Big Potential for Small Observation Satellites

By MERTON E. DAVIES
The RAND Corporation

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Some 250 lb of state-of-the-art equipment in a 125-n. mi. orbit will give ground resolution of 20 ft—a useful performance for arms-control inspections and other purposes

Space boosters already have been developed by the United States, the Soviet Union, and France; and they are under development by the European Launcher Development Organization, Japan, and Great Britain. The United Arab Republic has announced a satellite project, and other countries, such as China, India, and Germany, may well proceed with independent space programs in due time. Moreover, Italy, South Africa, Canada, Indonesia, and Israel have active rocket projects which might eventually lead to development of space boosters.

Thus it appears that during the second decade of space operations many nations will be eager to participate in the development of space systems.[1-4]

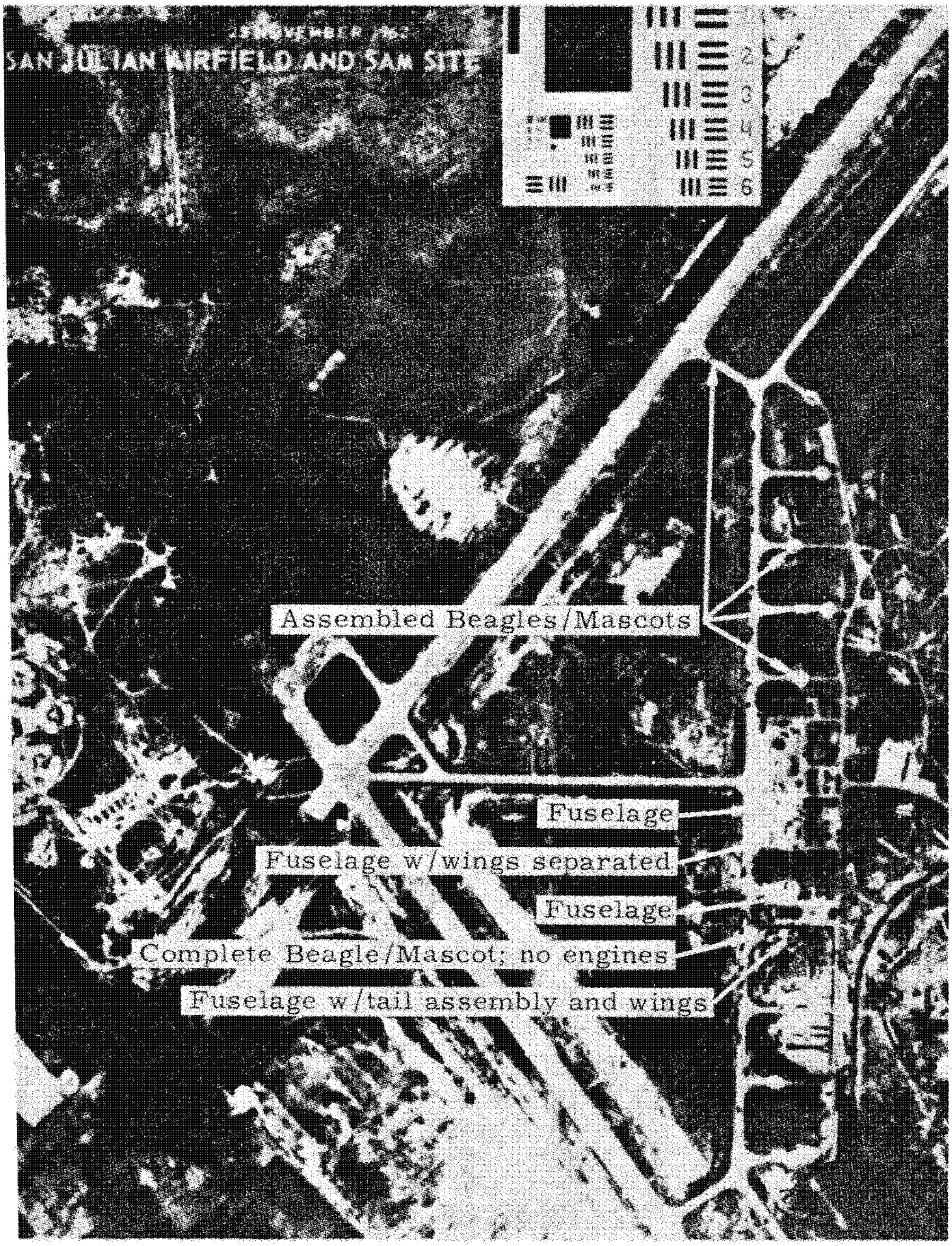
Space-booster proliferation will allow these other nations, if they choose, to launch and operate satellites to take pictures of the Earth from orbit. These observation satellites will be able to inspect the extent of compliance by all nations to arms-control agreements.

To be useful, pictures for this purpose will have to surpass, somewhat, the quality of those now taken by meteorological satellites and by orbiting astronauts. The ground resolution of pictures taken to date is measured *in miles, or in hundreds of feet,* whereas pictures used to inspect man-made facilities should have a ground resolution measured *in tens of feet.* Such performance, with a ground resolution of 10-50 ft, can be realized by relatively small payloads using available optical techniques.

Before examining inspection-satellite design that will give this performance, we should look in a little more detail at the design-conditioning booster picture.

International Scoreboard: The multi-nation

MERTON E. DAVIES (AF), a senior-staff member of RAND's Electronics Dept., invented the spin-pan camera referred to in this article and has engaged in aerial and space reconnaissance studies for some time. He has served as a consultant to DDRE and the Arms Control Agency, as RAND'S liaison to Air Force Intelligence, and, most recently, as a U.S. Antarctic Observer under Article VII, Antarctic Treaty. He is also a member of the TV experiment team, 1969 Mariner Mars mission.



San Julian Airfield, Cuba, November 25, 1962, depicted at 20-ft resolution.

European Launcher Development Organization (ELDO) has, of course, been developing a three-stage booster, Europa 1 (sometimes called ELDO A). Britain is responsible for development of the first stage, France for the second stage, and West Germany for the third. Italy is responsible for test satellites, Belgium for downrange guidance, the Netherlands for telemetry, and Australia for the range facility (at Woomera). The cost of this program has been much higher than estimated. Test firings are proceeding, however, and should lead to the orbiting of a satellite by 1968.[5, 6]

Current French satellites are orbited by Diamant boosters from the missile test range at Hammaguir, Algeria, in the Sahara Desert. As this range must be abandoned by July to meet the terms of the French-Algerian treaty, a new French space center and launch site is under construction near Kourou in French Guiana (about 5 deg north of the equator). This new facility should become operational by the beginning of 1969. Its favorable location will permit launching satellites into both polar and equatorial orbits.[7, 8]

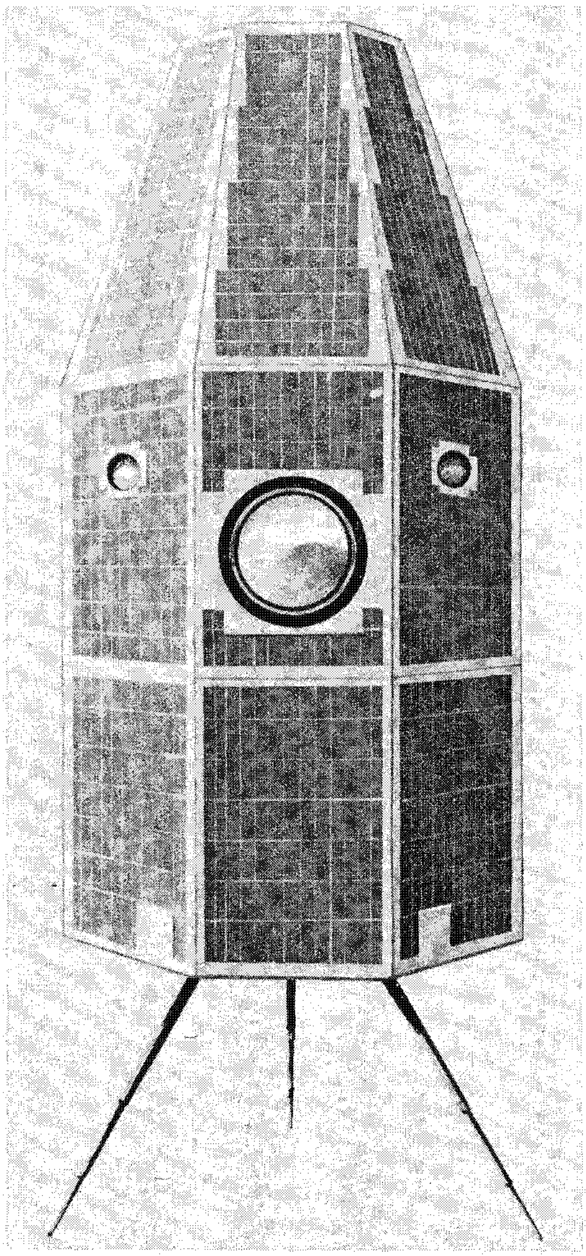
Japan expects to orbit a satellite next year with the Mu-4 booster from Kagoshima Space Center, on the southeastern tip of Kyushu Island. All four of the Mu-4's solid stages have been individually test-fired. The guidance-and-control system is currently being tested. If all goes as planned, Japan should be the fourth nation to participate in satellite operations.[9]

The British have been slow to support a domestic satellite program. In the fall of 1965, however, the Conservative government approved development of the Black Arrow booster, conceived as a further development of the Black Knight high-altitude rocket program, using much of the technology developed for that vehicle. The Labor government, however, has since given only limited support to this program—so a meaningful flight schedule is not available.[10, 11]

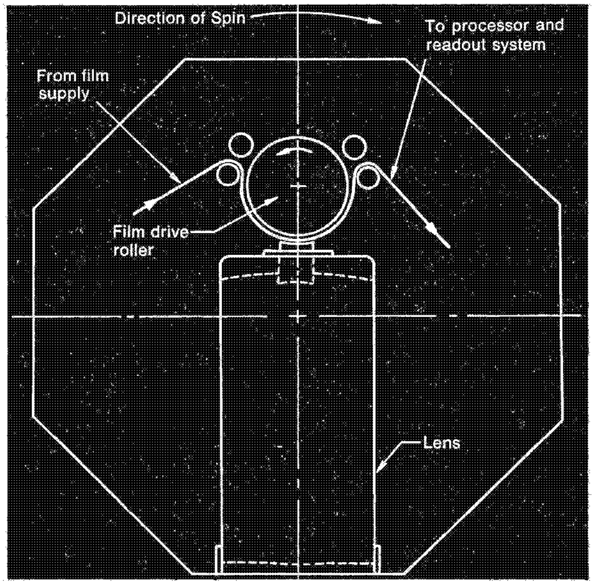
In 1963, the United Arab Republic announced plans to launch a satellite called Star. Its booster was expected to be an extension of the UAR's Al Ared missile. Launch of the Star is overdue, but reports indicate that the program has not been abandoned.[12, 13]

Inspection Satellite Design: As these new boosters will be able to orbit only small payloads, a design study of a particular inspection satellite has been used to test the feasibility of developing a lightweight system. Minimum weight being a requirement, a "spin-pan" type of camera was

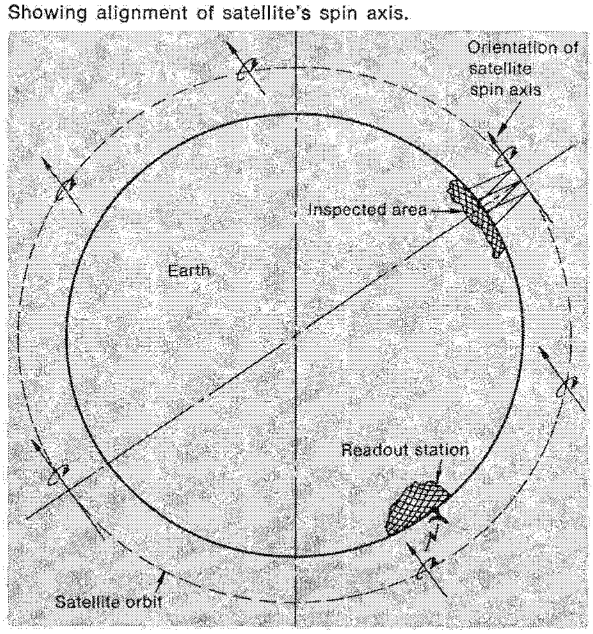
INSPECTION SATELLITE DESIGN—BOOMS UNEXTENDED



SPINNING PANORAMIC CAMERA SCHEME



SATELLITE OPERATION
Showing alignment of satellite's spin axis.



selected[14]—that is, a panoramic camera operating from a spin-stabilized vehicle whose spinning performs the cross-track scan of the camera while the film moves across a slit located at the focal plane. This takes place at a velocity that compensates for the spin during the exposure. Thus, a wide-angle picture is produced by scanning with a simple narrow-angle lens.

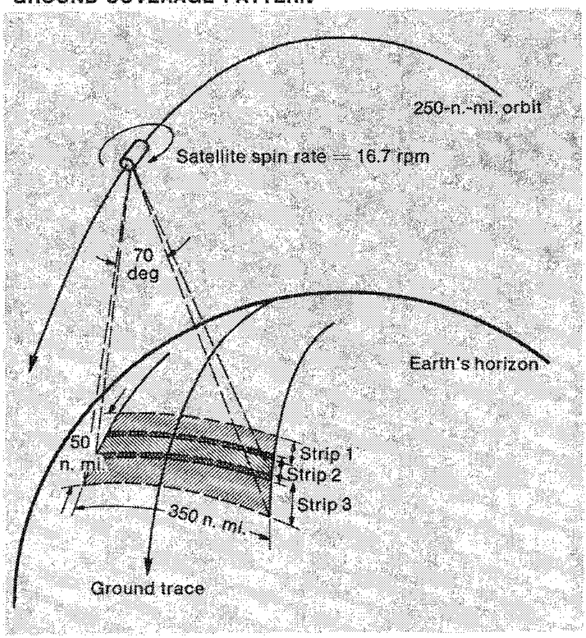
Film velocity is determined by a sensor which measures the satellite spin rate. A horizon sensor, a sun sensor, a gyroscope, or ground measurement can be used for this purpose. The spin axis of the vehicle can be changed by magnetic torquing. (This technique is planned for the French D-2,[15] and all Tiros satellites change spin axis in this way.[16]) Passive dampers simply and easily keep the nutation angle small.

Such a camera could record several pictures on film daily for 100 days. The film would be processed in the satellite and electronically scanned for picture transmission to ground stations by broadband telemetry. (The U. S. Lunar Orbiter and the Soviet space probes Lunik III and Zond 3 produced Moon pictures essentially this way.

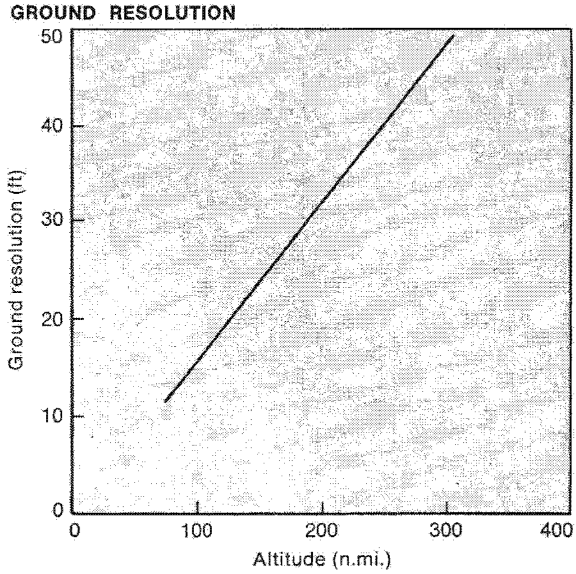
The illustrations just above show an external view of this spacecraft design, including the camera lens and the solar-cell panels. Booms which deploy in orbit are not shown. The spacecraft and all of its equipment, film, developer, etc. would weigh about 250 lb. A diagram at the top right indicates the internal configuration of the camera, which would have a catadioptric lens of 30-in. focal length.

The readout camera characteristics can be

GROUND-COVERAGE PATTERN



GROUND RESOLUTION



summarized as follows: Lens, 30-in. catadioptric, f/4.5; format, 2.25 by 36.6 in.; scan angle, 70 deg (± 35 deg from nadir); film, 70-mm SO-136 or equivalent; aerial exposure index, 20; exposure (nominal), 1/1500 sec, preset before flight; slit width, 0.030 in. fixed; IMC (image-motion compensation), fixed, cam action; cycling rate, 3.6 sec; mode of operation, three strips in sequence; and forward coverage, 20% overlap at center of frame.

The spin axis, which lies in the orbital plane, would be parallel to the surface of the Earth only twice on each orbit, as shown in the illustration on page 70. Consequently, the direction of the spin axis should be programmed to be horizontal over the desired inspection area. If the camera operates through a 70-deg scan, then an area 350 by 45 n. mi. would be photographed from an altitude of 250 n. mi. in a single pass, as illustrated at the left.

After exposure of the film, processing would be completed aboard the satellite by a web developer, and the film would be stored to await readout. When the satellite passed within range of a receiving station, film scanning and transmission to the ground would complete the operation. Readout characteristics would be as follows: Resolution, 50 line pairs/mm; scan rate, 860 lines sec; rate of film motion, about 0.50 ips; and video bandwidth about 4.5 Mhz.

Ground resolution expected of this design would be about 20 ft at a 125-n. mi. altitude and 40 ft at 250 n. mi. The graph at the bottom left shows ground resolution of the system as a function of altitude.

Inspection Satellite Applications: Photography with a resolution of 10-50 ft seems well suited to arms-control applications. It would be valuable in the inspection of military facilities such as forts, military basis, airfields, munition-storage facilities, docks and naval installations, missile ranges, and even manufacturing facilities for weapons and delivery systems.

To illustrate the capabilities and limitations of this spaceborne photography concept, selected pictures of Cuba taken by U-2 aircraft during the 1962 missile crisis have been re-photographed to simulate the resolution of satellite photography. The picture on page 69 shows the San Julian airfield in Cuba as though with a ground resolution of 20 ft. The runways, taxiway, parking areas, hangar facilities, and hardstands can easily be seen, even if individual aircraft, trucks, and trailers cannot be readily identified. The SA-2's site can also easily be spotted, although its operational status cannot be determined from the photo. Mobile SA-2s being used in North Viet Nam certainly would not be detected at this resolution.

The picture on page 72 shows the construction of the IRBM base at Remedios, Cuba, as though photographed with a 40-ft ground resolution. Without doubt this missile complex would be detectable from such a photo during construction. The characteristic road and cabling between the launch pads and control bunkers, the security fence, and the support buildings serve to identify the nature of the facility. It is difficult, however, to determine the status of the construction or to ascertain when the base would become operational. Obviously, destruction of the base, which occurred shortly after these pictures were taken, could not have been observed from such a picture.

Concluding Remarks: Inspection by small satellite can make a valuable contribution to world peace by aiding in the disclosure of military build-ups and violations of certain arms-control

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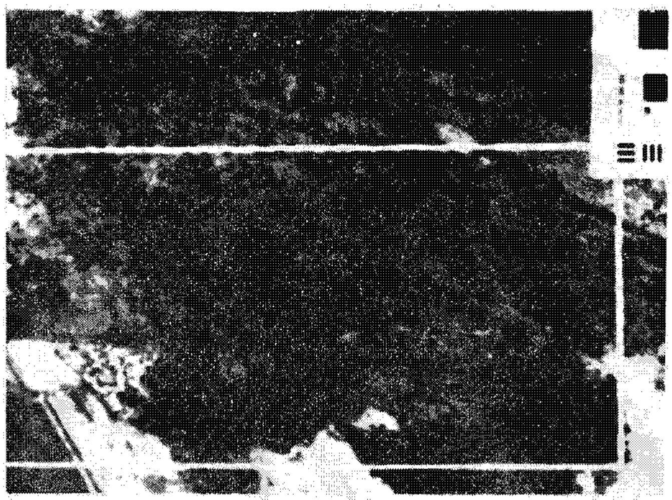

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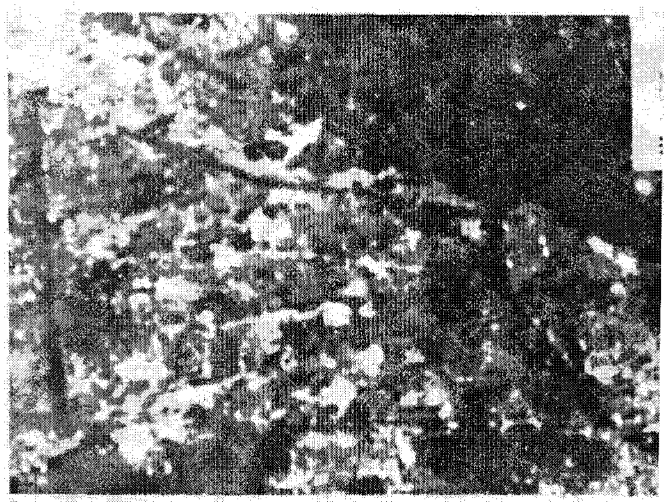

B

IRBM site at Remedios, Cuba, at 40-ft resolution. **A** Before construction, 5 September 1962. **B** Construction underway, October 17, 1962.

agreements. The wherewithal for such observations readily exists within the current state of the art, available not only to this nation but also to others—increasingly so in the next several years.

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