JPRS L/9526

5 February 1981

USSR Report

SPACE

(FOUO 1/81)

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THE 175-DAY SPACE FLIGHT: SOME RESULTS OF THE MEDICAL RESEARCH

Moscow VESTNIK AKADEMII NAUK SSSR in Russian No 9, Sep 80 pp 49-58

/Article by Academician O.G. Gazenko and A.D. Yegorov, doctor of medical sciences/

/Text/ As is well known, the flight of the third main expedition in the "Salyut-6"-"Soyuz" orbital complex, which was carried out in the USSR in 1979, was of unprecedented length: cosmonauts V.A. Lyakhov (commander) and V.V. Ryumin (flight engineer) remained in space for 175 days. The basic stages of this flight were joint work with three cargo transport ships, redocking of the "Soyuz-34" transport ship from one of the station's docking units to the other, a space walk on the 172d day of the flight, and the separation of the space radiotelescope's antenna from the station. During the flight a number of the most variegated assignments were carried out. As far as the medical objectives were concerned, they consisted -- as during the flights of the preceding main expeditions (96 and 140 days) -- of maintaining the crew in a good state of health with sufficient capability to work during the flight, performing medical research, administering a complex of prophylactic measures to prevent an unfavorable effect of flight factors on the human body, and preparing the cosmonauts for their return to terrestrial gravity.

In this article we present some of the medical and physiological research data that were obtained during the flight by a large collective of staff members from the USSR Ministry of Health's Institute of Medicobiological Problems, the Cosmonaut Training Center imeni Yu.A. Gagarin, and other organizations[1].

Before presenting these data, we should give a brief description of the conditions under which the cosmonauts worked.

The gas medium in the orbital complex's crew quarters was close to that of the Earth's atmosphere; its basic indicators fluctuated within the following limits: total pressure -- 750-832 mm Hg; partial pressure of oxygen -- 154-195 mm Hg, carbon dioxide -- 1.34-6.8 mm Hg, water vapor -- 5.3-17.1 mm Hg; air temperature -- 14.6-24.3°C.

The total radiation exposure during the flight was 3.2-5.7 Rem. The cosmonauts ate from a 6-day menu on which there were 70 products. The daily food ration, the calorie content of which was 3,100 available kilocalories (on the "Salyut-4" station it

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[1] A detailed account is supposed to be given in a separate publication.

was 2,800 kcal), contained the following basic nutrient and mineral ingredients: proteins -- 135 g, fats -- 110 g, carbohydrates -- 380 g, calcium -- 800 mg, potassium -- 3.0 g, phosphorus -- 1.7 g, sodium -- 4.5-5.0 g, magnesium -- 0.4 g, iron -- 50 mg. An "Aerovid" vitamin pill supplemented the food on a daily basis.

During the flight, cargo ships delivered fresh products according to the crew's wishes. On the whole, the food ration not only matched the probable energy expenditure levels, but also contained the basic components required for stress situations.

The crew's water consumption averaged 1.4-1.8 ℓ per day per man (not counting the water in the food ration and metabolic water), and was provided by water preserved with silver ions, as well as hot water from the regeneration system.

The established work and rest regime allocated 9 h per day for sleep (from 2300 to 0800 h, Moscow time), 2.5 h for physical training, 2.5 h for eating (4 times per day), about 8 h for experiments and other work, and 2 h of so-called "free time" (of which 1 h, as a rule, was spent on resting after meals). Saturday and Sunday were the crew's days off.

Beginning with the fourth day of the flight, every day the crew had physical training, in the morning and evening, on a veloergometer and an integrated trainer (KTF) with a moving track that was equipped with a "traction" system that created a load of about 50 kg along the body's longitudinal axis. In addition, strength exercises with shock absorbers and rubber ligatures were performed every day. The training exercises were based on the cyclic principle of load proportioning (3 days of training exercises, with active rest on the fourth day) with -- based on the experience of previous flights -- special attention being given to the development of strength and coordination skills using a specially developed system of exercises for individual muscle groups (research performed by I.B. Kozlovskaya, V.I. Stepantsov and V.A. Tishler). For 8-day cycles, the average amount of time spent exercising was geared to the individual and, on a daily basis, was as follows for the commander and the flight engineer, respectively: on the integrated trainer -- 37-60 and 34-56 min, on the veloergometer -- 33-35 and 37-50 min, strength exercises -- 8-16 and 18-35 min, for a total of 85-117 and 92-136 min. On the integrated trainer the cosmonauts increased the load by walking and running, primarily with the trainer's motor disengaged while the amount of traction on the track was increased gradually, as well as by running without supporting themselves with their hands. According to the data that were recorded telemetrically, the daily load on the cosmonauts while exercising on the veloergometer averaged 38,000-40,000 kgf·m, while the total distance covered on the trainer (walking and running) was 3.9-4.3 km. The cosmonauts almost always (except for sleep periods) wore "Penguin" suits that created a load on the motor-support system.

Training exercises for the crew members with the application of negative pressure to the lower part of the body with the help of a "Chibis" vacuum complex were begun 3 weeks before the end of the flight. The effect of the negative pressure was to cause a redistribution of the blood in the intertissue liquid toward the lower half of the body, which simulated the hydrostatic blood pressure under conditions of weightlessness and facilitated the maintenance of vascular tone in order to prevent a significant reduction in orthostatic stability after the flight. Preliminary training exercises of this type were performed, beginning with the 154th day, once every 4 days (on the day of active rest from physical training), 20 min at a time, with the amount of pressure being changed: on the 154th day -- -10, -15, -25, -35 mm Hg (5 min each); 158th day -- -15, -20, -35, -45 mm Hg; 162d and 167th days -- -25, -35, -40, -45 mm Hg. On the last 2 days of the flight (the 173d and 174th days) the final training was carried out, with alternating pressures: -25, -30, -35 and -40 mm Hg for 5 min each, and -25, -35 and -40 mm Hg for 10 min each. In order to increase their circulating blood volume, 20 min before the beginning of the training the cosmonauts had to drink 300 mℓ of water. Neither cosmonaut experienced any unpleasant sensations during this training, and the maximum systole rate during the rarefaction usually did not exceed 85-95 beats per minute.

On the day of the landing, saline-water additives (3 g of table salt in 300-400 mg of water, 3 times a day) were used to maintain the liquid in the body and increase the circulating blood volume, which contributes to an increase in orthostatic stability.

The postflight prophylactic suit was donned before the descent and was intended to create excessive pressure on the lower part of the body, thereby preventing the deposition of blood in this area immediately after landing, in order to improve the venous return of the blood and maintain orthostatic stability when the body was in a vertical position.

As a preventive treatment against metabolic changes in the heart muscle, the cosmonauts took inosin-F and panangin /translation unknown/ preparations (two tablets two times a day on the 90th-99th days and two tablets three times a day on the 147th-161st days), and in the last 2 weeks they took alimentary corrective additives that included a vitamin complex consisting of decamevit, methionine and glutamic acid, which cause an intensification of the metabolism, the synthesis of catecholamines and normalizing intestinal microflora, and lipin exchange.

An extensive program of measures aimed at organizing the cosmonauts' spare time, making up for the deficit in social contacts, and maintaining purposefulness in the area of new types of activity was provided. Here we have in mind the informational actions that served as a unique form of psychological support for the crew and were provided by an Earth-ship-Earth television link (meetings with families, scientists, artists, actors and athletes, relay broadcasts of parts of movies, concerts and variety programs, and so forth), daily broadcasts of news and printed materials, and the organization of an extensive network of scientific consultations.

THE FLIGHT PERIOD

On the whole, the cosmonauts' overall state during the flight was good. However, in connection with the transition to weightlessness, sensations of blood rushing to the head developed, some edema of the face tissues was observed, and the sound of the voices changed (a nasal shading was heard). These phenomena leveled out during the first week of the flight and disappeared completely after about 3 weeks. The degree to which they were expressed varied with the individual. On completion of the period of adaptive reaction, no changes in the crew members' states of health were observed. Their natural functions were not disrupted throughout the entire flight. Appetite was maintained. At least 7-8 h per day were spent sleeping.

During the flight the cosmonauts evaluated their own state of health, by investigating the effect of the orbital complex's rotation at 0.5 r/min for more than 4 h:

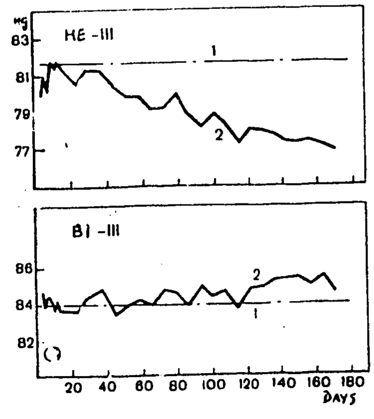

Figure 1. Dynamics of body mass of crew members during the flight of the third main expedition: KE-III = commander; BI-III = flight engineer; 1. average body mass before flight; 2. body mass during flight.

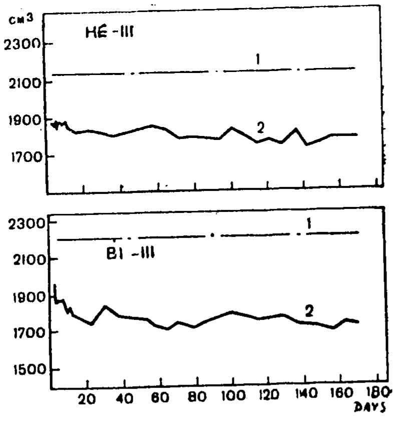

Figure 2. Dynamics of shin volume of crew members during the flight of the third main expedition: KE-III = commander; BI-III = flight engineer; 1. average volume before flight; 2. volume during flight.

neither near the center of rotation or at the maximum distance from it were any unpleasant sensations or differences in the state of health detected when at rest or when performing given movements of the head.

Anthropometric investigations showed that V.V. Ryumin's body mass, as determined with a massmeter, practically did not change or increased somewhat during and after the flight (Figure 1), while V.A. Lyakhov's body mass decreased gradually: on the 163d day of the flight the deficit in body mass was 4.4 kg, and after the flight it was 5.5 kg. For the commander, the loss in shin volume during the first 100 days of the flight was 13-15 percent, and later was 16-19 percent; for the flight engineer it was 11-19 percent after the first 12 days and then 20-24 percent (Figure 1). The strength of the commander's hands did not change during the flight, while that of the flight engineer's hands increased.

After the flight there was some decrease in the perimeters of the shins for both cosmonauts (2.8-3.0 cm). The reduction in body mass and shin volume can probably be related to liquid redistribution and losses during the initial period of weightlessness, as well as to some loss of muscle mass as the result of underloading of the motor-support system.

A study of the tissues' oxygen regime during the flight, which was made under the leadership of Ye.A. Kovalenko, showed a reduction in the partial pressure of oxygen (pO_2) and the rate of its consumption in the skin of the forearm on the part of both cosmonauts, which phenomenon progressed as the flight continued. For instance, before the flight the commander's pO_2 was 36.5 mm Hg and the flight engineer's was 37.9; after a month of flight the pO_2 values dropped to 26.8 and 33.4 mm Hg, respectively, and by the end of the fifth month they had decreased to 14.4 and 22.8 mm Hg, respectively. It is interesting that an analogous course also characterized the rate of O_2 consumption: before the flight -- 12.6 and 13.7 mm Hg/min; after a month -- 8.2 and 9.5; after 5 months -- 8.1 and 10.1. About a week after the end of the flight the oxygen regime indicators were approximately the same as the preflight ones. These data enable us to think that changes in the oxygen regime of peripheral tissues can indicate the development of venous congestion phenomena and changes in microcirculation within the broad circle of blood circulation that are the result of an increase in the pressure of the tissue liquid in the upper part of the body (some flabbiness in the tissues above the level of the heart), which in turn is caused by redistribution of the blood in weightlessness. In connection with this, it is possible that bypass (that is, extracapillary) blood circulation increases because of a decrease in capillary circulation, which has been confirmed indirectly by the results of research performed by O.G. Gazenko and A.M. Chernukh in model experiments with antiorthostatic hypokinesis during the study of microcirculation in conjunctiva.

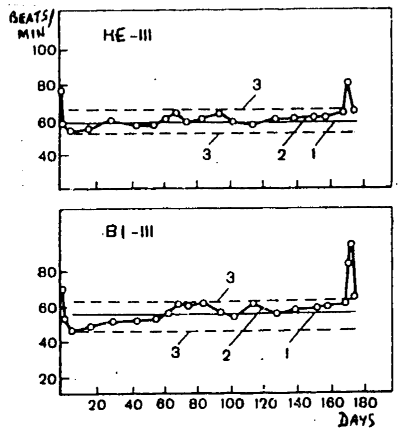

Figure 3. Dynamics of frequency of systole beats during flight:
KE-III = commander; BI-III = flight engineer; 1. average during the preflight period; 2. actual average frequency at different periods of the flight; 3. limits of fluctuations in preflight period.

As studies of the cardiovascular system have shown, the frequency of both cosmonauts' systole rate was practically the same as during the preflight period (Figure 3), except for the period of the space walk and work outside the ship on the 172d day of the flight: for the commander and the flight engineer this indicator was 80-105 and 74-130 beats per minute, respectively, before the hatch was opened; while working outside the station it was 66-112 and 108-146; during entry into the transfer compartment and lock cycling, it was 70-107 and 58-94 beats per minute.

Some arterial pressure indicators had a tendency to drop during certain stages of the flight. According to data gathered by rheography, the beating volume of the heart and the instantaneous blood circulation volume for the commander were lower during the first 3 months of the flight than the preflight levels, but after that did not differ from them, for all practical purposes. At the same time, the flight engineer's hemocirculation indicators -- in particular, the instantaneous blood circulation volume up until the 114th day -- exhibited a tendency to increase (which agrees with the corresponding data from the 96- and 140-day flights) and then to decrease.

For almost 3 months of the flight, the flight engineer's indicators for pulsed blood-filling of the brain's blood vessels (Figure 4) exceeded the average preflight levels , while there was a simultaneous decrease in the indicators for pulsed blood-filling of the shin's blood vessels on the part of both cosmonauts (Figure 5), as well as an increase in the filling of the forearm's vessels with blood. The venous pressure in the jugular vein (as determined by an indirect method) was increased throughout the entire flight, while in the shin vessels it dropped in connection with a simultaneous decrease in vein tone and an increase in vein elasticity.

Electrocardiograph studies (12 leads) revealed no substantial changes in the heart muscle's bioelectric activity during the flight. The only things noted were an

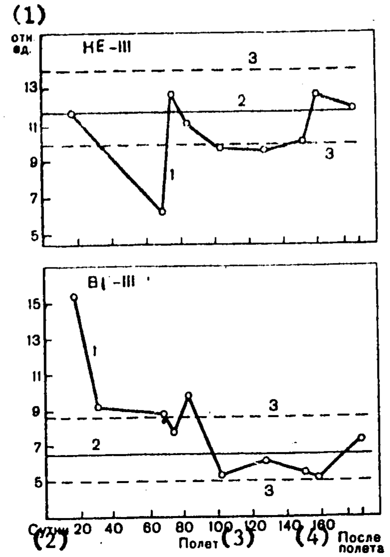

Figure 4. Dynamics of pulsed blood-filling of brain blood vessels during the flight: KE-III = commander; BI-III = flight engineer; 1. actual filling during different periods of the orbital flight; 2. average during preflight period; 3. limits of fluctuations during preflight period.

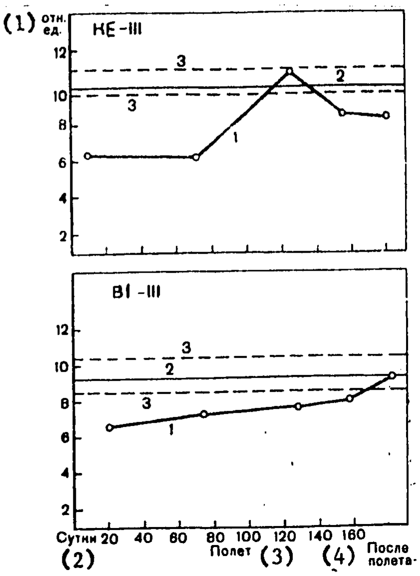

Figure 5. Dynamics of pulsed blood-filling of shin blood vessels during the flight: KE-III = commander BI-III = flight engineer; 1. actual filling during different periods of the flight; 2. average during preflight period; 3. limits of fluctuations during preflight period.

Key to Figures 4 and 5:
1. Relative units
2. Days
3. Flight
4. Postflight

intensification of sinus arrhythmia in the commander after being under a physical load, and some positional changes and a reduction in the T spikes' amplitude for the flight engineer when he was at rest, while after the flight there was a reduction of the T spike for all 12 leads. The change in the repolarization was probably related to changes in the metabolic processes and possibly to vegetative disbalance.

Endurance was tested on the veloergometer, under a physical load, and one of the other studies was the nature of the reactions to a functional test with the application of negative pressure to the lower part of the body.

For both cosmonauts, endurance under a physical load (the veloergometer's pedals were turned for 5 min under a load of 750 kgf·m/min) was evaluated as good for the entire duration of the 175-day flight. In connection with this, the reaction of the heartbeat rate and arterial pressure corresponded to the preflight levels. On the part of the commander, singular reactions to the test under a physical load were manifested by a sharper (than before the flight) increase in the specific gravity of the heartbeat rate, an increase in the instantaneous blood circulation volume, a reduction of the blood vessels' peripheral resistance, and in increase (in some studies) of the degree of markedness of the myocardium's hyperdynamics.

Thus, according to the data on the test under a physical load that was conducted throughout the flight, the cosmonauts exhibited no signs of deconditioning. At the same time, on the 140-day and (to a greater degree) 96-day flights, and mainly after the flights of all 3 crews on the main expeditions, the cardiovascular system's reactions to tests with a measured physical load were more pronounced than before the flights.

The functional test with the application of negative pressure to the lower part of the body (-25 mm Hg for 2 min, -35 mm Hg for 3 min) caused a circulation reaction that was generally similar to the preflight one as far as heartbeat rate and arterial pressure were concerned. However, on the part of both cosmonauts we noticed a more pronounced development of functional hypodynamism of the myocardium and an increase in the pulse wave's rate of propagation along the aorta, while for the flight engineer, in addition, there was a more pronounced reduction in the heart's pulsating volume and the instantaneous blood circulation volume in comparison with the preflight levels. Such types of reactions during the flight apparently reflects a decrease in the flow of blood into the heart in connection with the effect of the negative pressure on the lower part of the body during the flight, because of the deposition of blood in the decompression zone against a background of a supposed reduction in the circulating blood volume.

Generalization of the results of the investigation of the cardiovascular system during the extended manned flights in the "Salyut"-"Soyuz" program makes it possible to propose a hypothetical plan for the mechanism of the changes in this system under weightlessness. It is assumed that the basic factor determining the qualitative uniqueness and specifics of the physiological changes in the body under space flight conditions is weightlessness, while the main link in its effectuating mechanism is a reduction in the functional load on a number of systems in connection with the absence of weight and the mechanical stresses on body structures that are related to it.

In weightlessness there is a redistribution of the body's liquid mediums in the direction of the upper part of the body that is maintained persistently throughout a flight. This is indicated by the shifting of the body's center of mass, which was discovered during research done as part of the "Skylab" program, as well as a tendency toward an increase in cardiac discharge, venous pressure and the pulsed blood-filling of the brain, as registered during flights in the "Salyut" program. This redistribution of liquid is probably the cause of the engagement of a number of mechanisms that cause changes in physiological functions.

The general outline of the mechanisms of the change in physiological functions that are caused by the displacement of liquid in the cranial direction is represented in the following form:
an increase in transmural absorption of the tissue liquid;
a reduction in tissue pressure in the area of the lower extremities (a reduction in the volume of the lower extremities);
an increase in transmural pressure and filtration in the capillaries in the upper part of the body (edema of tissues above the level of the heart);
an increase in venous return, elongation of the central veins and auricles of the heart, and an increase in cardiac discharge;
an increase in the pulsed blood-filling of the brain and the jugular veins;
an increase in venous pressure in the jugular veins and a decrease in the shin veins, which leads to equalization of the pressure in different areas, up to the

level of the central venous or right arterial pressure;
a decrease in the pressure gradient in the venous system;
an enlargement of the role of active diastole (relaxing of the heart) in hemodynamics;
the development of a phase syndrome of loading by volume; that is, an increase in the influx of blood;
an increase in pressure in the heart and lung area and inhibition of the vasomotor centers;
an improvement in the tone of the vagus nerves and the engagement of relieving reflexes (V.V. Parin, 1965) from the lung blood vessels' receptors, which limit the influx of blood into the heart and lower the tone of the vessels of the large blood circulation circle (a tendency toward a reduction in arterial pressure and peripheral resistance);
elimination of part of the liquid by the (Genry-Gauer) mechanism (loss of weight and some electrolytes) and an enlargement of the blood deposition points as the result of stimulation of the receptors of the auricles and lung blood vessles, which compensates partially for the degree of markedness of the changes (a reduction in the facial edema and the sensation of rushing blood, among others);
stabilization of the new functional level of blood circulation, because of the engagement of compensatory mechanisms from the reflexogenic zones of the carotid artery (carotid sinus).

Later on during a stay in weightlessness, because of the constant physical underloading of the body (particularly when the physical training is inadequate) and, it is conjectured, the reduction in the function of the muscles that control posture (since there is no need to resist the force of gravity), the muscle system becomes deconditioned to a greater or lesser degree. As a result, it is possible to see a reduction in the activity of the intramuscular peripheral heart /sic/ (described by N.A. Arinchin in 1974), which shifts the blood from the arteries through the capillaries of the skeletal muscles and into the veins, thereby lightening the heart's work and facilitating the return of venous blood to the heart. A reduction of the skeletal muscles' intraorgan pumping function can also contribute to the development of venous congestion phenomena and an increase in venous pressure.

This plan gives a satisfactory explanation of the most common regularities of the changes in the cardiovascular system during space flight. However, the use of a complex of prophylactic measures and its significant expansion -- as was observed during the 175-day flight -- can smooth out some changes caused by a stay in weightlessness, which fact must be taken into consideration when interpreting the data that have been obtained.

THE READAPTATION PERIOD

After the landing, the cosmonauts felt tired at the landing site; it seemed to them that the weight of their bodies and surrounding objects that they were manipulating had increased (this sensation disappeared on the third day after the flight). When the cosmonauts were examined, the following features were observed: paleness of the skin and increased perspiration, limited locomotor function, moderately pronounced fatigue and asthenia, and a reduction in orthostatic stability when standing.

Examination by medical specialists at the cosmodrome on the day the flight ended and the next few days revealed changes in the cosmonauts' gaits, an increase in tendon reflexes (on the part of the flight engineer), dilation of the veins in the bottom of the eye, lowering of the sensitivity thresholds of the otolithic apparatus, with vegetative reactions when the body's position was changed (on the part of the commander), accentuation of the lung artery's second tone (on the part of the commander), and deconditioning relative to physical and orthostatic loads. The cosmonauts' states of health then improved progressively and motor activity was expanded gradually, so that 5-7 days after the landing they were taking about 10,000 steps during the walking period.

According to data from a resting exocardiographic examination (performed by O.Yu. Atkov and G.A. Fomina), after the flight both cosmonauts exhibited a transient increase in the volume of the left auricle and reductions in the volume of the left ventricle's cavity and the pulsating volume in the absence of changes in the myocardium's contractility.

An investigation of the motor apparatus after the flight, conducted by I.B. Kozlovskaya and associates, revealed changes in the electromechanical activity of muscle contraction (a loss of tone and a reduction in the perimeters of the shin muscles, an increase in the electromyographic "cost" of muscle exertion, and a reduction of the shin and back muscles' power characteristics while those of the thigh muscles were retained), an increase in the proprioceptive inputs' reactivity, disruption of the interextremity and postural synergies, and disruption of movement coordination and the vertical posture regulation mechanism.

On the fifth day after the flight, G.P. Stupakov and associates investigated the content of the mineral component (according to hydroxyapatite) in the calcanus by direct photon absorptiometry. They discovered reduction in the hydroxyapatite content that amounted to 8.3 percent for the commander and 3.2 percent for the flight engineer, which figures are substantially lower than those seen after extended bed rest.

A change in water-salt exchange (A.I. Grigor'yev) was manifested on the day the flight ended by a reduction in the kidneys' excretion of liquids (this became normalized in the next few days), an increase in the excretion of bivalent ions (calcium and magnesium), and an increase in the concentration of calcium in the blood. For the commander, in addition, there was a reduction in the potassium concentration. In the first few days after the flight, the extracellular liquid volume dropped for the commander and flight engineer by 11.0 and 4.1 percent, respectively. A test with a water-potassium load, which was performed for the purpose of studying the kidneys' ion-regulating function, made it possible to establish a mismatch in the ion-regulating system that was expressed as an increase in the excretion of potassium, calcium and magnesium and a simultaneous reduction in the excretion of liquids and sodium by the kidneys. An analysis of the data as a whole left the impression that the shifts in the water-salt exchange were caused by changes in the regulatory system and the hormonal status in weightlessness and during readaptation to Earth conditions, as well as a reduction in potassium retention while the kidneys' functions were preserved.

Hematological studies conducted after the flight indicated a reduction in the number of erythrocytes and hemoglobin (it progressed until the eighth day and recovered in the period between the 36th and 52d days of the readaptation period -- see the table on the next page), as well as a reduction of 16-18 percent in the total hemoglobin mass (studies performed by V.I. Legen'kov and associates).

Dynamics of Some Hematological Indicators After the Flight

Days	Number of erythrocytes, million/μℓ		Hemoglobin content, H%	
	Commander	Flight Engineer	Commander	Flight Engineer
Preflight	4.6	5.1	14.9	14.9
Postflight				
0 (day of landing)	4.4	4.4	13.9	15.0
1st day	3.8	4.1	14.0	14.4
3d day	3.8	4.2	14.2	13.2
8th day	3.7	3.4	12.5	13.0
36th day	4.0	4.2	14.1	14.4
52d day	4.5	5.9	15.8	17.2

Transient leucocytosis was also noted in the first few days after the landing. No changes were seen when urine samples were analyzed.

Immunological, allergy and microbiological studies were also made during the readaption period.

The immunological and allergy studies (I.V. Konstantinov) established that the commander had a reduction in thymus-dependent lymphocytes and that both cosmonauts exhibited reduced reactivity of these immunocompetent cells. After the flight, the commander displayed signs of sensitization to streptococcal microflora, while the flight engineer developed a delayed hypersensitivity to staphylococcus and streptococcus. Signs of sensitization to these micro-organisms were also observed in the flight engineer for up to 6 months before the flight, although they did not manifest themselves in the 2-3 weeks before it.

Thus -- as was also noted on the preceding flights -- changes develop in immunological reactivity under flight conditions, but they gradually normalize over different spans of time in the readaptation period.

Postflight microbiological studies (according to data gathered by V.M. Shilov and S.N. Zaloguyev) did not reveal any substantial changes in the staphylococcal flora in the upper respiratory passages or the microbe cenosis in the intestines. At the same time, a reduction in the lactobacillus content in the intestinal microflora was noted, as well as an increase in provisionally pathogenic enterobacteria that are not very sensitive or even resistant to six antibacterial preparations. On the whole, changes in the automicroflora were less pronounced than after the 96-day and 140-day flights.

In order to accelerate the normalization of the functional changes that developed under the influence of flight factors and the Earth's gravity after the protracted stay in weightlessness, during the readapation period a complex of recuperative measures was implemented. This complex was based on functional effect methods that included regulation of motor activity, the utilization and gradual expansion of physical exercise, regenerative muscle massage, athletic games, water, air and solar procedures (including swimming, showers and saunas), and measures aimed at having a psychoemotional effect. The effectiveness of the measures was evaluated by subjective feelings, the dynamics of the heartbeat rate, and the arterial pressure level during the procedures, as well as by the results of clinicophysiological examinations. The recuperative measures were implemented at the cosmodrome and then under sanatorium conditions on the Black Sea coast. The physical exercises both during and after the flight were based on the cyclic principle of loads (a 4-day cycle), individualization, and division of the exercises (three or four times a day, using different equipment and methods).

OVERALL RESULTS

The medical research carried out during and after the flight showed that man can not only adapt to a 6-month stay under space flight conditions, but can work actively under them and perform complex scientific and technical experiments and function outside the spacecraft.

Active medical control of the complex of prophylactic measures used during the flight, based on medical examinations of the crew and in combination with rational work and rest regimes, full-value nutrition, sufficient water consumption, and adequate sleep, insured the maintenance of the cosmonauts in a good state of health, with sufficient capacity to perform their work, during the 175-day flight. It also contributed to a smoothing out of their reactions and facilitated the process of readaptation during the postflight period.

The changes that were observed in different body systems at rest and during functional tests during all phases of the flight and after its completion were of an adaptive nature, corresponded to the influencing factors, and on the whole were not reflected in the cosmonauts' ability to do their work and carry out the flight program.

During and after the flight, no substantial changes that would prevent planned increases in the duration of space flights were observed in the cosmonauts' health.

The data that the "Salyut-6"-"Soyuz" program furnished on the human body's reaction to the factors of space flight are enabling us to more clearly define the basic directions for further medical research for future space flights.

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SPACE ENGINEERING

UDC 629.78:621.45

SPACECRAFT MAIN ENGINES

Moscow MARSHEVYYE DVIGATELI KOSMICHESKIKH APPARATOV in Russian 1980 signed to press 18 Jan 80 pp 2, 240

[Annotation and table of contents from book by Vladimir Fomich Safranovich and Lev Moiseyevich Emdin, Izdatel'stvo "Mashinostroyeniye", 800 copies, 240 pages]

/Text/ ANNOTATION

This book is devoted to questions of selecting the type and parameters of main engines for the interorbital flight of space vehicles during the solution of transport problems. The authors discuss engine installations with liquid, nuclear and electrojet engines, as well as methods for determining their areas of utilization and parametric series.

This book is intended for engineering and technical personnel who are concerned with the development and creation of engines and spacecraft.

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11746
CSO: 1866

UDC 629.78.05.001

ANGULAR STABILIZATION SYSTEMS FOR SPACECRAFT

Moscow SISTEMY UGLOVOY STABILIZATSII KOSMICHESKIKH APPARATOV in Russian 1980 signed to press 10 Dec 79 pp 2, 171-172

[Annotation and table of contents from book by Leonid Ivanovich Kargu, 2d edition, Izdatel'stvo "Mashinostroyeniye", 1,200 copies, 176 pages]

/Text/ ANNOTATION

In this updated and revised edition of a book that was first published in 1973, the author discusses different principles for the construction of angular stabilization systems for spacecraft. He describes passive stabilization systems, stabilization system that utilize motors, flywheels and gyroscopic actuating mechanisms, active stabilization systems that use jet nozzles, and stabilization and orientation systems for spin-stabilized spacecraft.

This book is intended for engineering and technical personnel who are concerned with systems for the angular stabilization of spacecraft.

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11746
CSO: 1866

UDC 629.735.001.2

PROBLEMS OF MECHANICS IN SPACE TECHNOLOGY -- CONTROLLABLE VIBRATIONAL PROCESSES UNDER WEIGHTLESSNESS CONDITIONS

Moscow PROBLEMY MEKHANIKI V KOSMICHESKOY TEKHNOLOGII in Russian 1978 signed to press 11 Sep 78 pp 2, 118-119

[Annotation and table of contents from book by R. F. Ganiyev, V. F. Lapchinskiy, Izdatel'stvo "Mashinostroyeniye", 970 copies, 119 pages]

[Text] A study is made of the problems of the mechanics of liquid media, including liquid media with solid and gaseous inclusions. The scientific statements of the problems with respect to controllable technological processes in space and mathematical models and methods of investigating them are substantiated. The problems of new vibrational resonance effects under weightlessness conditions and the expediency of their use in the performance of certain technological processes are brought up for discussion. The monograph is designed for scientific and engineering-technical workers dealing with the problems of space technology.

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SPACE APPLICATIONS

SPACE OCEANOGRAPHY: PROBLEMS AND PROSPECTS

Leningrad PROBLEMY ISSLEDOVANIYA I OSVOYENIYA MIROVOGO OKEANA in Russian 1979 signed to press 30 Oct 79 pp 111-133

[Article by B. A. Nelepo]

[Text] The world ocean is being studied with ever-increasing intensity. The measuring devices by means of which factual data are obtained are continuously being improved. However, the method for their use remains essentially unchanged. Observations are made either from automatic buoy stations set out in different regions of the ocean or at stationary platforms and on-shore oceanographic stations. The creation of a network of permanently operating oceanographic stations involves serious technical difficulties, including operational. Accordingly, the development and use of specialized oceanological satellite systems must be considered timely and promising as a direction in modern oceanology.

Space oceanography is based on remote methods for measuring oceanological parameters which have been recently developed. It has been found that there can be remote measurement of such ocean parameters as the global topography of its surface, state of the water surface, sea currents, the spectrum and direction of wave propagation, wind in the near-water layer, radiation balance at the ocean surface and temperature at the ocean surface. As carriers of remote measurement instruments it is possible to use both ships and aircraft, but the most promising is the use of artificial earth satellites (AES), having a whole series of advantages: long duration of operation, rapid scanning of a considerable area of the earth, etc.

The first results of use of artificial earth satellites, obtained both in the Soviet Union and in the United States, indicate the possibility of a satisfactory accuracy in the measurement of oceanological parameters.

However, today the role of remote methods for investigating the ocean with the use of artificial earth satellites is not so great as one would like. This is attributable, in particular, to the inadequate development of methods for making remote measurements, limited by the possibilities of the measuring instruments, the absence of thoroughly developed theories and methods for the processing and interpretation of the collected information. It should also be noted that remote methods make it possible to make measurements only of surface hydrophysical fields, being only a reflection of the processes transpiring in the depths of the ocean and in the foreseeable future these methods will scarcely make possible the direct "glancing" into the depths of the ocean, for example, below the layer of the seasonal thermocline. Accordingly, traditional research methods with the use of scientific research ships and buoy stations of different kinds will, as before, be developed and improved.

At the same time, the appearance of space oceanography methods will exert (and is already exerting) a considerable influence on the entire character of investigation of the ocean. This is forcing oceanologists to make a significant re-examination of established research methods and proceed to the implementation of major controllable oceanographic programs.

At their very basis the methods of space oceanography are methods of large-scale investigations making it possible to carry out a routine scanning of extensive areas of the oceans giving a general idea concerning the dynamics of the processes transpiring in the surface layer of the ocean and also to obtain quantitative evaluations of hydrophysical parameters in high-gradient zones.

The photograph cited here (Fig. 1; photography taken in September 1973 from the "Soyuz-12" spaceship by the flier-cosmonauts V. G. Lazarev and O. N. Makarov) gives some idea concerning the nature of the information obtained from the orbits of artificial earth satellites. This photograph, in particular, can be used in studying water masses and shallow seas.

On the basis of the first experiments it is difficult to give a reliable forecast of the further development of this direction in oceanography. However, it can be said with assurance that further scientific investigations, associated with the development of the theory, methods and means for remote sounding of the ocean from aboard space vehicles, will put into the hands of oceanologists a powerful tool.

On the basis of such data it is possible to plan expeditions of scientific research ships for detailed investigations using shipboard and buoy apparatus in characteristic regions in which the variability of transpiring processes determines the dynamics over considerable areas of the ocean.

Oceanologists still must create in the ocean a control network of measurement points to which will be "tied" the results of remote measurements, much as in meteorology the data obtained from meteorological satellites are "tied" to the ground network of meteorological stations. A system of automatic buoy stations, laid out in a definite way, will make it possible to obtain the vertical structure (beginning from the surface) not only of the active, but also the deep layers of the ocean. This will make it possible, on the one hand, to carry out regular calibration of the remote sounding sensors, and on the other hand, to solve the problem of transformation of the surface fields to a depth at least within the limits of the active layer.

By supplementing the mentioned measurement complex with a system of drifting buoys (with surface and neutral buoyancy) oceanologists will be able to trace surface and deep currents, eddies and rings, and also estimate their velocity. A geostationary satellite, whose field of view will take in the investigated ocean area, and a complex of measuring apparatus, including research ships, a system of anchored and drifting buoys and oceanographic measurement artificial earth satellites may become important elements determining the nature of exploitation of the entire system of buoy stations. In addition to other tasks, such satellites will

Fig. 1. Caspian Sea region (photograph taken from aboard "Soyuz-12" spaceship).

be able to collect information from a system of buoys (especially from "diving" neutral buoyancy buoys) and relay it to reception points.

1. Problems in Space Oceanography

During the last decade the intensive development of remote sounding methods has opened a new path to study of phenomena transpiring in the ocean, in particular, to investigation of its mesoscale or synoptic variability. The development of new instrumentation, the formulation of new methods for remote sounding and methods for the interpretation of information, as well as the employment of theoretical models which describe the processes transpiring in the ocean, these are the problems which must be solved before proceeding to solution of a number of fundamental problems in oceanology, and accordingly, creation of a closed hydrodynamic model of the ocean, and also subsequent prediction of its parameters.

One of such problems is a determination of the large-scale variability of the ocean. The synoptic, or mesoscale variability of macroscale ocean currents, and in particular, the variability of the most intensive of these, is manifested in changes in the position of the axis of currents, fluctuations of their intensity and meandering. These factors, in turn, lead to changes in such important characteristics as heat transport to the north by currents of the Gulf Stream type, the quantity of which determines the climate over a considerable territory of Europe and arctic regions.

The meandering of strong currents and the so-called barotropic instability associated with these processes lead to the appearance of isolated eddy formations of the cold and warm rings type. Having considerable reserves of kinetic energy, macroscale ocean currents and their variability play an important role in the general dynamic balance of the ocean, in the processes of interaction between the ocean and the atmosphere, and to a great extent determine the dynamics of the atmospheric processes themselves.

Synoptic eddies make a considerable contribution to the processes of redistribution of momentum, angular momentum, heat transport in the ocean. According to the calculations of specialists, allowance for the transport of heat by synoptic eddies can change by 30-40% the total balance of the meridional heat flow to the north.

In order to estimate the contribution of synoptic eddies to the total balance of transport of heat, momentum and angular momentum in the ocean it is necessary to know the regions of generation of eddies, the periodicity of their formation and direction of predominant propagation. Available experience indicates that remote methods for the detection of eddy formations and tracking them from orbital scientific stations are opening the way to routine prediction of "weather" in the ocean.

One of the most important factors determining macroscale variability of hydrophysical fields in the ocean is thermal anomalies and frontal zones. According to modern concepts, quite powerful and long-lived temperature anomalies and frontal zones to a great extent determine the nature of heat exchange processes between the atmosphere and ocean and exert an influence on the stability of global atmospheric processes, which, in the last analysis, is reflected in the formation of weather and climate over considerable areas of the earth's surface. It is entirely obvious that the problem of around-the-clock, and then longer-range forecasting, cannot be solved without taking the mentioned factors into account, routine collection of information on which is possible only by remote methods.

The active layer of the ocean is the connecting link in the chain of processes determining interaction between the ocean and the atmosphere. It constitutes the upper surface layer in which the physical parameters experience considerable seasonal fluctuations. Within it there is a quasi-isothermic layer characterized by a small vertical temperature gradient, the jump layer, in which the parameters of the medium experience jumplike changes, and the seasonal thermocline, characterized by a considerable vertical temperature gradient.

The variability of the active layer leads to the formation of temperature anomalies which as a result of the great thermal inertia of the ocean exert a considerable influence on the nature of atmospheric processes. In addition, the active layer of the ocean, being an intermediate link in the redistribution of heat flows, to a great extent also determines the nature of circulation of deep waters.

Quantitative estimates of macroscale interaction between the ocean and the atmosphere, including the exchange of energy, momentum, heat and moisture, can also be obtained by remote measurements of the radiation budget of the ocean surface, sediments and evaporation, the statistical characteristics of the surface waves and the wind regime in the near-water layer of the atmosphere.

The development of the enumerated fundamental problems in physics of the ocean, theory and methods for computing physical fields, and also a changeover to experimental investigations of the ocean from space is making it possible to proceed to solution of a number of applied and practical problems in the national economy. The most important of these are:
-- routine short- and long-range weather forecasting;
-- ensuring the safety of navigation, choice of the optimum routes for ships;
-- establishing monitoring of ecology of the sea, in particular, in determining the degree of contamination of the sea surface by petroleum products;
-- determination of the dynamics of formations of the ice cover;
-- determination of regions of increased biological activity and prediction of fish schools, etc.

The discussed problems can be solved in stages. The first stage is the mapping of the diagnostic fields of physical parameters (temperature, waves, etc.), obtained by remote methods. The further development of the theory and methods of observational data will make it possible to identify physical formations and proceed to the compilation of maps of these formations, to wit:
-- currents, reflecting the intensity, axial position, meandering and related processes of hydrodynamic instability, leading to the formation of rings and eddies, as well as the interaction of eddy formations with currents;
-- frontal zones with an indication of their position, intensity, places of maximum gradients;
-- zones of upwellings with an indication of the intensity of transport of biogenous elements;
-- thermal anomalies of the active layer of the ocean with an indication of their position, size and intensity;

-- contaminations of the sea surface by petroleum products with an indication of the position, extent and quantity of petroleum product;
-- color of the water with an indication of biologically productive regions;
-- ice fields with an indication of the positions and boundaries of fields, leads and polynias.

In this stage it is necessary to develop criteria and methods making it possible to discriminate and classify physical phenomena in the ocean.

The second, more complex stage is the development of prognostic models of physical formations in the ocean, based on material obtained during a quite prolonged period of observations.

Initially such a prediction will be made at the scales of synoptic variability, and thereafter at the scales of seasonal variability. In the future it is possible to expect solution of the problem of long-range forecasting, for example, for a year in advance. In this stage it is necessary to carry out a complex of organizational-technical measures.

On the other hand, it is necessary to create a powerful computer base on the basis of third-generation computers; a bank for the storage of data; mathematical support for the processing of information.

On the other hand, it is necessary to organize purposeful voyages of scientific-research ships for study of the physical phenomena transpiring in the ocean, to create control-calibration polygons making it possible to test methods for remote sounding and identification of physical formations in the ocean; set out a complex of "long-lived" buoys and neutral buoyancy buoys (drifters) for investigation, at least, of the upper 200-m layer of the ocean; develop a permanently operating network of self-contained buoy stations in the form of "clusters" consisting of one or two base buoys operating in a regime of measurement and storage of information and several minibuoys operating in a regime of measurement and relaying of information to base buoys.

All this is making it possible to solve problems in the hydrodynamics of the ocean, first within the limits of the active layer and then in the deeper layers of the ocean.

2. Informative Hydrophysical Parameters and Requirements on Their Determination

The experience accumulated at the present time in the interpretation of the images obtained from space in different ranges of electromagnetic waves is evidence of the good prospects for use of satellite information for studying the world ocean [4, 15]. After synthesizing this information with the measurement data obtained by traditional (contact) methods from aboard scientific research ships or automatic buoy stations, it is possible to proceed to study of the entire diversity of thermodynamic and other processes transpiring in the ocean.

The level of development of technical equipment and observation methods reached at the present time for work from space in most cases is making it possible to ascertain the qualitative characteristics of the parameters of state of the ocean of interest to us. However, even in the immediate future the accuracy of measurements will be substantially increased, which will make it possible to obtain their quantitative evaluations with the necessary information content level [21].

Now we will endeavor to formulate those minimum requirements which are imposed on the accuracy of measurement of hydrophysical parameters carried out by remote methods. The accuracy in determining these parameters is dependent on the specifics of solution of definite oceanographic problems. Thus, first it is necessary to formulate the problem and then on its basis formulate requirements on the apparatus and measurement accuracy.

Requirements must be imposed on measurement accuracy, spatial resolution and breadth of coverage of the investigated region of the ocean, time averaging and reading frequency.

One of the most informative parameters of the sea medium is the temperature of the ocean surface, which at the present time can be determined from the characteristic radiation of the ocean in the IR and SHF ranges.

This parameter is decisive in solving such problems in oceanography as study of the mesoscale variability of the ocean; discrimination of frontal zones and zones of intensive currents; prediction of the structure of the active layer in the ocean and interaction between the ocean and the atmosphere.

Taking these tasks into account, we will determine the requirements on measurement of temperature and other informative parameters.

Mesoscale variability of the ocean. The temperature field of the ocean surface to a considerable degree conforms to the nature of eddy movement in the main ocean thermocline. The principal characteristics in the distribution of this parameter are governed primarily by eddy advective currents disturbing the zonal distribution of temperature [13].

In contrast to the circulatory nature of eddy movement, in the main ocean thermocline the model of distribution of temperature of the ocean surface is characterized by the intrusive character of displacement of the isotherms.

The characteristic scales of formations in the upper layer of the ocean are 40-400 km. The mean velocity of spatial movement is 5-8 km/day. The temperature differentials at the mentioned distances are 0.2-2.0°C in the zones of influence of deep mesoscale eddies and up to 2-3°C in zones where there are intensive formations of the Gulf Stream rings type.

The discrimination (identification) of synoptic eddy formations on the basis of their appearance in the temperature field of the ocean surface makes it possible to evaluate both the kinematic characteristics of eddy formations and the nature of interaction between the upper boundary layer of the ocean and the layer of the main ocean thermocline. Recently there has been a sharp increase in interest in investigations of variability of the ocean at scales of 15-50 km, which is associated with the high energy characteristics of movements in these sectors. The temperature differentials are usually 0.2-1.0°C. Therefore, the accuracy in measuring these differentials is 0.1-0.2°C with an instrument resolution at the surface of 3-5 km.

Temperature anomalies are traced against the mean climatic background as formations with characteristic spatial scales from hundreds to thousands of kilometers, a characteristic lifetime from several to tens of months and a thickness (in depth) of tens of meters [20]. The extremal deviations of such formations from the climatic norm are not more than 2-3°C, but as a result of the great thermal inertia of the ocean in comparison with the atmosphere they exert a considerable influence on the weather of the planet at global scales. Accordingly, remote sounding apparatus must have an adequate breadth of coverage of regions of the ocean and the measurement frequency. It is best to obtain maps of surface temperature once or twice a week. In this case the spatial resolution must be 30-50 km; the accuracy in determining temperature is not less than 0.5°C.

Frontal zones and zones of intensive currents. At the present time the position of the principal frontal zones of the world ocean and zones of intensive currents have been determined quite well. Accordingly, the principal objective is study of the variability of the axis of currents and fronts, meandering, etc. [19]. The principal criterion for the recognition of "images" of ocean fronts and the boundaries of intensive currents is the temperature differential at their boundaries, which can attain 2-10°C. This makes possible its detection using apparatus operating in the IR range. With such great temperature drops the acceptable accuracy in its determination is 0.5-1.0°C. The spatial resolution must be 1-2 km.

We can add that information on the position of the boundaries of the frontal zones carries data on water color, the nature of the cloud cover over the ocean, the velocity and direction of currents, etc.

A determination of the velocity of currents is fundamentally possible using highly precise altimeters (radioaltimeters), making it possible to obtain evaluations of the large-scale level slopes of the ocean surface. However, the use of the dynamic method for determining the velocity of currents, as a result of the exceptional complexities of a methodological and technical character, remains problematical. For example, with a current velocity of 10 cm/sec the level drop across the current axis at a scale of 10 km is 10 cm. With an error to 20% the accuracy in determining the difference in heights is ±2 cm.

In this direction there are great possibilities for the use of drifting buoys (drifters), whose position can be determined by means of satellite navigational systems several times a day with an accuracy of about 1 km. This, in turn, will make it possible to estimate velocity with an accuracy to about 10% even for the most intensive currents, which fully satisfies the requirements of oceanography.

Prediction of structure of the active layer of the ocean. This is a highly important problem in oceanography because it is the principal intermediate link in processes of interaction between the ocean and the atmosphere. This prediction includes a determination of temperature of the ocean surface, position of the lower boundary of the homogeneous layer (layers), position (depth) of the density jump. The temperature and depth of the homogeneous layer determine the intensity of the temperature anomalies (heat content) and lifetime and the position of the jump layer determines the lower boundary of the zone of active photosynthesis of the upper layer of the ocean.

At the present time there is a rather great number of theoretical models making it possible to compute the mentioned parameters of the vertical structure of the active layer of the ocean. The "input" parameters of such models are air temperature, radiant energy flux, wind velocity, humidity, pressure and cloud cover, which can be measured by remote methods from artificial earth satellites. Computations on the basis of these models make it possible to use the temperature of the ocean surface, measured with an accuracy to 0.1°C, depth of the mixed layer and position of the jump layer with an accuracy to 1-2 m. Such an accuracy has not yet been attained when making measurements by remote methods.

When the necessary accuracy in measuring temperature of the ocean surface and other informative hydrophysical parameters has been attained, their use in theoretical models will make it possible to proceed to computation of the heat flows at the boundary of the jump layer and thus ascertain the receipts of heat in the main ocean thermocline.

On the basis of what has been said above, the following accuracies in measuring the temperature of the ocean surface, resolution at the surface and periodicity of revision of information, making it possible to carry out a quite correct subsequent interpretation of the collected data, appear reasonable.

Air temperature, like the temperature of the ocean surface, is a highly important informative parameter, making it possible to ascertain the rate of heat entry into the ocean as a result of contact heat exchange with the atmosphere. The computed value in the theoretical models is not the absolute temperature, but its anomaly relative to some value. Accordingly, with an "air-water" temperature difference of about 10°C a 10% accuracy in computing the contact heat exchange component can be attained with an accuracy in determining air temperature of ~1°C.

With a temperature difference of about 2-3°C the necessary accuracy is already 0.2° C. However, with such values of the "air-water" temperature difference the contribution of contact heat exchange to the general heat balance (budget) at the ocean surface becomes less than 10%. Accordingly, the accuracy in measuring air temperature of ~1°C is entirely acceptable from the point of view of assimilating this parameter in models of the active layer of the ocean.

In computations of the local structure of the active layer of the ocean the informative hydrophysical parameters are the wind velocity modulus, entering into the formulas describing the heat balance (budget) at the ocean surface, the rate of receipt (generation) of the mechanical energy of mixing in the homogeneous layer and the dissipation of mechanical energy in this layer. With a 10% accuracy in the computation of these parameters an entirely acceptable accuracy in measuring the wind velocity modulus in the velocity range from 1 to 15 m/sec is ~1 m/sec (we note that the mean minimum wind velocity over the ocean is 4-5 m/sec). In the case of wind velocities exceeding 15 m/sec the necessary accuracy can be reduced to 3-4 m/sec because the ambiguity in the choice of the empirical coefficients becomes important.

The scatterometry methods developed during recent years, based on determination of the backscattering diagrams for radio waves in the SHF range, make it possible to determine this parameter from the orbits of artificial earth satellites with an acceptable accuracy.

Pressure in the surface (near-water) layer is not of great importance in the formulas for computing the heat balance (budget) components. For example, in the ranges of pressure change 820-1080 mbar an error in determining pressure of ±1 mbar introduces an approximately 1% error in determining the corresponding heat balance. At the same time, a 10% accuracy in determining relative humidity is completely acceptable for computing the heat balance components for the ocean surface. Atmospheric pressure in the near-water layer can be estimated using the wind field.

The extent of cloud cover at the upper and lower levels, expressed in the number of octants of the sky covered with clouds, also serves as a computation value. At the present time cloud cover is estimated visually and the accuracy in determining this parameter is ±0.1 with a range of changes in this value 1-10. The information obtained by remote sounding apparatus in the visible, IR and SHF ranges makes it possible to obtain data on both cloud cover and air humidity.

The air humidity value for the near-water layer of the ocean enters into the computation formulas for the expenditures of heat on evaporation and the quantity of outgoing long-wave radiation. Taking into account that in the temperature range 0-30°C the pressure of saturated vapor varies in the range 2-50 mbar and adhering to a 10% accuracy in computing relative humidity, we find that with a mean relative humidity level of 50% the necessary accuracy in its determination is ±1 mbar. Two types of radiant energy flux participate in computations of the heat balance (budget) at the ocean surface: flux of incident short-wave radiation (direct plus the diffuse component) and the flux of reflected long-wave radiation.

Without going into the details involved in the specific choice of the empirical coefficients entering into the cited formulas, we will discuss the accuracy of the parameters necessary for computing these radiation fluxes. In determining the incident short-wave radiation absorbed by the upper layer extensive use is made of a method making it possible to tabulate the values of the radiant energy fluxes. In this method the principal parameter is the flux of radiant energy at the upper boundary of the earth's atmosphere Q_0. The Q_0 values tabulated for each of the seasons, latitude and longitude of the place of observations are available in the corresponding climatic atlases.

The direct measurement of the flux of radiant energy Q_0 from an artificial earth satellite makes it possible to proceed to its use as one of the informative parameters of existing theoretical models and those which can be developed. Assuming the range of changes of the Q_0 value to be

$$\{100\text{-}1000\}\ \mathrm{cal/(cm^2 \cdot day)}$$

and assuming a 10% accuracy in measurements of the flux, it can be assumed that the error in determining Q_0, equal to ±50 cal/(cm^2·day) in the lower latitudes, is entirely acceptable.

3. Influence of the "Skin Layer" on the Development of Methods for Remote Sounding of the Ocean

The central link in the system for interaction between the atmosphere and ocean is the surface homogeneous layer of the ocean. The temperature field in this layer is formed under the influence of different dynamic and thermal factors: wind over the ocean, short- and long-wave radiation, precipitation, waves, etc. In addition, as demonstrated in investigations of the synoptic variability of the ocean, the temperature field of the homogeneous layer to a considerable degree is subject to the influence of deep synoptic eddies forming mesoscale structures with horizontal scales from tens to hundreds of kilometers.

At the present time the problem of determining the temperature of the ocean surface can be solved most effectively by means of IR radiometric measurements made with artificial earth satellites. However, in general, the temperature measured in such a way cannot be identified with the temperature of the homogeneous layer. This is attributable to the fact that at the ocean surface there is almost always a so-called cold skin layer with a thickness of several millimeters, within which the thermodynamic properties of the medium change sharply.

Laboratory and field experiments for investigating the thermal structure of this layer have shown that a temperature drop of 0.4-2.0°C can be concentrated in the limits of 1 mm and a cold film is preserved when there is a wind up to 10 m/sec, that is, even under conditions of well-developed waves. With the collapse of waves small-scale turbulence is generated and the cold "skin layer" disappears. In addition, turbulent eddies can penetrate into it from the homogeneous layer and even out the temperature profile, which also leads to destruction of the "skin layer."

Despite the many factors responsible for the destruction of the "skin layer," its restoration occurs rather rapidly. According to the authors of [7], the restoration time is approximately 12 sec.

It can therefore be assumed that the existence of a cold film is a universal phenomenon and on the average is stable with time.

IR radiometers measure the radiation temperature of an extremely thin water film, but the temperature of the underlying homogeneous layer is of practical interest for researchers. Accordingly, the problem of the legitimacy of identification of temperatures of the quasihomogeneous layer and the surface film or the methods for correcting the measured brightness temperature is of great importance. As long as we have not established the true temperature distribution in the "skin layer," and also the patterns of horizontal distribution of its characteristics, inaccuracy in determining the homogeneous layer will considerably reduce the information yield of the collected data. This decrease in the information yield involves the following. First, since the characteristic time for carrying out an IR survey from a satellite is comparable to the characteristic lifetime of the "skin layer," uncertainty in determining the temperature of the homogeneous layer can attain the level of the temperature drop in the "skin layer." Second, the temperature in the "skin layer" exerts an important influence on the energy characteristics of processes of interaction between the ocean and the atmosphere. As a result of the small thickness its direct role in the energy budget of the upper layer of the ocean is insignificant. For example, the "skin layer" in a certain sense is optically transparent for the incident solar radiation. Other components of the heat balance, such as the heat expenditures on evaporation, contact heat exchange, outgoing long-wave radiation and the "skin layer" can change by 10-15%. Therefore, it is necessary to investigate the simultaneous influence of processes transpiring in the atmosphere and in the homogeneous layer on the dynamics of the cold surface film.

The purpose of these investigations is determination of the mechanisms of local formation and destruction of the "skin layer"; determination of the characteristic horizontal scales and the "lifetime" of this layer, as well as the limits of the meteorological parameters within which it exists; influence of the character and degree of fluctuation of individual meteorological parameters and the characteristics of the homogeneous layer on the structure of the "skin layer."

The solution of the enumerated problems will make it possible to relate the temperature of the ocean surface to the temperature of the homogeneous layer and proceed to formulation of a hydrodynamic model of the upper homogeneous layer of the ocean with inclusion of the cold "skin layer" in the picture with use of such a model. Due to satellite IR photographs it will be possible to make a thorough study of the processes transpiring in the homogeneous layer, and this, in turn, will make it possible to form some idea concerning the processes transpiring in the deep layers of the ocean.

4. Atmospheric Transfer Function and Allowance for its Influence

An investigation of the characteristics of the ocean surface by passive methods in the visible, IR and SHF ranges involves measurements of reflected solar radiation and the characteristic radiation of the ocean. Since the solar radiation and characteristic radiation are transformed during passage through the atmosphere, in solutions of the problems of remote sounding of the ocean it is necessary to take the atmospheric transfer function into account.

The atmospheric transfer function is determined as the ratio of the intensity of radiation I_ν with the frequency ν at the upper boundary of the atmosphere to the intensity of radiation at this same frequency I_ν at the level of the underlying surface [7].

This function, introduced in [6] for determining the temperature of the underlying surface from measurements of radiation from satellites, is determined by the vertical temperature and humidity profiles, on which is dependent the intensity of radiation in the particular frequency band, as well as the nature of aerosol attenuation of radiation in the atmosphere.

In order to determine the temperature of the underlying surface the measurements are made in the IR range in the transparency window 10-12μm and in the centimeter range at wavelengths 3 and 8 cm.

In the IR range, when measuring ocean radiation $S_{\Delta\nu} \approx 1$, the surface emissivity in the frequency range $\Delta\nu$ and the transfer function $P(\Delta\nu)$ are highly dependent on the profiles of temperature, humidity and aerosol attenuation.

In the radio range $P_{\Delta\nu}$ is virtually not dependent on the profiles of atmospheric temperature and humidity, whereas the $S_{\Delta\nu}$ value has a strong dependence on the height of waves on the sea surface. One of the principal merits of the microwave range is that the noise created by the atmosphere in remote sounding of the ocean is relatively small, even in the presence of a cloud cover. This circumstance is attracting much attention to the development and use of all-weather methods for microwave remote sounding.

The physical principles for the propagation of radiothermal radiation in the atmosphere have been well studied. Their detailed exposition and corresponding citations can be found, for example, in [1, 10, 12, 16, 22, 23].

Water vapor and oxygen are the principal absorbing components in the cloudless atmosphere. Oxygen has a system of absorption lines near a wavelength of 0.5 cm and an isolated line near 0.25 cm; water vapor has absorption lines at 1.348 and 0.164 cm. Variations of radiobrightness temperature of the atmosphere-ocean system, associated with these factors, can be caused by changes in humidity, temperature and atmospheric pressure. In the region of wavelengths greater than 3-4 cm they are negligible. Wavelengths shorter than 0.6-0.8 cm are unsuitable for passive microwave sounding of the ocean. Variations in the radiobrightness temperature, caused by the cloud cover, are most significant at wavelengths less than 1 cm, but even at greater wavelengths they are significant and must be taken into account when endeavoring to obtain reliable information on the ocean surface at wavelengths 8-10 cm.

Taking into account the considerations presented above, wavelengths of the SHF radiometric apparatus are selected which together with the IR apparatus makes it possible to determine the atmospheric temperature and humidity profile, as well as the parameters of the underlying surface.

The dependence of the radiothermal radiation of the ocean on the principal parameters of its surface -- state and temperature -- is manifested in virtually the entire microwave range. In the region of short wavelengths the influence of such effects as foaminess is comparable in magnitude with the influence of the cloud cover. It must also be remembered that the temperature of the sea surface is the least important of the enumerated factors, but it is necessary to have high accuracy of its determination. It is clear from this that the problem of interpretation of the results of passive microwave sounding must be solved jointly with simultaneous allowance for all the determining parameters, including atmospheric parameters. But in a complete formulation of the problem of remote sounding of the atmosphere-ocean system the number of atmospheric parameters is too great. If the problem involves only the ocean surface, it is sufficient only to take into account the effect of variability of the parameters, without finding the precise values of the parameters themselves.

The variability of the three principal parameters of the cloud layer -- altitude, thickness and liquid-water content -- leads to variations in the radiobrightness temperature indistinguishable in the spectrum. Accordingly, in order to take cloud cover into account in remote sounding of the ocean it is sufficient to have one general parameter.

Similarly, in order to take into account changes in atmospheric humidity it is also adequate to have a single parameter -- the total quantity of precipitable water (provided a special set of close wavelengths in the neighborhood of resonance 1.35 cm is not used). Moreover, if it is proposed that the basic information on the ocean be obtained in channels with sufficiently great wavelengths (more than 2-3 cm), for a formal allowance for variations of the radiobrightness temperature at these wavelengths, caused by any changes in the state of the atmosphere, it is sufficient to use one generalized parameter and auxiliary measurements at the one wavelength of about 0.8-1.0 cm. It also follows from the results of the studies that these variations can be taken into account by additive corrections linearly dependent on the mentioned formal parameter. With a more detailed allowance for the influence of the atmosphere such corrections can be used for a separate expression of the dependence of radiobrightness temperature on cloud cover and water vapor.

Such an approach is a linear approximation of the functionals expressing the dependence of the measured parameters on the distributed parameters of the medium through some formal coefficients obtained by numerical computations. For example, the dependence of the radiobrightness temperature on ocean parameters changes somewhat in the short-wave part with variations of atmospheric parameters, but these changes are small and can be corrected after a preliminary evaluation of the state of the atmosphere.

For a further increase in the reliability of multisided use of the microwave range it is necessary to carry out investigations of the dependence of the emissivities of the real sea surface on the radiation wavelength, angle of observation, polarization, etc. An important problem which is still far from solution is the development of a method for the interpretation of microwave measurements for the purpose of determining the parameters of the ocean surface in zones with allowance for possible precipitation.

Thus, allowance for the influence of the atmosphere in remote sounding of the ocean is assuming special importance, since it is a poorly reflecting surface and even under conditions of atmospheric transparency outgoing reflected radiation is determined for the most part by the atmosphere.

5. Investigations in the Visible Spectral Range

One of the most informative remote sources of information concerning the world ocean is measurements in the visible spectral range. This is attributable to the fact that in this range the transparency of the cloudless atmosphere attains maximum values and the absorption of light by ocean water is minimum. The solar radiation maximum is in this same range.

Among the shortcomings of measurements in the visible range it is possible to include a considerable dependence of the results of measurements on time of day and atmospheric conditions. Observations are impossible when there is a continuous cloud cover.

The most informative characteristic in the visible range is the spectral composition of the ascending light flux. In open parts of the ocean it carries information on the hydrooptical characteristics of ocean waters. This makes it possible to discriminate different water masses, determine their limits, detect eddies, zones of upwelling of water and other dynamic formations, and also biological productivity. In the coastal regions, on the basis of water color, it is easy to distinguish waters of continental runoff, their distribution and interaction with the waters of the open sea. Since an analysis of the spectral structure of the ascending flux makes it possible to detect the most important characteristics of the surface layers of the ocean, we will examine in greater detail the process of formation of the spectrum of radiation ascending over the ocean.

The sun's rays, passing through the atmosphere, are attenuated due to the absorption and scattering of molecules of gases and vapors and particles of aerosols constantly present in it.

The light reaching the ocean surface consists of a directed component -- direct solar rays -- and a diffuse component -- solar radiation scattered by the atmosphere. The light incident on the water surface is partially reflected from the air-water discontinuity, but a large part of it penetrates into the water layer. The intensity of the reflected light flux is dependent on the illumination conditions, direction of observation and state of the sea surface. Direct solar rays, mirror reflected from the water surface, form flashes whose brightness is exceedingly great. Outside the flash zone the brightness of the surface is determined by the reflection of skylight, that is, the light scattered by the atmosphere and by clouds, and also by the light scattered in sea water. The reflection of light is virtually nonselective in its spectrum and is dependent only on the distribution of sky brightness, primarily on the altitude and direction of observation. In observations close to the nadir it is approximately 2% of the sky brightness at the zenith.

In the scattering of light on large particles of suspension the scattering index can be assumed to be not dependent on wavelength. If the absorption of light by particles is also neglected, as is done in actual practice if the particles are of mineral origin, with an increase in the concentration of the terrigenous suspension we obtain an increase in the general level of intensity of the light ascending from the water with a virtually constant nature of the spectral distribution.

The presence of absorbing impurities in the water gives a completely different picture. The absorption spectrum of "yellow matter" increases exponentially with a decrease in wavelength. As a result, under the influence of "yellow matter" the spectral energy of the light emanating from the water is considerably reduced in the short-wave part, whereas in the long-wave part (with wavelengths greater than 530 nm) there are virtually no changes. A similar picture is also observed when the water contains absorbed particles, the most important of which are cells of phytoplankton, containing chlorophyll pigments, etc., the absorption of which increases in the regions 420-460 and 660-680 nm.

In the open parts of the ocean the hydrooptical characteristics are dependent for the most part on biological productivity: the greater the content of biogens, the greater is the attenuation of light in the short-wave part of the spectrum, that is, the color of the sea is greener.

In observations from a satellite distortions are introduced into the spectrum by atmospheric haze. Its influence is particularly great in the short-wave part of the spectrum, which requires the introduction of corrections.

Investigations of recent years have shown that the study of the cloud cover and its spatial structure is useful in solving such oceanological problems as determination of the rational regime of the ocean, recognition of the position of oceanological fronts, discrimination of storm zones, etc. For such investigations it is necessary to take into account different characteristics of the cloud cover: type of clouds, their form, levels at which they occur and texture. These characteristics can be determined from the images of clouds in different parts of the spectrum. For example, over relatively warm water masses with increased evaporation of moisture there is formation of a low continuous stratocumulus cloud cover, whereas over the colder waters the cloud cover is thin or entirely absent. Over the lines of such water masses the cloud cover has a sharp boundary which can serve as an indicator of an oceanological front. A cellular structure of the clouds is characteristic for regions with ordered convection over the warm surface of the ocean. A spiral-like cloud cover is usually formed in zones of generation of storms, whose evolution can be traced from the temporal changes in the spatial structure of the cloud cover and its texture.

The methods for study of oceanological phenomena on the basis of cloud cover characteristics have a number of limitations. The formation of the cloud cover occurs with a definite inertia and the local winds existing in the region of observations displace the cloud formations in unpredictable directions. Active cyclonic activity also masks the differences in water masses. However, with stable states of the meteorological fields in regions where oceanological processes transpire conditions are created for the formation of cloud structures which are caused by these processes and in the practice of oceanological investigations this makes it possible to use the cloud indicators method.

The mapping and study of sea ice is possible in the entire visible spectral range. The weak dependence of the radiation reflected by these features on wavelength makes it possible to use in their investigation technical apparatus which has a low spectral resolution, although allowance for the spectral differences of these natural formations makes it possible to analyze their structure.

In satellite optical observations the radiation picked up by the instruments is distorted to a considerable degree by the influence of the atmosphere, which is difficult to monitor. Accordingly, it is important to carry out, especially in the initial stages of development of satellite oceanography, synchronous contact and remote "subsatellite" measurements of different characteristics of ocean waters.

6. Use of Radar Systems in Oceanographic Investigations

The basis for the development of methods of active space radiooceanography is the advances in radiophysics in the field of study of the patterns of scattering of radio waves in different ranges by the wave-covered sea surface.

The physical nature of the scattering of radio waves by the wave-covered sea surface has now been established. A study has been made of its principal regularities and this has made it possible to develop methods for determining the principal parameters of sea waves and wind in the near-water layer of the atmosphere using radar apparatus operating in different ranges of radio waves at both small ($\psi < 10^\circ$) and large ($\psi \geqslant 85\text{-}90^\circ$) glancing angles [2, 3, 9, 14, 18].

The specifics of operation of apparatus in space and the peculiarities of radio wave propagation in the earth's atmosphere impose considerable restrictions on the possibilities of using different methods for radar determination of the parameters of sea waves. For example, radar systems operating in the meter and decameter ranges of radio waves, which have recommended themselves well in "surface" radiooceanography, have proven to be unacceptable [14].

Therefore, in space radiooceanography for the most part use is made of radar systems operating in the centimeter range (1-10 GHz), radar altimeters, scatterometers (devices for measuring the strength of the scattered signal) and side-scan radar systems.

Radar altimeters make it possible to make highly accurate measurements of the distance between space vehicles and the level of the calm ocean surface and also to estimate the degree of roughness of the scattering surface (height of sea waves).

An optimum design of a radioaltimeter and the optimum processing of the radar signal make it possible to bring the potential accuracy of measuring flight altitude to $\delta_{alt} \approx 10\text{-}15$ cm.

The solution of a wide range of problems in study of the topography and dynamics of the ocean surface is becoming possible. However, it is not possible to realize fully the high potentialities of altimetry methods due to the complexity in taking into account the nutations of the spacecraft orbit and the related errors in determining absolute altitudes and determination of the reading level in the reflected signal in the case of a wave-excited ocean surface.

Accordingly, at the present time only in the coastal regions can there be a quantitative solution of the problem of determining the dynamics of the ocean surface by means of a "tie-in" of the results of measurements to shoreline features or by means of a precise determination of the orbital elements of the space vehicle; in the open regions of the ocean it is possible to give only a qualitative evaluation of this phenomenon.

Satellite-borne instrumentation for measuring scattering (scatterometers) measures the scattering diagrams in the range of angles of incidence determined by the electric potential of the system. This makes it possible to obtain evaluations of characteristics of the wind field in the near-water layer of the atmosphere.

The physical basis for operation of scatterometer systems is the dependence of the parameters of the scattered signal on the characteristics of the scattering surface.

As is well known, the scattering of radio waves at small incidence angles (0-5°) conforms to the laws of physical optics and the decisive role in shaping of the scattered signal is played by the dispersion and correlation function of the angles of slope of the sea surface, sensitive to wind velocity W.

Scattering at angles of incidence greater than 5-10° is selective; the intensity of the scattered signal is determined by the spectral density of the corresponding wavelengths. In the SHF range the scatterers are ripple waves.

As a rule, satellite scatterometers must have a high resolution in angular coordinates ($\leqslant 1°$) since with a deterioration in resolution the response of the system to a change in the nature of the scattering diagram is sharply reduced as a result of its integration by the resolution element.

As indicated by the results of laboratory and field experiments [8, 11, 18], scatterometer systems in essence make it possible, with sufficient accuracy, to determine the characteristics of the wind field over a surface.

The results show that in determining the wind velocity over an ocean surface there are some complexities caused by the existence of a dependence of the effective scattering area not only on wind velocity, but also on the azimuthal angle between the wind direction and the direction of the orbital plane of the space vehicle and also imperfection of the method.

Improvement in methods for making measurements, calibration and processing of the signal will make possible full realization of the potentialities of the scatterometer as an all-weather device for measuring the wind and wave fields.

Side-view radar systems make it possible to register radar images of the surface of the land and ocean in the radar field of view, with orbital altitudes of 600-800 km ensuring a surface resolution of about 1-2 km. This makes it possible, with allowance for the characteristics of interpretation of the results of remote measurements, to study the spatial distribution of the wind fields, the characteristics of ice fields, etc.

In order to increase resolution in azimuth the side-view radar makes use of methods for synthesizing the radar directional diagram. High resolution along the radar ray is ensured by compression of the radio pulse. With respect to the potential resolution characteristics a side-view radar comes close to optical observation methods. A further increase in the resolution of side-view radar is held back by fluctuations of the dielectric characteristics of the atmosphere, resulting in a "decay" of both the directional diagram and the radar pulse.

Synthesizing methods in the case of a nonuniform and curvilinear movement of the radar carrier in space are also inadequately developed at the present time.

However, with the present level of development side-view radars make it possible to obtain images of the ground and water surface at considerable distances regardless of meteorological conditions at any time of day with a high detail of reproduction of different sectors of the surface. The resulting images can be used in determining the state of the surface of the seas and oceans, study of the dynamics and determination of the characteristics of ice fields, etc.

Despite a number of existing technical and methodological complexities in creating satellite side-view radar systems, they undoubtedly will become one of the principal remote sounding systems, especially in solving ice reconnaissance problems.

Space radiooceanographic systems, being a new tool in the hands of the researcher, differ fundamentally from the traditional means for oceanographic measurements with spatial averaging of the investigated characteristics, and this imposes corresponding requirements on the organization of the accompanying measurements.

First of all it is necessary to create a network of specialized monitoring-calibration polygons at sea with an extent comparable to a resolution element in the space radiooceanographic system.

In addition to traditional methods, for measurements in polygons there must be extensive use of radiophysical methods for the remote determination of the parameters of waves by means of on-shore (shipboard) and aviation radar systems making use of different methods for obtaining oceanographic information.

Their use is necessary in the interpretation of the results of oceanographic satellite measurements because the operation of these systems in fact is based on the use of one and the same regularities in scattering of radio waves by the sea surface when determining the investigated characteristics of the spatial wind and wave fields, comparable to a resolution element of the radiooceanographic system.

In conclusion it can be asserted with assurance that space oceanography methods, as a result of improvement in the theory and means for remote sounding of the surface, in the years immediately ahead will become an effective tool in implementing major oceanographic projects. This will make it possible to formulate the problem of studying the world ocean at a new, considerably higher level.

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[30-5303]

5303
CSO: 1866

UDC 551.46:528.7

ON THE INFLUENCE OF THE ATMOSPHERE AND THE OBSERVATION WINDOW OF A SPACECRAFT ON THE CONTRASTS OF NATURAL FORMATIONS VISIBLE FROM SPACE

Moscow ISSLEDOVANIYE ZEMLI IZ KOSMOSA in Russian No 5, Sep-Oct 80 pp 64-70 manuscript received 15 Apr 80

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[Text] *Introduction* The possibility of visual observations or equipment recording of natural formations from space depends on the frequency-contrast characteristics (ChKKh) [FCC] of the natural formations, the intervening medium and the viewing system in the case of visual observations or recording equipment [1]. The frequency-constrast characteristic is usually defined as the ratio of the contrast of an optical test pattern image in the form of a cosinusoidal grating to the constrast of the grating itself. When an image is transmitted, besides a change in the constrast, there also occurs a shift in the phase of the image which is determined by the frequency-phase characteristic, which shows the phase shift in the image of the cosinusoidal grating during the change in the spatial frequency. The frequency-contrast and phase-contrast characteristics are included in the transfer function which defines the quality of image transmission.

When studying natural formations from space, the phase-contrast characteristics most frequently do not exert any substantial influence on image quality. For this reason, when analyzing the possibility of these studies, frequency-contrast characteristics are usually employed. The major advantage of FCC method consists in the fact that it makes it possible to rather simply evaluate the possibilities of remote studies, when there are atmospheric layers, an observation window, etc. between the source of radiation being studied and the recording system, where these intervening media can be described by the FCC. In this case, the FCC of the entire system will be equal to the product of the FCC of its component elements.

Based on concepts of the FCC, an analysis is proposed in this article for the transfer function of the atmosphere and observation windows of spacecraft in

TABLE 1

Estimates of the Brightness of the Background Radiation of a Solar Observation Window B_1 and a Window Oriented in the Direction of the Earth's Surface B_2 in the "Salyut-6" Orbital Station in the Twilight Zone

δ_Θ, degrees	-5	0	10	30	60
B_1, $cd \cdot m^{-2}$	10^{-2}	1	10^3	10^3	10^3
B_2, $cd \cdot m^{-2}$	-10^{-4}	10^{-2}	1	10^2	$2 \cdot 10^2$

the visible range of the spectrum, this will make it possible to estimate the threshold values of contrast which can be observed or recorded from space during visual observations, photography and the transmission of a television image, as well as to consider the possibility of optimizing the conditions for observing and recording natural formations from space.

The transfer functions of the atmosphere and observation windows. The transmittance and radiation of the atmosphere of the earth and the observation window of the spacecraft exert the most substantial influence on the possibility of observing and recording point objects and extensive sources of optical radiation from space [1].

The observation windows of spacecraft are usually made in the form of double or triple glass windows with carefully hermetically sealed mountings. The transmittance and brightness of the background radiation scattered by the glass of the spacecraft observation windows depends both on the level of the illumination produced by external lighting sources, and on the state of the surface of the glass (dirt, dust deposits, fogging, frosting). It is natural that the luminescent and thermal radiation of the glasses has a considerable influence on the transfer function of the observation window in the ultraviolet and infrared regions of the spectrum.

We shall assume when making estimates of the scattered radiation of an observation window that all of its glasses (including the surfaces) scatter from one to five percent of the radiation incident on them in a diffuse manner. Then, the brightness of the observation windows on the night side of the earth, without taking into account background lighting by radiation sources within the vehicle, polar auroras and direct radiation of the moon, will not exceed either the natural space background brightness level or the brightness of the nighttime radiation of the atmosphere, clouds, and surface of the earth. This makes it possible to successfully observe and record on the night side of the earth such weak sources as the emission radiation of the upper atmosphere, cloud cover and the surface of the earth.

On moonlit nights, the background lighting from the direct radiation of the moon and that reflected by the atmosphere and surface of the earth markedly increases the brightness of the scattered radiation of observation windows, which during a full moon can attain $1 - 2 \cdot 10^{-4}$ cd $\cdot$ m^{-2}. In this case, the possibility of recording the weakest radiation sources is also degraded.

In the twilight zone, the background radiation brightness of an observation window will depend on the angle of the sun above or below the earth's horizon and the orientation of the observation window relative to the sun as well as the twilight halation. For the sake of determinancy, we shall initially consider a solar observation window, the axis of which is directed towards the sun, while in the twilight zone, it is directed towards the center of the twilight halo. This observation window will have the highest background radiation, the brightness of which will be primarily governed by the angle the sun is above or below the earth's horizon, δ_0 and the flight altitude of the spacecraft.

Estimates of the order of magnitude of the background radiation brightness of a solar observation window, as well as estimated values of the background radiation brightness of an observation window oriented in a direction towards the surface of the earth and not illuminated by direct solar radiation for various positions of the sun are given in Table 1.

When estimating the spectral density of the energy brightness, one can assume as a first approximation that the relative energy brightness spectral density of the scattered observation window radiation is close to the relative spectral density of the illumination of the observation window from all backlighting sources. Therefore, for a solar observation window, if the sun is above the horizon, it can be assumed that the radiation spectrum is similar to the solar spectrum, taking into account its changes in the earth's atmosphere. If the sun is below the horizon, then the radiation spectrum of the observation windows is close to the twilight halo spectrum, corresponding to the angle of the sun below the horizon.

On the day side of the earth, the background radiation brightness of observation windows will depend on their orientation relative to the sun and the subjacent surface, as well as on the level of brightness of the subjacent surface, which depends on the zenith angle of the sun and the albedo of the subjacent surface. The brightness of the background radiation of solar observation windows will be maximal when simultaneously lighted by direct solar radiation and the subjacent surface. Under these conditions, it can attain several thousands of cd $\cdot$ m^{-2}. The spectrum of this radiation is close to the solar spectrum. The brightness of the background radiation of observation windows opposite the sun and side windows on the day side of the earth will depend on their orientation relative to the subjacent surface.

Thus, the background radiation brightness of unprotected observation windows can vary in a wide range, depending on the lighting conditions of the orbital station. In the nighttime portion of the orbit (when the sun is more than

15° below the earth's horizon), it will apparently be below the brightness sensitivity threshold of the visual system, which amounts to about 10^{-5} cd · m^{-2}. At the same time, the maximum background radiation brightness levels of unprotected observation windows can attain several thousand cd · 10^{-2}, something which precludes the possibility of visual observations and optical studies of weakly shining sources.

For the purpose of creating more favorable conditions for visual observations and optical studies on the day side of the earth and in the twilight zone, it is necessary to take special steps to reduce the background radiation brightness level of observation windows. This can be achieved by means of light shielding blinds and an optimal orientation of observation windows relative to the direct radiation of the sun.

The transmittance of observation windows in a specified range of wavelengths depends both on the material of the glasses, their quality, the condition of the surfaces of the glasses and on the direction of observation.

For normally incident rays, the transmittance of a clean double glass observation window in the visible region of the spectrum is 85 percent, and that of a clean triple glass observation window is 80 percent. The transmittance of observation windows with dirty surfaces can be 20 to 30 percent worse than that of clean observation windows.

The transmittance of a cloudless atmosphere in the visible region of the spectrum depends primarily on the viewing direction, the aerosol humidity and content, while the radiation of the atmosphere also depends on the zenith angle of the sun, the scattering angle and albedo of the subjacent surface.

We shall consider the transmittance and radiation of the atmosphere for the case of a viewing direction from an orbital station at the nadir. In this case, the scattering angle (for a zenith angle of the sun of $z_0 \leq 90°$) will always be greater than 90°. In this case, the transmittance of the cloudless atmosphere depends substantially on the height of the observed sections of the earth's surface above sea level and the time of year. Values of the transmittance of the cloudless atmosphere in the visible region of the spectrum are given in Table 2 for seasons of the year and a number of altitudes of the observed sections of the earth's surface in the middle latitudes when observed from space at the nadir [2]. It is natural that the transmittance of the atmosphere when observing the surface of the earth from space in other directions will be less than at the nadir. For example, for the summer season, the atmospheric transmittance for the case of observation at an angle of 60° from the nadir for portions of the earth's surface at a height of 0 km amounts to about 0.15, and about 0.3 for a height of 2 km. The atmospheric transmittance likewise falls off sharply with the appearance of smoke, and especially with the appearance of fog.

TABLE 2

The Transmittance of a Cloudless Atmosphere in the Visible Portion of the Spectrum when Observed from Space at the Nadir of the Earth's Surface in Middle Latitudes

Сезон Season	(1) Высота наблюдаемых участков поверхности, км				
	0	1	2	3	
Лето	0,4	0,5	0,65	0,75	Summer
Весна, осень	0,5	0,65	0,75	0,8	Spring, Fall
Зима	0,75	0,80	0,85	0,9	Winter

Key: 1. The height of the sections of the surface being observed, km.

TABLE 3

The Brightness of a Cloudless Atmosphere when Observed from Space at the Nadir, cd · cm^{-2} [3]

τ	$z_{\odot}$, град Degrees						
	0	30	60	80	85	87	90
0,87	0,30	0,24	0,12	0,072	0,033	0,023	0,009
0,80	0,40	0,35	0,18	0,08	0,046	0,038	0,016

The brightness of the cloudless atmosphere in the visible region of the spectrum depends on the direction of viewing, the zenith angle of the sun and the scattering angle of the sun and albedo of the subjacent surface. A general conclusion has been drawn on the basis of an analysis of experimental studies that the brightness of the cloudless sky can be represented in the form of a product of three functions [2]. One of the functions depends on the scattering angle, the second on the zenith angle of the direction of observation, and the third is a function of the transmittance of the atmosphere and the zenith angle of the sun. In the case of a viewing direction from space at the nadir, the brightness of the cloudless atmosphere will basically depend on the transparency of the atmosphere and the zenith angle of the sun, since the brightness of the cloudless atmosphere for scattering angles of more than 90° does not greatly depend on the scattering angle. Values of the brightness of a cloudless atmosphere are given in Table 3 for two values of the atmospheric transparency τ_{atm} and a number of values of the zenith angle of the sun $z_{\odot}$.

To determine the transfer function of the atmosphere and the observation window, it is necessary to determine the change in the contrast of the radiation of an extended source which has passed through them. The following ratio is adopted as the contrast:

$$K=\frac{B_{max}-B_{min}}{B_{max}+B_{min}}, \qquad (1)$$

where B_{max} and B_{min} are the maximum and minimum values of the brightness of two adjacent extended sources.

The contrast of extended sources when observed through the atmosphere and an observation window is defined by the ratio:

$$K'=\frac{(B_{max}-B_{min})\tau_1\tau_2}{(B_{max}+B_{min})\tau_1\tau_2+B_1\tau_2+B_2}, \qquad (2)$$

where B_1, B_2, τ_1 and τ_2 are the brightness and transmittance of the atmosphere (subscript 1) and the observation window (subscript 2) respectively. Expression (2) can be represented in the form:

$$K'=\frac{K}{1+\frac{\beta}{\tau}}, \qquad (3)$$

where

$$\beta=\frac{B_1\tau_2+B_2}{B_{max}+B_{min}}; \quad \tau=\tau_1\tau_2. \qquad (4)$$

The amount of observation window transmittance usually is $\tau_2 = 0.8$--0.85; for the atmosphere, $\tau_1 = 0.7$--0.85. The observation window brightness is $B_2 \approx 10^2$--10^3 cd · m^{-2}, and the atmospheric brightness is $B_1 \approx (3$--$6) \cdot 10^3$ cd · m^{-2}.

During image transmission, the effect of image phase shift also occurs in addition to contrast changes, which is governed by the frequency-phase characteristic [1]. The influence of the phase response of the atmosphere and the observation window during visual observations from space at the nadir and in directions close to the optical axis of the observation window can apparently not be taken into account. The frequency-phase characteristic of the atmosphere begins to have an effect at resolutions of less than 1". In the usual photographic systems (a focal distance of f' = 500 mm, a resolving of 5 to 10", and a resolution of 100 lines/mm), the influence of atmospheric turbulence is insignificant during observations at the nadir. Under these observational conditions, the phase distortions introduced by the atmosphere and the observation window are significantly less than the resolving power of the visual system. In the case of observations in directions substantially different from the nadir and the optical axis of the observation window, the phase distortions can in some cases exceed the resolving power of the visual system.

It is well known that during the photographing of stars by ground telescopes, phase distortions are created by the earth's atmosphere which reach 3", and in individual worst case conditions, can run up to 5". However, during observations or photography from space at the nadir, the phase distortions which arise because of flickering of the image in the atmosphere are substantially less, and in the existing visual instruments and photographic set-ups, they can be neglected in practice. This related to the fact that during observations or photographing from space, the distorting layer of the atmosphere is located at a considerable distance from the spacecraft, and in the case of studies from the earth, it is positioned directly in front of the instrument. Shown in the figure is a schematic drawing of the phase distortions for space and ground studies. It follows from the figure that:

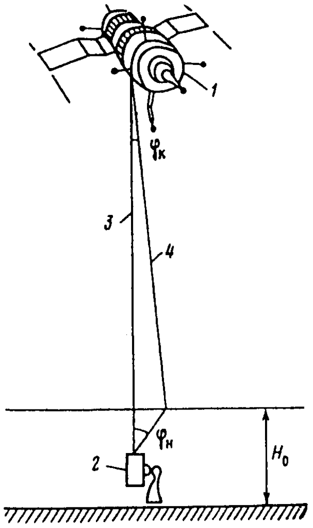
$$\frac{\varphi_{к}}{\varphi_{н}} = \frac{H_0}{H_{сп}}, \qquad (5)$$

where H_0 is the thickness of the distorting layer of the atmosphere; $H_{сп}$ is the orbital altitude of the spacecraft.

If it is assumed that H_0 is about 8 km (the thickness of the referenced layer of the atmosphere) while the orbital altitude of the spacecraft, $H_{сп}$, is about 350 km, then the phase distortions in the case of studies at the nadir from space will be tens of times smaller than in the case of studies at the zenith from the earth.

Threshold values of the contrast. The threshold conditions for the recording of individual details of an image are determined by the threshold contrast sensitivity and the visible contrasts. Under favorable lighting conditions and with angular dimensions of the object of 10' to 20', the eye is capable of distinguishing contrasts of down to 1 to 2 percent. At the same time, with photography one can register contrasts exceeding 10 to 15 percent, and a television transmits contrasts exceeding 15 to 20 percent.

In the case of observations, photography or TV transmission of an image of the earth from space in the direction of the nadir, both clouds and individual sections of the earth's surface are well distinguished. Ground clouds, when



The phase distortions introduced by the atmosphere in the case of photography or observations from space (ϕ_K) and from the earth (ϕ_H):

1. Spaceborn photographic equipment;
2. Ground photographic equipment;
3. Undistorted viewing lines;
4. Actual viewing line;

H_0 is the thickness of the referenced layer of the atmosphere.

observed or recorded from space, are clearly seen by virtue of the comparatively high contrast between the bright clouds and the darker portions of the water bodies or surface of the earth.

In this case, calculations show that under conditions of a clean, nonturbid atmosphere, the contrasts of individual areas of the earth's surface are reduced by 40 to 50 percent, while the contrasts between clouds and the surface are reduced by 20 to 30 percent. Then the minimum values of the contrasts which can be registered from space, during observations at the nadir, will be 3 to 4 percent for the visual system, 20 to 30 percent in the case of photography and 30 to 50 percent for TV image transmission.

In directions close to the horizontal, contrasts change so greatly that it is practically impossible to distinguish not just details on the surface of the earth, but frequently contrasts between clouds, the atmosphere and the earth's surface. The edge of the earth's disk is practically not seen from space, while the visible horizon lies at an altitude of several kilometers from the edge of the planet's disk.

The fact is that during observations or registering of an image at the horizon, the transfer function of the atmosphere changes the structure of the radiation of the earth's surface and clouds so much that it becomes impossible in this case to distinguish the contrasts of its elements, falling off by tens and hundreds of times.

Based on this analysis, the proposition can be put foreward the it is most expedient to study natural resources from space by combining visual observations and photographically recording the most interesting and sufficiently high contrast formations, and for the objects and formations with the greatest contrast, to transmit a television image.

The selection of the optimum observation and recording conditions for objects and formations on the surface of the earth most frequently involves the determination of the maximum values of the contrast for various recording conditions and various objects. Various methods are employed to increase the contrast visible from space, among which, spectral and spatial selection, the utilization of differences in the polarization characteristics, etc., should be noted.

Spectral selection methods are based on a choice of regions of the spectrum in which the contrasts observable from space for various formations on the earth's surface reach the maximum value. The correct choice of the working region of the spectrum for the study of natural formations depends primarily on the spectral distribution of the contrasts of the objects and formations, the spectral transfer function of the atmosphere and the observation window, as well as the spectral characteristics of the threshold contrasts of the visual system or recording equipment.

Spatial selection can be used to single out contrast objects and formations of small size against a comparatively homogeneous and extended background. Spatial selection includes those methods related to enhancing the possibility of isolating one or several objects and formations against a radiating background and which use the comparison of the radiation parameters of individual portions of an image by optical methods.

When studying natural resources from space, it is of definite interest to have studies using windows which are transparent in the infrared region of the spectrum. Here, heat vision transducers [3] can be used to register the infrared image of objects and formations visible from space. It is preferable to use Fourier spectrometers to record infrared spectra [4]. It is natural that when analyzing infrared images, the transfer functions of the atmosphere and the observation window, as well as the frequency-contrast characteristic of the instrumentation must be taken into account.

The prospects for the development of optical methods of studying the environment from space are closely related to both the development of more sophisticated optical equipment and the intelligent choice of the experimental conditions. In this case, it is most effective to combine various methods of study: visual observation, photographic recording, television image transmission, the registration of television images in the infrared region of the spectrum and the measurement of infrared spectra in the region of atmospheric transparency. In all cases, the influence of the atmosphere, the observation window and the measurement equipment on the frequency and contrast characteristics of the contrasts and images visible from space must be taken into account.

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[26-8225]

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CSO: 1866

UDC 629.19:551

LAWS GOVERNING THE CHOICE OF THE DESIGN PARAMETERS OF A SPACE SURVEY SYSTEM FOR STUDYING THE EARTH

Moscow ISSLEDOVANIYE ZEMLI IZ KOSMOSA in Russian No 5, Sep-Oct 80 pp 104-108
manuscript received 25 Mar 80

[Article by V.S. Avduyevskiy, V.K. Saul'skiy and G.R. Uspenskiy]

[Text] From the viewpoint of the requirements placed on the information obtained by spaceborne photographic equipment sets, the tasks of studying the earth in the interest of the national economy are basically differentiated in terms of spatial resolution and periodicity of the survey, in which case, the range of variation in these parameters is quite great: from episodic (once over several years) to almost continuous observations in terms of periodicity and from several meters to tens of kilometers in terms of the resolution. An analysis of the entire aggregate of these tasks makes it possible to cite the following governing law: the increase in the requirements placed on the details obtained from satellite photographs leads, as a rule, to a reduction in the rate at which it is necessary to take them. For this reason, to satisfy future demands of the national economy, it is economically expedient to utilize different types of spaceborne complexes, which differ primarily in terms of resolving power and survey period. An important problem is the intelligent choice of the composition and design parameters of future space tools for observation, treated as a unit whole. A methodological approach to the resolution of this problem is given below.

We shall introduce the following formalization:

--A set of points in a system of coordinates specified by the major requirements placed on the information corresponds to the set of tasks: the resolution of the terrain and the survey period;

--Any spaceborne complex in such a system is depicted in the form of a right angle, formed by rays parallel to its axis which diverge from a point, the coordinates of which are the observation resolution and periodicity which are to be provided, where these coordinates are directed toward decreasing stringency of these requirements;

--Each problem is considered solved if the point corresponding to it falls at even one of the angles representing the spaceborne complexes;

--A set of space complexes is considered optimal which completely solves a specified set of observation tasks and has a minimal cost.

It follows from [1] that the set of points in a plane, which represent the actual requirements placed on the resolution, r, and the periodicity, t, can be bounded to the left (i.e., on the side of the most stringent requirements) by an envelope which is approximately described by the equation:

$$\frac{1}{r^{\gamma}t^{\delta}} = A \qquad (1)$$

with positive parameters of γ, δ and A. This envelope is depicted in Figure 1 in the form of straight line 1 in a logarithmic system of coordinates.

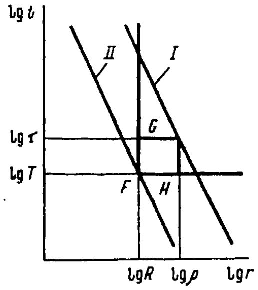

Figure 1. The substitution of a pair of equipment sets G and H, which carry out the same mission volume, for a spaceborne equipment complex F.

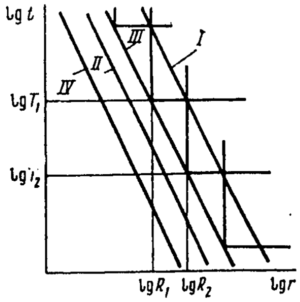

Figure 2. The positioning of an optimal system of spaceborne equipment complexes relative to the envelopes I, II, III and IV.

The law governing the cost C of a spaceborne equipment complex can be written in the following form with a high degree of generality:

$$C = \frac{b}{r^{\alpha}t^{\beta}}, \qquad (2)$$

where $\alpha > 0$, $\beta > 0$ and $b > 0$.

Before moving on to the design of an efficient spaceborne system, we shall find the answer to the following question: how can one replace a particular spaceborne equipment complex with $r = R$ and $t = T$ by two complexes, which perform the same mission volume and have a minimum overall cost? This is shown graphically in Figure 1, where the complex F is replaced by a pair of complexes G and H. The solution of the problem reduces to a determination of the parameters $r = \rho$ and $t = \tau$, and can be formulated in the form of the following problem of finding the conditional extremum:

$$\begin{cases} \rho^{-\gamma}\tau^{-\delta}=A, \\ bR^{-\alpha}\tau^{-\beta}+b\rho^{-\alpha}T^{-\beta}=\min. \end{cases}$$

By employing the method of Lagrange factors, we obtain the following condition for the optimal breakdown of the spaceborne equipment complex into a pair of internal ones:

$$\gamma\beta\rho^{\alpha}T^{\beta}=\delta\alpha\tau^{\beta}R^{\alpha}. \tag{3}$$

It is obvious that the substitution of the pair G and H for F should be made only when this leads to a reduction in expenditures. If the spacebourne equipment complex F is positioned close to the envelope 1, then such a substitution is not advantageous, since it will cause almost a doubling of the expenditures. In step with the increasing distance of F from 1, the amount the expenditures for the internal pair of equipment complexes exceeds the cost of the internal one gradually falls off, and at some point, becomes equal to zero, and then moves over into the region of negative values. We shall find the geometric locus of the points $r = R$ and $t = T$, for which the substitution does not change the expenditures, i.e.:

$$C(F)=\min\{C(G)+C(H)\}.$$

Taking (1), (2) and (3) into account, the following conditions should be met in this case:

$$\begin{cases} \rho^{-\gamma}\tau^{-\delta}=A, \\ bR^{-\alpha}\tau^{-\beta}+b\rho^{-\alpha}T^{-\beta}=bR^{-\alpha}T^{-\beta}, \\ \gamma\beta\rho^{\alpha}T^{\beta}=\delta\alpha\tau^{\beta}R^{\alpha}. \end{cases}$$

By transforming this system of equations to exclude the variable ρ and τ, we obtain:

$$R^{-\gamma}T^{-\delta}=VA, \qquad (4)$$

where

$$V=\frac{(\gamma\beta+\delta\alpha)^{\gamma/\alpha+\delta/\beta}}{(\gamma\beta)^{\gamma/\alpha}(\delta\alpha)^{\delta/\beta}}. \qquad (5)$$

Line II in Figure 1 corresponds to the derived equation (4). Any spaceborne equipment complex, the vertex of the angle of which in the graph is located to the left of line 2 can be replaced without loss to carry out the observation missions by a less expensive pair of complexes which meet condition (3). Such a substitution yields a negative result to the right of line 2. We will note that the form of equation (4) is similar to the equation of the envelope of tasks (1). Thus, the conclusion can be drawn that to assure minimum expenditures, it is necessary to chose the terrain resolution and survey periodicity of the spaceborne equipment complexes so that they fall in the region between lines I and II. This makes it possible to designate line II as the envelope to the left of efficient spaceborne observation complexes.

We shall next find the line which is the geometric locus of the spaceborne equipment complexes, each pair of the adjacent ones of which satisfy optimality condition (3). In Figure 2, this line is designated with the Roman numeral III, while the straight lines I and II have the same meaning as in Figure 1. The points of intersection of the sides of the angles alongside the arranged complexes are located on envelope I. We shall seek the equation for line III in a form similar to I and II, i.e.:

$$r^{-\gamma}t^{-\delta}=BA, \qquad (6)$$

where B is a new constant.

If line III exists, then the following should be observed simultaneously (Figure 2):

--The condition that the spaceborne complexes belong with line III:

$$R_1{}^{-\gamma}T_1{}^{-\delta}=R_2{}^{-\gamma}T^{-\delta}=BA,$$

--The condition that the sides of the angles of adjacent complexes on line I intersect:

$$R_2{}^{-\gamma}T_1{}^{-\delta}=A,$$

--The optimality condition (3):

$$\gamma\beta R_2{}^{\alpha}T_2{}^{\beta}=\delta\alpha R_1{}^{\alpha}T_1{}^{\beta}.$$

We shall determine the quantity B from this system of equations:

$$B = (\gamma\beta/\delta\alpha)^{\frac{\gamma\delta}{\gamma\beta-\delta\alpha}}. \qquad (7)$$

The values of B exist and are continuous for any positive parameters γ, β, δ and α, with the exception of the singular point:

$$\gamma\beta/\delta\alpha=1.$$

However, in this case too, one can restore the continuity of the values of B by assuming:

$$B = \lim_{\gamma\beta/\delta\alpha\to 1} (\gamma\beta/\delta\alpha)^{\frac{\gamma\delta}{\gamma\beta-\delta\alpha}}.$$

By computing the limit here using L'Hospital's rule, we find that in this case:

$$B=\exp(\gamma/\alpha)=\exp(\delta/\beta).$$

By comparing the values of the constants B and V, specified by equalities (5) and (7) respectively, one can establish the fact that for positive parameters γ, δ, β and α, it is always the case that

$$V > B \qquad (8)$$

It follows from this that line III passes between I and II, and therefore, none of the spaceborne equipment complexes belonging to it can be replaced by a pair of less expensive (total) internal ones. Moreover, it is not difficult to see that the breakdown of each of its complexes into any number of internal ones increases the total expenditures even more. We shall further check the expediency of the opposite operation: the combining of adjacent complexes lying on the line III. We find the equation of a line IV, to which the vertices of the spaceborne complexes obtained by means of such combining belong (Figure 2). For a point with coordinates of r = R and t = T which belongs to line IV, the following equalities should be observed:

$$\begin{cases} R_1^{-\gamma}T_1^{-\delta}=R_2^{-\gamma}T_2^{-\delta}=BA, \\ R_2^{-\gamma}T_1^{-\delta}=A. \end{cases}$$

It can be found from this that:

$$R_1^{-\gamma}T_2^{-\delta}=B^2A,$$

and consequently, line IV is specified by the equation:

$$r^{-\gamma}t^{-\delta}=B^2A.$$

One can establish the fact that it is always the case that

$$B^2 > V$$

and therefore, line IV is located to the left of line II. It follows from this that the combining of adjacent complexes for line III likewise leads to a rise in the expenditures, and is thus inexpedient.

Simple relationships which can be derived from equation (6) exist between the major parameters r and t of adjacent spaceborne equipment complexes belonging to line III (Figure 2). Since in this case:

$$\begin{cases} R_1^{-\gamma}T_1^{-\delta}=R_1^{-\gamma}T_2^{-\delta}=BA \\ R_2^{-\gamma}T_1^{-\delta}=A, \end{cases}$$

Then

$$\begin{aligned} &R_2/R_1=B^{1/\gamma}, \\ &T_2/T_1=B^{-1/\delta}, \end{aligned} \qquad (9)$$

or, taking (7) into account,

$$\begin{aligned} &R_2/R_1=(\gamma\beta/\delta\alpha)^{\frac{\delta}{\gamma\beta-\delta\alpha}} \\ &T_2/T_1=(\gamma\beta/\delta\alpha)^{\frac{\gamma}{\delta\alpha-\gamma\beta}}. \end{aligned} \qquad (9_1)$$

It can be shown that the adjacent subsystems on line III not only satisfy condition (III), but for them, a stronger assertion is also justified: the total expenditures for a set of n = 2, 3, 4, ... alongside the arranged spaceborne equipment complexes are lower than for any other set of complexes which perform the same observation missions. To check this fact, we shall first derive a condition similar to (3) for the case of a breakdown into n complexes. Here, the following relationships should be observed:

$$\begin{cases} bR_1^{-\alpha}T_1^{-\beta}+bR_2^{-\alpha}T_2^{-\beta}+\ldots+bR_n^{-\alpha}T_n^{-\beta}=\min, \\ R_2^{-\gamma}T_1^{-\delta}=R_3^{-\gamma}T_2^{-\delta}=\ldots=R_n^{-\gamma}T_{n-1}^{-\delta}=A. \end{cases}$$

By employing the Lagrange method, we obtain (n - 1) equations:

$$\gamma\beta R_{i+1}^{\alpha} T_{i+1}^{\beta} = \alpha\delta R_i^{\alpha} T_i^{\beta}, \quad i=1,2,\ldots,n-1. \tag{10}$$

By substituting the values of R_{i+1}/R_i and T_i/T_{i+1} from (9_1) in (10), we convince ourselves of the justification of the assertion made above.

Thus, the aggregate of spaceborne equipment complexes located on line III possesses a series of optimum properties from the viewpoint of economy of the observation process. This makes it possible to draw the following conclusions.

1. If the set of observation missions, represented in a two-dimensional system of coordinates (terrain resolution vs. survey periodicity) can be bounded on the left by an envelope having equation (1), while the cost function for the satellite system has the form of (2), then for a complete solution of these problems, it is efficient to utilize the set of spaceborne complexes which provide for the survey periodicity resolution which satisfy equation (6).

2. The ratios of the values of the spatial resolutions and survey periodicities of adjacent complexes are the same for any such pairs from the efficient set. They are determined from formulas (9) or (9_1).

3. The replacement of either several adjacent complexes by one which performs the same mission volume, or vice versa, the replacement of any of the efficient sets by a set equivalent to it in terms of the mission to be performed can lead only to an increase in the expenditures, and is therefore not expedient.

For example, to perform a set of tasks, for which condition (1) has the form:

$$r^2 t = 400 \ [\mathrm{m}^2 \cdot \mathrm{day}],$$

the cost function (2) is

$$C = 3{,}500/r^{1/2} t^{1/3}$$

while the terrain resolution r and the survey periodicity t change within a range of from 2m up to several kilometers and from 0.1 days up to several years respectively, the efficient space system should consist of the following three complexes: R_1 = 2m, T_1 = 100 days; R_2 = 11m, T_2 = 3 days; R_3 = 60m and T_3 = 0.1 days. In this case, the relationship between the parameters of the complexes considered here is as follows:

$$R_2/R_1 = R_3/R_2 = 5.5; \qquad T_1/T_2 = T_2/T_3 = 30.$$

In the case where equation (1) assumes the form:

$$r^2t = 10{,}000\ [m^2 \cdot \text{day}],$$

while the ultimate requirements placed on the resolution r and the periodicity t are taken equal to 6m and 0.25 days respectively, then to maintain the preceding cost function, the composition of a system of efficient complexes will be as follows: R_1 = 6m, T_1 = 250 days; R_2 = 35m, T_2 = 8 days; R_3 = 200m and T_3 = 0.25 days.

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[26-8225]

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CSO: 1866

SPACE AND INTERNATIONAL ORGANIZATIONS: INTERNATIONAL LEGAL PROBLEMS

Moscow KOSMOS I MEZHDUNARODNYYE ORGANIZATSII: MEZHDUNARODNO-PRAVOVYYE PROBLEMY in Russian 1980 signed to press 17 Mar 80 pp 2-7, 166-167

[Annotation, introduction and table of contents from book by Ye. P. Kamenetskaya, Izdatel'stvo "Nauka", 1950 copies, 168 pages]

[Text] A study is made of a broad class of urgent problems of cooperation in the exploitation of space within the framework of international organizations. The author analyzes the theoretical problems arising in this field, she evaluates the activity of the space organizations, and she develops specific proposals with respect to further improvement of this form of international cooperation.

Introduction

The third decade of the space age of man began on 4 October 1977.[1] During this short historical period cosmonautics has gone from the first artificial satellite, the first interplanetary automatic station and the first cosmonaut to flights by man to the moon, the lunokhods [Soviet unmanned lunar vehicles] and the long-range orbital stations with replacement of crews.

The Soviet Union opened up the road to space for mankind. The great progress of the USSR in the mastery of outer space "has become the symbol of creative efforts of victorious communism, the pride of all mankind."[2]

A great deal of attention has been given to the development of cosmonautics in the Soviet Union. The mastery of outer space became possible as a result of

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[1] The reckoning of the space age from the 4th of October 1957 -- the day the Soviet Union launched the first artificial earth satellite in the world -- was approved by resolution of the Congress of the International Astronautics Federation in September 1967 (KOSMONAVTIKA: MALEN'KAYA ENTSIKLOPEDIYA [Cosmonautics: Small Encyclopedia], 2d edition, Moscow, Sovetskaya entsiklopediya, 1970, p 210).

[2] 22d Congress of the Soviet Union: Stenographic Report. Moscow, Gospolitizdat, Vol 3, 1962, p 238.

achievements of our science and engineering which "found its concentrated expression in the study of outer space."[1] In the "Basic Areas of Development of the National Economy of the USSR 1976-1980," defined by the 25th Congress of the CPSU, a broad space research program has been planned which provides not only for the study of the universe, but also the use of space and the achievements of space science and engineering for the solution of many national economic problems.[2]

Emphasizing the significance of the Soviet space program, Comrade L. I. Brezhnev emphasized that "expanding our activity with respect to the study of outer space, we not only are laying down the foundation for future gigantic gains by mankind, the fruits of which will be used by succeeding generations, but also we are deriving practical benefit today for the population of the earth, for our people, for the business of our building of communism."[3]

The mastery of outer space began under the symbol of international cooperation. The fact that the launching of the first artificial earth satellite was by the Soviet Union during and within the framework of the International Geophysical Year -- an important event in the history of the cooperation of governments which was participated in by 67 countries -- is profoundly symbolic. Today the progress in the field of international cooperation in the study and use of outer space has become the symbol of overall political detente, its materialization and graphic results for millions of people on the earth.

The cooperation of governments in the mastery of outer space is closely connected with the development of international agreements which will define the conditions of outer space, the goals of space activity and the principles of the development of international cooperation itself.

The Soviet Union was an initiator of the conclusion of international agreements and the arrangement of broad cooperation in the study and use of outer space for peaceful purposes.[4]

Since the first days of the space age the USSR has constantly promoted the investigation and use of space explicitly in the interests of peace and security of people. The Soviet Union considers the peaceful exploitation of space as the basic principle of its space activity. The consistent and persistent struggle of the USSR for peace in space serves as a logical continuation and one of the areas of the struggle of the Soviet Union for peace on earth. As was noted at the 25th Congress of our party, the Soviet Union cannot ignore the solution of such important and urgent problems as the mastery of space which touches on the

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[1] 50th Anniversary of the Great October Socialist Revolution: Topics of the Central Committee of the CPSU, Moscow, Politizdat, 1967, p 45.

[2] Materials of the 25th Congress of the CPSU, Moscow, Politizdat, 1976, p 215.

[3] L. I. Brezhnev, LENINSKIM KURSOM: RECHI I STAT'I [Lenin Course: Speeches and Articles], Moscow, Politizdat, Vol 2, 1970, p 352.

[4] See the proposal of the Soviet Government on the problem of prohibiting the use of space for military purposes, elimination of foreign military bases in foreign territories and international cooperation in the field of studying outer space, 15 March 1958 (PRAVDA, 1958, 16 March).

interests of all mankind and will have more and more active influence on the life of all people and the entire system of international relations.[1]

The active role of Soviet diplomacy in the growth and development of the legal principles of studying outer space is a characteristic feature of international space law. The basic space agreements were developed and signed by the initiative of the Soviet Union, including the agreement on the principles of the activity of governments in the study and use of outer space, including the moon and other heavenly bodies.[2]

The Communist Party of the Soviet Union and the Soviet Government consider the international cooperation in the study of outer space as one of the manifestations of a policy of peaceful coexistence, one of the important conditions of international detente and insurance of the exploitation of space for peaceful purposes for the good of and the interests of all countries and people.

Initially the international cooperation in the exploitation of outer space was realized on a bilateral basis, and it was primarily limited to joint optical observations of satellites and the exchange of scientific information. Later, as the problems of the investigation and use of space became more and more complicated and a larger and larger number of countries became involved in the sphere of international cooperation, along with the two-way cooperation the countries began to make wider and wider use of the methods of multilateral coordination and cooperation. Today the united efforts of many countries have created spacecraft and booster rockets, scientific research has been performed, and international manned flights have been made. The national space programs of the countries are inevitably and naturally supplemented by broad-scale joint research.[3] At the present time dozens of countries are participating in one form or another in the international cooperation in the mastery of outer space.

However, the progress in this area could be more significant. International cooperation must be based on trust and mutual understanding among peoples, and the effort of some political circles of the western countries to convert space to an arena of military competition is having a harmful effect on the expansion of international cooperation in the study and use of outer space for peaceful purposes.

International cooperation is an important factor of the successful mastery of outer space. Combining the efforts of the countries facilitates the solution of

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[1] L. I. Brezhnev, LENINSKIM KURSOM: RECHI I STAT'I [Lenin Course: Speeches and Articles], Moscow, Vol 5, 1976, p 512.

[2] The significant contribution of the USSR to the development of international space law has also been recognized in western literature (see, for example: G. Reijnen, LEGAL ASPECTS OF OUTER SPACE, Utrecht, 1977, pp 152-163).

[3] For more details see: R. Sagdeyev, "Universal Cooperation in Space," NOVOYE VREMYA [New Times], No 39, 1975, p 21.

the most complicated problems of studying the universe; it is promoting the coordination of the activity of the various countries and the elimination of the unnecessary duplication. It permits more efficient use of available means and possibilities.

The exploitation of outer space can be realized by the efforts of individual countries and without international cooperation. This is indicated by the great progress made by some countries, above all, the Soviet Union and the United States of America, in the implementation of their national space programs. However, the course of curtailment of international cooperation and promotion of tension in the relations between governments pronounced by the President of the United States J. Carter at the beginning of the 1980's can do serious harm to cooperation in the exploitation of space. As Comrade L. I. Brezhnev emphasized, "refusal to cooperate in the field of economics, science, engineering and culture means the rejection of significant advantages which each side could receive. The main thing is that this would be an entirely purposeless rejection which cannot be justified by any intelligent reasoning."[1]

The coordination of the activity of the governments in the exploitation of outer space implies the necessity of creating the international mechanism of cooperation with countries and the application of various organizational and legal forms of coordination and cooperation in our field.

This paper is devoted to an all-around analysis of the international legal problems of the cooperation of governments in the study and use of outer space for peaceful purposes within the framework of international organizations. Joining of efforts of different countries within the framework of international organizations is one form of international cooperation. As the range of space research expands, the role of the number of international organizations dealing with the problems of cooperation in the exploitation of space will grow. This fact leads to the necessity for investigating the legal principles and activity of such organizations and also the analysis of possible trends and prospects for the development of this form of joining of efforts of the governments and search for means of improving the mechanism of cooperation in the exploitation of space.

Contents

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[1] L. I. Brezhnev, LENINSKIM KURSOM: RECHI I STAT'I [Lenin Course: Speeches and Articles], Moscow, Politizdat, Vol 4, 1974, p 171.

Appendix

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