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FABRICATION OF TRANSPARENT OPTICAL TEST PANELS.(U)
MAR 76 J E MAHAFFEY F41609-75-C-0036

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LEVEL II

FABRICATION OF TRANSPARENT OPTICAL TEST PANELS

FINAL REPORT

Contract F41609-75-C-0036

AD A080475

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PPG INDUSTRIES, INC.

Glass Division

Aircraft and Specialty Products

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J. E. Mahaffey

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1.0 Introduction

The objective of the program described in this report was the fabrication of a series of optical test panels for the Air Force School of Aviation Medicine, Brooks AFB, Texas, under Contract F41609-75-C-0036. The optical quality of the test panels was to vary in magnitude in each panel to within limits specified in the statement of work for that contract. The test panels were designed to be installed in the pilot's viewing area of the Air Force Flight Dynamics Laboratory/Calspan Corporation Total In-Flight Simulator (TIFS). Under a separate contract, the test panels are to be used in a flight test program to determine the effect of optical degradation in the viewing area of the pilot on flight performance.

The original contract specified delivery of one non-optical sizing panel and nine optical test panels. The optical quality of the nine test panels was to be controlled to the lens factor and displacement grade values listed in Table I. The lens factor and displacement grade inspection techniques used for evaluation of the optical quality of the F-111 windshield were specified to evaluate the optical quality of the test panels.

After evaluation of the first series of test panels fabricated for this program, the contract was modified by adding two optical test panels to the contract for a total of eleven optical panels in addition to the non-optical sizing panel. This report describes the fabrication of the optical test panels and lists the results of the optical analysis of each test panel.

2.0 Process Development

2.1 Calspan Total In-Flight Simulator

Early in the program, a trip was made to the Calspan Corporation, Buffalo, New York, to establish the procedures for taking gridboard optical photographs from the TIFS cockpit and to evaluate the optical quality of the existing TIFS cockpit windshield. The non-optical sizing panel, fabricated to drawings submitted by the Calspan Corporation, was delivered at that time. The test panel configuration and position in the TIFS cockpit is illustrated in Figure 1.

With the assistance of Calspan Corporation personnel, the TIFS cockpit, detached from the C-131 forward fuselage, was positioned in front of a standard optical gridboard consisting of one inch on-center grid lines. A series of optical photographs were taken of the gridboard from the pilot's eye position through the existing windshield. These optical photographs were subsequently analyzed for lens factor and displacement grade in accordance with the optical inspection procedures established for the F-111 windshield which were specified for this program. The lens factor was determined to be 1.02 and displacement grade negligible which indicates the optical quality of the windshield is good. There was distortion across the forward section extending approximately three inches into the daylight opening. It is planned to mask off this area in the flight test program.

Based on this evaluation, the concensus was that the optical quality in the viewing area would not be significantly affected by the existing windshield when viewing through the combination of that windshield and an optical test panel.

2.2 Fabrication Process Development

The contract requirements for this program consisted primarily of controlling the lens factor and displacement grade to the values specified in Table I in each test panel over a minimum of 70% of the viewing area. It was necessary to develop fabrication processes to control optical distortion to these specified values.

Two basic methods of test panel fabrication were evaluated early in the program. The first consisted of inducing distortion in monolithic 5/16 inch acrylic sheet by pressing the acrylic under heat and pressure between two pressing plates which contained surface irregularities. This process is described in detail as Method 1 in the PPG Industries proposal for this program. Several pressing tools were fabricated using materials and tool fabricating processes previously used by PPG for aircraft transparencies except surface irregularities were intentionally induced in the tool surface. Flat 5/16 inch acrylic panels were pressed under heat and pressure using this type tooling.

After several trial runs, it became evident that this approach was not feasible for this program. While some distortion was induced in the acrylic sheet, the magnitude of distortion was insufficient when viewing through the panel at a 70° slope, the installation angle of the test panels in the TIFS cockpit. The fabrication of matched tooling to induce greater distortion was considered to be too costly and difficult to control.

The second approach, identified as Method 2 in the PPG proposal, consisted of laminating two plies of 1/8 inch acrylic sheet with an elastomeric interlayer where optical distortion was induced by varying the interlayer thickness in a predetermined pattern. Subscale test panels were fabricated initially to evaluate this processing approach. Evaluation of the subscale parts indicated this approach was feasible and offered a degree of control of optical distortion.

3.0 Initial Test Panel Fabrication

Several full-scale panels were fabricated using the laminated panel approach. Some difficulty was encountered with entrapped air in scaling up to full-size panels but processing was modified to alleviate this problem. Five full-scale panels fabricated by this process and one panel fabricated by a modification of this process were trimmed to the prescribed configuration for optical evaluation.

These six test panels were taken to the Calspan Corporation for optical evaluation in conjunction with the TIFS cockpit windshield to determine if the optical quality was compatible with the program objectives. Each panel in turn was installed in the TIFS cockpit as illustrated in Figure 1 and gridboard optical photographs taken through each panel using procedures previously established during the first visit to Calspan. Optical quality degradation induced in the vision area was also evaluated visually by the program monitor and four Calspan test pilots. Based on this visual examination, five of the six panels were tentatively accepted pending analysis of the optical photographs.

3.1 Optical Analysis

After the optical photographs had been developed, the lens factor and displacement grade values were determined for each test panel by PPG Quality Control. The techniques used to determine the optical quality of the F-111 windshield were used to the extent feasible. The lens factor and displacement grade values for these panels are presented in Table II. Comments pertaining to the optical analysis are listed as follows:

1) In an F-111 windshield optical photograph, a portion of the gridboard appears on the photograph which is not taken through the windshield. This area of the photograph is used as a reference for optical anlaysis. A reference area was not possible with these photographs because the photographs were taken from inside the cockpit. Consequently, horizontal and vertical reference lines were estimated as close as possible.

2) Optical zoning is required for determining lens factor and displacement grade values for the F-111 windshield. The zoning of the photographs for this program was arbitrarily selected as illustrated in Figure 2 with the approval of the program monitor.

3) The displacement grade values were measured in the horizontal direction only starting at the right edge of the photograph. The maximum grid line displacement was determined in each of the four zones. In most cases, the maximum grid line displacement was incurred in the same horizontal grid line. In these cases, the displacement grade values are cumulative across either Zones I and II or III and IV (see Figure 2). Where the maximum displacement did not occur in the same horizontal grid line, the maximum displacement in each zone was recorded.

3.2 Program Modification

The results of the optical analysis of the six panels and the optical photographs of each panel were forwarded to the program monitor at Brooks AFB for review. After review of the photographs and the data, four of the six test panels were considered acceptable. At that time, a modification was made to the contract to increase the total number of optical test panels from nine to eleven, leaving a total of seven additional panels required for completion of the contract. The modification to the contract also listed ranges of lens factor and displacement grade values desired for the remaining seven test panels. Optical quality data for the four accepted panels and the optical requirements for the seven remaining panels to be delivered are presented in Table III.

4.0 Fabrication of Remaining Test Panels

During the course of evaluating the first series of optical test panels, additional process development was performed to improve control of optical quality in subsequent panels. Several alternate fabrication approaches were evaluated including special thermoforming techniques, different types of interlayer, cast-in-place interlayer versus film type, and resurfacing the acrylic using hand polishing techniques. As noted in Table II, the lens factor of the initial test panels was low in all cases and, consequently, the additional process development was directed primarily toward increasing lensing in the test panels.

As a result of the additional process development effort, several modifications were made in the test panel fabrication procedures. These consisted primarily of modifications in the patterns used to vary interlayer thickness and the use of cast-in-place interlayer in addition to film type interlayers. A series of nine additional optical test panels were fabricated utilizing the modified processing techniques with emphasis on increasing lens factor. The test panels were fabricated in a rectangular shape up to 30 by 60 inches in size. The optical quality of the final trimmed part depends to a certain degree upon its orientation in relation to the rectangular blank panel. Consequently, optical photographs were taken at four different orientations in each test panel to permit selection of the final trimmed test panel which most closely approached the desired lensing and displacement grade values. The photographs of these nine panels were taken at PPG Industries using the same procedures that were used for previous photographs at the Calspan Corporation, e.g. camera location, test panel installation angle and identical viewing distances.

The lens factor and displacement grade values for all orientations of the nine test panels are presented in Table IV. These data and a copy of all photographs taken of each panel were forwarded to the program monitor at Brooks AFB for review and selection of the desired orientation for the final trimmed test panel.

Six of the panels were considered acceptable by the program monitor and the desired orientation of each panel was forwarded to PPG. The six panels were trimmed to the specified configuration and shipped to Brooks AFB. The lens factor and displacement grade values for all accepted test panels and test panel identification are listed in Table V. A copy of all optical photographs taken on this program have been forwarded to Brooks AFB.

5.0 Discussion

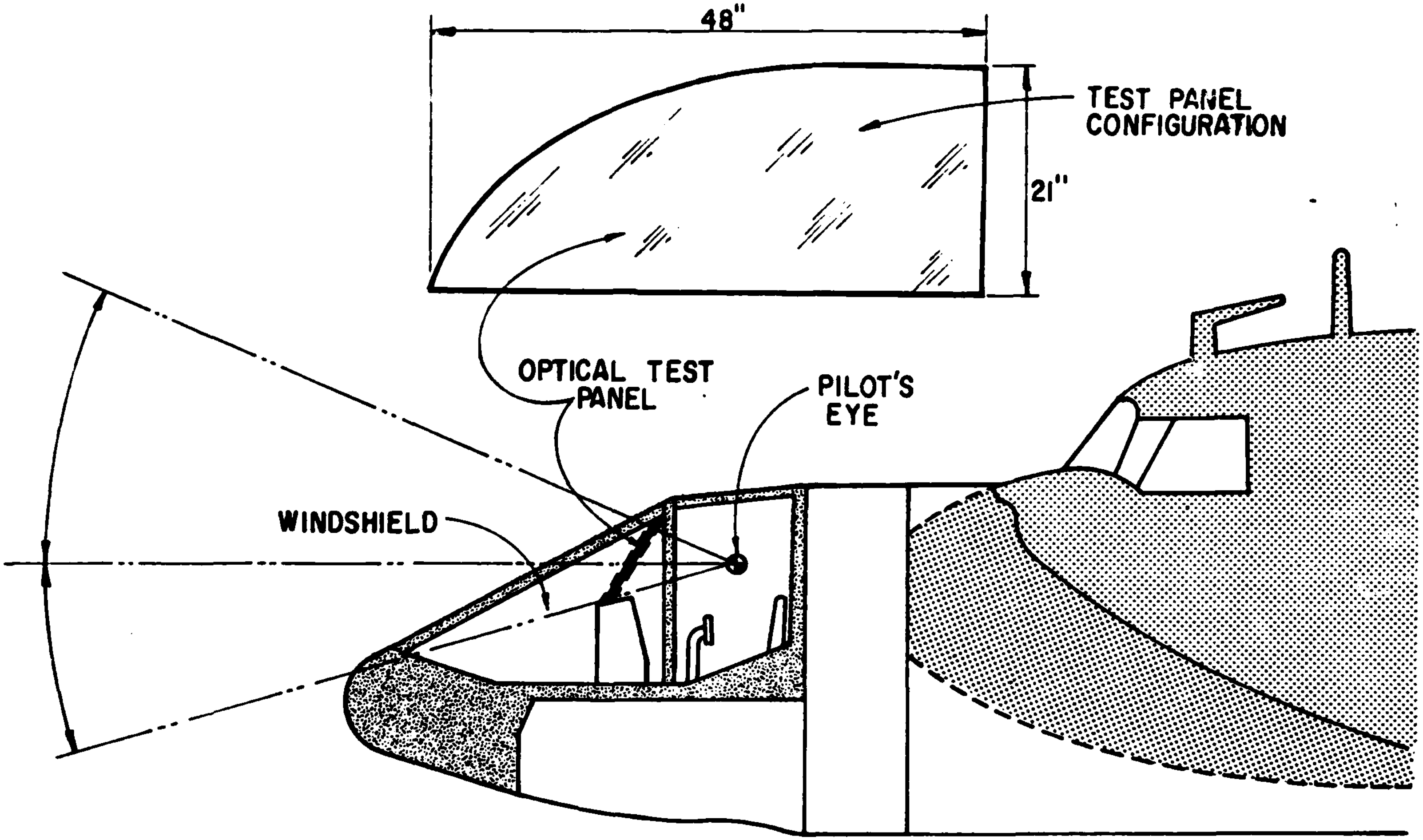
Difficulty was encountered in this program in obtaining the combination of desired lensing and displacement grade values in 70% of the area of each test panel. It was found that very precise control of processing is required to approach the specified optical quality. The tooling and processing techniques used in fabricating the test panels provided a range in the magnitude of optical distortion in each successive test panel, but the precise lensing and displacement grade values specified were not met in all cases. It is believed, however, that the range in optical distortion represented by the test panels submitted should be satisfactory to accomplish the objectives of the proposed flight test program.

The primary problem area in fabricating the test panels was obtaining the magnitude of lensing specified. Part of this problem was the relatively low angle of incidence of the test panel (20°) and the close proximity of the pilot to the test panel in the TIFS cockpit, restrictions imposed by the cockpit configuration. Very extreme irregularities in the test panel were required to induce lens factor values greater than 1.3. Two methods of increasing lensing in the existing test panels were evaluated. The first consisted of increasing the angle of incidence from 20° to 40°. Analysis of optical photographs of a test panel set at 40° angle of incidence showed that lensing was not significantly affected by this procedure.

The second approach was to move the pilot'e eye position farther aft from the test panel. This would be more difficult to accomplish in the TIFS cockpit since the test panel would have to be moved forward of its present position. It could be done, however, by modifying the holding structure for the test panels in the TIFS cockpit. Optical photographs were taken of test panel X-11, position 3, with the camera lens at six inches and twelve inches aft of the pilot's eye position to evaluate this approach. The lens factor and displacement grade values with the camera lens at these locations are presented in Table VI. As noted in the table, the lens factor was increased from approximately 1.2 to 1.6, a significant increase. Since the maximum lens factor requested was 1.6, this appears to be a feasible approach to increase lensing in the test panels. As expected, the displacement grade is also increased by this approach. The effect of the increase in displacement grade in combination with the increase in lensing will have to be considered. The effect of moving the pilot's eye position farther aft is also dramatically illustrated by examination of the optical photographs. The optical photographs and optical analysis of panel X-11 using the modified camera lens location have been forwarded to the program monitor, Brooks AFB.

Based on the experience gained in this program, it is believed that a more sophisticated approach is required to produce optical test panels of this type to precisely control optical quality. One possible approach is precision grinding and polishing of acrylic blanks where surface irregularities are accurately controlled to produce the required optical degradation in the pilot viewing area. This approach would require development of equipment and processes to accurately control the grinding and polishing operation. A computer program would also be required to identify the surface profile for each level of optical quality. Obviously this approach would be very expensive.

If additional test panels are required in the future, a more logical approach is believed to be additional development of the processes used in this program using the data generated in this program as a basis for modification of processing techniques. Corrleation of surface geometry with precise optical quality data for each panel fabricated in this program could be used to establish interlayer thickness geometry to more closely approach the optical distortion requirements.



FIGURE—1 TIFS COCKPIT AND TEST PANEL LOCATION

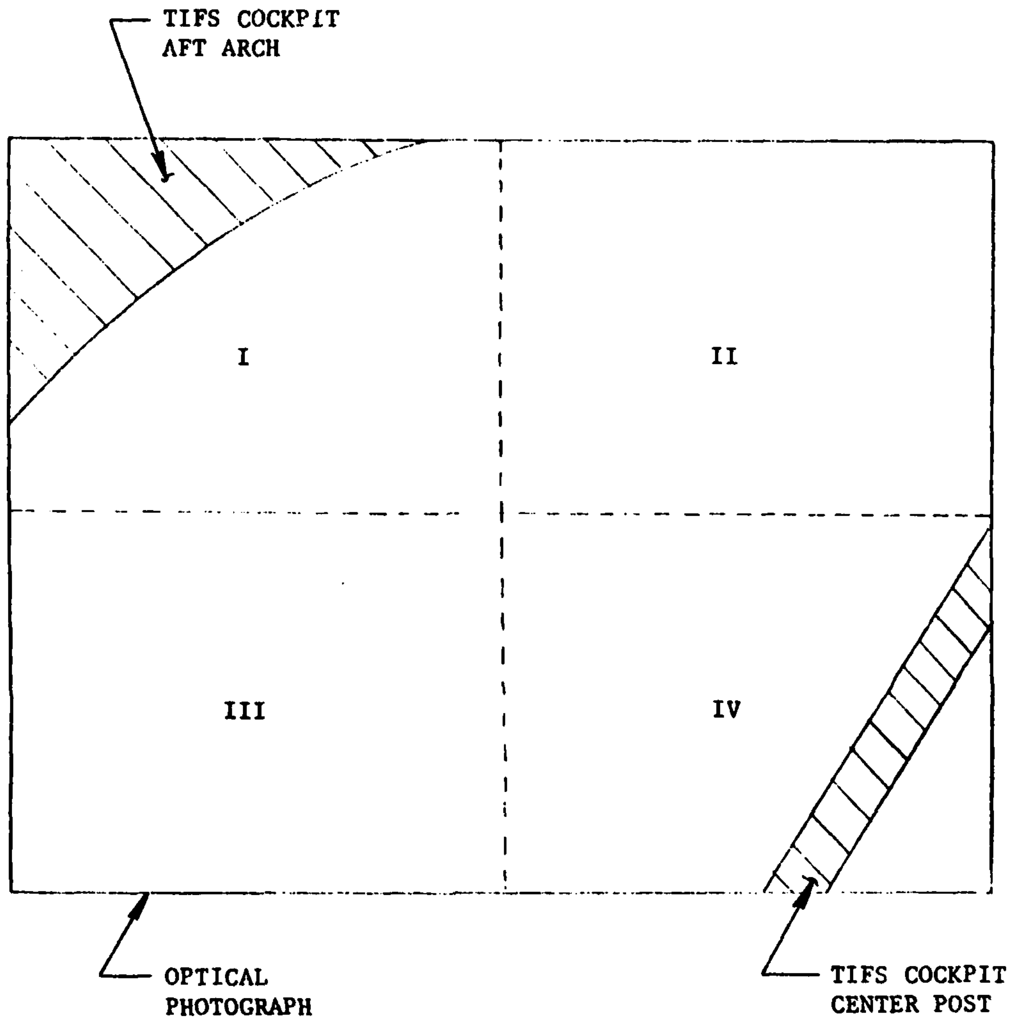


FIGURE-2 ZONING OF OPTICAL PHOTOGRAPHS

TABLE I - TEST PANEL OPTICAL REQUIREMENTS

Panel No.	Grid Slope No Greater Than	Lens Factor	Displacement Grade
1	Non-optical sizing panel	--	--
2	1 line in 3	1.8	300
3	1 line in 3	1.7	280
4	1 line in 5	1.6	260
5	1 line in 7	1.5	240
6	1 line in 10	1.4	200
7	1 line in 13	1.3	160
8	1 line in 15	1.2	120
9	1 line in 20	1.1	80
10	1 line in 20	1.0	40

TABLE II - OPTICAL ANALYSIS OF INITIAL TEST PANELS

Test Panel Number	Zone I		Zone II		Zone III		Zone IV	
	LF	DG	LF	DG	LF	DG	LF	DG
1	1.00	125	1.02	115	1.04	80	1.00	50
2	1.02	135	1.02	100	1.09	60	1.02	60
3	1.09	160	1.02	160	1.06	155	1.04	150
4	1.04	75	1.06	110	1.02	170	1.03	170
5	1.12	190	1.02	150	1.09	100	1.02	100
6	1.09	210	1.02	160	1.09	130	1.02	80

NOTE: LF = Lens Factor
DG = Displacement Grade

Displacement readings in Zones I and III are cumulative and all displacement values are horizontal.

TABLE III - SUMMARY OF ACCEPTABLE TEST PANELS AND ADDITIONAL TEST PANELS REQUIRED

Panel	Zone I		Zone II		Zone III		Zone IV	
Number	LF	DG	LF	DG	LF	DG	LF	DG
PANELS ACCEPTABLE:								
1	1.00	125	1.02	115	1.04	80	1.00	50
2	1.02	135	1.02	100	1.09	60	1.02	60
3	1.09	160	1.02	160	1.06	155	1.04	150
4	1.04	75	1.06	110	1.02	170	1.09	170
ADDITIONAL PANELS TO COMPLETE DG SCALE:								
5	1.00-1.09	30- 50	1.00-1.09	30- 50	1.00-1.09	30- 50	1.00-1.09	30- 50
6	1.00-1.09	110-130	1.00-1.09	110-130	1.00-1.09	110-130	1.00-1.09	110-130
7	1.00-1.09	200-230	1.00-1.09	200-230	1.00-1.09	200-230	1.00-1.09	200-230
ADDITIONAL PANELS FOR LENS FACTOR SCALING:								
8	1.15-1.20	80-120	1.15-1.20	80-120	1.15-1.20	80-120	1.15-1.20	80-120
9	1.29-1.31	80-120	1.29-1.31	80-120	1.29-1.31	80-120	1.29-1.31	80-120
10	1.40-1.50	80-120	1.40-1.50	80-120	1.40-1.50	80-120	1.40-1.50	80-120
11	1.50-1.60	80-120	1.50-1.60	80-120	1.50-1.60	80-120	1.50-1.60	80-120

ACCEPTED PANEL: No. 12, Non-Optical

TABLE IV - OPTICAL ANALYSIS OF THE SECOND SERIES OF TEST PANELS

Panel No. and Orientation		Zone I		Zone II		Zone III		Zone IV	
		LF*	DG*	LF	DG	LF	DG	LF	DG
X-7	Position 1	1.05	110	1.05	60	1.05	230	1.02	80
	Position 2	-1.05**	140	1.05	60	1.05	230	1.05	100
	Position 3	1.02	150	1.05	50	1.07	250	1.05	100
	Position 4	-1.07	115	1.02	30	1.09	200	1.02	85
X-8	Position 1	1.11	20	1.05	30	1.16	50	1.07	70
	Position 2	1.11	25	1.05	25	1.14	60	1.16	70
	Position 4	1.07	50	1.11	45	1.09	50	1.07	70
X-9	Position 1	1.12	90	-1.15	80	1.09	145	1.07	90
	Position 2	1.18	100	1.05	100	1.12	120	1.09	120
	Position 3	1.12	155	1.05	20	1.05	210	1.09	150
	Position 4	1.09	100	1.02	90	1.09	150	1.14	130
X-10	Position 1	1.09	195	1.02	145	1.09	135	1.07	70
	Position 2	1.09	100	1.05	100	1.09	150	1.12	105
	Position 3	1.05	190	1.05	140	1.05	70	1.05	55
	Position 4	1.12	75	1.02	65	1.09	85	1.09	95
X-11	Position 1	1.28	135	1.09	100	1.18	100	1.23	70
	Position 2	1.28	150	-1.15	120	-1.20	155	1.28	145
	Position 3	1.23	160	1.18	140	1.21	110	1.21	80
	Position 4	1.23	140	1.15	145	1.05	145	1.28	150
X-12	Position 1	-1.18	250	1.26	240	1.31	400	-1.23	370
	Position 2	1.19	260	-1.18	230	-1.18	320	1.26	310
	Position 3	-1.18	190	1.31	250	1.26	210	-1.16	210
	Position 4	1.18	230	-1.18	170	-1.23	400	1.31	390
X-13	Position 1	-1.13	180	1.10	180	1.24	190	-1.18	190
	Position 2	1.14	85	-1.03	90	-1.13	220	1.12	240
	Position 3	1.10	100	1.10	100	1.12	140	1.12	150
	Position 4	-1.13	180	-1.16	160	-1.13	200	1.12	200
X-14	Position 1	-1.16	100	1.10	80	1.19	180	-1.18	190
	Position 2	1.10	140	1.02	130	1.07	150	1.14	110
	Position 3	1.07	60	1.12	60	1.12	60	-1.08	60
	Position 4	1.12	170	1.10	140	-1.13	100	1.12	100
X-15	Position 1	1.12	120	1.19	110	1.17	150	-1.13	130
	Position 2	-1.16	185	1.12	165	1.19	180	-1.18	165
	Position 3	-1.16	230	1.12	210	1.19	170	-1.18	170
	Position 4	1.07	100	-1.08	100	1.12	220	1.14	220

*LF = Lens Factor; DG = Displacement Grade
**The minus sign indicates negative lensing.

TABLE V - OPTICAL DATA FOR ACCEPTED TEST PANELS

Test Panel Number	Zone I		Zone II		Zone III		Zone IV	
	LF	DG	LF	DG	LF	DG	LF	DG
X-1	1.00	125	1.02	115	1.04	80	1.00	50
X-2	1.02	135	1.02	100	1.09	60	1.02	60
X-3	1.09	160	1.02	160	1.06	155	1.04	150
X-4	1.04	75	1.06	110	1.02	170	1.03	170
X-8	1.11	25	1.05	25	1.14	60	1.16	70
X-9	1.18	100	1.05	100	1.12	120	1.09	120
X-10	1.12	75	1.02	65	1.09	85	1.09	95
X-11	1.23	160	1.18	140	1.21	110	1.21	80
X-13	1.10	100	1.10	100	1.12	140	1.12	150
X-15	1.07	100	-1.08	100	1.12	220	1.14	220

TABLE VI - ADDITIONAL OPTICAL DATA FOR PANEL X-11

Lens Camera Position	Zone I		Zone II		Zone III		Zone IV	
	LF	DG	LF	DG	LF	DG	LF	DG
Pilot's Eye (Table V)	1.23	160	1.18	140	1.21	110	1.21	80
Six Inches Aft of Pilot's Eye	1.38	200	1.55	190	1.33	240	1.60	280
Twelve Inches Aft of Pilot's Eye	1.27	250	1.60	300	1.65	290	1.60	290