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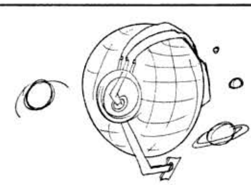

REPORTS

AUTOMATIC DOCKING IN COSMOS AND ITS APPLICATION TO AVIATION SAFETY AND SPACE STATIONS

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Only 11 years have passed since the launching of the first man-made satellite on October 4, 1957. It was hardly possible to foresee at that time that this experiment, which seemed to be a purely academic one, would give rise to more and more complex cosmic experiments, such as flights to the moon, Venus, Mars—flights of man in space ships. Professor Raushenbakh, of the Soviet Academy of Sciences, described the Russian system of joining space vehicles in orbit at the first United Nations Space Conference in Vienna, August 14–28, 1968.

The principal direct benefit of launching man-made earth satellites is at present associated with using them for meteorological observations and communication purposes. The next few years and decades will, no doubt, lead not only to a quantitative and qualitative growth of work associated with weather forecasting and creating a cosmic communications system integrating all the countries of the world, but also to the use of man-made earth satellites. There may even be moon stations for other, still not quite clear, economic and cultural purposes.

A wide application of man-made earth satellites for industrial, agricultural, and cultural purposes will, to a great extent, depend on the cost of launching such satellites. Cutting costs may be achieved by simplifying designs and decreasing dimensions of satellites; the latter also greatly reduces the costs of carrier-rockets and all the launching equipment. This way will certainly be used; even now comparatively cheap and simple satellites are put into near-earth orbits along with heavy satellites.

It should be noted, however, that not quite all problems can be solved by means of small satellites. It is quite conceivable that a communication satellite will be created for the purpose of transmitting television programs, and its radiation power may be so great that its signals will be received directly by home television sets. Such a satellite would make needless an expensive and complex network of ground and receiving stations, which is especially important for small and developing countries. However, simple calculations show that such a satellite must be large in size and provided with a heavy power plant, most likely using atomic power. This example, by no means the only one, shows that the creation of large and complex earth satellites is indispensable if we are to cope with a wide program of creating cosmic systems for economic and cultural purposes.

Putting large and heavy satellites into orbit may conceivably be effected by two basically different methods. It is possible to make more and more powerful carrier rockets. The other possibility is to put heavy satellites into orbit in parts, using comparatively small carriers, and then to assemble the required structure in the cosmos from the separate parts.

The first of the above methods is associated with vast expenses, for even now large carrier rockets are as tall as a 30-story house and the advisability of further increasing their height is questioned by many experts. It should be borne in mind that with an increase in dimensions of a rocket, not only its cost but also the cost of all the ground launch installations climbs drastically.

The second way is free of this shortcoming for it permits the use of existing launch installations and rockets, already produced by industry, for creating in near-earth orbits practically unlimited large cosmic stations for various purposes.

COSMIC ASSEMBLY

The method of assembling cosmic stations directly in orbit has a number of merits. It is useful when there is a need to have a heavy satellite in orbit; but it is indispensable in all those cases when necessity arises to construct a bulky cosmic station. Lifting a large-size object by rocket is associated with almost insurmountable difficulties: If the size of the object substantially exceeds the carrier rocket diameter, the forces arising as the result of the supersonic ascent in the atmosphere may either destroy the object, or require unjustified strengthening, consequently increasing the weight of the object, as well as requiring protection against aerodynamic drag forces. Besides, aerodynamic forces and movements may render the ascent of the rocket generally impossible, either disturbing its stability or requiring inadmissibly great fuel consumption.

None of these problems arise if a cosmic station is constructed by lifting and assembling in parts. This method will permit constructing relatively light cosmic objects of arbitrary dimensions and configurations.

The rendezvous and docking method for cosmic ships permits accomplishing such operations as the relief, at regular intervals, of the crew of a large orbital station; supply of food, fuel, repair parts, and so forth. The method is also essential in case of rescue work in the cosmos, when rendering help to a cosmic ship in distress.

Rendezvous and docking of man-made earth satellites is a complex scientific and technological problem. Basically, it can be achieved by two different methods: manual and automatic. With the manual method the cosmonauts on board the space ships, first by responding to command from the earth and then by measuring the distance between the approaching ships (after they have approached sufficiently), control their ships just as a flier controls his aircraft. Automatic rendezvous and docking presupposes that absolutely all operations are performed by means of corresponding automatic devices.

It is only natural to compare these two methods to ascertain if the more complex automatic method has any advantages over the manual.

Automatic rendezvous and docking is an absolutely indispensable element of the modern cosmic flight technique. It is more rational in all those cases when the cosmonaut piloting the ship has no tasks other than rendezvous and docking. Thus, for example, it is better to deliver fuel, spare parts, and other supplies to an orbital station by automatic rendezvous and docking, since this operation does not make obligatory the presence of a cosmonaut. The absence of a cosmonaut on board the spacecraft permits a simpler type of operation because there is no necessity to provide a life-support system, a pilot's cabin with its equipment, braking plant, heat insulation for protection during re-entry from orbit, etc. This makes it not only simpler and less expensive, but also increases cargo capacity, since the life-support equipment is relatively heavy. An increase in cargo capacity simultaneously means a decrease in the cost of delivery per kilogram of useful load delivered to the orbit.

The need for automatic rendezvous and docking is, however, dictated not only by economic considerations. Operations may be foreseen in which the participation of a cosmonaut is in fact completely excluded. One such operation is the delivery to orbit of hazardous cargo such as nuclear fuel for reactors by means of which, probably, power supply will be provided for long-term space stations, say, for the communication satellite which was mentioned above. Another operation of this kind may be the assembly of an orbital station in a cosmic zone hazardous to man: for example, in central regions of radiation belts surrounding the earth.

The examples given here show that the creation of earth satellite automatic systems capable of bringing two satellites close together and then docking them means significant progress on the way to man's conquest of cosmic space.

SOVIET STUDIES

In the Soviet Union the problems of automatic docking in space have been profoundly studied over the last few years. This technique, more complex than manual rendezvous and docking, has required a wide application of automatic control methods. It may be considered as an outstanding achievement of present-day cybernetics. The creation of a completely automatic system, which without any assistance from man and without rendezvous and docking control from earth, is capable of accomplishing a search for each other by the two spacecraft, rendezvous, final closure, and docking, is based on most extensive use of modern achievements in the theory and practice of automatic control.

The process of rendezvous and docking may be subdivided into three successive stages: rendezvous, final closure, and docking. The first stage comprises all the operations intended to bring the space vehicles into the immediate vicinity of one another. This involves a mutual search by the vehicles in space, measuring distance between them, and calculating their relative velocity. These data must be processed in the so-called logical devices and subsequently there must be generated a command for the corresponding turns, rocket engine start, shut off, and so forth.

The second stage—final closure—begins when the space vehicles have come close together. This stage comprises a number of operations intended to accomplish final closure; this must be done softly enough and provide for such accuracy that, as the result, the attachment points come into contact. These operations also require making continuous measurements of the relative position, distance, and velocities, although the entire maneuver should be accomplished carefully, without tight turns. This requires a different program of the operation of the logical devices and a different mode of starting jet engines.

The third stage—docking—takes place when the attachment points have come into contact. This stage involves the rigid joining of the space vehicles, and not only mechanically, since the electrical systems also become connected. In short, after docking, the two space vehicles become a single complex with a common electrical system, specifically, common control circuits.

Occasionally a fourth stage—disengagement—may become necessary. This process involves to some extent the reverse operations and terminates in pushing apart the previously docked space vehicles after which they continue their flights independently.

The accomplishment of such a complicated and integrated operation of a great number of devices installed on the space vehicles is possible only under conditions of a wide application of radio electronics and automatic control.

MUTUAL APPROACH

The operation of mutual search involves a scan of the space by a system of radiolocation devices for the detection of the other space vehicle. After mutual detection, radio communication is established between the moving vehicles, radiolocation methods permitting continuous measurement of the relative distance and approach velocity. The on-board gyroscopic devices simultaneously give signals on turns of the vehicle in space. All this information enters the logical block, which, processing the measurement data, gets the whole picture of the relative motion of the vehicles and generates control signals optimum under the given conditions. In general these signals are intended to impart to the active vehicle, which is performing the approach maneuver, a velocity in the direction of the passive; the value of this velocity must vary depending on the distance between the two vehicles. With great distances the approach velocity must also be great, to lessen the approach time, although velocity must gradually decrease with decreasing distance. Besides, no large lateral velocity should occur during the approach.

At distances measured by kilometers or by tens of kilometers an approach maneuver should be carried out vigorously and, consequently, relatively large rocket engines should be used. As the impulse direction will vary during the approach (boost, braking, lateral-velocity quenching), the space vehicle will correspondingly perform fast turns to position the rocket engine alternately in one or another required direction. In the final closurepath portion (from hundreds of meters to the touch point) the approach velocity should be small. Turns are impermissible and therefore the control is performed by a whole group of relatively small final-closure engines, each of which gives an impulse only in one direction: forward, backward, to the left, to the right, upward, downward.

It is thus apparent that logical block functions are complicated and diverse, although they can be completely handled by modern automatic control techniques using computers.

FIRST DOCKING

The first successful experiment of rendezvous and docking of two man-made earth satellites was accomplished in the Soviet Union in autumn 1967. Orbiting satellite Cosmos-186 was subjected to all-round tests during three days. When all the required experiments had been completed, its flight trajectory was corrected so that by the start time of satellite Cosmos-188, intended for taking part in docking, the orbit of the first satellite was to pass approximately over the start point of the second. Precisely at the prescribed time on November 30, 1967, the rocket carrying Cosmos-188 was launched; the time was selected so that by the end of the rocket climb, Cosmos-188 was to be in the area of Cosmos-186.

As has been subsequently shown by the decoded measurement data, the actual distance between the active and the passive satellites at the time of the approach beginning was about 24 kilometers, and the relative velocities were about 25 meters per second.

As soon as the second satellite was put into orbit, the corresponding apparatus on board the two satellites was brought into operation; the mutual search was carried out; and the active satellite in the required succession accomplished the operations of approach, final closure, and docking, while the passive satellite was oriented so that its attachment point was directed toward the active.

It should be noted that all these processes took place completely automatically and even out of the area visible from the territory of the Soviet Union, so that the scientists controlling the flight of the satellites had not the slightest possibility of observing the process of the rendezvous or to interfere in its progress. All the processes of the automatic docking have been studied subsequently on the basis of the telemetered data which were first sent to the storage unit installed on board each satellite, and then, after the appearance of the previously docked satellites over the territory of the Soviet Union, these data were transmitted from the space to the ground command and data acquisition stations.

Although the telemetered data subsequently permitted thorough study of all the maneuvers performed by the satellites, the fact of a successful docking became evident through television images transmitted from space as soon as the docked satellite complex appeared over the territory of the Soviet Union. The decoded telemetered data showed that the approach was completed when the distance between the satellites was about 300 meters, and then the final closure began. At the instant the satellite attachment points came in contact with each other the approach velocity was from 0.1 milliseconds to 0.5 milliseconds within the calculated range.

The satellite complex flew in the docked state for three and a half hours. During this time all the experiments specified by the program were accomplished and it was possible to carry out the disengagement and to start the independent flight of each satellite. To observe the disengagement process by means of television, the corresponding command was given so that disengagement took place over one of the flight control stations. Thus, as distinct from docking, the reverse process was observed visually.

The successful accomplishment of this historic experiment showed a high reliability of the whole system of control over such a complex process.

AVIATION APPLICATION

The automatic docking of Soviet satellites, Cosmos-186 and Cosmos-188, bears witness to the present high level achieved in the theory and practice of automatic control. This experiment would have been impossible if most recent achievements of automation and radio electronics had not been used. However, the conception that only space technology uses the achievements of science and engineering would be erroneous. The specific requirements which space technology places upon automatic control devices —high reliability, low weight, small dimensions, small power consumption, carrying out diverse and complex control programs, analyzing the progress of a control process and, if necessary, passing to another variant of solving the problem in hand—are requirements which are placed by modern industry upon automatic devices in general.

Therefore, space technology, using the achievements obtained in other branches of technology, in turn spurs their development. Automatic docking will eventually become one of the usual methods for work in space. To facilitate the further progress of this method requires the development of more and more perfect means of mutual detection of space vehicles and measurement of their relative movement parameters. The development of methods for solving this problem will, no doubt, be useful for aviation, too. Modern airlines cannot function without radiolocation devices, and development of methods for blind landing, which should significantly increase the safety and regularity of air traffic, is in many aspects similar to the problem of docking in space. No less useful for future automatic control of factories and even whole branches of industry should be the impact of the development of highly reliable, simple, small computers and logical devices, without which no complex cosmic automatic programs—particularly, automated docking systems—are feasible.

Finally, finding theoretically optimum rendezvous methods for various space problems will at the same time be useful for mathematical development of methods for technological process and factory control.

The foregoing shows that automatic docking in space, being an outstanding achievement of modern automatic control technique, at the same time has been furthering and will continue to further the development of automatic control in general, regardless of its particular application. Furthermore, automatic docking in space opens vast prospects for the creation of large satellite stations which will become indispensable to the economic and cultural needs of humanty in the not very distant future.