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Memorandum

TO : M/Associate Administrator for Manned Space Flight

DATE APR 11 1967

FROM : ML/Director, Saturn/Apollo Applications

SUBJECT: Comparison of Lunar Orbiter and LMSS

With results now in hand from three unmanned Lunar Orbiter missions; we have re-examined the need for continuing development of the Lunar Mapping and Survey System (LMSS). The attached matrix compares the baseline and proposed augmented versions of the Lunar Orbiter and the LMSS.

Lunar Orbiter vs. Baseline LMSS

To date, Lunar Orbiter has performed close to its specification levels in both ground resolution and photographic coverage, and it is providing data which appears adequate for selecting Apollo landing sites. However, the recent MSC presentation to the Apollo Site Selection Board indicated that, despite intensive data reduction efforts involving sophisticated photogrammetric and computerized photoclinometric analysis as well as painstaking photointerpretation efforts, the Lunar Orbiter photographs appear marginal for high confidence certification of Apollo landing sites in two critical areas: terrain slope measurements and extrapolation of soil characteristics from Surveyor surface photography.

The terrain slope problem is in two parts: general slopes over tens of miles along the ground trace under the LM approach to the site, and local, LM-sized area slopes within the 2-3 mile landing ellipse. Along the LM approach path, average terrain slopes between 1^{o} and 2^{o} are required for the LM landing radar to assure initiating the terminal phase maneuvers with sufficient accuracy for landing in the selected ellipse. Photogrammetric analysis of Lunar Orbiter data has resulted in slope measurements which are uncertain by several degrees. These errors are caused by distortions introduced in the basic camera system, the onboard readout system and the telemetry system, none of which were designed for precision photogrammetric measurements. For measurement of local, LM-sized area slopes, a complex photoclinometric analysis technique utilizing the full capacity of an 1108 computer at MSC is being used to statistically sample selected sites

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to deduce a probability of safe LM landing. Error analyses of this technique, which must rely on the essentially monoscopic, 1-meter resolution Lunar Orbiter photography, have not yet been performed. Although the data being generated is statistically impressive, its accuracy and, thus, its validity in certifying LM landing sites is subject to question.

The problem of extrapolating soil mechanics data from Surveyor photography requires, according to MSC and USGS geologists, stereoscopic orbital photography with ground resolution considerably smaller than 1 meter (20 centimeters has been mentioned). The monoscopic, 1 meter resolution capability of the Lunar Orbiter has proven incapable of meeting these requirements from its nominal perigee altitude of 25 nm. To achieve 20 cm stereo photography, the Lunar Orbiter would have to fly at a perigee of 5 nm and would have to undergo rapid, accurate, precisely timed oscillating maneuvers to provide convergent stereo. These maneuvers appear well outside the design capabilities of the system.

Apollo has identified work-arounds for the slope problem involving procedures and software which indicate no need for additional photography prior to the first lunar landing.

The baseline IMSS has been adapted from DOD technology with the primary objective of providing Apollo landing site certification photography, and test data and analysis to date indicate that it should be able to accomplish this task. In particular with regard to terrain slopes, the geometric characteristics of the Mapping camera (including its stellar index camera for fine attitude determination, its calibrated lens to minimize effects of distortion, its reseau to offset effects of film shrinkage, its convergent stereo capability controlled by 3 millisecond timing /as compared to 100 millisecond timing for Lunar Orbiter/ and the recovery of the exposed film for laboratory processing) all contribute to the IMSS ability to measure general terrain slopes to better than 2°. In addition, this metric capability will permit photogrammetric location of lunar landmarks and landing sites to better than $\pm$1500 feet anywhere on the lunar surface as specified for the landmark navigation technique used to update the Apollo Guidance and Navigation Computer. With regard to LM-sized areas within a selected landing ellipse, the Survey camera will provide convergent stereo photography with ground resolution considerably better than 1 meter, and analysis by Eastman Kodak (contractor for both the Lunar Orbiter cameras and the Survey camera) indicates approximately 2% accuracy for the Survey camera in determining slopes of LM landing spots as compared to an estimated 8% accuracy for the monoscopic high resolution Lunar Orbiter camera. Based on this analysis, the LMSS offers a factor of 4 improvement over the Lunar Orbiter in determining LM landing area landability.

Other comparative features of the LMSS and the Lunar Orbiter include the orbital characteristics, the area coverage and cost. Lunar Orbiter's nominal orbit is a 25 x 1100 nm ellipse, with perigee over the area of interest and with site selection coverage limited to a small region near perigee. The LMSS has been designed for circular lunar orbits in the range of 25-45 nm altitude, resulting in site certification coverage of any area along its orbital path. High resolution lunar orbital coverage at 1 meter (monoscopic) per 28-day photographic mission totals 3200 sq nm; Survey camera coverage on a 14-day mission totals 73,500 sq nm monoscopic or approximately half that area in stereo on 52 pounds of recoverable film. Lunar Orbiter's medium resolution (8 meter) convergent stereo coverage totals 27,600 sq nm; the Mapping camera is designed to provide 1,900,000 sq nm of convergent stereo metric photography on 2½ pounds of recoverable film. The Lunar Orbiter can fly in orbits of any inclination and thus theoretically can acquire its design coverage of any area of the moon. Initial Apollo missions with the LMSS will be limited to equatorial lunar regions between $\pm 10^\circ$ latitude because of the Apollo free return trajectory constraint. Later Apollo/LMSS missions to higher inclinations (up to polar) should be unconstrained by the free return trajectory requirement.

The five Lunar Orbiter spacecraft represent an expenditure under the Boeing contract of approximately $150 M, with an additional $8 M per launch for boosters-launch operations support. The initial two LMSS payloads will represent an expenditure of approximately $48 M, with Saturn V/CSM spacecraft costs estimated at approximately $225 M per mission.

Augmented Lunar Orbiter vs. Extended Capability LMSS

The augmented LMSS described in the attached matrix represents one of several modified versions of the basic LMSS which have been under study by MSC and the LMSS contractor team since last fall. These modifications are being designed on the basis of retro-fit of the basic

LMSS system, and current indications are that the first of three augmented LMSS's could be ready for flight in the first half of 1969. The augmented (Block III) Orbiter described on the matrix is understood to be in a Phase A study status by Boeing and IITRI and represents essentially a new, 2,500 pound spacecraft for launch on an Atlas-Centaur in the 1972 time frame, as compared to the Atlas-Agena launch, 800 pound current Lunar Orbiter. The significant point here is that the augmented LMSS represents a relatively minor augmentation of a basic configuration to take advantage of the relatively unlimited payload capability when substituting an LMSS payload module (4,600 pound baseline) for the LM (32,000 pound control weight) in a standard Saturn V lunar mission launch. The three year gap in lunar orbital sensing capability which would result from a decision to implement the Block III Orbiter instead of the augmented LMSS corresponds to a critical period of lunar exploration phasing in going from the one day Apollo landings in 1968-69 at near equatorial sites to missions of up to two weeks duration perhaps at higher latitudes in 1970-71 for exploration of regions of greater scientific interest.

The Block III Orbiter concept envisions a 400-pound experiment package as compared to a 137-pound package on the current Orbiter. This compares with several thousand pounds of simultaneously flown experiments possible with the augmented LMSS. The significance here is that simultaneous operation of several sensors such as metric photography, high resolution sample photography, gamma or x-ray spectroscopy, etc., would have significant scientific value in contrast to flying each experiment individually at different periods of time and thus losing the correlation of time, changing phenomena on the surface, and lighting angles.

The Block III Orbiter concept envisions the return to earth of approximately 30 pounds of data, while the augmented LMSS has a capability for returning film or other data totalling between 250 and 1,000 pounds, depending on the size of the crew (3 men or 2 men, respectively).

The first payload being considered for the Block III Orbiter is a 3 inch focal length Mapping camera derived from the (-6) system earlier included as part of the LMSS but deleted last year in favor of the less expensive and more mature system now in the baseline LMSS. The system being considered for the Block III Orbiter would be capable of better geometry--therefore better lunar maps--than the LMSS system, although the highly elliptic Lunar Orbiter orbit would preclude uniform mapping coverage of the entire lunar surface on a single Block III mission as compared with the augmented LMSS 100% lunar mapping capability on a single 28-day polar orbit mission.

Cost estimates for the Block III Lunar Orbiter are necessarily quite vague in this stage of definition, but $300-$400M for six flight payloads beginning in 1972 has been estimated, excluding the Atlas-Centaur booster and flight operations which are roughly estimated at $15-$20M per launch. The POP figures for the three remaining LMSS's, including an ROM estimate of $10M for the augmentation, totals approximately $30M, excluding the cost of the supplemental experiments which could total an additional $20-$30M.

In summary, this comparison shows that, as indicated during the recent Apollo Site Selection Board review, the current Lunar Orbiter is only marginally capable of certifying Apollo landing sites, while the LMSS offers significantly better performance in the two most critical areas: terrain slope measurements and high resolution stereo for extrapolating Surveyor measurements of soil characteristics. In comparing the augmented LMSS with the advanced Orbiter concept, factors of design maturity, earlier availability, spectral and resolution capability, return film weight capability, and cost of development all strongly favor the augmented LMSS.

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Attachment

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COMPARISON OF LUNAR REMOTE SENSING SYSTEMS

	CURRENT PROGRAMS		FOLLOW-ON PROGRAMS		
	Lunar Orbiter	Baseline LMSS	Blk III Orbiter	Extended Capability LMSS	Remarks
Current Status	Operational	Hardware design complete; mfg and test underway	Phase A studies in progress by Boeing and IITRI	Preliminary design of mods in progress; basic units to be modified in fab.	
Available Launch Date	2 remaining flts - Orbiter D 6/67; Orbiter E 8/67; proposed Orbiter F in '68	Lunar contingency - 6/1/68 Earth test - 7/1/68	1972	AS-510 in last quarter '69; remaining flts when desired	Without LMSS at least a 4 year gap in lunar orbital missions would result
Orbital Characteristics					
- Staytime	28 days (Photo)	14 days	>28 days	14 days on AS-510, >28 day subsequent	
- Altitude	25nm perigee - 1100nm apogee	25-45nm and circular	Probable 25nm perigee	Same as baseline	
- Inclination	Any	<10° free return constraint	Any	Any	
Astronaut Participation	None	Limited capability to participate in other experiments (e.g., S065)	None	As desired to operate or conduct experiments, and aid in targeting, etc.	IVA for data retrieval, etc. on early missions
General Experiment Support	Present 137 lb. photo subsystem package plus micrometeoroid experiment is all that can be accommodated	A few additional experiments can be accommodated in the PM and CM	Estimated 400 lb. experiment package. First mission would be mapping; second - compositional expts.	A large capability would accommodate 600+ lbs of experiments in over 30 cu. ft. of internal volume - other experiments externally or in CM	The extended capability LMSS is well suited to support multi-sensor missions Both the Orbiter and Baseline LMSS have thorium isotopes precluding gamma ray and X-ray spectrometry. Problem is being studied
Return Wgt/ Volume	TM Data Only	80 lbs/4 ft³	~30 lbs/<1 ft³	>250 lbs/10 ft³	

COMPARISON OF LUNAR REMOTE SENSING SYSTEMS (Cont'd)

	CURRENT PROGRAMS		FOLLOW-ON PROGRAMS		Remarks
	Lunar Orbiter	Baseline LMSS	Blk III Orbiter	Extended Capability LMSS	
Present Photo Subsystem Capabilities				Same as baseline	
- Geometry (Stereo and Analytical Photogrammetry)	24"F.L. Camera has limited stereo; is lacking in premission calibration, time data, orientation data, and suffers from readout/TM/reconstruction induced deformations 3"F.L. has fair stereo; is lacking in premission calibration, time data, orientation data, has no glass reseau, and suffers from readout/TM/reconstruction induced deformations	Survey camera provides stereo at high resolution, and photos are combined analytically with concurrent mapping photography having careful premission calibration, accurate time data, accurate orientation data, and glass reseau, and film is recovered to preserve geometry - slope data accurate to $<2^o$ - relative position accuracy of two points 5nm apart < 100 ft - Contour interval/formlines ~100 ft	3"F.L. Mapping camera has excellent geometry, and geometry is preserved by film recovery, but ground resolution (of any Mapping camera) is unsuited for detailed stereo survey of surface features		Regarding the Lunar Orbiter: - Poor B/H ratio (both cameras - Poor premission calibration - Time uncertainty -- 0.1 sec. - Orientation uncertainty ~1/2° (all 3 axes) - TM destroys any photogrammetric value by adding geometric deformations Regarding the LMSS: - Survey camera features high resolution stereo with photography well suited for photoclinometric analysis - Mapping camera is always operated concurrently with survey camera to provide system geometry - Time accuracy both cameras -< 3 milli. - Orientation from stellar imagery accurate to < 5 minutes of Arc - Mapping camera has glass reseau - Both systems must be well calibrated for geometry and photometry (premission) - Film is recovered--geometry is preserved

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COMPARISON OF LUNAR REMOTE SENSING SYSTEMS (Cont'd)

	CURRENT PROGRAMS				FOLLOW-ON PROGRAMS			
	Lunar Orbiter		Baseline LMSS		Block III Orbiter	Extended Capability LMSS		Remarks
- Photoclinometry	EKC Study estimated 8% accuracy in slope Determination of LM pad, discounting effects of small protruberances		EKC Study estimated 2% accuracy in slope Determination of LM pad, discounting effects of small protruberances		No data	Same as baseline		Survey camera is well suited to obtain photography suitable for photogrammetric analysis. Photoclinometric analysis relys on geometry to provide geometric datum.
- Resolution	24" F.L.	3" F.L.	Survey Camera	Mapping Camera	Mapping Camera Only	Survey Camera	Mapping Camera	
Spacial	1.0-1.5M	8-10M	<1M	> 12M	8M	<1M	>12M	All ground resolutions for 30nm altitude
Specral	4,000-7,000 Å-no color	4,000-7,000 Å-no color	4,000-10,000 Å	4,000-7,000 Å	4,000-7,000 Å	4,000-10,000 Å	4,000-7,000 Å	survey camera is well suited for IR & color as well as panchromatic emulsions
Temporal	~100 milli sec.	~100 milli sec.	<3 milli sec.	<3 milli sec.	<3 milli sec.	<3 milli sec.	<3 milli sec.	
- Area Coverage	3,200nm^2 - ~11b - 7 mil film	27,600nm^2 - ~11b - 7 mil film	73,500nm^2 - 52 lbs - UTB (2 mil film) - Monoscopic	1,900,000nm^2 - 2.5 lbs - 3 mil film - Stereo - 60% forward overlap	5,000,000nm^2 Lunar Hemisphere/miss. - ~30 lbs - 3 mil film	73,500nm^2 - 52 lbs - UTB (2 mil film) - Monoscopic	10,000,000nm^2 - entire moon - <28 lbs - 3 mil film - 60% forward overlap	All areas computed for 30 nm altitude
- Program Cost	Five Mission Program - Boeing Contract $150M ~$35M EKC ~$25M RCA - Booster-Launch Additional ~$8.0M/mission		Two flights thru CY '68 ~$48.0M - does not include booster/opr's or photo data reduction		Study underway is for six flight program - First two in 1972 - ~ $300-400M (very preliminary study number) & does not include Atlas/Centaur booster & flight operations, etc.	Delta to baseline program ~$30.0M for three flight program, minus other opt's and data reduction		