NASA CR-66495

CORNELL AERONAUTICAL LABORATORY, INC.
BUFFALO, NEW YORK 14221

PROJECT SLOPE

A STUDY OF LUNAR ORBITER PHOTOGRAPHIC EVALUATION SECONDARY ANALYSIS TASKS

Prepared By:

M.J. Mazurowski
and
T.M. Holladay

CAL REPORT NO. VS-2182-D-5
PHASE III FINAL REPORT
CONTRACT NO. NAS1-5800

15 SEPTEMBER 1967

PREPARED FOR:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER, LANGLEY STATION
HAMPTON, VIRGINIA 23365

ABSTRACT

The results of several secondary analysis tasks conducted under Phase III of Project SLOPE are presented. The primary task, the analysis of the performance of the Lunar Orbiter II imaging system, is reported elsewhere.

The analyses reported involve: (1) evaluation of the detail rendition or modulation transfer function to assess the extent of image motion compensation in an oblique photographic mode, and (2) evaluation of increased detail rendition in the image when compensation is employed at the lower image motion rates (i.e., low V/H rates). In addition, improvements in the data processing techniques implemented at the beginning of the Phase III effort are described.

It was found that in the oblique photographic mode required to obtain high resolution convergent stereo pairs, the ground resolution will show a decrease from 1 meter to 2 to 4 meters. It was also determined that image motion compensation is effective for V/H rates as low as 3 milliradians/second.

TABLE OF CONTENTS

LIST OF FIGURES

1. INTRODUCTION

This document is the final report on the third phase of Project SLOPE conducted under NASA Contract No. NAS1-5800 for the Lunar Orbiter Project Office at the Langley Research Center. The primary effort of this portion of this program was directed towards the analysis of photographs received from Lunar Orbiter II. The results of that analysis are presented in a separate document entitled "Project SLOPE, Analyses of the Performance of Lunar Orbiter I and II Imaging Systems". A detailed discussion of the techniques developed and employed in the analyses appears in the final report on the second phase of the program.

This report deals with the results of several miscellaneous tasks performed during the Phase III effort. Included in the report are discussions of the improvements made in the data processing techniques utilized in the analysis of the quality of Lunar Orbiter photography, the results of a study of the effectiveness of the IMC system of Lunar Orbiter II for oblique photography, and the results of the analyses of the tests of the IMC system on photo subsystems 7 and 9. Each of these tasks are described separately in the following three sections of this report.

2. IMPROVEMENTS IN DATA PROCESSING TECHNIQUES

During the Phase II effort of Project SLOPE which was directed primarily towards the analysis of Lunar Orbiter I photographs, it became apparent that certain areas of the data processing techniques required modification to render the techniques more suitable for the large volumes of data involved in such an analysis.

The statistical nature of the analysis of the performance of the Lunar Orbiter imaging system dictates the use of many samples of data to yield reliable results. Initially, the data was obtained using a microdensitometer with a punched paper tape output. The paper tape was then used to generate punched cards which were then sorted, identified, and processed on an automatic computer. The quantity of punched cards generated in this way for the analysis of the Lunar Orbiter I photographs was quite large, making it apparent that any subsequent analyses should employ magnetic tape storage for the data. The data processing techniques detailed in the Phase II Final Report were altered to accommodate data stored on magnetic tape. While the changes themselves are of little importance, they represent a refinement necessary in the system performance analyses to accommodate the volume of data required for reliable results.

A second data handling problem encountered in the reduction of the data was the removal of the scan lines from edge trace data used to evaluate modulation transfer functions prior to smoothing the edges for computer processing. In the analysis of the Mission I data, the edge traces obtained from digitizing the microdensitometer output were read into a computer and the effect of the scan lines was removed by convolving the edge trace function with a numerical filter whose frequency response is shown in Figure 1. The filtered edge trace function was plotted by the computer and these plots were hand smoothed to remove the incoherent noise and extract the edge spread function for analysis of the modulation transfer function of the system. To eliminate the need for computer processing of the initial edge trace data prior to the hand smoothing, and consequently

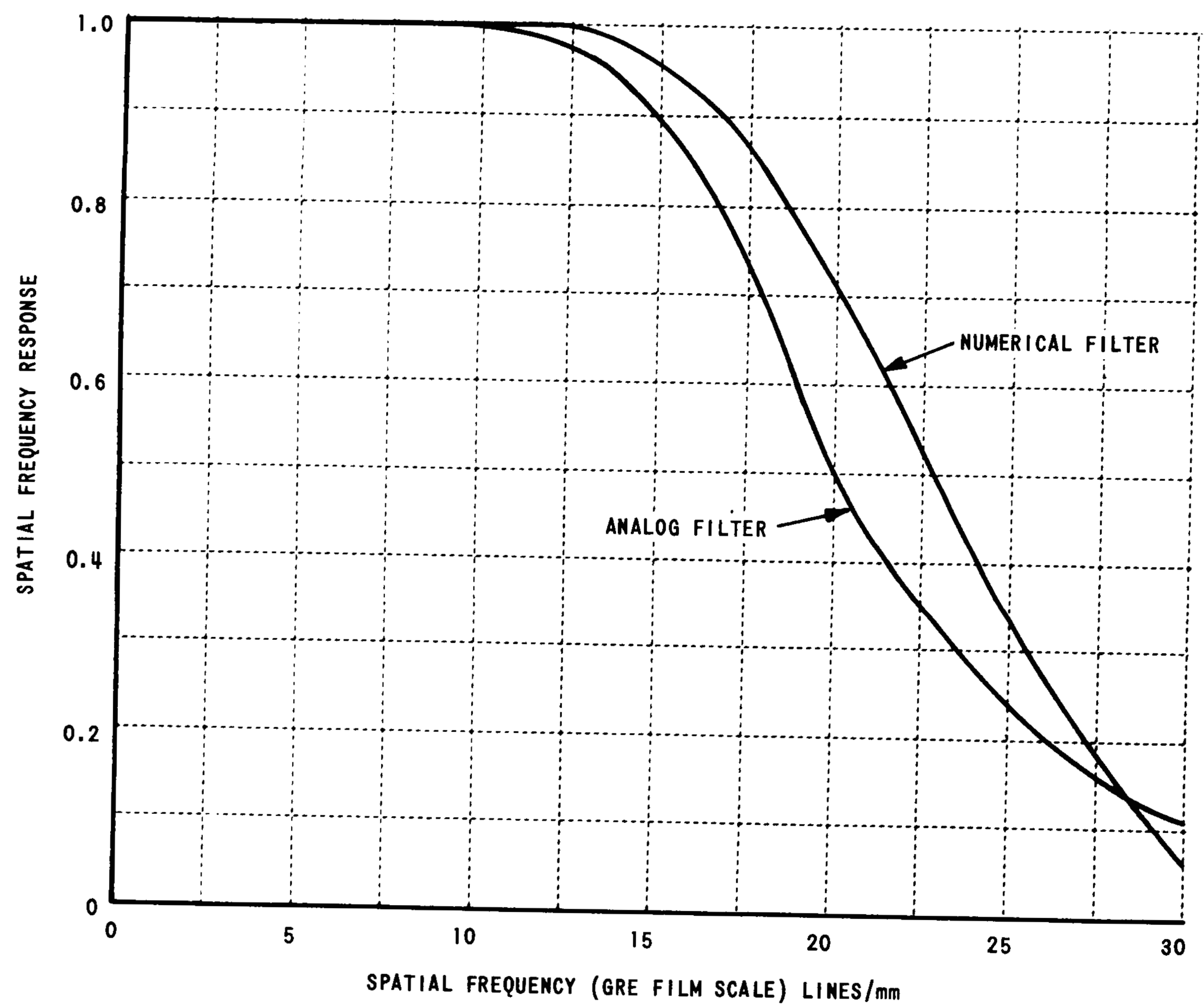


Figure 1 FREQUENCY RESPONSE FOR THE DIGITAL AND ANALOG SCAN LINE REMOVAL FILTERS

reduce the time required in the analyses, an electronic filter was employed which closely matched the response of the numerical filter. This "analog" filter, whose response is also shown in Figure 1, was used directly in series with the microdensitometer output to provide a graphic display of the edge trace with the effect of the scan lines removed. The difference between the response of the numerical and analog filters beyond 15 lines/mm is not significant since very little signal power exists beyond that frequency. The edge trace without the scan lines (or coherent noise) is then hand smoothed and the data digitized for processing by the computer.

3. ANALYSIS OF THE IMAGE MOTION COMPENSATION IN OBLIQUE LUNAR ORBITER PHOTOGRAPHS

To utilize the Lunar Orbiter imaging system to obtain high resolution convergent stereo photographs, the spacecraft must photograph the area of interest on two subsequent orbits obtaining near vertical photographs from one orbit and oblique photographs from the other orbit. In oblique photography, the operation of the image motion compensation system is rendered less effective than for vertical photography since increasing the angle between the optic axis of the camera system and the nadir produces varying amounts of motion compensation in the photographic image across the format. In addition, the V/H sensor, which is aimed at a point ahead of the area covered by a high resolution frame, senses a lower relative velocity than would exist anywhere within the format of a high resolution frame.

To determine the magnitude of this effect, an oblique high resolution frame from Mission II was analyzed. Sixty-one crater edges were selected from HRF 26, from 11 different areas in the format, and an evaluation of the imaging system modulation transfer function at each of the areas was performed. The ground resolution was determined for each of the 11 areas by noting the frequency at which the MTF decreases to 9% and converting this value to meters of resolution on the lunar surface. The 9% point was selected to be consistent with the point at which the preflight calibration of Lunar Orbiter II indicated ground resolution of 1 meter on the lunar surface.

The high resolution photo frame with the areas sampled and the corresponding ground resolutions obtained is reproduced in Figure 2. The results are also presented in Table 1, which includes the 68% confidence interval. The V/H sensor was aimed, in this case, just above area 'G', resulting in the most effective image motion compensation near that area of the format. The ground resolution can be seen to deteriorate as the

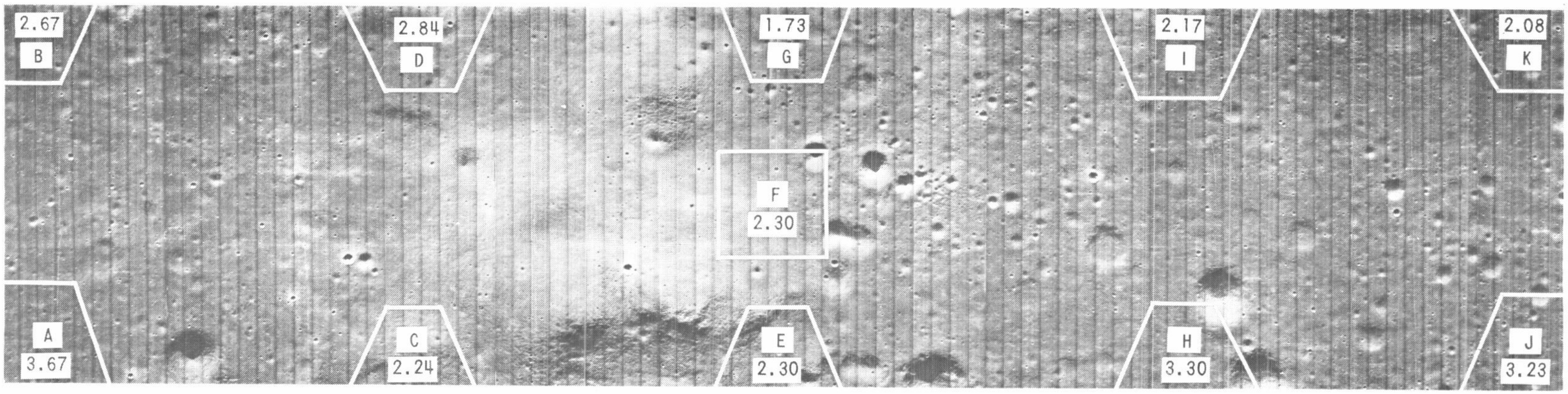


Figure 2 MISSION II OBLIQUE PHOTOGRAPH - HRF 26

Table I
MEASURED GROUND RESOLUTION FROM OBLIQUE
PHOTOGRAPHIC FRAME HRF 26, LUNAR ORBITER II

AREA	AVERAGE RESOLUTION (METERS) CORRESPONDING TO 9% RESPONSE POINT	68% CONFIDENCE INTERVAL (METERS)
A	3.8	3.1 - 4.1
B	2.7	2.5 - 2.8
C	2.2	1.8 - 2.9
D	2.8	2.8 - 3.0
E	2.3	1.8 - 2.6
F	2.0	1.6 - 2.8
G	1.7	1.5 - 2.2
H	3.3	3.1 - 3.9
I	2.2	2.0 - 2.4
J	3.2	3.1 - 3.5
K	2.1	1.4 - 3.3

distance from area 'G' increases. In addition to the reduction in resolution due to the lack of motion compensation, the effect of the off-axis resolution of the camera lens can also be noted to cause a decrease in resolution as the distance from the center of the photograph increases.

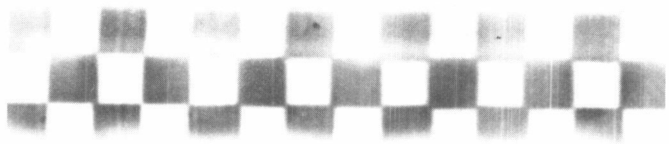
It can be concluded that obtaining high resolution convergent stereo pairs will yield resolution values three to four times less than that obtained in the vertical photography, hence yielding stereo resolutions approximately twice those obtained from the medium resolution system.

4. A COMPARATIVE EVALUATION OF IMAGE MOTION COMPENSATION AT LOW V/H RATIOS OF TWO PHOTO-SUBSYSTEMS FOR LUNAR ORBITER V

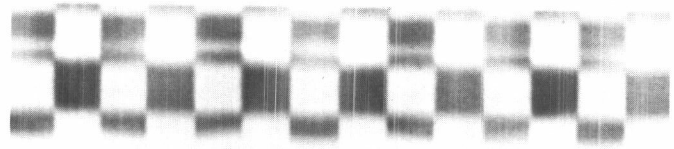
During the operation of Lunar Orbiter IV it appeared that when the image motion compensation system was operated at low values of V/H (i. e., less than 3 milliradians per second) the image quality was less than the quality achieved with the IMC off. It was felt that at low V/H ratios, the operation of the IMC system may have introduced more degradation (possibly due to vibration) in the quality of the photograph than would the image motion if the IMC were left off.

To determine the optimum range of operation for the image motion compensation system for Lunar Orbiter V, a series of tests were conducted in which both the primary and 'backup' photo-subsystems (PS-7 and PS-9, respectively) were used to generate test films. A checkerboard test pattern on a moving belt was photographed by each system with the belt being driven to simulate image motion rates of 3, 4, 6, 8 and 37. 5 milliradians per second. At each rate, a photograph was obtained with the IMC operating and with the IMC turned off. Typical examples of the resulting imagery are shown in Figure 3.

An analysis of the effectiveness of the IMC system was conducted by making several edge traces from the checkerboard pattern in the direction of image motion and determining the modulation transfer function for each of the recorded images. Approximately 5 edge traces were analyzed from each of the photographs of the test pattern. Due to some undetermined degrading factor, probably the quality of the checkerboard test pattern (i. e., sharpness), the resolution of the experimental system is only of the order of 20 lines/mm. This is sufficient to enable the effect of the IMC operation at the low V/H ratios to be determined.

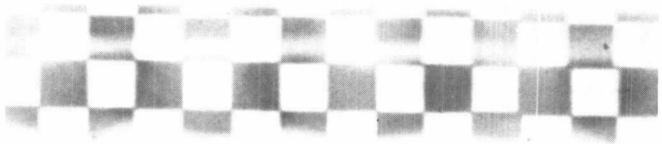


IMC ON

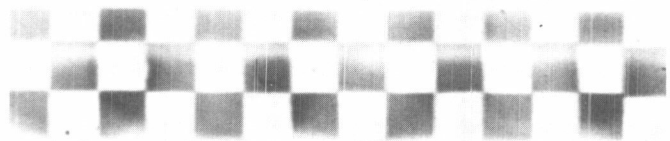


IMC OFF

(a) 37.5 MILLIRADIANS/SEC
(PS7)



IMC ON



IMC OFF

(b) 8 MILLIRADIANS/SEC
(PS9)

Figure 3 TYPICAL TEST PATTERNS IMAGES FOR IMC TESTS

An improvement in the performance of both photo-subsystems was noted at all image motion rates when the IMC was operating. The system transfer functions obtained for the two lowest motion rates, which were of principal interest in the analysis, are presented for each photo-subsystem in Figures 4 through 7. The response with and without the IMC operating is shown in each case. The dashed lines indicate the 68% confidence interval for each of the measured responses. The results of the analysis for all image motion rates simulated are presented in Table II.

Table II
20% RESPONSE POINT FOR VARIOUS IMAGE MOTION RATES

IMAGE MOTION RATE (MILLIRADIANS/SEC)	IMC CONDITION	20% RESPONSE POINT LINES PER MILLIMETER	
		(PS-7)	(PS-9)
37.5	OFF	1.0	1.0
37.5	ON	15.0	12.0
8.0	OFF	4.0	4.0
8.0	ON	16.0	12.0
6.0	OFF	5.0	5.0
6.0	ON	9.0	13.0
4.0	OFF	7.0	7.0
4.0	ON	12.0	11.0
3.0	OFF	9.0	9.0
3.0	ON	13.0	10.0

An examination of Figures 4 through 7 indicates that both systems exhibited a measurable and significant improvement in performance when the IMC system was used to compensate for image motion rates as low as 3 milliradians per second. The low resolution of the test system precluded a determination of the actual amount of compensation achieved since residual image motion below approximately 3 milliradians per second results

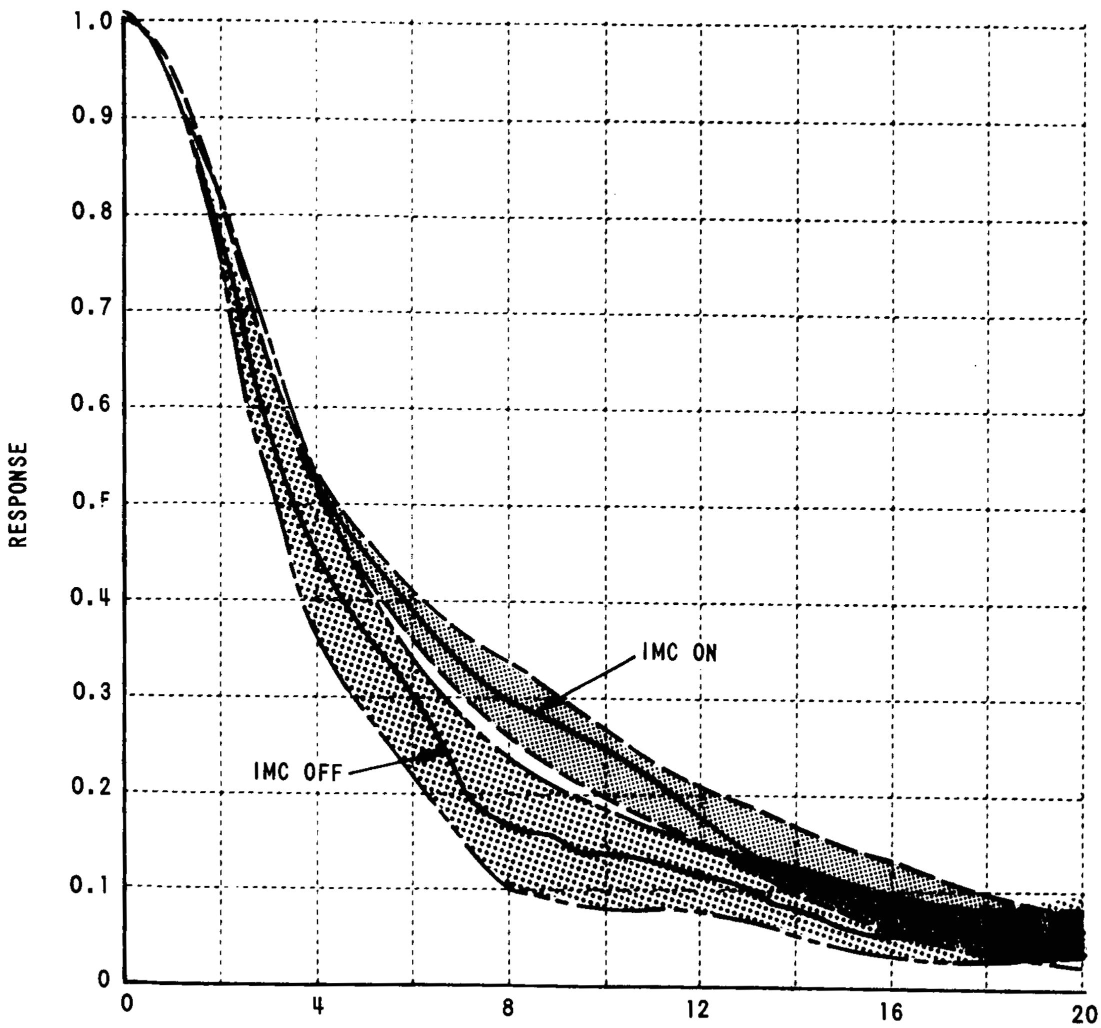


Figure 4 MEASURED FREQUENCY RESPONSE WITH AND WITHOUT IMC AT A V/H RATE OF 4 MILLIRADIANS/SEC (PS-7)

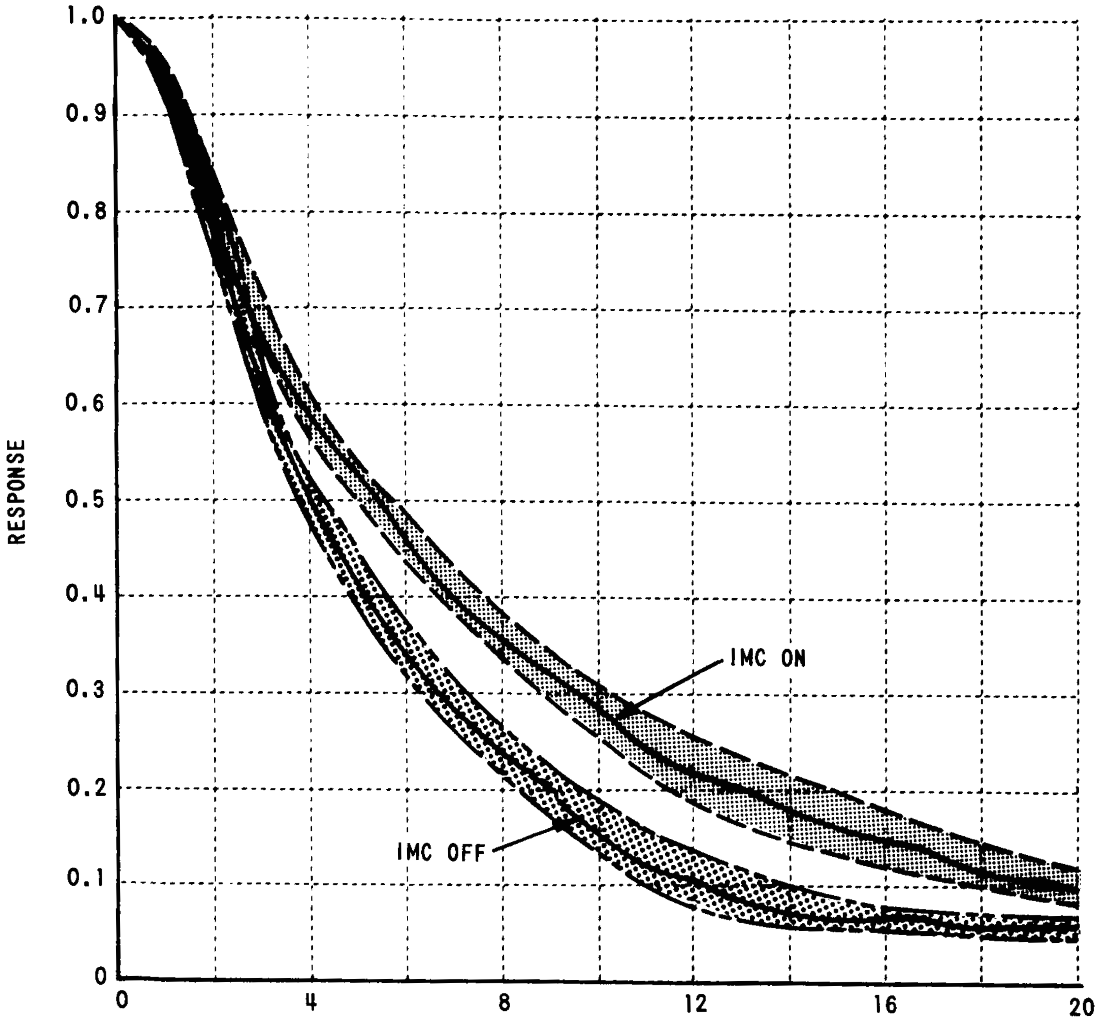


Figure 5 MEASURED FREQUENCY RESPONSE WITH AND WITHOUT IMC AT A V/H RATE OF 3 MILLIRADIANS/SEC (PS-7)

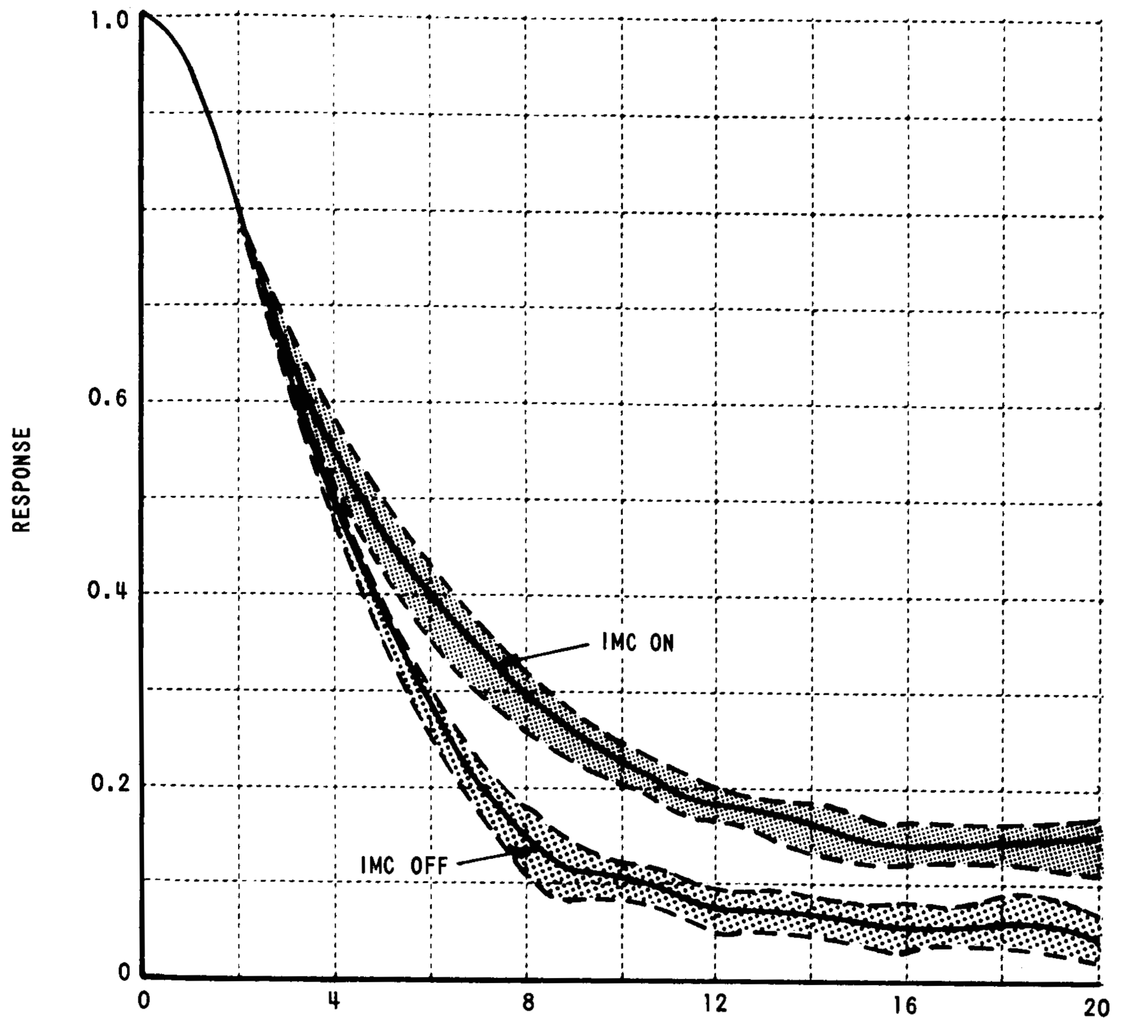


Figure 6 MEASURED FREQUENCY RESPONSE WITH AND WITHOUT IMC AT A V/H RATE OF 4 MILLIRADIANS/SEC (PS-9)

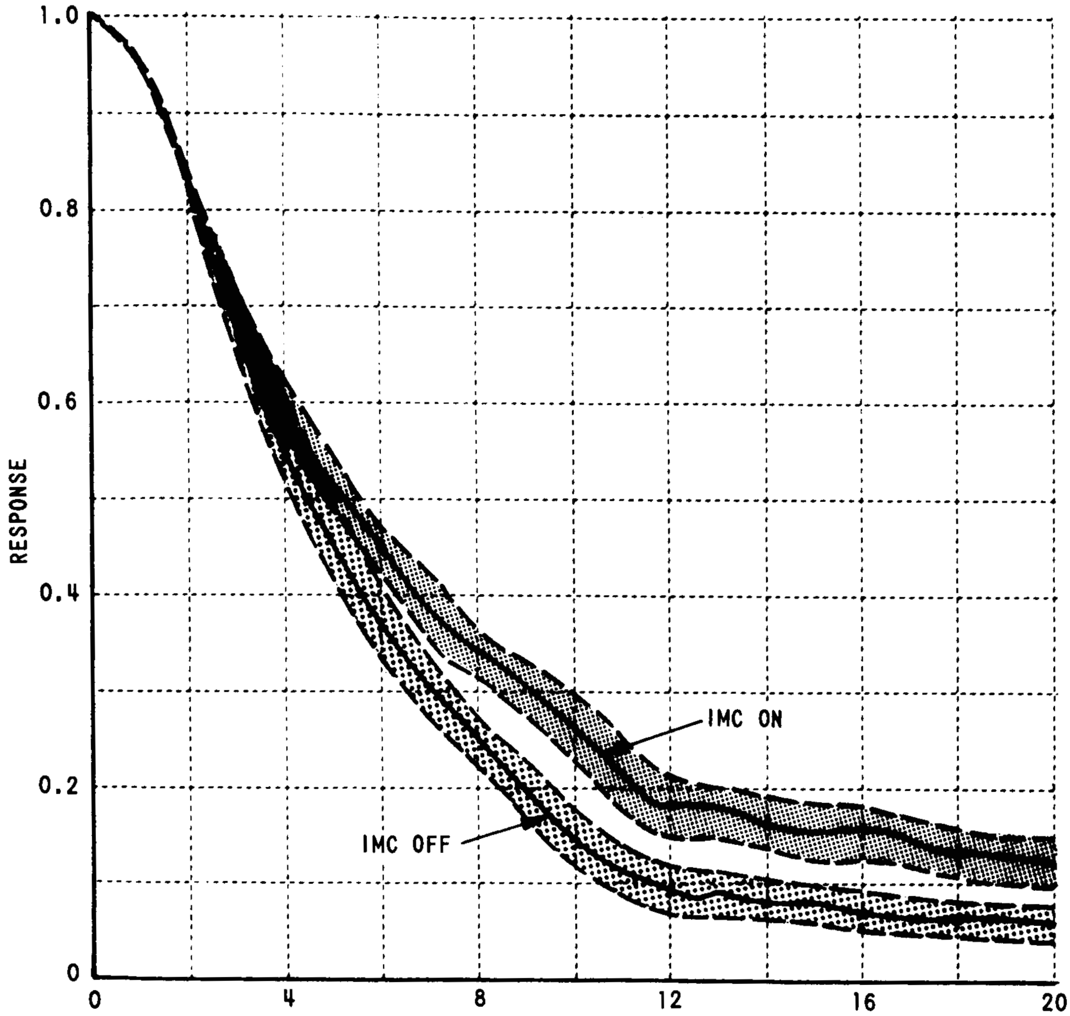


Figure 7 MEASURED FREQUENCY RESPONSE WITH AND WITHOUT IMC AT A V/H RATE OF 3 MILLIRADIANS/SEC (PS-9)

in the first zero of the transfer function occurring at frequencies near the test object resolution frequency. A reliable conclusion about the ability of the IMC to compensate for image motion rates less than the lowest value at which the tests were performed cannot therefore be inferred from the data.

It can also be seen from a comparison of Figures 4 and 5 to Figures 6 and 7 that no significant difference between the two photo-subsystems was detected.

5. CONCLUSIONS

From several secondary tasks performed during the Phase III effort, it is concluded that:

(1) High resolution convergent stereo pairs obtained on successive orbital passes will show a decrease in ground resolutions from 1 meter to 2 to 4 meters depending upon format position,

(2) The image motion compensation is effective for V/H rates as low as 3 milliradians per second in photo-subsystems 7 and 9. There was no indication of additional degrading mechanisms at the lower V/H rates.