to forming of an operational control algorithm, we will formulate the auxiliary problem of optimization for determining algorithms for controlling the moment of CE firing (and thereby the minimum value of orbital eccentricity after making the next correction). In this case model (2) can lead to the form

$$x_{i+1} = A_i(\tau_i) x_i + B_i(\tau_i)(1 + \mu_i) u_i + F_i, \tag{3}$$

where x_i denotes the vector of state after the $(i-1)$-st correction with the components: x_{1i} is the angular deviation of the SAES from the required angle; x_{2i} is the diurnal displacement of the satellite in longitude, the drift velocity; x_{3i} and x_{4i} characterize the orbital ellipticity and are related, in particular, to eccentricity by the expression

$$e_i = \frac{1}{r_0}\sqrt{x_{3i}^2 + x_{4i}^2}\,. \tag{4}$$

In this case the expressions determining the moment of CE firing, in the indicated sense, have the form

$$t_{ni} = \frac{\varphi_i}{2\pi} - \tau_i,$$
$$\varphi_i = \begin{cases} 2\pi k_i - \frac{\pi}{2} - \operatorname{arctg}\alpha_i, & \text{if } [x_{4i}(1-\cos\omega_0\tau_i) - x_{3i}\sin\omega_0\tau_i]\,u_i < 0 \\ 2\pi k_i + \frac{\pi}{2} - \operatorname{arctg}\alpha_i, & \text{otherwise} \end{cases} \tag{5}$$
$$\alpha_i = \frac{x_{3i}(1-\cos\omega_0\tau_i) + x_{4i}\sin\omega_0\tau_i}{x_{4i}(1-\cos\omega_0\tau_i) - x_{3i}\sin\omega_0\tau_i}\,.$$

The whole-number parameter k_i in (5), appearing as a result of the ambiguity of the solution, must be selected in such a way that the duration of the passive flight segment t_{ni} will not be less than some value t_{mi} required for obtaining estimates of the orbital parameters with a sufficient accuracy and adoption of a decision concerning the need for carrying out the next correction, that is

$$t_{ni} > t_{mi}. \tag{6}$$

The problem of optimizing the transfer process can now be formulated as the problem of determining the sequences $\{k_i\}$, $\{u_i\}$, ensuring the transformation of system (3), with (4)-(6) taken into account, from an arbitrary state into the final state with the required accuracy, characterized by the conditions (1) for the minimum number of corrections. As before, the transfer time and the fuel supply are considered limited.

The algorithm for solution of this problem, in essence, is also proposed as an operational control algorithm. In order to obtain it we will examine two approaches: stochastic ("optimistic") and minimax ("pessimistic"). Whereas in the first case an optimum solution is obtained as an average from a set of all possible cases of the transfer process, in the second case it is optimum for the worst of the possible cases, that is, the guaranteeing case.

Within the framework of the stochastic approach the random perturbations are considered to be normally distributed, whereas the restrictions imposed on the final accuracy for the transfer process are considered in a statistical sense, that is, their satisfaction is accomplished on the basis of probability. The combined optimization method was used in solving the problem.

The essence of the method is as follows. In the sought-for optimum control it is possible to discriminate two components -- programmed (in this case the sequence $\{k_i\}$) and synthesizable (sequence $\{u_i\}$), relative to which step-by-step optimization is used. In the first stage there is determination of the synthesizable component by means of joint use of the dynamic programming method and the statistical (or any other) linearization. The result is the law of suboptimum control with an arbitrary programmed component. In the second optimization stage, by direct search methods, it is possible to determine the programmed component, taking into account the results of the first stage.

Applicable to the considered problem the method was used in those cases when for transfer of the SAES it is necessary to have at least three corrections. In this case the admissible finite region (1) was approximated by an ellipsoid and as the finite accuracy criterion we considered the value

$$I^1 = M\,[\tilde{\mathbf{x}}_{N+1}^T \lambda \tilde{\mathbf{x}}_{N+1} + \beta e_{N+1}^2], \qquad (7)$$

where x denotes the vector with the components x_1, x_2. In the course of use of the dynamic programming method in the first optimization stage the function of future losses was approximated by a quadratic expression. As a result, the control algorithm can be represented in the form

$$u_i = -L_i \tilde{\mathbf{x}}_i + L_{ei} e_i \,\mathrm{sign}\,(L_i \tilde{\mathbf{x}}_i), \qquad (8)$$

where the feedback coefficients $L_i = L_{1i}, L_{2i})^T$, L_{ei} are determined by the corresponding system of recurrent expressions. In those cases when the transfer of the SAES can be accomplished by means of one or two corrections, in order to increase operativeness we employed a simpler control algorithm. Its sense is the choice of such $\{k_i\}$, $\{u_i\}$ under which the conditions (1) and the restrictions will be satisfied. A single-impulse correction was selected so that in the absence of thrust perturbations the residual drift velocity is eliminated, whereas in the case of a two-impulse correction the entire region of the vector of state is broken down into two parts: when there must be an additional correction in order to decrease the residual eccentricity and when this is not required; in both cases in each correction the control was selected in such a way that on the one hand there is restriction on the total time with some reserve allocated for completion of the transfer, and on the other hand, there is no impairment of transfer conditions without reregulation, with a high initial drift velocity making it possible to save fuel.

When using the stochastic approach definite difficulties can be encountered. These are associated, first, with adequate initial technical information (reference is to the stipulated probabilities of satisfying different requirements, choice of the statistical characteristics of the transfer process, etc.), and second, with the lack of reliable information on the acting perturbations (in particular, on the errors in producing the correcting effect). These difficulties are automatically eliminated if one converts to the minimax approach, in this case considering optimization of the transfer process in the worst of the possible cases. In this case there is no need of a knowledge of the statistical characteristics of the perturbations. It is sufficient to know only the range of their possible changes. As the criterion of final accuracy we must now use the value

$$\varphi_m = \max_{|\mu_i| \leqslant \mu_{im}} \left\{ \frac{|x_{1N+1}|}{\Delta\theta_m}, \quad \frac{|x_{1N+1} + t_m x_{2N+1}|}{\Delta\theta_m}, \quad \frac{e_{N+1}}{e_m} \right\}, \qquad (9)$$

where μ_{im} denotes the limiting value μ_i. The condition of ending of the transfer process in this case can be represented in the form

$$\varphi_m^* = \min_{\{u_i\}, \{k_i\}} \varphi_m \leqslant 1. \qquad (10)$$

For solution of the problem, that is, for the choice of the $\{k_i\}$ sequences, from condition (10) we again use the combined optimization method. For the purpose of obtaining a simpler and accordingly a more operational control algorithm we used a quadratic approximation of the criterion (9):

$$\varphi_{KB} = \max_{|\mu_i| \leqslant \mu_{im}} [\tilde{x}_{N+1}^T \lambda \tilde{x}_{N+1} + \bar{\beta} e_{N+1}^2]. \qquad (11)$$

[KB = quadratic]

Allowance for the restrictions on the total time and total impulse is accomplished indirectly by choice of the whole-number parameters k_i.

In the process of using the dynamic programming method we employed a modification of statistical linearization, assuming determination of the averaged characteristics of the transfer process in all possible cases with $\mu_i = \pm \mu_{im}$. Limiting ourselves, as before, to a quadratic approximation of the function of future losses, the control algorithm, which now determines the guaranteeing strategy, can be represented formally in the same form as in the stochastic approach, that is, in the form (8). However, the feedback coefficients are determined using other recurrent expressions.

For the purpose of checking the operability of the proposed control algorithms we carried out statistical modeling of the closed system for control of the process of SAES transfer on the assumption of ideal operation of the data processing unit. The beginning of operation of this system was planned from the moment of launching of the SAES by the carrier. The adoption of a decision about the moment of the next firing and shutdown was accomplished by turning at the current moment in time to the corresponding control algorithm (stochastic or minimax). The ending of system operation occurred with satisfaction of conditions (1). The investigation was carried out in a broad range of initial data. As an illustration, the table gives only some results of such an investigation. They correspond to the transfer of an SAES in longitude by the value $\Delta\theta_1$ = 15° with the required final accuracy, characterized by the parameters $\Delta\theta_m$ = 0.9°, e_m = 0.0025, t_m = 15 days. It is assumed that the CE at the nominal develops a controlling acceleration of about $0.25 \cdot 10^{-3}$ m/sec^3. The limiting error in producing the correcting impulse is 15% (σ_μ = 0.05). The fuel supply is characterized by a value of the total velocity impulse of about 40 m/sec. It was assumed that the carrying out of the next correction is possible no sooner than 24 hours after the preceding one. The total transfer time was limited to about 15 days. The table, for different launching conditions with respect to period and eccentricity, gives the minimum and maximum number of corrections (N^{min} and N^{max}) which was required as a result of the modeling carried out and also the minimum and maximum values of the total transfer time (t^{max}_{Σ} and t^{min}_{Σ}) in days and the total velocity impulse (ΔV^{max}, ΔV^{min}) in m/sec. The upper rows of numbers for each variant correspond to a stochastic approach; the lower rows correspond to the minimax approach.

Table

e_1	N^H a	N^B b	t^H_Σ	t^B_Σ	ΔV^H_Σ	ΔV^B_Σ	N^H	N^B	t^H_Σ a	t^B_Σ b	ΔV^H_Σ	ΔV^B_Σ
			ΔT_1=300 c c						ΔT_1=800 c c			
0	1	2	12	13,4	3,4	4,5	2	3	6,5	8,5	9,2	10,7
	1	2	12,4	13,4	3,4	4,1	3	4	6,0	7,5	9,2	9,5
0,25	1	2	12	13,4	3,4	4,6	2	3	5,5	7	9,2	10
	1	2	12,0	13,4	3,4	4,6	3	5	5,5	7,9	12,3	15,4
0,5	2	2	13,5	14,9	3,8	6,1	2	3	6	8	9,2	9,7
	2	3	13,4	14,9	4,2	6,9	3	4	6,9	8,4	9,4	11,0
0,75	2	4	4,3	7,5	20,8	28,8	2	3	6	8	9,2	9,9
	3	4	14,0	15,4	10,9	14,3	2	3	7,0	20,9	9,4	11,2
			ΔT_1=1300 c c						ΔT_1=1800 c c			
0	2	4	3,6	8	15,1	19,1	1	3	2,5	6	21,2	28,2
	2	4	3,6	6,4	15,3	20,3	4	5	7,0	9,4	29,7	36,3
0,25	1	3	3,3	7	15,1	24,5	1	4	2,5	7	21,2	29,7
	3	4	5,0	6,4	15,2	16,1	1	4	2,46	7,9	21,6	25,5
0,5	1	3	3,3	6,5	15,5	26,9	3	4	5	11,5	22,6	29,7
	2	4	4,5	7,9	17,8	20,5	3	4	5,5	8,9	23,9	27,3
0,75	2	3	4,1	6	15,1	17	2	4	5,6	12,5	27,3	37
	3	5	6,0	10,5	19,9	25,6	4	5	6,5	8,5	28,9	36,2

KEY:

a) H = min
b) B = max
c) s = sec

The results of our investigation show that the proposed algorithms for operational control work successfully in a broad range of initial launching conditions and therefore can be used as working control algorithms in the process of SAES transfer to a stipulated "hovering" point. The use of the stochastic control algorithm in this case (by virtue of its "optimistic" nature) makes it possible, on the average, to save one or two corrections in comparison with the minimax algorithm (see Table). We also note that the stochastic algorithm in general is the more operational. In some cases (in the most difficult) the required computer time with its use is an order of magnitude lower than when using the minimax algorithm. Nevertheless, the latter algorithm makes it possible to obtain a solution of the problem and therefore is of great (and sometimes decisive) importance in the adoption of a final solution about the control strategy. We note also that in the field of small required numbers of corrections (one-two) both algorithms give close results.

3. Data processing algorithm. It was pointed out above that the purpose of the DPU is obtaining optimum evaluations of the components of SAES state. It should be noted that the organization of operation of facilities of the command-measurement complex (CMC) is an important reserve of accuracy of the evaluations obtained. Thus, a real DPU must carry out evaluation with, from some point of view, optimally organized operation of CMC facilities.

For DPU synthesis use is made of the method of stage-by-stage optimization in which, during the first stage, with an arbitrary organization of operation of CMC facilities, an algorithm is determined for obtaining optimum evaluations of components of the vector of state, and in the second stage, with the adopted algorithm for obtaining optimum evaluations, a solution is obtained for the problem of optimum organization of operation of CMC facilities.

Now we will examine the first stage in DPU synthesis. In order to obtain optimum errors of the components of the vector of state for the controlled object it is proposed that use be made of a nonlinear recurrent Bayes algorithm described in [1]. The use of the recurrent Bayes algorithm for obtaining current evaluations of the components of the vector of state for the object makes it possible to carry out an evaluation in the active segment in the process of operation of the low-thrust CE. In the considered technical problem the information sources are the ground measurement stations (GMS), discretely supplying data in the course of the measurement session with some fixed time interval. The processing of measurement data in the active segment at the rate of their receipt from the GMS and refinement of the strategy of control on the basis of current evaluations will make it possible to reduce the CMC operating time and reduce the necessary number of corrections. [GMS, GMP = ground measurement station, point]

The investigations reported in [1] demonstrated that in processing data on the motion of an SAES it is feasible to employ such a modification of a nonlinear recurrent Bayes algorithm which in the stage of determination of a posteriori characteristics and in the stage of prediction will require computations of only two a posteriori moments (semi-invariants) of the SAES vector of state distribution. The distinguishing characteristic of the employed algorithm is that the nonlinear dependences relating the components of the vector of state and the measurement vector are approximated by polynomials of the approximation, best in the mean square sense, in the region whose dimensions are determined by the accuracy in evaluating the components of the vector of state obtained in the preceding step. These investigations indicated that the mathematical model of the controllable process and the measurements, used in processing the real measurement data, must take into account the noncentrality and anomaly of the earth's gravitational field and also the influence of the moon and sun. Also taken into account are the radio signal delay, inaccuracy in tie-in to the place of the receiving and transmitting antennas of the CMP, errors in tie-in of measurements to the computed moment in time, initial launching errors, errors in realizing CE thrust, and rapidly and slowly changing measurement errors. The mathematical models of errors in realizing CE thrust and the slowly changing measurement errors constitute first-order forming filters whose coefficients are determined by the a priori dispersion and the correlation interval for the corresponding statistical factor.

Thus, the components of the expanded vector of state ϑ are subjected to evaluation

$$\vartheta^T = (\tilde{\vartheta}^T \mu g^T \eta^T), \tag{12}$$

where $\tilde{\vartheta}^T$ is the six-dimensional vector of spherical coordinates of the object, μ is the error in realizing the controlling effect, g is the three-dimensional vector of geodetic coordinates of the CMP, η is the vector of slowly changing measurement errors.

The dimensionality of the η vector is determined by the makeup of measurements used for the processing. In the case of measurement of the total range ρ_Σ, constituting the extent of the "CMP transmitting antenna - SAES - CMP receiving antenna" lines, the $\dot{\rho}_\Sigma$ value, the dimensionality of the η vector, is equal to 2, whereas in a case when there is measurement of the total range and the line of sight direction cosines -- 3. As a result, the dimensionality of the ϑ vector is equal to 12 or 13 respectively.

The a posteriori characteristics of the ϑ vector are computed using the expressions [1]

$$\hat{S}_{\vartheta_j} = S_{\vartheta_j} + \frac{S_{\eta_j\vartheta_j} + S_{\vartheta_{n+1}\vartheta_j}}{\sigma^2_{\xi_i}(1+K^i_l)} - (y_i - S_{\vartheta_{n+1}} - S_{\eta_i}); \tag{13}$$

$$\tilde{S}_{\vartheta_j\vartheta_k} = S_{\vartheta_j\vartheta_k} - \frac{(S^i_{\eta_j\vartheta_j} + S_{\vartheta_{n+1}\vartheta_j})(S_{\eta_i\vartheta_k} + S_{\vartheta_{n+1}\vartheta_k})}{S_{\eta_i\eta_i} + S_{\vartheta_{n+1}\vartheta_{n+1}} + 2S_{\vartheta_{n+1}\eta_i} + (1+K^i_l)\sigma^2_\xi}; \tag{14}$$

$$j, k = 1, \ldots, n,\ i = 1, \ldots, m.$$

In (13), (14) n is the dimensionality of the ϑ vector; m is the dimensionality of the measurement vector y; $S_{\vartheta j}$, $\hat{S}_{\vartheta j}$ are the first a priori and a posteriori semi-invariants of the ϑ_j component respectively; $S_{\vartheta_{n+1}}$,

S_{η_i} are the first a priori semi-invariants of the additional measured component ϑ_{n+1} and the slowly changing measurement error η_i respectively; K_t^i is a coefficient taking into account the error in tie-in to the measurement time y_i; $S_{\vartheta_j \vartheta_k}$, $\hat{S}_{\vartheta_j \vartheta_k}$ are the a priori and a posteriori second semi-invariants of the ϑ_j, ϑ_k components respectively; σ_ξ^2 is the dispersion of the rapidly changing measurement error ξ_i. The complex of programs ensuring operation of the DPU also makes it possible to compute the evaluations and a posteriori dispersions of the Cartesian coordinates of the object and the orbital osculating elements.

The possibilities of the described DPU were checked in the processing of data on motion of the AES in an inclined high-elliptical orbit with parameters close to those given in [3].

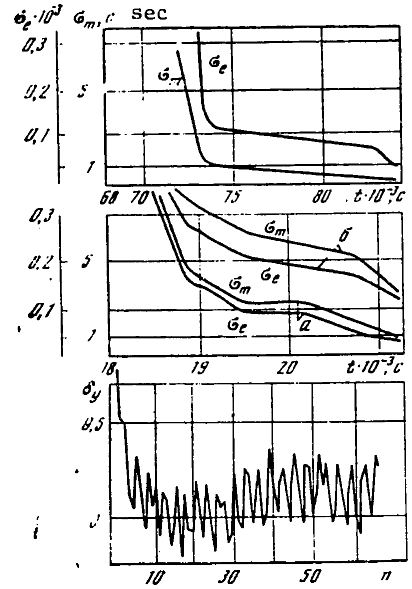
Figure 1 shows the change in the standard deviation (SD) of evaluation of the period T of revolution and eccentricity e of the AES orbit. The accuracy in evaluating the period u of eccentricity is an extremely important index of filtering quality in the particular problem because the transfer method and the control law, as follows from what has been presented above, in particular require the most precise possible evaluation of period and eccentricity. The processing of information was carried out using data on ρ_Σ and $\dot{\rho}_\Sigma$ arriving with a 5-sec interval. Figure 2 shows the change in SD of the evaluation of period and eccentricity in the processing of information with this same discreteness in the active segment of AES motion close to the apogee of a high-elliptical orbit. In this figure the line a corresponds to the results of processing on the basis of measurements of the ρ_Σ parameter; the line b corresponds to the results of processing of measurements of the ρ_Σ and $\dot{\rho}_\Sigma$ parameters in nonintersecting measurement intervals.

An important index of DPU operating quality, characterizing the stability of filtering, is the behavior of the so-called normalized nonclosure of measurements

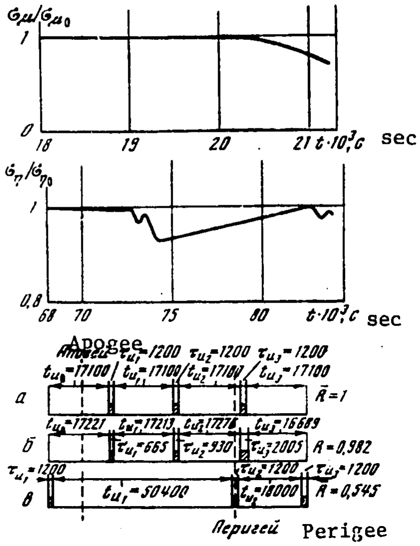
$$\delta_y = \frac{y_i - S_{\vartheta_{n+1}}}{\sqrt{S_{\vartheta_{n+1}\vartheta_{n+1}}}}. \tag{15}$$

In (15) y_i is the measurement result; $S_{\vartheta_{n+1}}$, $S_{\vartheta_{n+1}\vartheta_{n+1}}$ are its a priori mathematical expectation and SD respectively. Figure 3 illustrates the fact of a satisfactory change in δ_y in the processing of results of measurements of ρ_Σ in the active segment of AES motion. In Figure 3 n is the number of the processed measurement.

Figure 4 illustrates the evaluation of the error in realization of control. Figure 5 shows the relative change in SD of evaluation of the changing (systematic) error η in measuring the total range ρ_Σ in processing data in the passive segment of AES motion. Figure 5 shows σ_{η_0} -- the a priori SD of the η value.



Figures 1, 2, 3



Figures 4, 5, 6

These results indicate that the adopted data processing algorithm makes it possible to determine the orbital elements with an accuracy adequate for control purposes.

Now we will proceed to the second stage in DPU synthesis -- solution of the problem of optimum organization of operation of CMC facilities with the selected data processing algorithm. By the term "organization of operation of CMC facilities" we will understand the choice of:

1. Position of CMPs from among those stipulated.
2. Position of the measurement intervals and their duration in a stipulated time segment.
3. Position of measurements in the measurement intervals.

Points 1-3 do not include the requirement of choice of the functions to be measured since the choice of the CMP unambiguously determines the type of apparatus, and accordingly, the makeup of the measurements. As the optimality criterion use is made of the dispersion of the error in evaluating the period of revolution T with a limitation on the dispersion of the error in evaluating eccentricity e at the end of the passive or active SAES flight segment in which the operation of CMC facilities is organized. It follows from an analysis of the requirements on the accuracy in evaluating eccentricity and the results of data processing with a sufficiently arbitrary organization of the CMC facilities operation that the restrictions imposed on the value of a posteriori dispersion are satisfied. Therefore, below we examine solution of the problem of organizing measurements in the following formulation. The total duration of the measurement intervals and CMP coordinates are stipulated. It is necessary to determine the optimum organization of operation of CMC facilities in the time segment $[t_0, t_N]$, with the length T, ensuring a maximum accuracy in evaluating the period T to the moment t_N with the adopted data processing algorithm. The functions to be measured are fixed: ρ_Σ and $\dot{\rho}_\Sigma$ are used for this purpose. The dispersion of evaluation of the period at the time t_N can be written in the form

$$R = \sigma_T^2 = \frac{\partial T}{\partial \tilde{\vartheta}}(t_N)\,\hat{P}(t_N)\,\frac{\partial T}{\partial \tilde{\vartheta}}(t_N), \tag{16}$$

where $\tilde{\vartheta}$ is the vector of state of the object, whose components are subject to evaluation; $\hat{P}(t_N)$ is the a posteriori correlation matrix of the vector of state at the time t_N. The modification of the nonlinear recurrent Bayes algorithm described above does not make it possible to write in explicit form any expressions for elements of the a posteriori correlation matrix as functions of the measurement times, lengths of the measurement intervals, CMP coordinates, etc. The investigations in [1] show that within the framework of this problem the behavior of the elements of the a posteriori correlation matrix is slightly dependent on the used modification of the recurrent Bayes algorithm. In solution of the problem of optimum organization of measurements for the formation of elements of the a posteriori correlation matrix this makes it possible to use a very simple linear recurrent algorithm, such as a Kalman filter. In this case it is possible to write

$$\hat{P}(t_N) = P^{-1}(t_N) + \sum_k G_k(t_k), \tag{17}$$

where $P(t_N)$ is the a priori correlation matrix; $G_k(t_k)$ is a matrix whose elements are dependent on the measurement times t_k, the functions to be measured, the correlation matrix of measurement errors, the dispersion of error in realizing the controlling effect and the fundamental matrix of equations of motion of the object, linearized in the neighborhood of the selected reference orbit.

It was demonstrated in [2] that with an organization of CMC facilities operation optimum from the point of view of criterion (16) the measurements must fall in the measurement intervals with the maximum possible density. Thus, the optimization problem involves the choice of placement of the measurement intervals for each CMP from among the stipulated intervals.

Taking this fact into account for each j-th CMP, from among the ✓ stipulated intervals $[t_0, t_N]$, in which the organization is planned, we will have

$$[t_0, t_N] = t^j_{u_0} \cup \tau^j_{u_1} \cup t^j_{u_1} \cup \dots \cup \tau^j_{u_{k_j}} \cup t^j_{u_{p_j}}, \tag{18}$$

where $\tau^j_{u_i}$ are the measurement intervals, kj is their number, $t^j_{u_i}$ are passive segments in which no measurements are made; Pj is their number.

We introduce vectors stipulating the organization of CMC facilities operation.

$$\mathbf{V}_\Sigma = \begin{pmatrix} \mathbf{V}^1 \\ \hdashline \mathbf{V}^2 \\ \hdashline \vdots \\ \hdashline \mathbf{V}^v \end{pmatrix} = \begin{pmatrix} V_1 \\ V_2 \\ \vdots \\ V_r \end{pmatrix}; \ \mathbf{V}^j = \begin{pmatrix} \tau^j_{u_\Sigma} \\ \hdashline t^j_{u_\Sigma} \end{pmatrix}; \ \tau^j_{u_\Sigma} = \begin{pmatrix} \tau^j_{u_1} \\ \vdots \\ \tau^j_{u_{k_j}} \end{pmatrix}; \ t^j_{u_\Sigma} = \begin{pmatrix} t^j_{u_1} \\ \vdots \\ t^j_{u_{p_j}} \end{pmatrix} \tag{19}$$

It is necessary to take into account restrictions on the total duration of the measurement intervals and the passive segments

$$\sum_{i=1}^{K_j} \tau^j_{u_i} + \sum_{i=0}^{P_j} t^j_{u_i} = \widetilde{T}, \quad j = 1, \ldots, v, \tag{20}$$

$$\sum_{j=1}^{v} \sum_{i=1}^{k_j} \tau^j_{u_i} = \tau^*_{u_\Sigma}, \tag{21}$$

where $\tau^*_{u\Sigma}$ is the total admissible time of operation of the CMPs.

With (19) taken into account, the restrictions are written in matrix form

$$A\mathbf{V}_\Sigma = \mathbf{b}. \tag{22}$$

For finding the minimum $\tilde{R} = R/R^*$, where R^* is the initial R value, it is proposed that use be made of the "projective gradient" method.

The possibilities of the proposed optimization method and the importance of the optimum organization of CMC facilities operation are illustrated in the following example. We studied the organization of CMC facilities operation in the interval $[t_0, t_N]$ with a length of 20 hours; the total admissible time of operation of the CMP is $t^*_{u\Sigma} = 1$ hour. The orbit for which the problem was solved is close to stationary and has an eccentricity 0.00160. The point t_0 corresponds to a true anomaly of 321°. The initial organization is illustrated in Fig. 6,a. It corresponds to a value R = 1. The lengths of the intervals are indicated in seconds. The organization obtained as a result of one step in the direction of the antigradient is shown in Fig. 6,b. In this case R = 0.982. Figure 6, c shows an organization for which $\tilde{R} = 0.545$.

Thus, due to an organization of CMC facilities operation which is correct from the point of view of the adopted criterion it is possible to bring about a considerable increase in the accuracy of the evaluations obtained using the DPU.

Summary. We synthesized a command system for the orbital control of a SAES with transfer into a stipulated position with the use of algorithms for operational control and data processing. The proposed algorithms make possible a considerable broadening of the possibilities of the technical facilities by means of which SAES orbital control is realized.

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III. SPACE APPLICATIONS

RADIOTELESCOPES IN ORBIT

Paris AIR ET COSMOS in French 27 Oct 79 and 3 Nov 79

[Two-part article by Albert Ducrocq]

[27 Oct 79 pp 54-55]

[Text] When one rises above the earth's atmosphere, one escapes the screen which it represents. One can then receive all of the radiation which is emitted by the universe through the vast electromagnetic spectrum, and consequently benefit from "total" information, whereas in former times scientists had to be content with the restricted information conveyed by the radiation to which this atmosphere is transparent.

This was the reasoning used in the past--and these considerations are more valid than ever--to justify space astronomy. It was essential to equip satellites with instruments to detect, in particular, the ultraviolet rays, X-rays, or gamma rays emitted by hot sources or cataclysmic regions of space, and which our atmosphere intercepts. In past years, an extraordinary body of new data has thus been collected, but this information has, unfortunately, not been made very familiar to the general public nor even to the scientific community itself, except for the specialists who are directly involved in these experiments. For example, hardly anyone is aware of the extraordinary performances of the IUE satellite.

But the new factor now is the appearance of extra-atmospheric astronomy, which is undoubtedly due for startling developments, even for radiation which penetrates our atmosphere, that is, for radiation which was the object of traditional astronomic methods; this proves how limited was the information which the conventional approach could provide to earth-based observation.

In the case of optical astronomy, as we recently indicated, the advantages of space were ascertained rather early by scientists in America and in Europe, with the LAS program. These advantages will be pursued during the next 10 years, using the totality of the means which are known and which do not need to be listed here, under the major ST (Space Telescope) program, whose importance is likely to exceed all expectations since it promises a degree of progress with respect to present optical instruments, comparable to that which was achieved in the 17th Century thanks to Galileo's lens.

The advantages of studies conducted in orbit are well known. Satellites have a view of a black sky against which very weak light sources stand out perfectly (which is not the case in our observatories, where the atmosphere overhead is always somewhat illuminated by diffusion, even when it is thought to be dark). Moreover, observations from a satellite are free of atmospheric turbulence.

But it appears that the second layer of atmospheric transparency--that of electromagnetic radiation, at and below the metric band--is itself on the verge of becoming a major asset to space resources. We are seeing the means emerge for extra-atmospheric radio-astronomy, whose future is certain to be fantastic.

Size and Temperature

Here again it is importat to thoroughly grasp the import of a development which mandates recourse to space.

The theory of radio-astronomy is well known: it is a very young discipline compared to optical astronomy, since it only began after WW II, when scientists noticed that many sources in the electromagnetic spectrum generate signals which are useful to record, as they provide both a continuous spectrum (thermal emission from objects at all wavelengths) and a discontinuous spectrum containing the signatures of certain atoms or molecules, beginning with that of the neutral hydrogen atom at a wavelength of 21 cm.

At first, radio-astronomy was often presented by some as an adjunct of minor importance. But in fact, this opinion soon had to be reversed as results accumulated. This did not imply any conflict between radio-astronomy and optical astronomy: on the contrary, they proved to be remarkably complementary, the results of the one discipline acquiring their full significance when compared to the results of the other. One attitude among astronomers is now in fact characteristic: when an event in the optical spectrum is brought to their attention, they immediately apply themselves to finding its counterpart in the electromagnetic one. If they find it, they then possess the certainty that they have found a phenomenon affecting the totality of radiation, and that they are therefore in the presence of a property which characterizes a region of the universe.

However, radio-astronomy initially has a disconcerting effect because of its methods. Its instrument is the radiotelescope, in this case a parabolic dish at whose focus is located an antenna coupled with a receiver.

This dish has to be very large. Or rather, the larger it is, the more electromagnetic energy it can capture, just as in the case of optics where the number of photons collected by an instrument is proportional to the diameter of its objective, be it lens or primary mirror. Furthermore, as in optics, and all other factors being equal, the resolving power of a radiotelescope depends on its diameter, the dimensions being in any case an order of magnitude larger than that of optical instruments. The measurements of the latter are such that a telescope with a 3-meter aperture is a fine piece of equipment. The diameters of radiotelescopes attain tens of meters at the very least. Today's standard earth-based radiotelescopes are instruments measuring some 30 meters.

It must be added that in order to avoid masking out with their own noise the frail signals which they collect, the receivers located at the focus of radiotelescopes must be kept at very low temperatures. A temperature of 20°K or less is desireage, implying an appropriate cooling system with all its ancillary equipment.

These two requirements--large size of instruments and necessity of a cooling systerm--are pre-existing handicaps to space operations. Efforts are devoted to radiotelescope installations in satellites only in cases where particular considerations justify in-orbit operations.

This is precisely the case.

Interferometry

Extra-atmospheric radio-astronomy is proving to be promising in several ways.

First, it is noteworthy that recourse to orbital radiotelescopes of medium or even small size is useful in combination with earth-based radiotelescopes in the development of interferometry techniques. On this point, the opinion of specialists is unanimous: the future of radio-astronomy lies in this direction.

As was just mentioned, the resolving power of radiotelescopes depends on their diameter. In reality, no matter how large this diameter, the resolving power will not be at all of the same order as that of optical instruments, for the simple reason that in radio-astronomy, wavelengths are about 100,000 times larger than in the visible range. Thus, while an optical telescope can resolve an arc segment to some thousands of a second, the resolving power of a radiotelescope is measured in minutes; obviously, it would be futile to attempt to increase their size until they can achieve comparable results. On the other hand, if two radiotelescopes are separated by a distance d, calculations show that in terms of power of resolution (and not, obviously, in terms of energy collected), the results will be the same as those which would be obtained with an instrument of diameter d.

This is the consideration which led specialists, first, to separate their radiotelescopes as the Americans have done with the VLA, and then to connect radiotelescopes located at great distances from one another in different countries.

From this standpoint, it is clear that space offers resources which cannot be in any way compared with anything that may be expected on the ground. The Russians have shown us the way with the KRT 10 radiotelescopes, used aboard Salyut 6 between 18 July and 8 August last. As its model number indicates, this was an instrument 10 meters in diameter, whose mission was and the two others in geostationary orbit 60° apart so that the group forms an equilateral triangle whose side would measure 35,900 km; the deformation of this triangle would be very slow, obeying laws which have become familiar to us through communications satellites in geostationary orbits.

With this concept, the theoretical resolving power, in centimeter waves, would reach 10,000 km at 100 light-years.

If this does not seem sufficient, the instruments can be placed in lunar orbit, to obtain one more decimal, because the interferometer base will be 10 times larger.

Better yet, there is nothing to prevent the orbiting of a radiotelescope around a close or distant planet of our system--and scientists in the Soviet Union are already preparing important projects of this nature. It would thus become possible to immediately obtain two or three new decimals, that is, to hope to resolve 100 km or 10 km at 100 light-years, with the corollary that the distance of sources in a large portion of the universe could be determined considerably better.

This promise of proliferating decimals may appear as a gamble or even a fantasy at present. But let us not forget that since the beginning of the space age, no less than 6 decimals have been obtained in the determination of distances within the solar system. As we have stated, in a certain sense the exploration of the solar system is now a thing of the past, and the major discoveries of the last 2 decades of the 20th Century will certainly involve the distant universe.

The remarkable thing is that these interferometry experiments carried out in space are possible with small radiotelescopes.

And this is only one of the advantages provided by space. The prospect of large orbital radiotelescopes holds out equally great promise for extra-atmospheric radio-astronomy, since the size of instruments will increase very rapidly, given the new means available to space technology.

Radio-astronomy, which was riveted to the ground for such a long time by the magnitude of its installations, has thus suddenly leaped into space.

This is the beginning of a fantastic movement. The extraordinarily interesting orbiting of radiotelescopes is now technically possible. We have described its primordial value.

Even at the wavelengths for which our atmosphere can be considered technically transparent to electromagnetic radiation, the orbiting of a radiotelescope is of interest because of the services that can be derived from a small instrument as a result of its position. It allows interferometry experiments over very great distances, such as the one carried out last summer with the combined use of KRT 10 on Salyut 6 and RT 70 in Crimea. In near-earth orbit, the studies can be conducted over a 10,000 km base;

of course experimental. The purpose was two-fold: first, to acquaint the cosmonauts with techniques for the installation and above all for the maintenance of a radiotelescope in space--which raises many problems that we will examine--and secondly, to initiate specialists into the operation of an orbital radiotelescope in interferometry with an earth-based instrument, in this case the RT 70, a 70-meter diameter radiotelescope located in Crimea.

With Salyut 6 orbiting at 400 km above the earth, calaculations show that the distance between KRT 10 and RT 70 varied geometrically between 400 and 13,000 km. Observations from the latter distance were out of the question (because RT 70 would have aimed at the horizon), the Russians having set a maximum distance of 10,000 km for this first wide-base interferometry experiment.

Listening to Pulsars

One of the targets of KRT 10, once Lyakhov and Ryumin had oriented their station, was the pulsar PSR 0329 + 54 toward which RT 70 itself was aimed. As we know, the name of pulsar is given to compact objects spinning very rapidly on their own axes, the study of which by interferometry was a first priority. We hardly need to point out that there is no hope of resolving a pulsar: even with a 10,000-km base, the resolving power of two radiotelescopes 10,000 km apart cannot distinguish formations whose dimensions are smaller than several tens of thousands kilometers at a distance of 100 light-years; these would be the optimum figures for perfectly stabilized instruments, quite unencumbered by any problems of data transmission. On the other hand, we know that pulsars produce scintillation which can be analyzed under excellent conditions by such pairs of radiotelescopes, the study of this scintillation--attributed to interstellar plasma--being one of the best means imaginable to study this plasma and to determine the density of its free electrons.

In the future, we also expect interferometric monitoring to provide information about the pulsars, based on comparisons of signals recorded by two radiotelescopes at the moment when they find themselves at different distances from a pulsar. A separation of 10,000 km will result in a delay of 0.03 s in the reception of signatures. As it turns out, these signatures are so "coded" that they could be identified to the nanosecond, provided that the data collected by the radiotelescopes could be plotted with the same precision on the universal timescale.

[3 Nov 79 pp 38-39]

[Text] Proliferation of Decimals

A radiotelescope in orbit around the earth is no simple matter, especially since the speed of its motion is unquestionably a handicap: the value of the interferometric base changes at every instant. Technology will have to adapt to this, scientists having already set their sights on the next stage, which will consist in placing radiotelescopes in geostationary orbits. The ideal would be to operate three radiotelescopes simultaneously, one on earth, the base will be bound to increase when radiotelescopes are orbited around the moon or the planets, with all the attendant resolving power than can be gained.

At the same time, an orbiting radiotelescope offers unquestionable advantages, while remaining in the range of small or medium sized instruments.

We mentioned the prodigious field of millimetric radio-astronomy which is currently undergoing a well-publicized development. In Crimea, not far from their RT 70, the Russians have built a 22-meter radiotelescope, designed to operate in the millimeter range. Elsewhere, the U.S. has two radiotelescopes of 11-meter and 30-meter diameters respectively; Sweden has a 25-meter radiotelescope; and Japan, a 45-meter radiotelescope.

These instruments are now geared to millimetric radio-astronomy; it goes without saying that they resemble ordinary radiotelescopes, with this difference, that the collector's dimensions must be respected with much greater precision: construction imperfections must be negligible with respect to wavelength. This implies a much more painstaking construction, with tolerances within one-tenth of a millimeter at the very most.

Such rigorous standards are not always easy to guarantee on the earth's surface because of the effect of gravity on the collectors and because of the deformations which the latter will inevitably undergo when orientations are shifted. In orbit, the absence of gravity itself should make things immediately much easier.

At the same time, it should be remembered that in this millimeter range, the transparency of the earth's atmosphere is far worse than in the centimeter or meter range. Millimetric studies reach layers where radiation absorption begins to be significant, so that conditions will be infinitely more interesting if operations can be conducted in space.

Installation Technology

The launch of the KRT 10 radiotelescope caused great surprise.

In absolute terms, scientists should not have been surprised. They had had the opportunity to know of the recommendations of the Academy of Sciences in the USSR: as early as 1974, this agency had emphasized the need to develop space radio-astronomy, both in the context of the CETI programs for monitoring signals from extra-terrestrial civilizations, and in terms of the advantages offered by the collection of electromagnetic radiation beyond the atmosphere in order to study many of the phenomena of the universe. But outside of the Soviet Union, this report had been virtually overlooked. In any event, the Russians are following the schedule they adopted. They announced that the first phase of their plan would occur "before 1980", and this led us to expect that 1979 would in some way mark the starting point of the technology which would result in a major Russian CETI program.

The very fact that KRT 10 was in use for such a short time was also cause for surprise. In fact, the Russians considered the nature of the operation as essentially experimental. The purpose was to test conditions under which wide-base interferometry could be performed with two instruments, one on the ground and the other in orbit. Other objectives were to study the operations needed to install an orbital radiotelescope, to examine its performance, and to test its utilization.

The least that can be said is that the installation of a radiotelescope in orbit did not prove to be easy. It probably never will be, for two reasons:

When leaving earth, the collector must be housed in the space available, taking into account the launcher's characteristics: in other words, the only recourse is to use collapsible or inflatable structures.

Clearly, the radiotelescope cannot be reduced to a simple antenna, meaning a collector with some sort of resonator placed at its focus. The receiver must be mounted on "something", in this case an orbital station, which will naturally serve as a platform for orientation as it shelters the control facility and the signal relay system.

Salyut and Progress

Of course, available vehicles had to be used for these operations. The Russians quite naturally exploited the possibilities offered by Salyut and Progress, KRT 10 having been adapted to these vehicles. A certain amount of information is now available, enabling us to reconstruct the installation procedure for the first radiotelescope of the space age.

The collector was very light (approximately 5 kg), but KRT 10 as a whole was much more massive. Aboard Progress 7, it was a bulky unit which the cosmonauts first brought into Salyut through the transfer compartment. This reveals a very specific constraint: the diameter of the package had to be such as to allow clearance, which meant that it had to be considerably smaller than if it had only needed to fit into the space available in the nosecone of an R 7 rocket. Having brought the equipment into their station's main cabin, Lyakhov and Ryumin proceeded to connect the electronic cables. It goes without saying that prior to launching, Salyut 6 had been equipped with a "KRT 10 plug" so that its transmitter could relay the readiotelescope modulations.

The cosmonauts then introduced the antenna support, with the folded dish, into the transfer compartment, which thereby became blocked: for this reason, the operation could only be performed after all equipment to be unloaded into Progress 7 had been transported inside Salyut. The antenna support was encircled by a clamp of slightly smaller diameter than that of the compartment and adjustable by a method well-known to mechanics and occasionally used in mending garden hoses. Thus, by increasing its diameter, the cosmonauts were able to enlarge the clamp and ultimately to lodge it inside the compartment.

At this stage, the situation was as follows: in the transfer compartment between Salyut and the pressurized orbital compartment of Progress, the antenna support became physically integrated with Salyut by means of this clamp. The cosmonauts then proceeded to examine the equipment while they could still approach it at will, knowing that soon they would no longer be free to do so.

With this verification accomplished, the Salyut side of the compartment was closed, in anticipation of the separation of Progress and because the antenna support did not constitute a sealed part in this compartment.

The Progress vehicle was then separated, automatically depressurizing the compartment. The antenna support--on which the antenna was mounted, in a folded position, inside the compartment--found itself exposed to a vacuum, like everything else located on the other side of the door connecting Salyut 6 and the aft bay.

This support contained, along its axis, a telescopic device to allow the dish to slide beyond the rear section of Salyut. Once this operation was performed, the still-folded dish was in position beyond the anchoring part. The last phase of the operation was its final unfolding, like an umbrella. This was obviously the most spectacular step, but a relatively simple one at this stage as long as all previous operations had been performed correctly.

Metallic Cloth

This dish was extremely light: it was made of a knitted mesh of 0.05 mm diameter wire, or in electricians' terms, 0.5/10 wire. In addition it is noteworthy that in order to improve its reflective power, this fabric had been metallized by depositing a highly conductive layer on its surface.

As we know, the final phase of these operations took place on 18 July, after separation of Progress 7 and positioning of the freight transport some distance from Salyut allowed technicians on the ground to follow the unfolding of KRT 10, which was televised by a camera aboard Progress 7. Naturally, the technicians were less concerned with witnessing a spectacle than with observing a phenomenon which cannot be simulated on earth: the opening of the dish in weightlessness.

An essential part of the program was the rehearsal of all these operations, the Russians wanting to gather the knowledge needed in the future to perfect a procedure for installing a KRT on a Salyut.

Once the mission was accomplished, the separation of KRT 10 in August was not a simple operation either.

This separation served two purposes. In the first place, the Russians intended to free the aft port of Salyut 6 so that if need be, the station could still be used as in the past: its forward port would still be able to receive a Soyuz with a maintenance crew, and its aft port could still receive either a Soyuz with a visiting crew or a Progress freight transport. But here again one must also consider that the Russians were interested in acquiring the experience of a separation procedure.

A complication arose because the dish got jammed against a Salyut aft part used for targeting during rendezvous. The cosmonauts realized this when, having entered the compartment, loosened the clamp, and attempted to eject KRT 10, they observed that the equipment was not moving. For this reason, Lyakhov had to exit, as we know, leaving Salyut through the hatch located near his forward anchor (this is the only Salyut door leading out to space when the transfer compartment to the rear is obstructed). Once this separation was achieved, it was enough to push KRT 10 to the outside: its inertia enabled it to slowly move away from Salyut 6.

Why did this revealing incident take place? The answer is that one must take into account the deformation of the dish. In space, there is neither wind nor gravity, but objects conserve their inertia. At the same time, they are exposed to solar radiation whose relative power per unit area is considerable in the case of light objects, raising many problems whose solutions will affect the installation of larger antennas.

The lightness of the KRT 10 dish is remarkable: 5 kg as we have indicated. This is tantamount to saying that with the same materials it should be possible to orbit antennas of several tens of meters in diameter--a size comparable to earth-based radiotelescopes--for a mass of some tens of kilograms.

And why stop along such a promising path?

The Russians have shown us the major directions of their program. Beyond the present KRT 10, whose resources they are first going to exploit thoroughly, they plan to launch KRT 30 in coming years, and for the end of the decade they are considering KRT 200, that is, a 200-m diameter telescope which will itself be only a step toward kilometer-size instruments.

This is another goal of the orbital radiotelescope, probably the most extraordinary one, with the prospects offered by the use of giant instruments.

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SOME NEW TRENDS IN LANDSCAPE INDICATIONS OF HYDROGEOLOGICAL AND GEOLOGICAL ENGINEERING CONDITIONS IN CONNECTION WITH THE USE OF SPACE SURVEY MATERIALS

Moscow IZVESTIYA VSESOYUZNOGO GEOGRAFICHESKOGO OBSHCHESTVA in Russian Vol 111, No 4, 1979 pp 306-310

[Article by A. L. Revzon]

[Text] During recent years aerial landscape indication, in connection with the development of small-scale high-altitude and space photoinformation, has depended for the most part on the use of complex landscape indicators [1, 5, 7]. As is well known, complex landscape indicators bring together elements of relief, vegetation and the hydrographic network. Geographical landscapes have a definite internal structure, characterized by a spatial relationship of complexes of a lower rank (facies, natural landscape complex, locality) [9]. The external visible level of these landscape complexes, defined by S. V. Viktorov as the "ectolevel" [3, 4], is the indicator of their invisible components.

Modern aerial landscape indication is based on the use of aerial and space photographs for interpreting the "ectolevels" of landscape complexes and their indication interpretation for hydrogeological and geological engineering purposes. Different indicators are used, depending on the level of generalization. In the interpretation of aerial photographs at large and intermediate scales to a great extent use is made of special indicators; in the interpretation of small-scale aerial photographs the leading role is played by complex indicators, primarily at the level of facies, simple and highly varied natural landscape complexes.

Logically continuing this thought, one could assume that in the interpretation of space photographs with different levels of generalization use would also be made of landscape indicators, but already at the level of more complex landscape elements. But this is only partly true. At the local level of generalization an important role is played by the "ectolevels" of highly varied natural landscape complexes. However, when using photographs at the regional level of generalization the characteristics of the soil-vegetation cover, as a result of the high degree of generalization, are not manifested sufficiently clearly and are not differentiated. Because of this, in their analysis it is virtually impossible to detect those landscape interrelations

Features of Landscape-Indication Mapping for the Purposes of Hydrogeology and Geological Engineering and Systematic Peculiarities of Their Detection on Aerial and Space Photographs With Different Levels of Generalization

Уровень генерализации a	Объекты ландшафтно-индикационного картирования b	Структурные элементы ландшафтов, соответствующие объектам индикационного картирования c	Физиономичные компоненты ландшафта, определяющие их эктопрусы d	Парагенетические сочетания наиболее физиономичных компонентов ландшафта, формирующих структуру фотоизображения e	Деципиентные компоненты ландшафта (объекты индикации) f		Глубинность индикации i
					гидрогеологические g	инженерно-геологические h	
1	2	3	4	5	6	7	8
j Глобальный	n Мегакомплексы	r Группы типов ландшафтов	v Морфоструктуры I и II порядков	z Эндоморфогенные	dd Гидрогеологические структуры I и II порядков, которым соответствуют крупные артезианские бассейны dd	Геоструктурные зоны и отвечающие им группы инженерно-геологических формаций горных пород hh	Сотни метров ll
k Региональный	o Макрокомплексы	s Типы ландшафтов	w Морфосистемы (комплексы экзогенных форм рельефа, развитые в отдельных морфоструктурных и ландшафтно-климатических условиях)	aa Экзоморфогенные	Гидродинамика подземных вод (региональные области питания, транзита и разгрузки); характер связи грунтовых и напорных вод; обводненность разрывных нарушений; гидрогеологические структуры II и III порядков ee	Геоструктуры II и III порядков и соответствующие им инженерно-геологические формации горных пород; геолого-генетические комплексы покровных отложений; парагенетические комплексы экзогенных процессов ii	Десятки метров mm
l Локальный	p Мезокомплексы	t Сложные урочища, местности	x Мезоформы рельефа, морфогенетические типы рельефа, группировки растительных сообществ	bb Экзоморфобиогенные	Процессы влагопереноса в зоне аэрации на значительных площадях (сотни километров). Глубины залегания грунтовых вод и их минерализация; местные области питания, транзита и разгрузки грунтовых и напорных вод; характеристика взаимосвязи поверхностных и подземных вод ff	Локальные структурно-тектонические условия, геолого-генетические комплексы пород, их литологический состав; проявление экзогенных процессов, степень их активности jj	Первые десятки метров nn
m Детальный	q Микрокомплексы	u Фации, простые урочища	y Растительные сообщества, микроформы рельефа	cc Биоэкзоморфогенные	Процессы влагопереноса в зоне аэрации на небольших площадях (десятки километров). Глубины залегания грунтовых вод и их минерализация gg	Литолого-петрографические особенности и некоторые физико-механические свойства пород зоны аэрации на небольших площадях, а также оценка их засоленности и обводненности. Выявление преобладающих экзогенных процессов, стадий их развития и степени активности kk	Метры oo

KEY TO TABLE

a. Level of generalization
b. Features of landscape-indication mapping
c. Structural elements of landscapes corresponding to indication mapping features
d. Physiognomic components of landscape determining their ectolevel
e. Paragenetic combinations of the most physiognomic landscape components forming the structure of the photographic image
f. Decipient landscape components (indication features)
g. Hydrogeological
h. Geological engineering
i. Depth of indication
j. Global
k. Regional
l. Local
m. Detailed
n. Megacomplexes
o. Macrocomplexes
p. Mesocomplexes
q. Microcomplexes
r. Groups of types of landscapes
s. Types of landscapes
t. Highly varied natural landscape complexes, localities
u. Facies, simple natural landscape complexes
v. 1st- and 2d-order morphostructures
w. Morphosystems (complexes of exogenous relief forms developed in individual morphostructural and landscape-climatic conditions)
x. Relief mesoforms, morphogenetic types of relief, groupings of plant associations
y. Plant associations, relief microforms
z. Endomorphogenic
aa. Exomorphogenic
bb. Exomorphobiogenic
cc. Bioexomorphogenic.
dd. 1st- and 2d-order hydrogeological structures which correspond to large artesian basins
ee. Hydrodynamics of ground water (regional areas of origin, transit and release); nature of relationship between ground and head waters; flooding of dislocations; 2d- and 3d-order hydrogeological structures
ff. Processes of moisture transfer in aeration zone over considerable areas (hundreds of kilometers). Depths of ground water and its mineralization; local areas of origin, transit and release of ground and head waters; characteristics of interrelationship between surface and ground water
gg. Processes of moisture transfer in aeration zone in small areas (tens of kilometers). Depths of ground water and its mineralization.
hh. Geostructural zones and corresponding groups of geological engineering rock formations

ii. 2d- and 3d- order geostructures and corresponding geological engineering rock formations; geological-genetic complexes of covering deposits; paragenetic complexes of exogenous processes
jj. Local structural-tectonic conditions, geological-genetic rock complexes, their lithologic composition; appearance of exogenous processes, degree of their activity
kk. Lithologic-petrographic peculiarities and some physicomechanical properties of rocks in the aeration zone in small areas and also an evaluation of their salinity and flooding. Detection of predominant exogenous processes, stages in their development and degree of activity
ll. Hundreds of meters
mm. Tens of meters
nn. First tens of meters
oo. Meters

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as are the basis for hydroindication, lithoindication and haloindication [5]. In this case we have in mind the interrelationship between the soil-vegetation cover, relief, composition of rocks and ground water. The role of the principal indicators is played by major geostructural complexes, expressed in the modern relief. This circumstance makes it possible to speak of the necessity for introducing a structural-tectonic indicator having great importance in detecting regional patterns of formation of hydrogeological and geological engineering conditions [1, 8].

Accordingly, in the interpretation of space photographs with different levels of generalization the principal synthetic indicators are landscape-indication and structural-tectonic. A structural-tectonic analysis to some degree is based on the results of landscape indication interpretation.

The main content of a landscape-indication analysis of materials from a space photographic survey is the clarification of landscape interrelationships, determination of the system of landscape indicators and indication objects corresponding to them, and also the preparation of landscape-indication schemes. Landscape-indication schemes are tables whose principal content is the characteristics of the interrelationship among physiognomic and decipient components. Landscape-indication tables are divided into two parts. The first gives a standard photoimage and a characterization of the physiognomic landscape components (indicators); the second gives the indicated objects, the elements of hydrogeological and geological engineering conditions. Such tables are of independent importance, but also can serve as map legends. During recent years it has also become commonplace to compile map legends in the form of landscape-indication tables.

Landscape-indication maps (schemes) in the interpretation of materials from a space photographic survey are compiled on the basis of a synthesis of three sources: interpretation of the landscapes on space photographs, analysis of the interrelationship of the results of analytical interpretation (hydrographic net, geomorphology, geobotany), analysis of data in the literature and archives and the results of field work on the ground.

The experience in aerial landscape indication which has now been accumulated provides much factual material on the landscape indicators in different regions of the USSR. Accordingly, prior to the compilation of landscape-indication schemes it is necessary to study the available experience of landscape indication in the investigated region and on this basis develop a diagnostic interpretation, that is, form some idea about those landscape indicators which are characteristic for the studied territory. For example, in the compilation of a landscape-indication scheme of the Ustyurt on the basis of space photographs we analyzed all the available material from aerial landscape investigations not only in this particular region, but also in general in deserts, after which the problem involved a generalization of these data applicable to the space indication level. However, this does not at all mean that in this case the task only amounts to a generalization of already known data. The generalization of special indicators into microcomplex indicators and microcomplex indicators into macrocomplex indicators leads to a generalization of the indicated objects and this is often a source for detection of regional patterns of hydrogeological and geological engineering conditions not always possible when using aerial photographs.

The use of space photographs makes possible a somewhat new approach to determination of the content of landscape-indication maps and the interpretation of the basic concepts of indication analysis.

In the studies of a number of authors [3, 4, 6] who have carried out landscape-indication investigations on the basis of materials from a space photographic survey, the indicated objects involved were tectonic elements (plicative and disjunctive tectonic structures). However, these were not reflected on landscape-indication maps. However, the use of space photographs in landscape-indication investigations frequently rests precisely on the elements of tectonic structure, which play an indication role with respect to hydrogeological and geological engineering conditions. This circumstance makes it possible to regard structural-tectonic conditions as a landscape component [2] which at some levels of indication mapping plays the role of an indicator, and at others -- in the role of the indicated object.

Depending on the level of generalization of space photographs the objects of indication mapping are natural complexes of different rank, each of which is characterized by a structure determining the relationship of physiognomic and decipient components. Now we will examine the specifics of indication mapping on the basis of materials from aerial and space surveys in dependence on the level of their generalization (see Table).

At the global level of generalization of space photographs the objects of indication mapping are megacomplexes corresponding to groups of landscapes. The physiognomic components of the megacomplexes on the photographs are first- and second-order morphostructures, being indicators of first- and second-order hydrogeological structures, corresponding to major artesian basins and also geostructural zones of the earth's crust which correspond to groups of geological engineering rock formations. The nature of these indicators can be arbitrarily defined as endomorphogenic. At this level the effective depth of indication is hundreds of meters. At the regional level of generalization the objects of indication mapping are macrocomplexes corresponding to types of landscapes. The physiognomic components of the macrocomplexes are morphosystems [8], representing complexes of exogenous relief forms developed under definite structural-tectonic and landscape-climatic conditions [10]. In this case the soil-vegetation cover, as a result of the high degree of generalization on the photoimages, is not adequately differentiated and cannot be used as indicators. The paragenesis of this interrelationship can be interpreted as exomorphogenic. The objects of indication at this generalization level are: in hydrogeology -- the elements of hydrodynamics of ground water (regional areas of origin, transit and discharge), nature of the relationship between ground water and head water, occupation of dislocations by water, second- and third-order hydrogeological structures; in geological engineering -- rock formations, geological-genetic complexes of covering deposits, paragenetic complexes of exogenous processes. The effective depth of indication at this level is tens of meters.

At the local level of generalization of space photographs the objects of indication mapping are mesocomplexes, spatially corresponding to highly varied natural landscape complexes and localities. The physiognomic components of mesocomplexes are the peculiarities of mesorelief and the grouping of the plant associations determining their ectolevels. In this case the structure of this indicator can be interpreted as exomorphobiogenic. At this level the objects of indication in hydrogeology are the processes transpiring in the aeration zone over considerable areas, attaining hundreds of square kilometers, the depth of ground water and its mineralization, local areas of sources, transit and discharge of ground and head waters, and the nature of the interrelationship between surface and ground water. The geological engineering indication objects at this level are: local structural-tectonic conditions, geological-genetic rock complexes, their lithological composition, manifestations of exogenous processes. In this case the effective depth of indication is the first tens of meters.

At the detailed level of generalization, to which in most cases large- and medium-scale aerial photographs belong, the objects of indication mapping are microcomplexes corresponding in spatial respects to the facies of both the smallest morphological landscape elements and also to simple natural landscape complexes. The physiognomic components of microcomplexes include plant associations and microrelief peculiarities. These components of microcomplexes determine their ectolevels, being indicators of elements of the hydrogeological and geological engineering conditions. Their paragenetic relationship can be defined as bioexomorphogenic. The principal indication object in hydrogeological respects here are the processes transpiring in the aeration zone over small areas not exceeding several square kilometers. Indication of the depths of ground water and its mineralization is possible. In geological engineering respects at this level of indication mapping it is possible to ascertain the lithological-petrographic peculiarities and physicomechanical properties of rocks in the aeration zone, evaluate their salinity and flooding, and also detect the predominant important exogenous processes, stages and degrees of their activity. The effective depth of indication in this case is determined in meters. At this generalization level of space photographs the experience of landscape-indication mapping is varied.

At the present time landscape-indication maps are being compiled primarily at detailed and local levels of generalization of space photographs. However, the introduction of space methods in the practice of hydrogeological and geological engineering work requires a reevaluation of existing regional representations, as a result of which the need arises for compilation of small-scale landscape-indication maps with the use of space survey materials.

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USSR

DETERMINATION OF SPATIAL-TEMPORAL VARIATIONS OF AN AEROSOL IN THE ATMOSPHERE BY LASER APPARATUS FROM SPACE VEHICLES

Moscow TRUDY TSENTRAL'NOY AEROLOGICHESKOY OBSERVATORII in Russian No 138, 1979 pp 11-15

BIRICH, L. N., GERMAN, A. I., KOSTKO, O. K., MEL'NIKOV, V. YE.

[From REFERATIVNYY ZHURNAL, 62. ISSLEDOVANIYE KOSMICHESKOGO PROSTRANSTVA, OTDEL'NYY VYPUSK No 10, 1979 Abstract No 10.62.136]

[Text] The possibility of using laser apparatus (lidars) for investigating the dynamics of aerosol layers and the aerosol background over extensive territories of the land and oceans is considered. It is noted that apparatus with physicotechnical parameters ensuring the reliable registry of an aerosol scattering signal (30-40% to altitudes 70 km from the earth's surface) can be created on the basis of a ruby laser and the optical receiving system of an on-board submillimeter telescope. The principal parameters of the on-board lidar were determined. It is demonstrated that the multialkali FEU-84 is the most suitable for the photodetectors of on-board lidars operating at the wavelength $\lambda = 0.694$ µm. The mean counting rate of noise pulses at the output of this photomultiplier is $3\text{-}7 \cdot 10^3$ pulses/sec and with cooling of the photomultiplier to a temperature of -20°C it can be reduced to $\sim 3 \cdot 10^2$ pulses/sec. The minimum time for registry of the mean number of signal photoelectrons on the dark side of the earth was estimated. In the case of measurements in the altitude range 35-80 km with an error of 40% it is necessary to carry out from 2 to 100 soundings. Due to the great velocity of the space vehicle, in an investigation of local sources of aerosol particles with given errors the maximum interval for the measurement grid must not exceed 1 km and the minimum lidar pulse repetition rate must be equal to 10 Hz in the case of measurements to altitudes of 20 km and 100 Hz to altitudes of 70 km. In measurements of the aerosol background the lidar pulse repetition rate varies from 1 to 1/10 GHZ. The principal shortcomings of the proposed lidar are its relatively great weight (up to 300 kg) and power consumption (up to 20 KW), which considerably limits the possibilities of its installation aboard a space vehicle. References 10.
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USSR

ACCURACY IN CONSTRUCTING REGIONAL GEODETIC NETWORKS BY THE GEOMETRICAL SATELLITE METHOD

Moscow TRUDY SEMINARA "NOVYYE METODY SPUTNIKOVOY GEODEZII:" LENINGRAD, 24-30 NOYABRYA 1975. "NABLYUDENIYA ISKUSSTV. NEBESN. TEL," in Russian No 15, Part 2, 1975 (1977-1978) pp 358-366

[From REFERATIVNYY ZHURNAL, 62. ISSLEDOVANIYE KOSMICHESKOGO PROSTRANSTVA, OTDEL'NYY VYPUSK No 10, 1979 Abstract No 10.62.237]

[Text] A model of a space triangulation network of 14 stations, distributed approximately uniformly over the territory of the USSR, has been created. In lieu of actual measurements there was modeling of azimuths, zenith distances and lengths of chords connecting observation points. The model was adjusted in 11 variants with different combinations of varieties and accuracies of measurements. The adjustment included space bases and data from radiointerferometer measurements. An analysis was made of the influence of individual types of measurements on the final accuracy in construction of the network. It is concluded that the use of the entire considered set of measurements makes it possible to obtain, as an average for the entire network, a mean square error for each coordinate of $\leqslant 2$ m.
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USSR

ACCURACY IN DETERMINING POSITION USING THE "TRANSIT" SATELLITE NAVIGATION SYSTEM

Leningrad TRUDY ARKTICHESKOGO I ANTARKTICHESKOGO NII in Russian No 360, 1979 pp 136-142

ABRAMOV, B. I. and IONOV, YU. A.

[From REFERATIVNYY ZHURNAL, 62. ISSLEDOVANIYE KOSMICHESKOGO PROSTRANSTVA, OTDEL'NYY VYPUSK No 10, 1979 Abstract No 10.62.243]

[Text] The accuracy in determining position using the "Transit" satellite navigation system, based on the integral Doppler method, is governed by the following determination errors: position of the AES at the time of communication, position of the vessel relative to the satellite, ship's speed during the time of the contact, elevation of the antenna above the ocean surface and calculation error (reduction of data from all observations to the same zenith). The total mean square error in determining a vessel's position using the "Transit" satellite navigation system can be obtained by the quaratic addition of the enumerated errors. The numerical estimates obtained for these errors made it possible to compute the total mean square error in determining a vessel's position, which in the latitude zone 0-65° was found to be 110-165 m. However, taking into account the systematic error caused by an inaccurately determined current velocity, this value attains 235 m. It is noted that this value corresponds to modern concepts concerning coordination accuracy. There is a brief analysis of the merits and shortcomings of the "Transit" satellite navigation system. The data collected on operation of the "Transit" satellite navigation system in implementation of the scientific program POLEKS-Yug-77 over the course of a prolonged time period (December 1976-April 1977) and over a large territory have great importance for the further study and improvement of methods for coordination, using the satellite navigation system, in the ocean. A more thorough analysis will be made as the corresponding material is accumulated. References 6.
[93-5303]

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USSR

PREDICTION OF TIME PERIODS FAVORABLE FOR SIMULTANEOUS OBSERVATIONS OF ARTIFICIAL EARTH SATELLITES FROM TWO STATIONS USING AN ELECTRONIC COMPUTER

Moscow NABLYUDENIYA ISKUSSTV. NEBESN. TEL in Russian No 70, 1978 pp 28-48

YERPYLEV, N. P., SOBOLEVSKIY, V. D. and PETROVA, O. A.

[From REFERATIVNYY ZHURNAL, 62. ISSLEDOVANIYE KOSMICHESKOGO PROSTRANSTVA, OTDEL'NYY VYPUSK No 10, 1979 Abstract No 10.62.315]

[Text] A method is proposed for computing a prediction of the visibility of artificial earth satellites from two stations stipulated by their geographical coordinates. Such a prediction can be used in organizing synchronous observations from the ends of geographic chords for the needs of space geodesy. In computing a prediction the possibility of transit of an artificial earth satellite simultaneously over the selected almucantar at the two stations, its illumination by the sun and nighttime conditions at the stations are taken into account. The computation algorithm is based, for the most part, on analytical solutions, which makes it possible to get by without tests of many orbital points requiring great expenditures of computer time and use both large and small electronic computers having a relatively low speed and a small memory. The formulated program is intended for an MIR-2 electronic computer using the "Analitik" algorithmic language. [93-5303]

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IV. SPACE POLICY AND ADMINISTRATION

PLANS FOR FRENCH-SOVIET SPACE COOPERATION OUTLINED

Talks Held at Ajaccio

Paris AIR & COSMOS in French No 784 (27 Oct 79) pp 46-47

[Article by Pierre Langereux: "A new dimension in the Intercosmos-CNES cooperation"]

[Text] The annual French-Soviet space cooperation talks, which this year were held 14-21 October in Ajaccio (Corsica), brought together nearly 140 representatives from the Centre National d'Etudes Spatiales (CNES) and the Intercosmos Council of the USSR Academy of Sciences as well as from a number of space research laboratories in France and the Soviet Union. The Soviet delegation, which was comprised of 50 members, was led by Academician Boris N. Petrov, president of Intercosmos and a vice-president of the USSR Academy of Sciences. The French delegation was headed by Professor Hubert Curien, president of CNES.

"These talks, like all preceding ones, proceeded in a productive and friendly atmosphere," said President Petrov referring to the occasion. The discussions proceeded "in a perfect atmosphere of friendship" and "with the common desire to realize the unique experiments which place France and the USSR at the forefront of scientific research," stated President Curien.

Soviet and French officials enumerated the various space experiments conducted in 1979 (SAMBO 2, ELMA 01, CYTOS M, IPOCAMP 3, etc.) and programs under preparation for the next few years in the four fields covered by French-Soviet space cooperative efforts: space biology and medicine, aeronomy and space meteorology, space telecommuncations, and space research which encompasses astronomy, geophysics and the study of cosmic radiation, studies of the moon, the planets and the interplanetary medium, and materials processing in space as well as satellite data processing within the framework of a special agreement between the CNES space center at Toulouse and the Space Research Institute (IKI) in Moscow.

"French-Soviet space cooperation, which was undertaken in 1966 (already 13 years ago now) has reached a more intensive stage," said President Petrov.

The most important French-Soviet space programs now under development are: the first flight of a French astronaut aboard a Soviet SALYUT orbital station in mid-1982 and the VENERA 84 project for exploring Venus with two Soviet interplanetary probes that will be launched in December 1984 to release two French-designed balloons into the planet's atmosphere, according to President Curien.

According to Petrov, the other two major joint projects in geophysics and astronomy which will be realized in the next few years are (in chronological order): the ARCAD 3 project--a satellite to be launched in the spring 1981 for studying the earth's ionosphere and magnetosphere, the UFT project--an ultraviolet astronomy satellite to be launched in 1982, and the GAMMA 1 project--a gamma astronomy satellite to be launched in either 1982 or 1983.

President Curien revealed that a new initiative was undertaken by CNES and Intercosmos during these meetings: to create a "long-term working group" which will be charged with "the study and preparation of joint operations for the next ten years." It would be up to this group in particular to propose a future major French-Soviet cooperative project designed to succeed VENERA 84, which until now has been the most important space project undertaken within the framework of French-Soviet cooperation.

Our readers will find the results of these talks on the following pages.

French-Soviet Manned Mission Slated

Paris AIR & COSMOS in French No 784 (27 Oct 79) p 47

[Article by Pierre Langereux: "The Selection of French Astronaut Candidates Has Begun," p 47]

[Text] The flight of the first French astronaut--together with a Soviet cosmonaut on board a SALYUT orbital station--will take place in mid-1982, the date chosen at the request of scientists, announced CNES President Hubert Curien in response to a question from AIR & COSMOS at the close of the French-Soviet talks in Ajaccio.

CNES and Intercosmos must now establish a training schedule for the French-Soviet crew and define the mission's scientific objectives. French and Soviet officials will meet three weeks from now in Moscow to discuss this, revealed Boris Petrov, president of Intercosmos.

The French astronaut candidates, which will be selected by CNES, must begin their training at Zvezdnyy Gorodok (Star City) near Moscow in mid-1980, announced the CNES president in explaining that the process of selecting the French candidates would begin within the next few days and progress rapidly from now until the end of the year.

The chief criteria for selection of the French candidates are, according to Hubert Curien: physical stamina (to satisfy the training norms established by the Soviets), scientific and technical education (to conduct the experiments planned for the flight), and "a good knowledge" of the Russian language.

There will be at least two French astronaut candidates selected for this mission and trained jointly until the launch date, said Petrov. As for all manned spaceflights, the astronaut designated for the flight always has a "back-up" in case of a problem at the last minute. Boris Petrov explained that the choice of the astronaut to be flown will be the prerogative of the French.

A French woman in space?

Protocol for the French-Soviet agreement on this mission notes, in particular, that the French would like to send a woman into space--let it be understood that the two candidates must satisfy the selection criteria imposed by CNES and Intercosmos.

The Soviets have been somewhat reticent on the idea that the French astronaut could be a woman. However, "the USSR has not eliminated this possibility," said Hubert Curien. At the end of this year France will confirm whether or not it will hold to the principle of sponsoring a female candidate and the USSR will have to make it known whether it can technically accept this candidate. The presence of a woman on board a SALYUT would require certain modifications to the station's facilities. This would not present any particular technical difficulties, the Soviets have told us, but it is not certain whether these modifications could be implemented within the necessary timeframe. The Soviets, who have not flown a woman in space since the unique flight of Valentina Tereshchkova in 1963, had not expected to change operations in the near future; several Soviet officials, including the head of the Soviet cosmonaut training center at Zvezdnyy Gorodok, General Beregovoy, confirmed this. The main reason for this attitude seems to stem from difficulties in adaptation and physical problems encountered by Tereshchkova during the flight. We should remember that France had already selected a woman (Mme Anny-Chantal Levasseur-Regourd) among the five French candidates for flight on board NASA's SPACELAB (the other candidates were Jean-Jacques Dordain, Jacques Susplugas, Laurent Stieltjes and Philippe de Guillebon). These former candidates could obviously be reconsidered for the French-Soviet flight.

A one-week mission

President Petrov announced that the flight of the French-Soviet crew will be about one week long. It will, therefore, take on the guise of a "visiting crew" to another crew of Soviet cosmonauts already on board the SALYUT station, in accordance with the scenario implemented and repeated several times by the USSR with cosmonauts of the East European countries.

The French-Soviet crew will have a full research program. From the list of experiments proposed and presently being examined, Academician Roald Sagdeyev, director of the Space Research Institute (IKI) in Moscow, cited the following: experiments in materials processing under conditions of microgravity (which hold great interest for CNES), space biology and medicine (involving the crew), studies of the upper atmosphere (with sophisticated instrumentation) and astronomy. A very interesting experiment in infrared astronomy with a telescope cooled by liquid helium was proposed, but it seems that it would be too difficult to carry out at this time, according to Sagdeyev.

The choice of experiments for this mission will be made by the end of the year, said the CNES president in explaining that it will be determined by the "added value" of the presence of the astronauts to undertake them. They will, therefore, be experiments that cannot be conducted automatically from satellites.

A decisive step for French-Soviet cooperation

Soviet officials also emphasized that the flight of a French astronaut together with a Soviet cosmonaut on board Soviet space vehicles (SOYUZ and SALYUT) will have a particular significance.

President Petrov believes that this will be a "decisive" step in French-Soviet space cooperation and "testimony to the friendly relations and a strengthening of ties between the two nations."

Right now the offer made to France by Leonid Brezhnev last April to launch a French astronaut concerns only one flight. But President Curien said that if this flight is a success, the "French hope that the success will be repeated." He thus confirmed that in the minds of French officials this is not simply an immediate and spectacular operation, but one that gives a new dimension to French-Soviet space cooperation and makes France a still more involved partner to the USSR.

This will, in effect, be the first time that a non-Communist country will have access to the great capabilities of the USSR in human spaceflight, rockets, transport ships and orbital stations!

French-Soviet Venus Mission

Paris AIR & COSMOS in French No 784 (27 Oct 79) p 48

[Article by P. L.: "Two French Balloons in the Venusian Atmosphere in 1985"]

[Text] It is expected that the French-Soviet VENERA 84 project will be launched in December 1984 (instead of June 1983), sending two Soviet automatic probes to Venus by mid-1985; each will release into the planet's atmosphere a French-designed balloon which will float at an altitude of 56 km for a prolonged period of time to study the dynamics and chemistry of the Venusian atmosphere, explained Professor Pierre Morel, assistant general director of CNES, at the French-Soviet talks at Ajaccio.

At present this is the most important project within the French-Soviet cooperative program; it will involve most of the French space research laboratories and several Soviet labs. The definitive commitment to the VENERA 84 project must be confirmed by CNES and Intercosmos through a protocol accord awaiting signature within the next few months. But, according to both parties, this is nothing but a formality. The project's technical feasibility was just confirmed and the talks in Ajaccio made it possible to define the scientific objectives. They will involve measures complementary to those already implemented on Soviet and American probes, explained President Curien, who expects that this mission will yield "truly original results that will contribute to our understanding of Venus."

The Soviet satellites orbited around Venus will photograph in succession, at regular intervals, the planet's cloud cover in order to reconstruct its movement. They will also be equipped with several spectrophotometers to reveal the vertical temperature profile of the Venusian atmosphere. The French balloons, which will drift at the mercy of the winds, will serve to "trace" the atmospheric circulation. In addition, the Balloon's instrument package will make it possible to analyze the ambient atmosphere where a complex chemistry dominates.

Two balloons 9 meters in diameter

The two Soviet satellites, which will aproach Venus 1-2 days apart will repeat the same scenario. Having been placed into orbit around the planet, each of them will eject a spherical capsule 2 m in diameter, containing the French balloon and its instrument package as well as the guidance system. In its flight configuration, the entire aerostat will weigh approximately 400 kg: the instrument package with its 25 kg of scientific equipment weighs 200 kg, and the spherical balloon, which is little more than 9 meters in diameter, accounts for the remaining weight.

The descent of the capsules will be slowed by several parachutes to be deployed in succession: first Soviet-manufactured parachutes and then a parachute of French design (a shuttered cruciform) for final braking and extracting the balloon (which will have been folded throughout the flight).

At Ajaccio CNES also presented a film on the balloon tests, in particular, two rather spectacular sequences of inflation tests on a truck traveling the roads at CEL and free fall tests from a Transall plane. Next year CNES will execute a complete flight simulation including inflation of the balloon in the earth's atmosphere. The sequence of releasing the balloon into the Venusian atmosphere will last about 1 hour. The balloon will be rapidly inflated (in 5 min) after free fall (10-17 m/s), and then it will rise slowly (about 40 min) under the effect of heating the aerostatic gas in order to attain its nominal flight altitude.

Through clouds of sulfuric acid

These high pressure balloons are designed to fly in a constant density in the atmosphere, such as at an altitude of about 56 km (layer C), corresponding to the principal circulation of Venusian clouds. In fact, as explained by Professor Blamont, we are not talking about clouds at all, but rather a relatively light fog (200-300 drops/cm^3) where visibility is several kilometers. This "condensed phase" consists, for the most part, of sulfuric acid (86% in mass) as well as hydrochloric acid, hydrofluoric acid and a little water vapor. The "gas phase" (the atmosphere) consists almost entirely of carbon dioxide (96.5%) and a little nitrogen (3.5%) with some traces of minor substances (carbon monoxide, argon). And the temperature at this altitude exceeds 100°C. The balloon casing, therefore, must be developed according to a very special technique for tolerating such a set of mechanical, thermal and chemical constraints.

The balloons will be ejected into the equatorial atmospheric circulation on the dark side of the planet at about midnight in order to drift onto the illuminated side. It is expected that their flight will terminate at midday, the equivalent of 4 earth days in operation.

ARCAD 3 Project

Paris AIR & COSMOS in French No 784 (27 Oct 79) p 49

[Article by P. L: "The ARCAD 3 Satellite Will Be Launched in the Spring 1981"]

[Text] The Soviet Avos T-type satellite of the French-Soviet ARCAD 3 project, which is devoted to the study of the auroral ionosphere and magnetosphere, will be launched in the spring 1981. The decision was made, as expected, during the French-Soviet talks at Ajaccio. The satellite will be launched from the secret military launch site at Plesetsk (UUSR) in the presence of Soviet officials alone. French specialists, however, will be invited to attend a sort of "practice session" for launch operations, but at another Soviet launch site at Kapustin Yar near Volgograd--where some French specialists have already been admitted for the launch by the Soviets of the French scientific satellite SIGNE 3. On the other hand, French technicians will be able to participate in the final integration of the ARCAD 3 satellite, which will take place at the Space Research Institute (IKI) in Moscow. The ARCAD 3 project is, therefore, the first project of "profound" space cooperation (level 3 according to the French-Soviet classification) between the USSR and France in the construction of a satellite.

Cooperation in Space Communications

Paris AIR & COSMOS in French No 784 (27 Oct 79) p 49

[Article by (P.L.): "Experimental Links by OTS 2 and STATSIONAR Satellites"]

[Text] French-Soviet cooperation in satellite telecommunications is essentially experimental. In past years some experimental television transmissions were realized via the French-German SYMPHONIE satellites. Professor P. Morel, assistant general director of CNES, announced at the French-Soviet talks at Ajaccio that more sophisticated experiments will be conducted by the two countries, particularly in the field of digital transmission of telephone communications and television programs at 11-14 GHz with the European Space Agency's experimental OTS 2 telecommunications satellites. Experimental sound and video transmissions between Paris and Moscow are also anticipated with a Soviet STATSIONAR series geostationary satellite. Furthermore, studies are being jointly conducted regarding the future growth of space telecommunications traffic between the USSR and France beginning in 1990.

Gamma Radiation Detector To Be Tested

Paris AIR & COSMOS in French No 784 (27 Oct 79) p 49

[Unsigned article: "Tests on the GAMMA 1 Satellite Detector To Be Conducted on a SALYUT"]

[Text] It was learned at the French-Soviet talks at Ajaccio that work on the large Soviet gamma astronomy satellite GAMMA 1 will be undertaken. The launch of the GAMMA 1 satellite, which has already been pushed back to 1982 (from 1980), will probably take place in 1983, considering delays expected in the development of the satellite and its instrumentation.

This satellite is destined for a very interesting French-Soviet experiment to study the fine structure of galactic gamma radiation and discrete gamma sources that are already known as well as to search for new sources of gamma radiation. The major instrument for this experiment is a large Soviet-made sensor (spark chamber) detecting radiation of energies greater 50 keV which must be installed on a large Soviet satellite. It appears that such a large satellite will--despite some uncertainty earlier--be available. But the realization of some of the on-board equipment--such as the stellar sensor--still pose some problems, more financial than technical. France will supply the Vidicon imaging system and the high-speed processing electronics needed for the Soviet detector. At present it is expected that this detector will be tested on a future SALYUT orbital station in order to improve its angular resolution.

UFT Satellite To Be Developed

Paris AIR & COSMOS in French No 784 (27 Oct 79) p 50

[Unsigned article: "The Development of the UFT Ultraviolet Satellite Is Assured"]

[Text] The future of the UFT ultraviolet astronomy satellite "is now assured," said CNES President Hubert Curien at the talks at Ajaccio.

The UFT (ultraviolet telescope) satellite should be launched in 1982 (instead of 1981), announced Academician Andrey Severnyy, director of the Crimean Observatory, who is promoting the project together with his French colleague Professor Courtes, director of the Space Astronomy Laboratory (LAS) in Marseilles. This satellite is designed to study stellar atmospheres using an ultraviolet telescope with an 80 cm aperture manufactured in the USSR and a spectrometer provided by France. Academician Severnyy said that it will be of great interest to modern astrophysics, especially for the study of "black holes."

This "very nice project," as President Curien described it, has required that the Soviet Union develop a special satellite. It is necessary to have a satellite of sufficient size to carry the large ultraviolet telescope and its triaxial precision orientation system. The USSR has, therefore, provided a VENERA-type satellite (usually used for Venus missions) which will be launched into a high elliptical near-earth orbit comparable to that traced by Soviet PROGNOZ satellites.

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Space Biology and Medicine

Paris AIR & COSMOS in French No 784 (27 Oct 79) p 50

[Article by Pierre Langereux: "Expansion of Experiments in Space Biology and Medicine"]

[Text] The French-Soviet working group on space biology and medicine has decided to substantially develop physiological research on humans and animals subjected to long periods of weightlessness, announced Professor Pierre Morel, assistant general director of CNES, at the talks in Ajaccio.

Until now the research conducted jointly has been relatively modest; it has concerned, for the most part, the effects of radiation on microorganisms (the CYTOS experiments). However, the plan to send a French astronaut into space opens greater prospects.

BIOBLOC 3 and BIOBLOC 5, new experiments in radiobiology, are expected to be flown on the next Soviet biosats. At the talks in Ajaccio, Yuriy Nefedov, deputy director of the Institute of Space Biology and Medicine in Moscow, also presented the CYTOS 2 and DS 1--KROVOTOK (alias MINERVA) experiments. The CYTOS 2 experiment is designed to test the resistance of microorganisms to antibiotics in order to determine which drugs are indispensable to the astronauts on board space vehicles; the Soviets are not excluding the possibility that infectious diseases may arise during long-term spaceflights. The MINERVA experiment is a unique experiment to study blood circulation in the brain with a sonographic flowmeter using non-invasive techniques. Another French-Soviet joint experiment being developed is also designed to study physiological phenomena in the brain.

Finally, an important joint program in radiation protection, conducted this time with ground-based experiments, is currently underway with Soviet charged particle accelerators at Dubna (USSR).

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