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A Large Format Camera for Shuttle*

This 30.5-cm focal length camera, orbiting the Earth at an altitude of 300 km, will provide a ground resolution of 14 to 25 m and permit compilation of contours at 20 to 30 m intervals.

Abstract: *NASA is building a high-performance cartographic camera with a 30.5-cm focal length and a 23 by 46-cm format. Initially the camera will be carried in the cargo bay of early Shuttle flights. From a nominal altitude of 300 km, each frame will cover 225 by 450 km with a ground resolution of 14 to 25 m, depending upon the choice of film. With the long dimension of the frame in the direction of flight, base-height ratios of up to 1.2 can be obtained, permitting compilation of topographic contours at 20- to 30-m intervals.*

If photography from the sortie missions proves to be as useful as expected, the camera may be mounted in a free-flying spacecraft which can be placed in near-polar orbit and remain operational for many months, with film being recovered and returned to Earth by the Shuttle.

Introduction

From the time that the first space photographs were made with a hand-held Hasselblad camera on the Gemini missions, photogrammetrists have considered that orbiting spacecraft should be the next step in the logical progression from planetable to aerial photography to space photography. But despite the widely acclaimed success of the Landsat program, photogrammetrists have generally been dissatisfied with the low resolution and the lack of stereocoverage, which prevent the Landsat imagery from contributing to conventional stereomapping programs.

As long ago as 1967, the National Academy of Sciences Committee on the Useful Applications of Earth-Oriented Satellites recommended a camera system which would contribute to worldwide topographic mapping. The proposed approach comprised a cartographic frame camera to be used for establishing control and a panoramic camera to provide the resolution needed to compile planimetric detail. The fundamental feasibility of this approach was demonstrated on the Apollo 15, 16, and 17 missions, on which a similar system was carried into lunar orbit. Based on the measurement of these photographs, a lunar control net with an internal consistency of 30 m in all three coordinates has been developed, and topographic orthophotomaps at scales as large as 1:25,000 have been produced. Such a system has

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been proposed to NASA for operation in Earth orbit on several occasions, but for a variety of reasons the system has never been implemented.

CAMERA DESIGN

Now, however, NASA is developing a Large Format Camera (LFC) as a payload for the cargo bay on the Space Shuttle. The fundamental parameters of the camera are—

focal length = 30.5 cm

format = 23 by 46 cm

aperture = f/6.0

The camera will be mounted with the long dimension of the format in the direction of flight.

The lens consists of eight optical elements plus an antivignetting filter as shown in Figure 1. It has a maximum distortion of 15 μm over the entire format and 10 μm over the center 23 by 23 cm portion of the format. The lens is color corrected for wavelengths from 0.40 to 0.90 μm. Optical filters can be inserted in the center of the lens to correct the color balance for black-and-white, natural color, or color infrared film. These filters will be mounted in a motor-driven turret which can be changed by external command. The lens has a resolution of 80 line pairs per millimetre AWAR, with a minimum of 50 line pairs per millimetre in the corner of the format. The dynamic ground resolution produced by the lens is indicated in Figure 2. At the nominal operating altitude of 300 km, the ground resolution is approximately 14 m on high-resolution black-and-white film and 25 m on color infrared film. It is worthy of note that this is photographic resolution and not pixel dimension as normally given for electro-optical systems such as Landsat. In terms of detail visible in the images, 14-m photographic resolution is approximately equivalent to a 6-m pixel dimension. A prototype lens has already been built and tested, and the expected values for distortion and resolution have been verified.

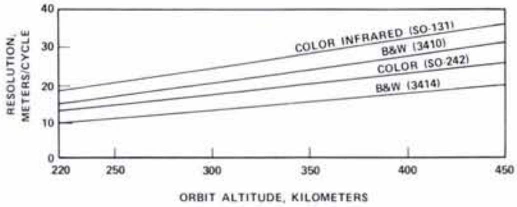

FIG. 2. Dynamic ground resolution at 2:1 contrast.

The between-the-lens shutter is more or less conventional with rotating disks and a capping blade. Relatively slow shutter speeds are required to expose high-resolution black-and-white and color films. Exposure times covering the range of 0.003 to 0.024 s can be established from the operator control panel or by a scene brightness sensor. This sensor has a 5° field of view and integrates the scene brightness for 15 s prior to shifting the exposure duration. This technique nullifies the effects of high brightness levels from clouds, snow patches, sun glint, etc.

The camera magazine, as illustrated in Figure 3, will have a maximum capacity of 1200 m of film, sufficient for 2400 frames. A film spool containing this much film is very heavy, and it is necessary for it to rotate continuously during camera operation to avoid the serious vibration effects of starting and stopping. Lightweight dancer rollers are provided on both the supply and takeup sides to accommodate the film unspooled during camera cycle time. The film will be held against the platen by a negative pressure differential between the lens cone and the camera back. This pressure differential will be provided by a gaseous nitrogen sys-

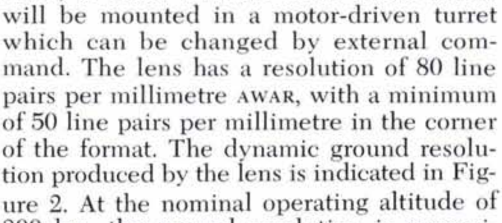

FIG. 1. LFC lens configuration.

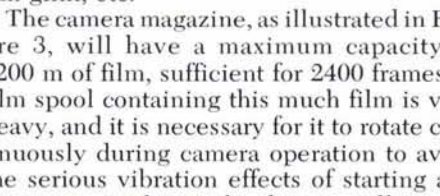

FIG. 3. LFC film magazine.

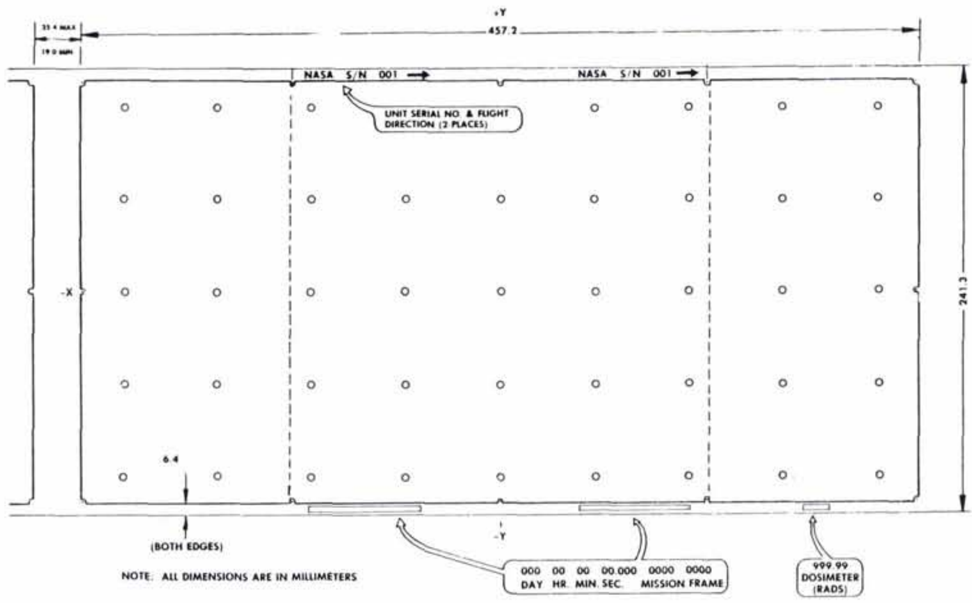

FIG. 4. Focal plane fiducials and reseau.

tem, which will also prevent static electricity buildup and film brittleness. While the film is held in contact with the platen, the platen will be translated in the direction of flight to provide forward motion compensation. The FMC range is 0.010 to 0.045 rad/s, which is adequate for all normal operating altitudes of the Space Shuttle. This FMC will permit the long exposure times required by high-resolution films. The platen will also contain a reseau at 5-cm intervals. The reseau will be provided by 0.05-mm holes, illuminated by light emitting diodes from the rear of the platen. The reseau can be switched on or off on command. It will probably be used for a few frames at the beginning and end of each photographic pass.

The photograph format is illustrated in Figure 4. Fiducials at the midpoints of the leading and trailing edge and both sides of the film will define the principal reference system. Additional fiducials will be provided to define any 23 by 23-cm portion of the overall frame. Digital data blocks will provide the time of exposure, mission, and frame numbers.

CAMERA OPERATION

The normal operating mode will be 80 percent forward overlap, but 60 percent and 10 percent are also available on command. As illustrated in Figure 5, appropriate selection of frames can provide stereo-models with a base-height ratio of 0.3 to 1.2. It is worthy of note that, when the camera is operated in the 80 percent forward overlap mode, the central 23 by 23 cm portions of consecutive frames have a forward overlap of 60 percent with a B/H ratio of 0.3. The central portions are thus amenable for plotting in any standard photogrammetric instrument that will accommodate the 30.5-cm focal length. Maximum advantage of the full frame overlap with 1.2 B/H ratio can be obtained with analytical plotters in which the principal point can be offset from the center of the 23 × 23-cm diapositive.

As shown in Figure 6, the terrain coverage

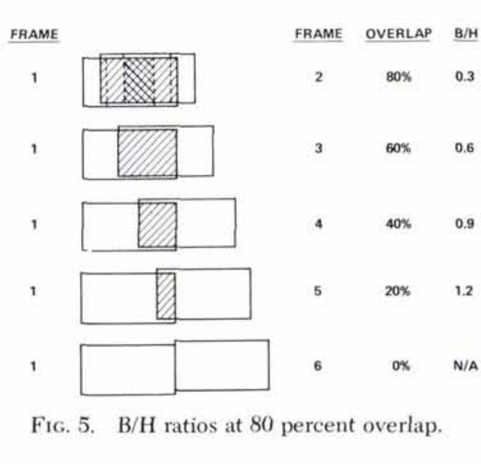

FIG. 5. B/H ratios at 80 percent overlap.

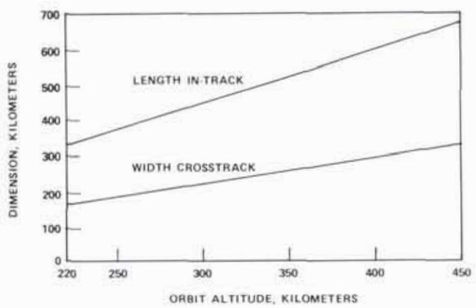

FIG. 6. Terrain coverage dimensions.

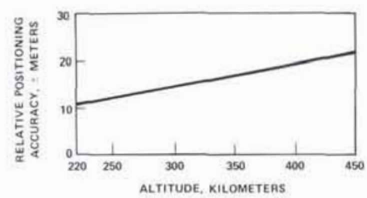

FIG. 7. Position accuracy.

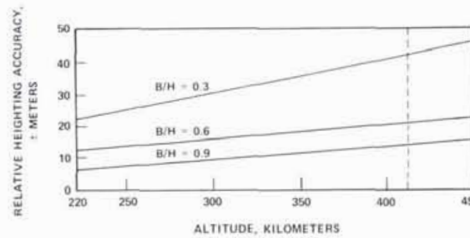

FIG. 8. Elevation accuracy.

available from orbital altitude is enormous. At the nominal altitude of 300 km, for example, each frame covers 225 by 450 km with the long dimension in the direction of flight.

Figure 7 shows the positioning capability, presuming measurements are made with a precision of 0.015 mm on the photograph. At 300 km altitude this is equivalent to 15 m on the ground, which is adequate for map compilation at scale 1:50,000. Figure 8 shows the elevation accuracy obtainable at various B/H ratios. A precision of better than 10 m is available at 300 km altitude. This should be adequate for compiling contours at 30 m vertical interval.

SPACECRAFT MOUNTING

For the initial flight the camera will be mounted in its own environmental enclosure

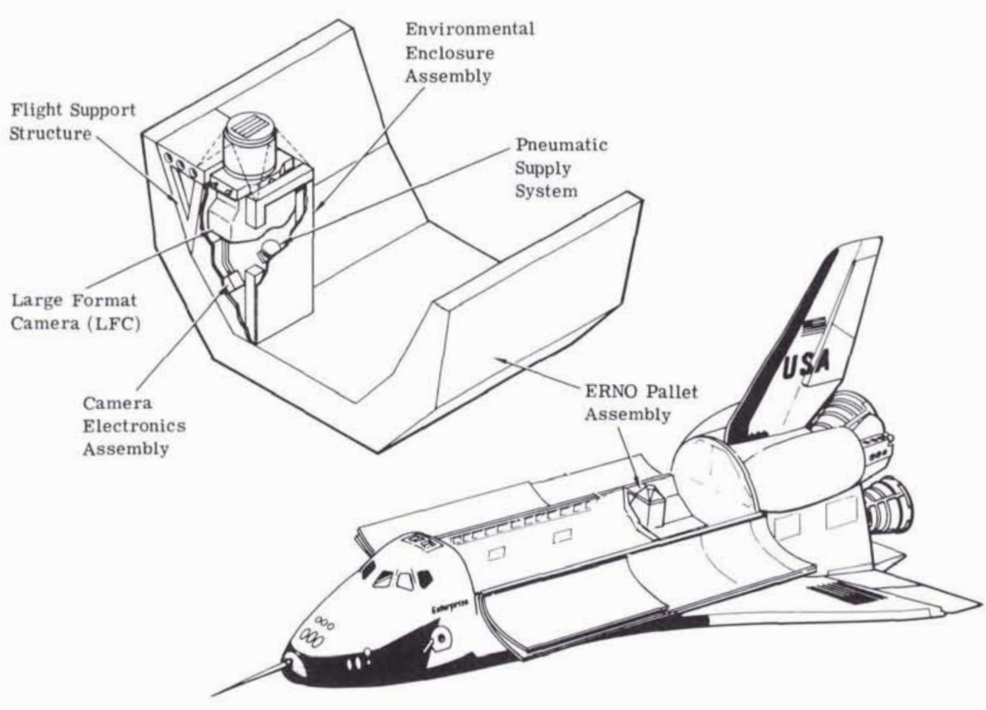

FIG. 9. LFC on pallet in cargo bay.

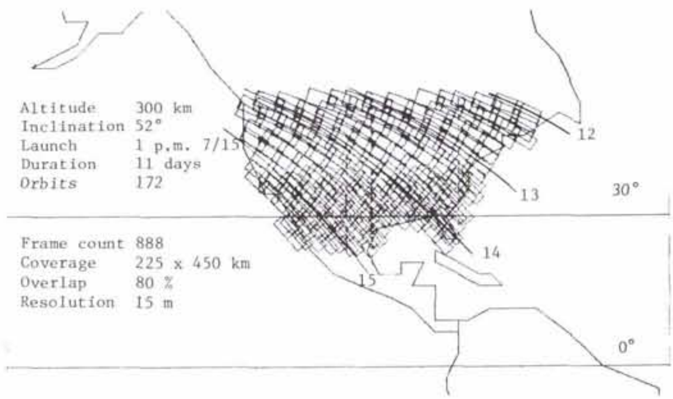

FIG. 10. Optimized United States coverage.

on a pallet, which will be carried in the aft end of the Shuttle cargo bay as shown in Figure 9. A study has been completed to define the interface between the camera controls and the Shuttle systems. It is contemplated that the camera will be operated whenever the Shuttle is in the Earth-viewing mode and illumination conditions are satisfactory. Crew participation will be required to evaluate cloud cover so that maximum advantage can be taken of the film load. The camera will, of course, be only a small part of the Shuttle payload, and orbit parameters will be dictated by the primary payload. Unfortunately, all early Shuttle flights will be at low inclinations, and the time on orbit will be restricted to 5 or 7 days. Payload space has been requested on Shuttle Mission 9, now scheduled for August 1980. The potential coverage on this mission will be limited by latitudes 28.5° north and south. This will provide good coverage of South America, Africa, Southeast Asia, and Australia, but very little over the United States, Europe, USSR, and China. Later missions will operate at higher orbital inclinations, and coverage provided by a mission optimized for the United States is shown in Figure 10.

It is obvious that short-lifetime, multipurpose manned missions are not an efficient way to acquire photographs from space. There are always conflicting requirements on crew time, spacecraft capabilities and attitude, and orbital parameters. If photography from the early sortie missions proves to be as useful as expected, the camera may subsequently be mounted in a free-flying spacecraft, such as the Multi-mission Modular Spacecraft (MMS), which is specifically designed for launch and service by the Shuttle. Polar-orbit capability should be available in 1983, when Shuttle launch facilities are operational at Vandenberg Air Force Base on the West Coast. One or two cameras

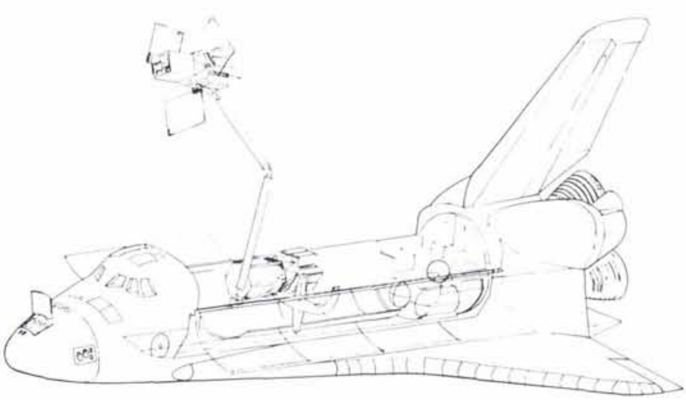

FIG. 11. LFC on free flying spacecraft.

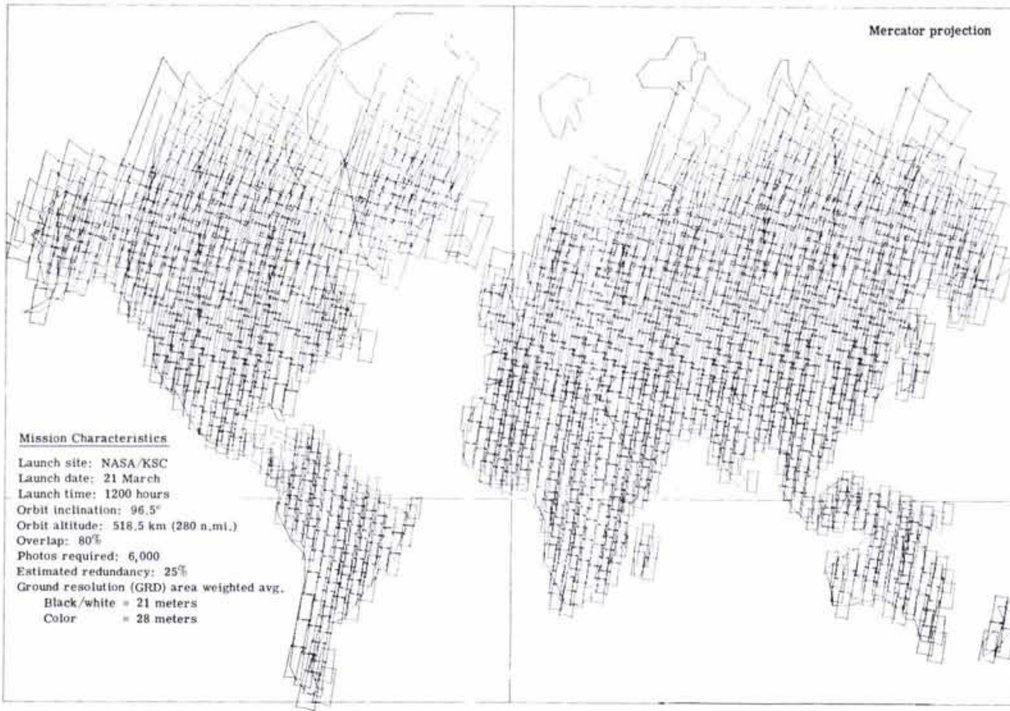

FIG. 12. LFC world-wide coverage.

can be mounted in the MMS, which contains its own power supply, attitude control, and command and data handling systems. Spacecraft power would be provided by solar arrays. As illustrated in Figure 11, the spacecraft would be placed in orbit by means of the remote manipulating arm on the Shuttle. When the film load is expended, the Shuttle will rendezvous with the MMS and bring the spacecraft back into the cargo bay, where film magazines could be exchanged manually by an astronaut or automatically by the flight-support system being developed for the MMS. The spacecraft can then be placed back into its own operational orbit. Periodically the entire spacecraft could be returned to Earth in the cargo bay for major overhaul. Figure 12 shows the type of global coverage pattern which would be available from this mode of operation.

When this system is realized, photogrammetrists will finally have the opportunity of compiling 1:50,000-scale topographic maps from space photographs anywhere in the world.

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Erratum

In the article, "Applications of DTM in the Forest Service" by Terry G. Gossard, on pages 1581 and 1583 of the December 1978 issue of *Photogrammetric Engineering and Remote Sensing*, the figures and captions were transposed. The photograph in the Figure 5 position should go in the Figure 6 position, the photograph in the Figure 6 position should go in the Figure 8 position, and the photograph in the Figure 8 position should go in the Figure 5 position.