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EVALUATION OF EPOXIES TO PROVIDE STRESS-FREE BONDING OF PYROCER--ETC(U)
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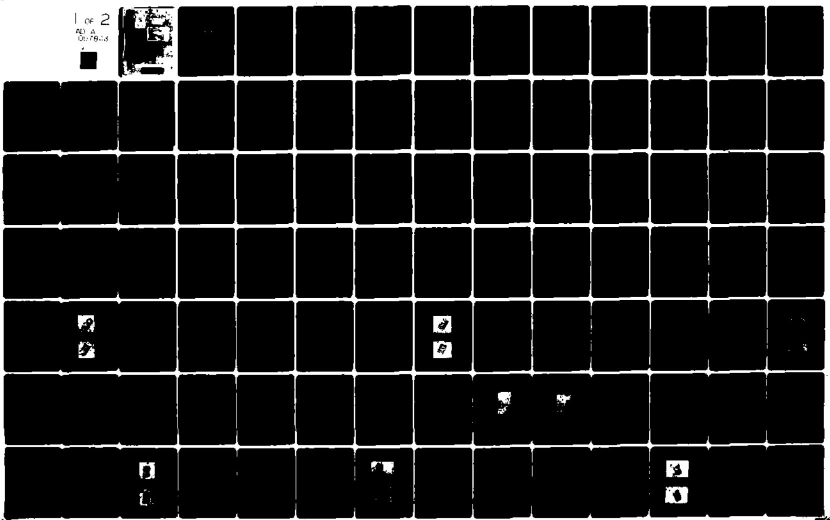

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AEROFLEX LABORATORIES INCORPORATED

LEVEL II

EVALUATION OF EPOXIES TO PROVIDE STRESS-FREE BONDING OF PYROCERAM MIRRORS.

PREPARED FOR

NIGHT VISION & ELECTRO-OPTICS LABORATORY, FT. BELVOIR, VA 22060

CONTRACT NO. DAAK70-77-C-0186

DTIC

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163

MARCH 1979

TABLE OF CONTENTS

SUMMARY

This report describes the effort undertaken by Aeroflex Laboratories to achieve mirror assemblies (SM-D-657649) which are capable of meeting the required optical performance under environmental conditions.

In the course of a 9 month study, 22 mirrors were assembled using variations in techniques and controls to obtain good mirrors. The results of this effort have shown that the specified two-part epoxy cement presents major difficulties in achieving these results. Moreover, even under carefully controlled conditions, the final result (from an optical performance viewpoint) may still be random and the production yield severely affected. This would be reflected in cost impact to the applicable systems. The study also shows that an alternate cement has been identified which permits a simpler (and cheaper) assembly technique to be used with a consistently excellent optical performance achieved. As of this report date, 9 mirrors out of 9 have been successfully assembled and passed the required MTF test specifications.

INTRODUCTION

During the course of the IPF implementation, it became apparent that additional work was required on the mirror assembly in order to assure that production units could meet the MTF requirements.

Although difficulties in meeting the optical requirements of this assembly had not been reported previously to the initiation of the IPF effort, the first pilot production of an airborne (Helicopter) system highlighted the need for a mirror assembly study.

It should be understood that at the time of the initiation of the IPF contract, a set of baseline drawings were released so that these drawings could be used for tooling design. Part of this baseline set included the mirror assembly, its associated parts and the requirements for the cement to finish the assembly.

After 6 months of effort it became apparent that the mirror assembly involved many factors which were interrelated and in some cases extremely subtle. From the drawings it was assumed that if the cementing procedure outlined was followed, a successful mirror assembly would result. This, in the final case, turned out to be only partially true. If the assembly was left at room temperature after initial cure, the assembly could meet the physical and optical requirements. However, once this assembly was subjected to various temperature limits the resultant optical performance was severely degraded. This report describes the study effort performed by Aeroflex Labs to isolate the specific problems associated with the mirror assembly and the approaches taken to overcome them.

After 12 mirror assemblies had been completed and tested for MTF responses, it became apparent that the Stycast resin was the prime source of the distortion evidence after temperature cycling. It was also evident that even under the most carefully controlled stress relief and care in assembly, the results could not be predicted with any reasonable certainty. At that point, an alternate cement was tried with outstanding initial results. This cement was then pursued with increasing attention as the results began to show better performance and more significantly better consistency or yield.

The section which follows describes the techniques employed and the results obtained on each mirror as it was assembled and tested. A summary chart for the entire series is also included as part of this section.

The MTF measurements and data shown in this report were made with the support and cooperation of the NVL Staff. Appreciation of this help is hereby expressed.

The final section of this report lists the conclusions drawn and the recommendation made as a result of this effort.

III MIRROR STUDY EFFORT

This section describes the detailed effort undertaken to achieve successful mirror assemblies using the specified materials specified in the NVL baseline drawing set.

The effort is summarized in Table I which follows and essentially shows the variations attempted and the results achieved.

The initial test was made on a mirror supplied by TRANSWORLD OPTICS to establish if any "bowing" occurred in this mirror after a temperature cycle. This test was made to ensure that the test mirror to be supplied to NVL for evaluation would pass the flatness requirements.

The results of this test showed something entirely different than what was expected.

The mirror was supplied with a Certificate of Compliance which indicated that the four fringe requirement had been met. The mirror was then assembled with the top cap and the arm return. After assembly, the unit was taken to TWO and a preliminary check was made of the visible side. Since the arm return projection prevented the use of the normally used interferometer (requiring about 1/8" clearance to the surface) a modified set up was used. In this set up, the mirror was

TABLE I - MIRRO

			MIRROR THICK.					TEMP CYCLE			MIRROR MAT'L.	
MIRROR #			ARM RET.		TOP CAP		BOND GAP					
1			.114		.1136		.0025		X		P	
2			.114		.1138		.0025		X		P	
3			.1137		.1137		.002		X		P	
4			.1112		.1118		.002		X		P	
5			.1136		.1125		.002		X		P	
6			.1130		.1132		.0015		X		P	
7			.1133		.1128		.0015		X		P	
8			.1120		.1132		.0015		X		P	
8A			.1143		.1146		.002		X		G	
9			.1102		.1107		.002		X		P	
9A			.1140		.1146		.003		X		P	
10			.1118		.1115		.002		X		P	
11			.1135		.1139		.0015		X		P	
11A			.1147		.1147		.002		X		G	
12			.1115		.1123		.002		X		P	
9B			.1102		.1107		.005		X		P	
13			.1115		.1111		.0045		X		P	02
14			.1122		.1119		.004		X		P	
15			.1119		.1115		.004		X		P	02
16			.1124		.1119		.005		X		P	
17			.1141		.1143		.0045		X		P	
18			.1126		.1122		.004		X		P	

BLE I - MIRROR STUDY SUMMARY

MIRROR MAT'L.	LOT #	MFG	CEMENT	SINGLE/DOUBLE	MTF PASS	MTF FAIL	TEMP CYCLE INIT CURE	TEMP CYCLE ROOM TEMP CURE	TEMP CYCLE NVL CURE	REMAR
P	13	T	S	D	X		X		X	
P	13	T	S	D	X		X		X	
P	16	T	S	D		X	X		X	
P	16	T	S	D		X	X		X	MIRRO
P	16	T	S	D	X		X		X	
P	16	T	S	D		X	X		X	300°F
P	16	T	S	D	X			48 HR	X	
P	6	T	S	D	X		1st LAYER	2nd 48 HRS	X	
G		T	S	D		X	1st LAYER	2nd 48 HRS	X	ALTERN
P	20	T	S_1	D		X			X	PRE-PA
P	12	T	M	S	X		X		X	
P	21	T	S	S		X		X		EVACUA
P	21	T	S	S		X		X	X	EVACUA
G		T	M	S	X		X		X	EVACUA
P	20	T	S	D		X		48 HR	X	EVACUA
P	12	T	M	S	X		X		X	REWORK
P	021-152	B	M	S	X		X		X	
P	22	T	M	S	X		X		X	
P	021-158	B	M	S	X		X		X	
P	22	T	M	S	X		X		X	
P	24	T	M	S	X		X		X	
P	24	T	M	S	X		X		X	

CODE:

MP CYCLE: ROOM TEMP CURE	NVL CURE	REMARKS
	X	
	X	
	X	
	X	MIRROR DESTROYED AT DISASSEMBLY
	X	
	X	300°F OVEN CYCLE FOR STRESS RELIEF, DESTROYED AT DISASSEMBLY
48 HR	X	
2nd 48 HRS	X	
2nd 48 HRS	X	ALTERNATE SUBSTRATE FOR TEST PURPOSES
	X	PRE-PACKAGED 4.1% MIX, EVACUATED
	X	
X		EVACUATED MIX, MIRROR DESTROYED @ DISASSEMBLY
X	X	EVACUATED MIX,
	X	EVACUATED MIX
48 HR	X	EVACUATFD MIX, FRESH EPOXY USED, FAILED OPTICAL FLAT TEST, MTF NOT RUN
	X	REWORK MIRROR #009 WITH MILBOND
	X	
	X	
	X	
	X	
	X	
	X	

CODE:
- P = PYROCERAM
- G = GLASS
- T = TRANSWORLD OPTICS
- B = BROOMER MFG.
- S = STYCAST
- S_1 = STYCAST PRE-PACKAGED MIX
- M = MILBOND

supported on the IR side by means of blocks and a felt pad. Using a monochromatic light source, the interferometric patterns were obtained using a small optical flat. The flat was placed at verious points on the test unit surface. The sketches shown in Figure 1 are essentially what was observed. The immediate reaction of the optical expert at TWO was that the mirror had been distorted by the metal parts cemented to it. The curvature of the lines across the center (II) and at either mounting point (IV or V) showed that the epoxy had hardened in such a way that the flatness of the surface had been disturbed. When the optical flat was moved closer to either mount, the curvature of the patterns increased. TWO then stated that this effect was typical. Whenever two parts or metal to glass were joined this happened. Further, the effects shown by such assemblies on the optics were not predictable.

A careful examination of the mounting structure was then made. Figure 2 is a sketch of the interface in question. The epoxy cement fills in the space between the mirror and the metal support structure (either aluminum in the arm return or stainless in the top cap.) The epoxy is then cured and becomes a hard material which adheres to both pieces with sufficient strength to survive repeated temperature and mechanical vibratory cycles.

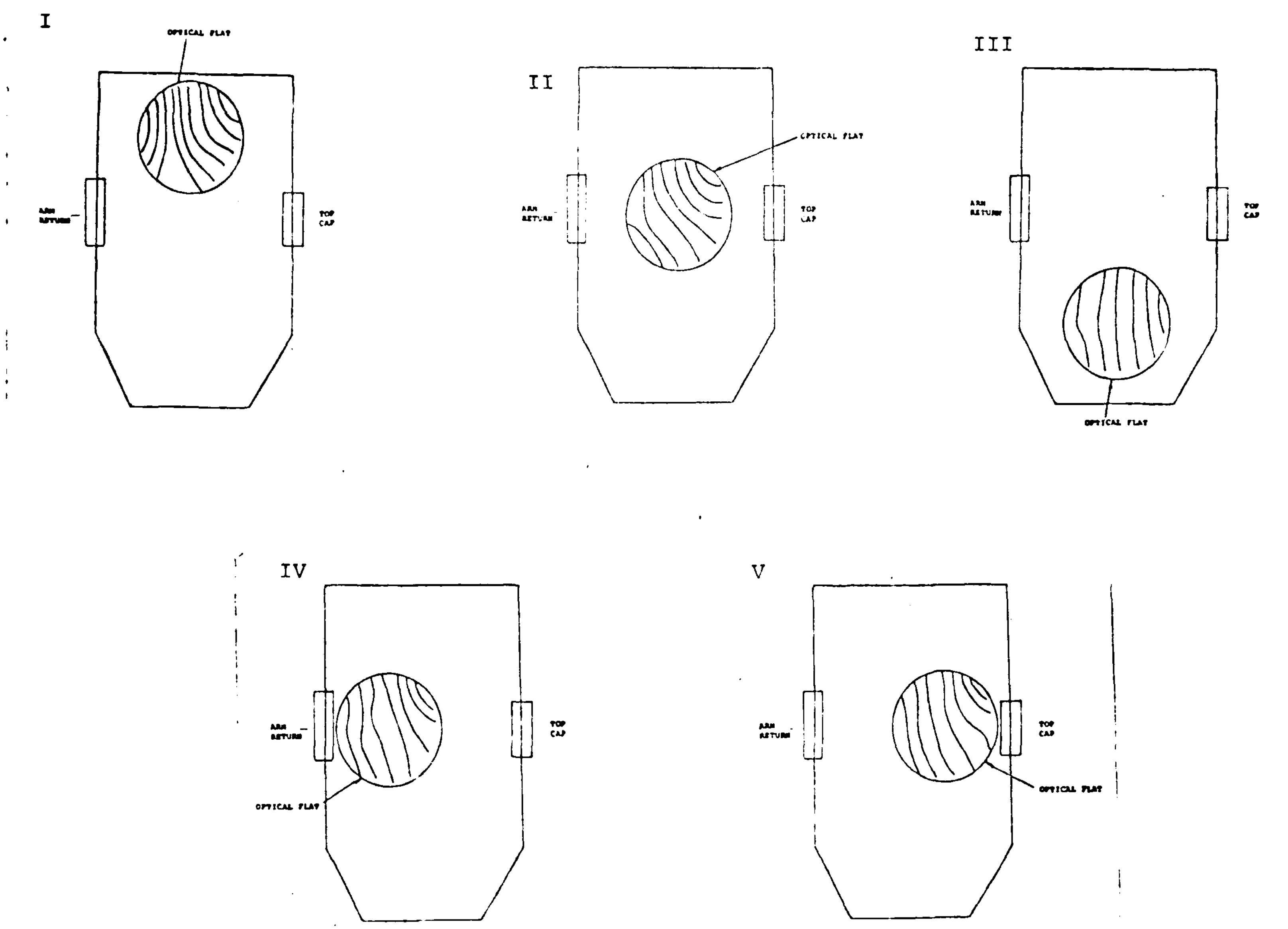


FIGURE 1. OPTICAL FLAT SURVEY OF TEST MIRROR

The Stycast had been specifically selected to provide a good compromise in thermal expansion coefficient between the metal and the substrate.

Now, in the process of curing, the epoxy goes through a chemical change and as a rule tends to shrink while adhering to both interface surfaces. In the figure shown, the force resulting from this shrinkage is represented as a series of vertical arrows on the upper and lower surfaces of the mirror. With such a force distribution, two conditions are possible. First, if the mirror had zero thickness, these forces would tend to cancel. Second, if the mirror substrate was perfectly rigid, the surface would not react to this force. However, neither of these conditions exist. Thus the reaction to these forces is such that the mirror surface would tend to move (however minutely) and result in a deviation from optical flatness. Moreover, the resultant distortion would go beyond the contacting surface dimensions since the substrate must have a gradual diminishment versus linear distance. A general representation of this distortion is sketched onto the surface in Figure 2.

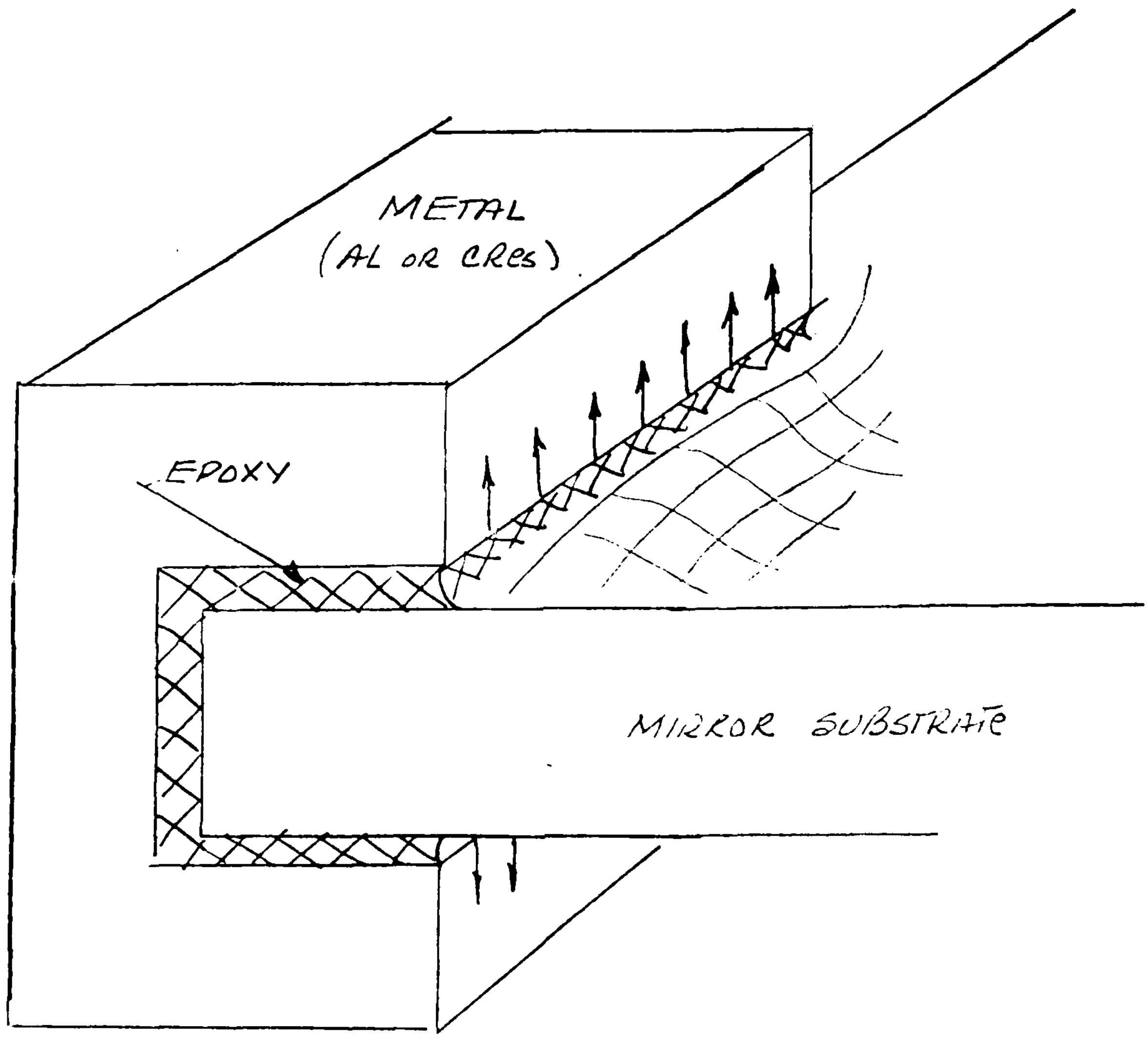


Figure 2. MIRROR SUBSTRATE - METAL BOND

The optical flat survey taken on the test mirror reflects this distortion and indicates that the maximum distortion occurs near the two mounting parts. Thus, it appears that even if a 1 or 2 fringe flatness mirror is used in this assembly, the mounting of its associated parts gives rise to distortions and while they may not impinge on the clear aperture, these distortions do occur with the mirror in the free state. For the mirror under test, it was estimated that a 1-2 fringe unit was stressed to about 4 fringe

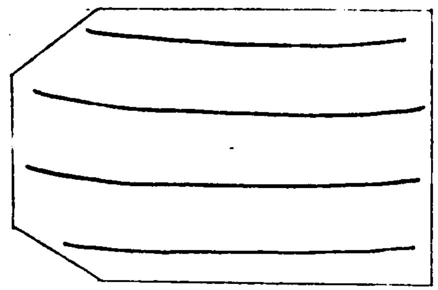
In the interest of completing the test for temperature effects, the survey was made and the mirror was then put in an oven. The temperature was raised to +70°C and held for about 1 hour. The temperature slopes in the cycles were about 1/2 hour for each direction. The mirror was then returned to room temperature and another survey was made. The distortion in the fringe patterns remained the same with the metal contact points showing maximum curvature or stress.

After return to room temperature, the mirror was then placed in a freezer and the temperature reduced to approx. 25°F and held for about 1 hour. (Note: There were no facilities immediately available at TWO to run the temperature to the -54°C spec value). After return to room temperature, the survey was run once again with no change observed in the fringe patterns. Although the spec value at low temperature was not reached, TWO stated that most of the distortion due to temperature occurs at high temperatures.

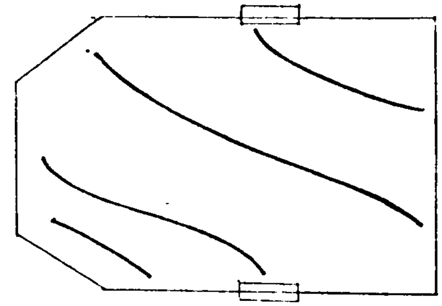
The results of this test showed that the distortion of the mirror by the metal parts is much more of a difficulty than was anticipated. From the discussion above, it appears that the stresses built into the mirror by the cementing process were a function of the linear contact dimensions. Yet in the top cap, a drawing change has resulted in more surface contact on the visible side and in the arm return, a longer contact surface has been generated by a drawing change as well.

Since the optical flat survey could not result in an overall surface flatness measurement, a pair of modified parts were fabricated to permit overall interferometric measurements to be made.

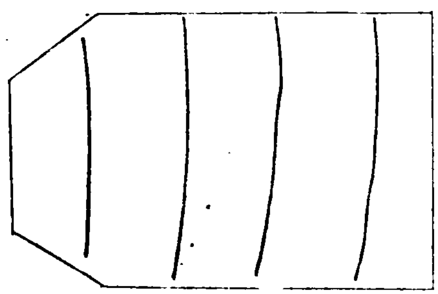
Particular care was taken in this assembly to keep the arm return slot width to a minimum. In this case, the slow was made equal to that of the top cap. After the cement was cured, an interferometric measurement was made of both the IR and the visible side of the mirror. The results of these tests are shown in Figures 3 and 4. The left hand sketch shows the mirror pattern before installation of the cemented parts for both the IR and visible sides. Although a photograph of the patterns could not be made, the sketches are representative of the patterns observed. The results show that considerable improvement in the final fringe patterns can be achieved if the slot dimensions (or the cement lines) are reduced. For both sides of the mirror, the fringe patterns showed less than 3 fringes and were within specification.



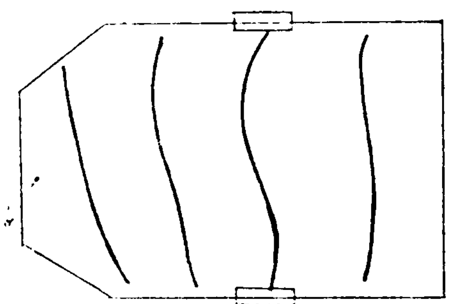
a) 1 Fringe



b) < 2 Fringes

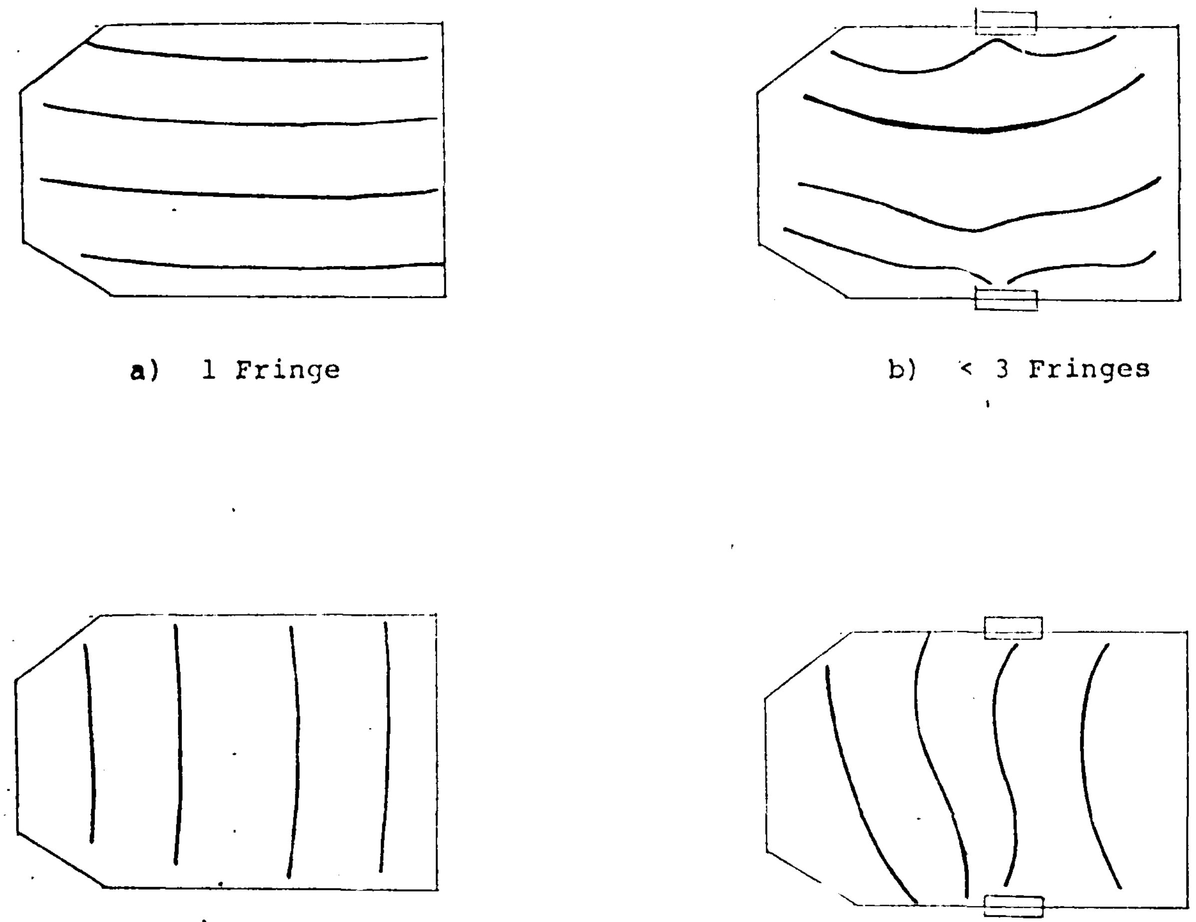


c) 1 Fringe



d) < 2 Fringes

FIGURE 3. FRINGE PATTERNS, IR SIDE



a) 1 Fringe

b) < 3 Fringes

c) < 1 Fringe

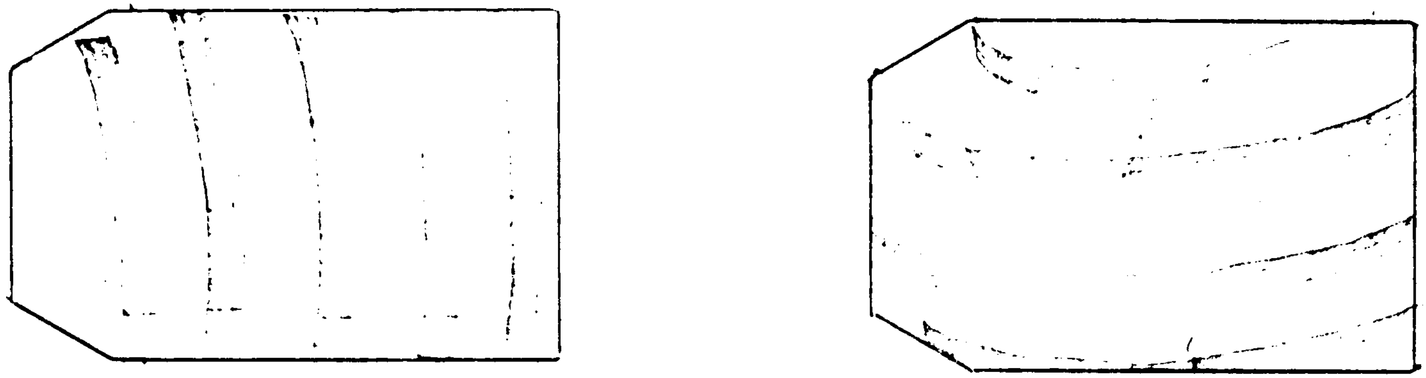
d) < 3 Fringes

FIGURE 4. FRINGE PATTERNS, VISIBLE SIDE

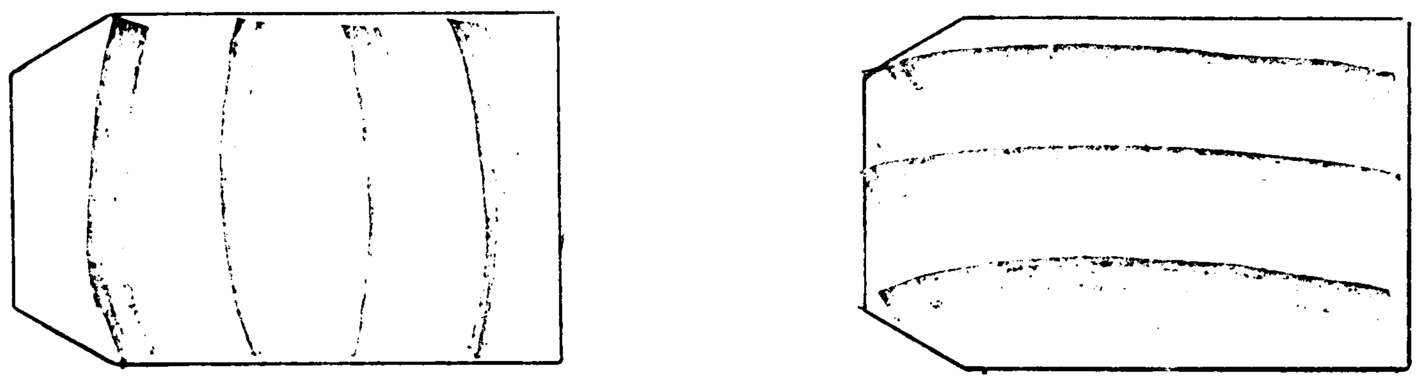
A trip was made to NVL during which the temperature cure of the epoxy material used to mount metal parts to the mirror was discussed in great detail with various NVL personnel. As a result of this discussion, a preliminary temperature cycling technique which had been investigated at NVL was given to Aeroflex personnel for trial on this assembly. A pair of mirrors were checked with an interferometer for fringe distortion (see Figures 5, 7.) Both of these mirrors show less than two fringe distortion with some concavity on one surface but met the mirror specs overall. These two test mirrors were then assembled to the associated parts and were subjected to the recommended temperature cycle for curing of the epoxy. The percentage of hardener used in this two-part epoxy was approximately 3-1/2% (per manufacturer's recommendation).

The next set of mirrors were subjected to the full temperature cycle for cure (up to 110°C) and then re-cycled back to room temperature. The mirrors were then subjected to -62°C for 4 hours and then up to +95°C for an additional 4 hours before return to room temperature. This additional cycle was incorporated into the temperature test to provide for annealing and stress relief of the entire assembly.

MIRROR #1, UNMOUNTED



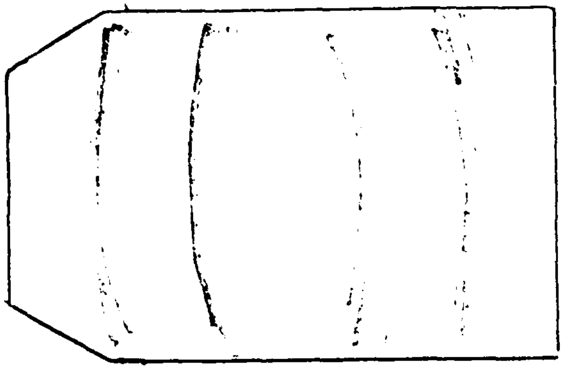
IR SIDE
1½ FRINGE

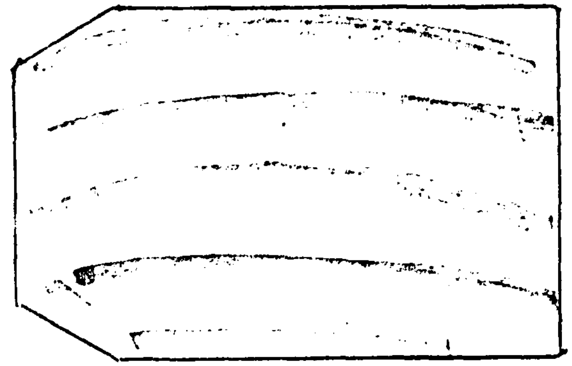


VISIBLE SIDE
1½ FRINGE

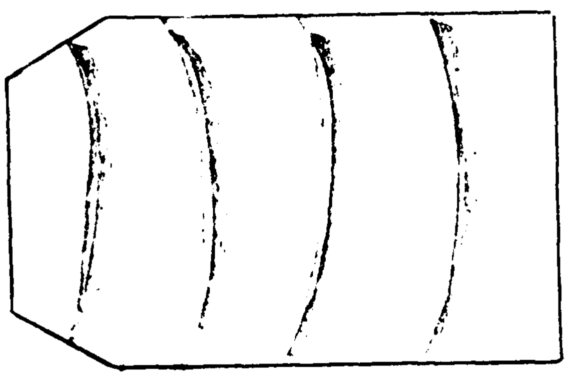
FIGURE 5. TEST MIRROR #1 FRINGE PATTERNS

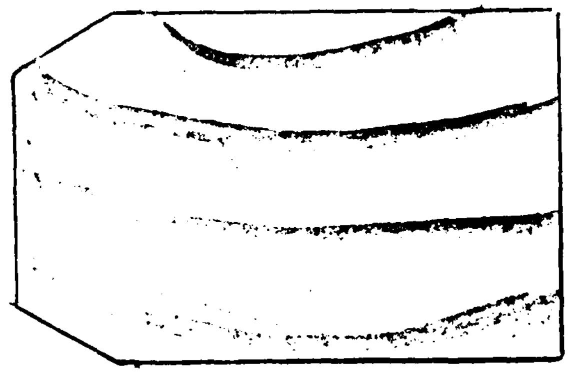
MIRROR #2, UNMOUNTED





2 FRINGE VISIBLE SIDE 1 FRINGE





1 FRINGE IR SIDE 2 FRINGE

FIGURE 7 · TEST MIRROR #2 FRINGE PATTERNS

Figures 6 and 8 are sketches of the interference patterns obtained after temperature cycling. The mirrors were then tested statically at NVL using their optical test set up.

The first test was run on a completed scanner which was subjected to the recommended cure cycle after assembly. This unit was placed in an oven and subjected to the temperature curve shown in Figure 9. It should be noted that the upper temperature was limited to +95°C since there was some concern over the stress imposed by the completed assembly on the mirror. The lower temperature limits reached below the recommended -62°C, but this did no apparent harm to the mirror or the assembly.

Figures 10 and 11 are print outs of the MTF curves achieved for both the Visible and IR sides under dynamic conditions. From this curve, the MTF at .667 cycles/milliradian is 95% or slightly better for both sides. This met the specification. There was an improvement of about 2-3% from the test results obtained previously on this unit (before hat treat cycling). The static MTF performance of the mirror was also measured.

MIRROR #1, MOUNTED

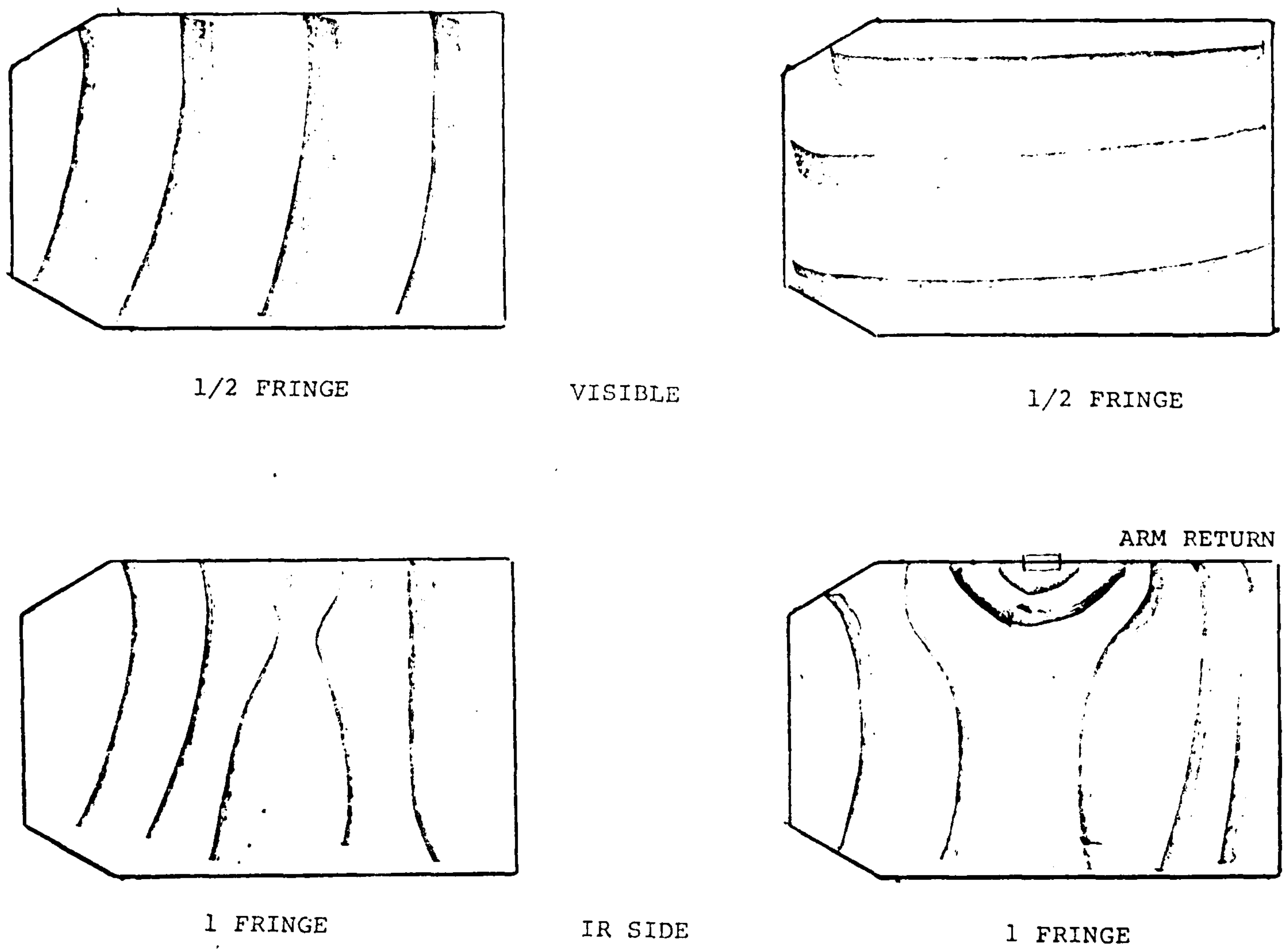


FIGURE 6 .- TEST MIRROR #1 FRINGE PATTERNS

MIRROR #2, MOUNTED

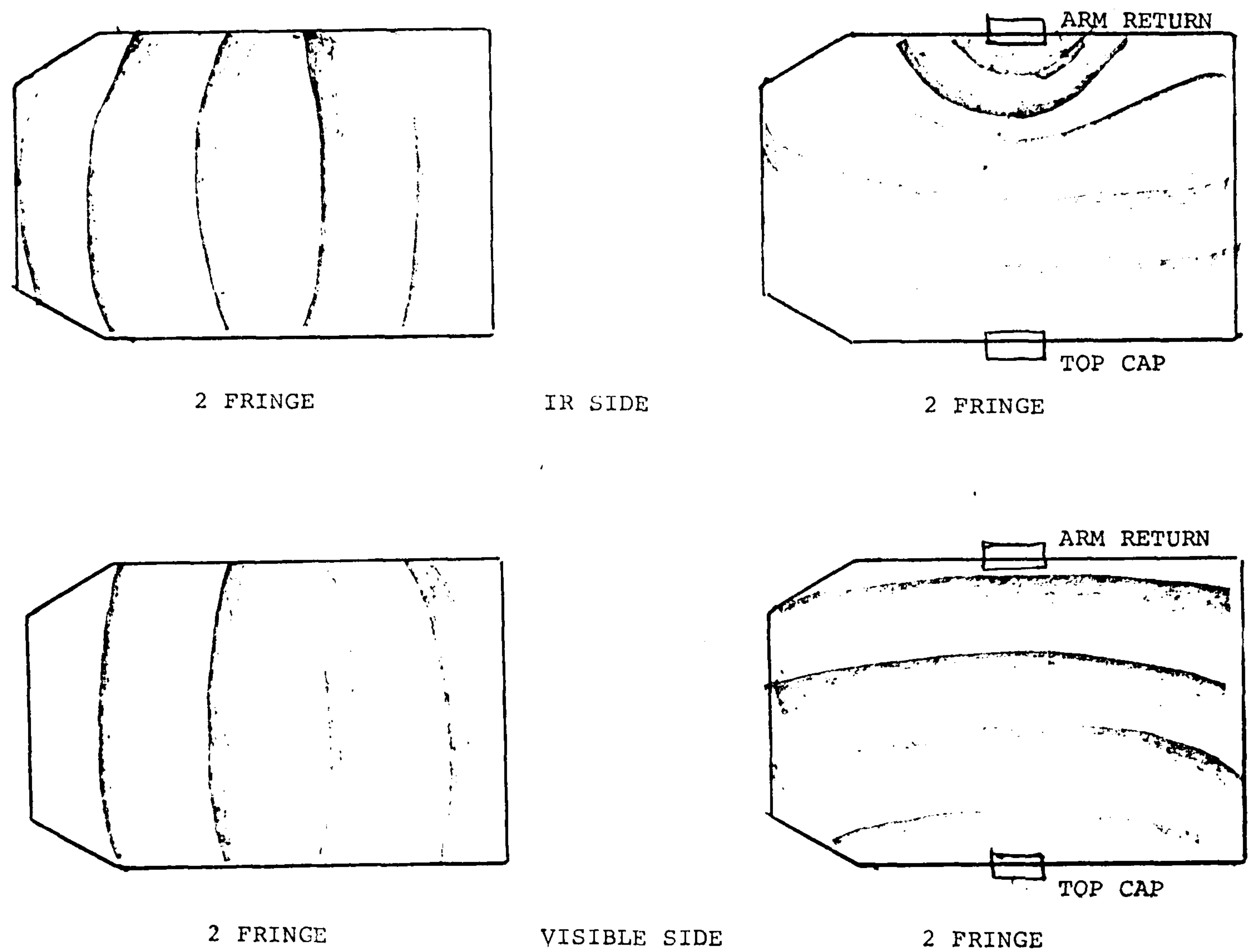


FIGURE 8.. TEST MIRROR #2 FRINGE PATTERNS

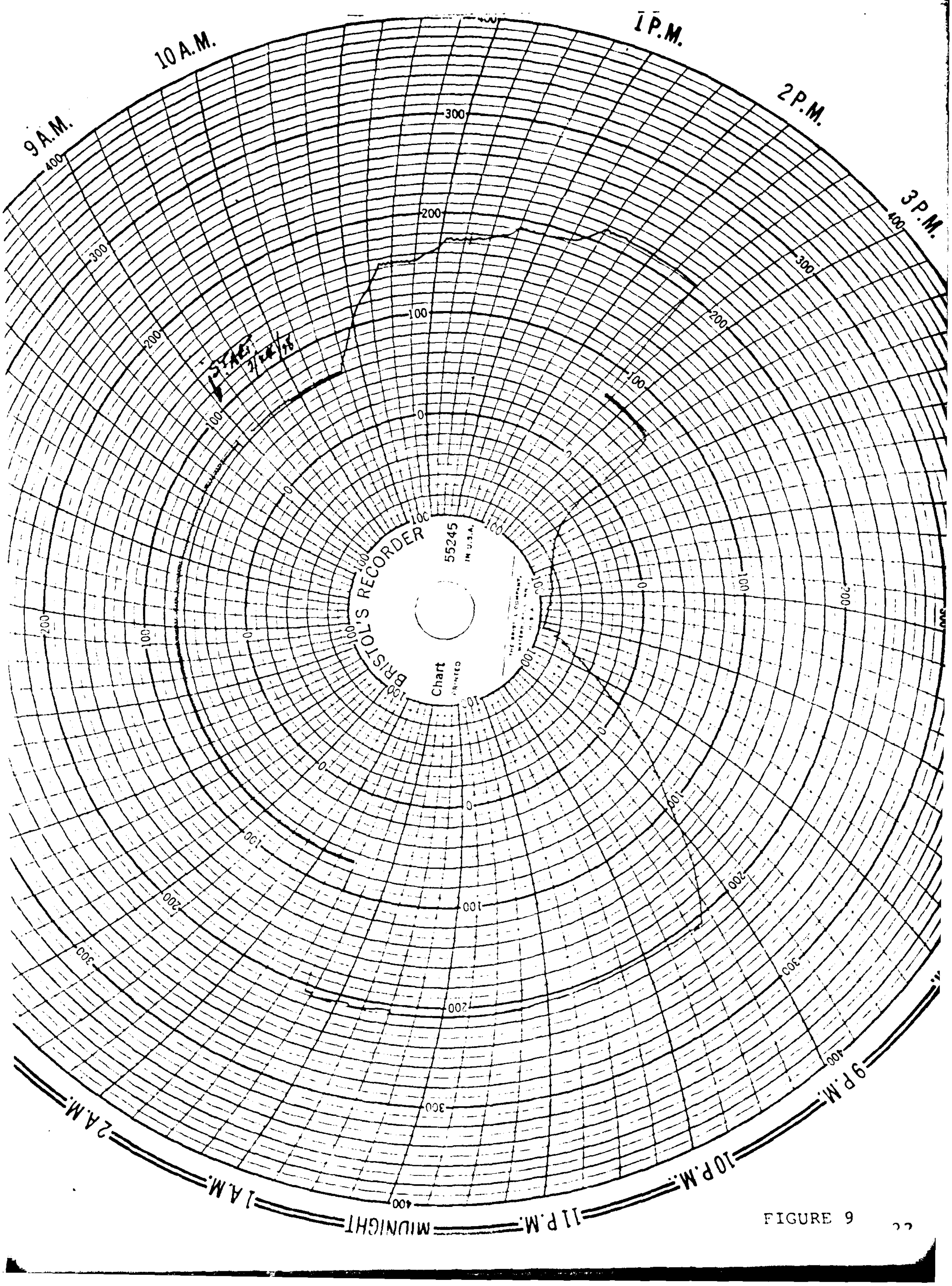

9 A.M.
10 A.M.
1 P.M.
2 P.M.
3 P.M.
9 P.M.
10 P.M.
11 P.M.
MIDNIGHT
1 A.M.
2 A.M.
BRISTOL'S RECORDER
Chart
55245
0
100
200
300
400

FIGURE 9

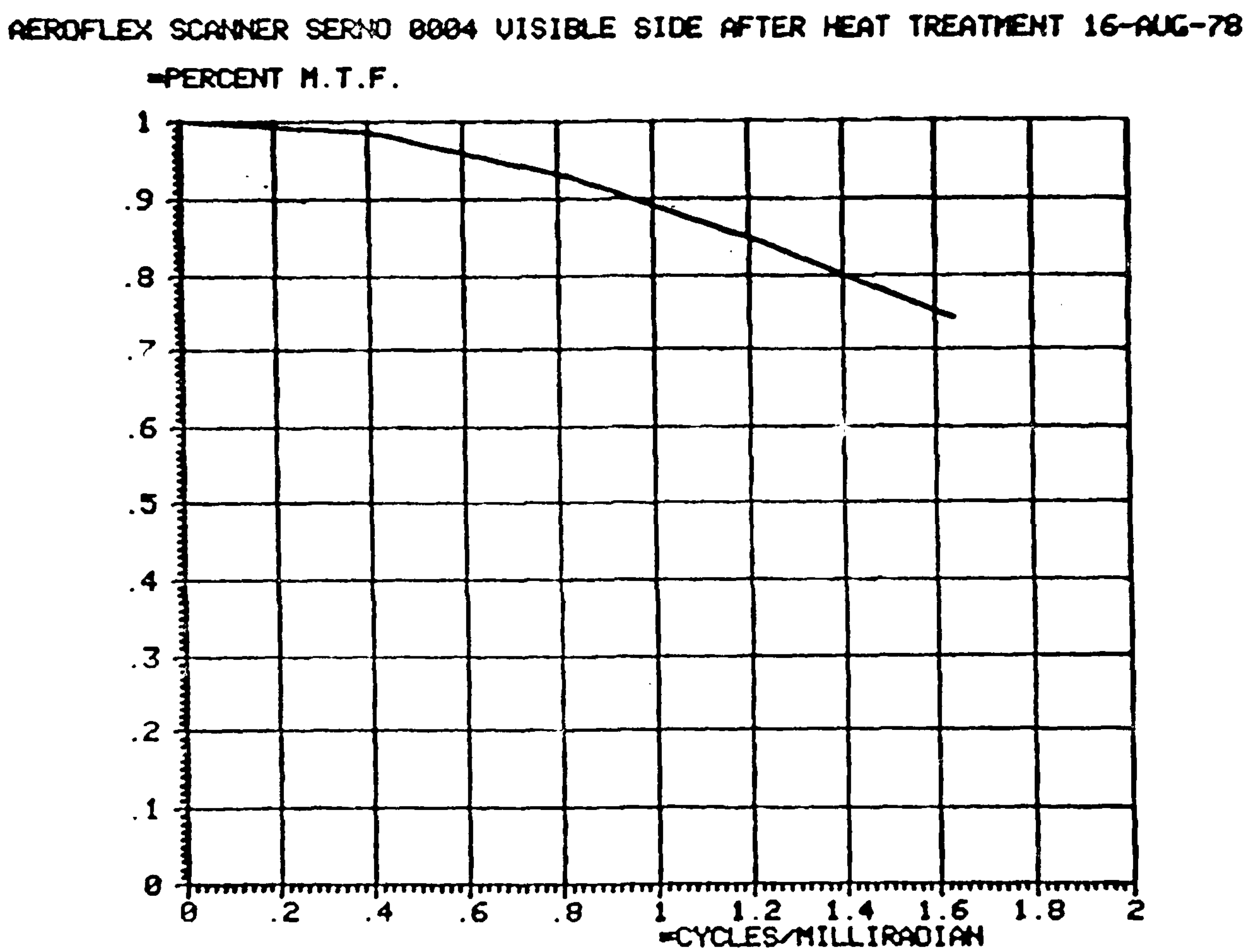

AEROFLEX SCANNER SERNO 0004 VISIBLE SIDE AFTER HEAT TREATMENT 16-AUG-78
=PERCENT M.T.F.
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0
.2
.4
.6
.8
1
1.2
1.4
1.6
1.8
2
=CYCLES/MILLIRADIAN

FIGURE 10

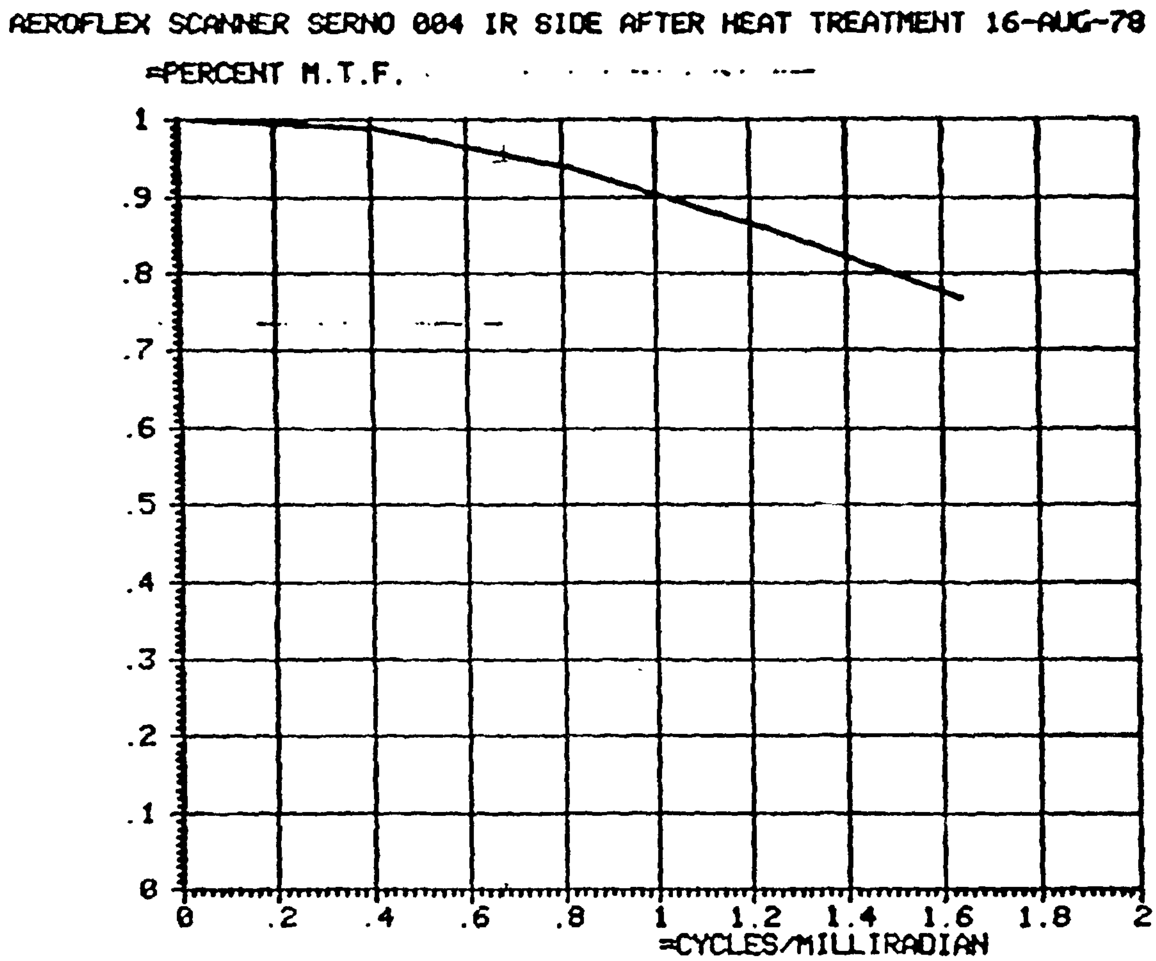
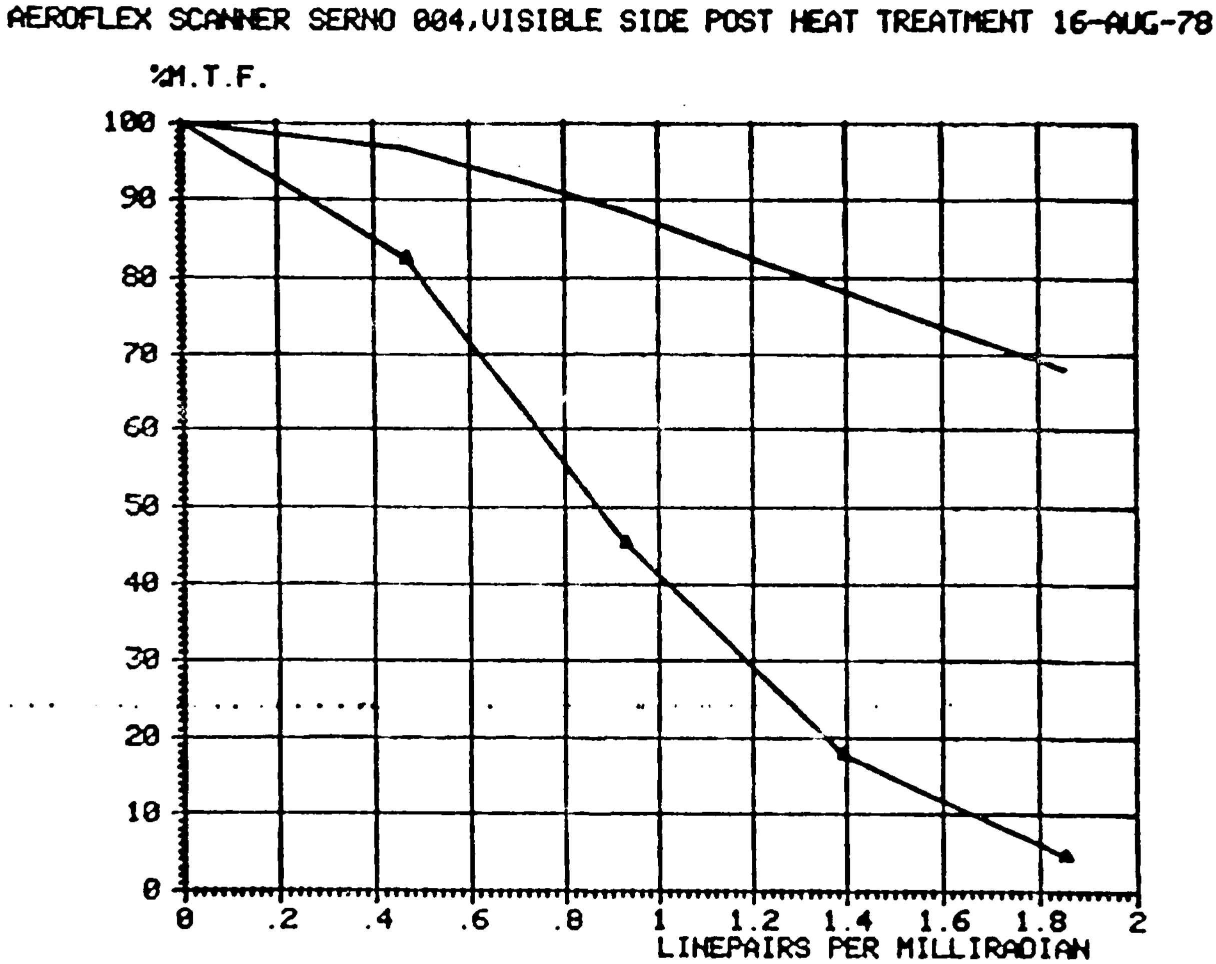

AEROFLEX SCANNER SERNO 004 IR SIDE AFTER HEAT TREATMENT 16-AUG-78
=PERCENT M.T.F.
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0 .2 .4 .6 .8 1 1.2 1.4 1.6 1.8 2
=CYCLES/MILLIRADIAN

FIGURE 11.

Figures 12 and 13 are the printouts of the static MTF curves achieved. In these curves, the azimuth pattern still meets the required MTF limits. However, the elevation pattern shows that there is considerable vertical astigmatism in this mirror. Based on the curves shown in Figures 5-8 for a typical mirror, it was assumed that this astigmatism is a result of assembly.

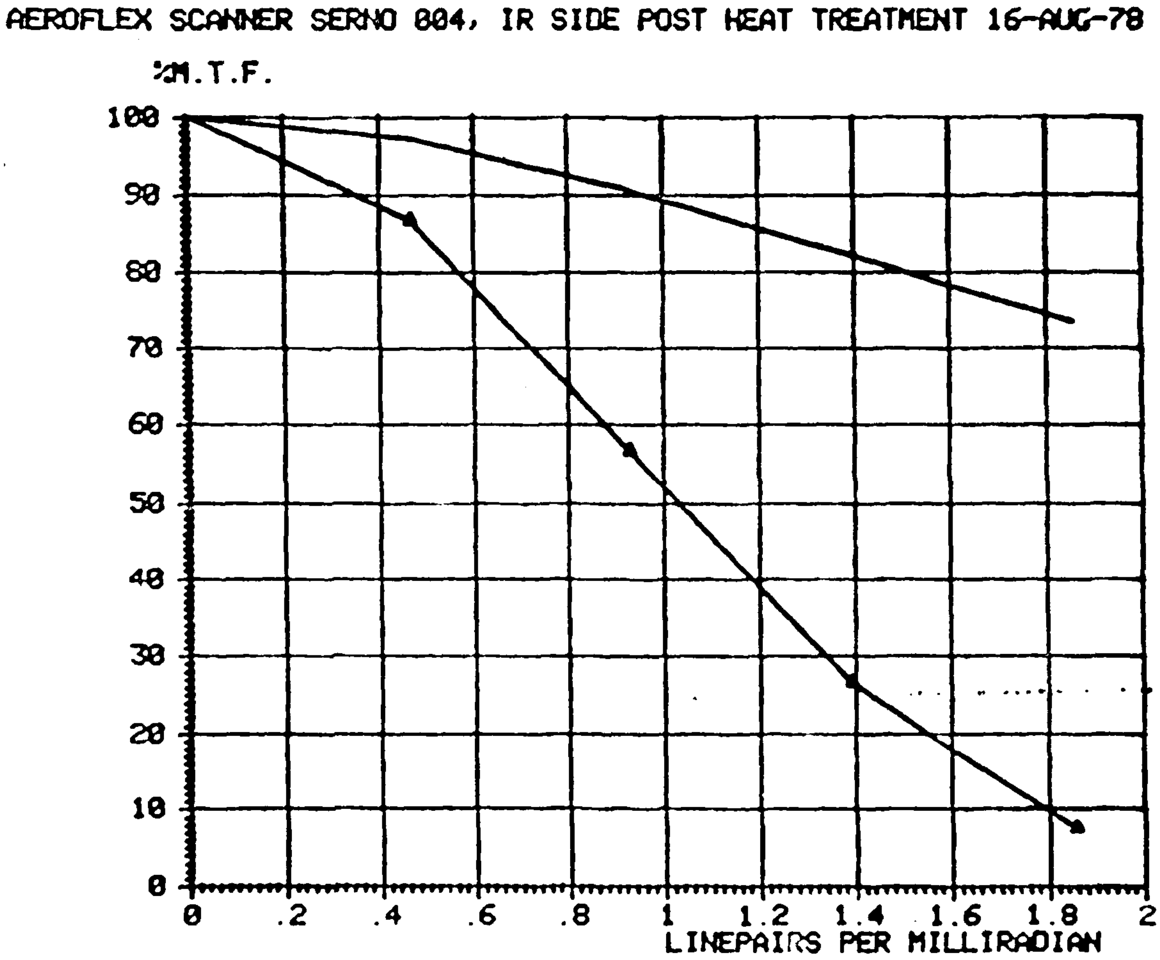
Two additional mirrors were also subjected to the static MTF tests. Figure 14 is a plot of this curve and shows that the maximum temperature was limited to +95°C. In addition, the epoxy mix (3.5% hardener by weight) was subjected to a preliminary heat cycle before the overall chamber cycle shown in Figure 14 was run. In this case, the pre-treat may have been the prime curing cycle rather than the step cycle shown. Discussion with NVL personnel suggested that the moment the epoxy is subjected to an elevated temperature, curing begins. However, the annealing cycle shown at the end of the cam served to relieve the stresses built up during the cure cycle.

Figure 15 and 16 show the results obtained on Mirror #001 for the static MTF test. As can be seen, the MTF in the azimuth plane, as well as the elevation plane, meet the specification requirement for both sides. In particular, there was a marked improvement in the elevation plane response.



AEROFLEX SCANNER SERNO 004,VISIBLE SIDE POST HEAT TREATMENT 16-AUG-78
%M.T.F.
100
90
80
70
60
50
40
30
20
10
0
0
.2
.4
.6
.8
1
1.2
1.4
1.6
1.8
2
LINEPAIRS PER MILLIRADIAN

FIGURE 12



AEROFLEX SCANNER SERNO 004, IR SIDE POST HEAT TREATMENT 16-AUG-78
%M.T.F.
100
90
80
70
60
50
40
30
20
10
0
0
.2
.4
.6
.8
1
1.2
1.4
1.6
1.8
2
LINEPAIRS PER MILLIRADIAN

FIGURE 13

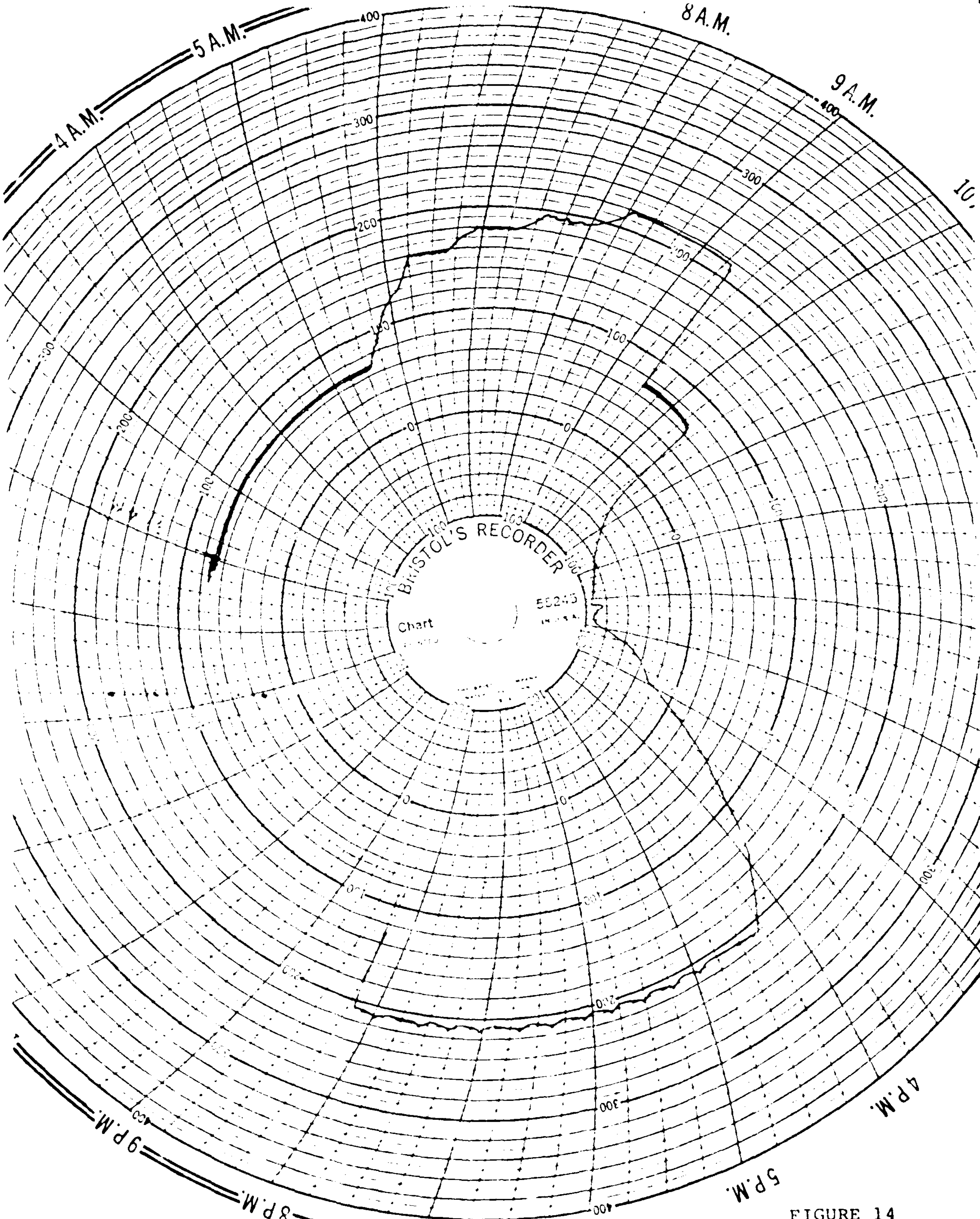

4 A.M.
5 A.M.
8 A.M.
9 A.M.
BRISTOL'S RECORDER
Chart
55245
4 P.M.
5 P.M.
8 P.M.
9 P.M.

FIGURE 14

AEROFLEX MIRROR ASSEMBLY 20113 SERNO 001 POST HEAT 16-AUG-78

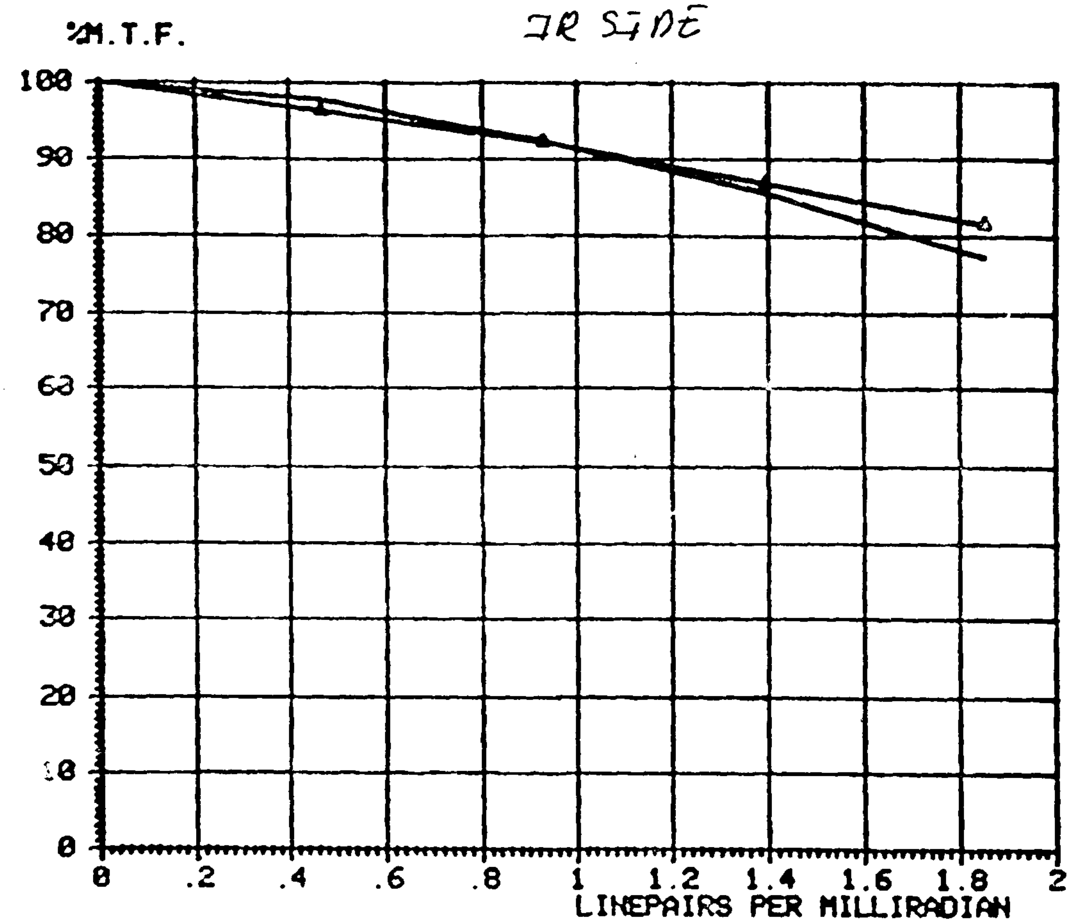


FIGURE 15

AEROFLEX MIRROR ASSEMBLY 20113 SERNO 001 POST HEAT 16-AUG-78

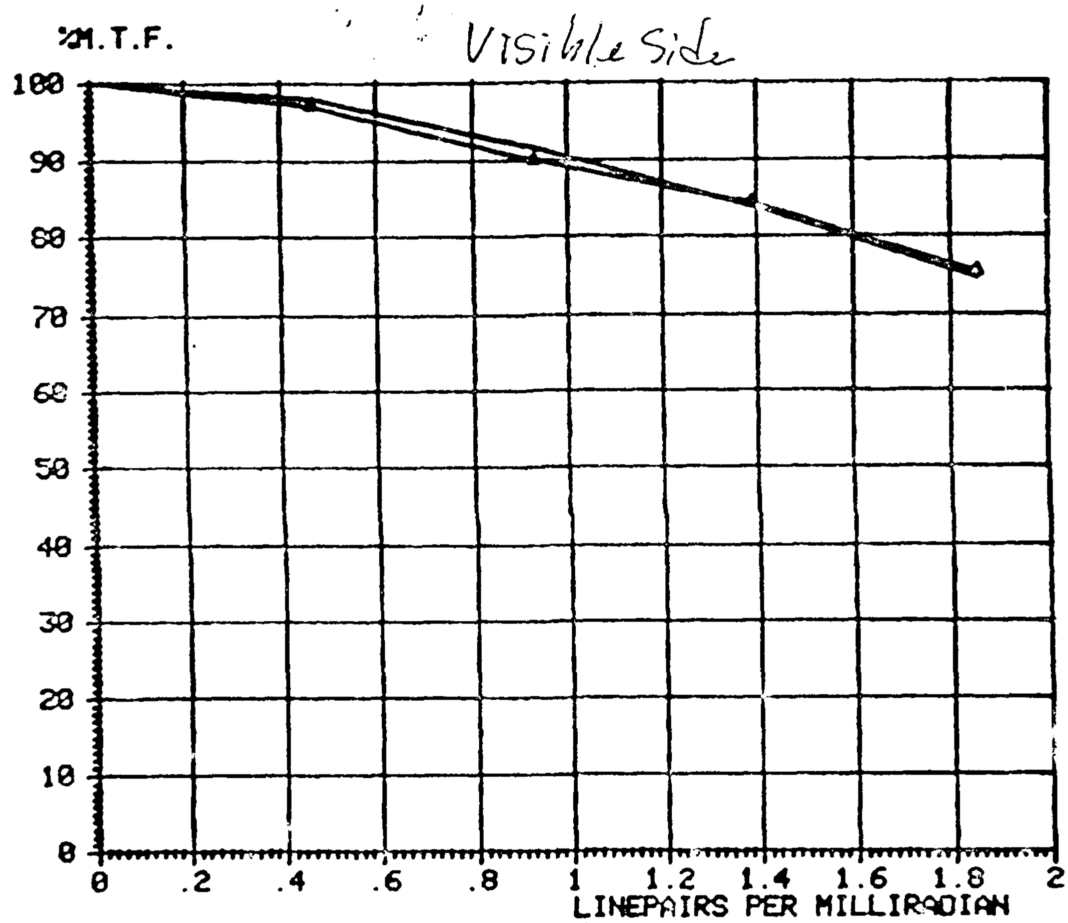


FIGURE 16

Figures 17 and 18 show equally good results on Mirror #002 for the same static test.

At the conclusion of these tests, discussions were held with NVL personnel as to the changes which were incorporated into these assemblies. In this case, the thickness of the epoxy glue line between the mirror and the metal part was kept to a minimum. When a tolerance analysis is run between the mirror (.110 + .005, -.000), the arm return (.130 ±.005) and the top cap, mirror (.120 +.005, -.000) it is seen that for a minimum thickness mirror and a maximum slot width in the arm return, a total of .0125 inch cement thickness is possible on each side of the mirror. From an optical performance viewpoint, it has been strongly recommended by the mirror manufacturer that an absolutely minimum glue line be achieved. On this basis, a two-step procedure was tried in order to reduce the "active" glue line between the mirror and the metal parts.

In this procedure, a substrate at the nominal thickness of the mirror is used. A thin tape is then placed over the mounting areas of the mirror on the substrate. This tape is selected so that the epoxy cement will not adhere. The substrate is then placed into the mirror assembly fixture and an initial coating of epoxy is used to fill the resulting

AEROFLEX MIRROR ASSEMBLY SN 02 IR SIDE POST TEMP 16-AUG-78

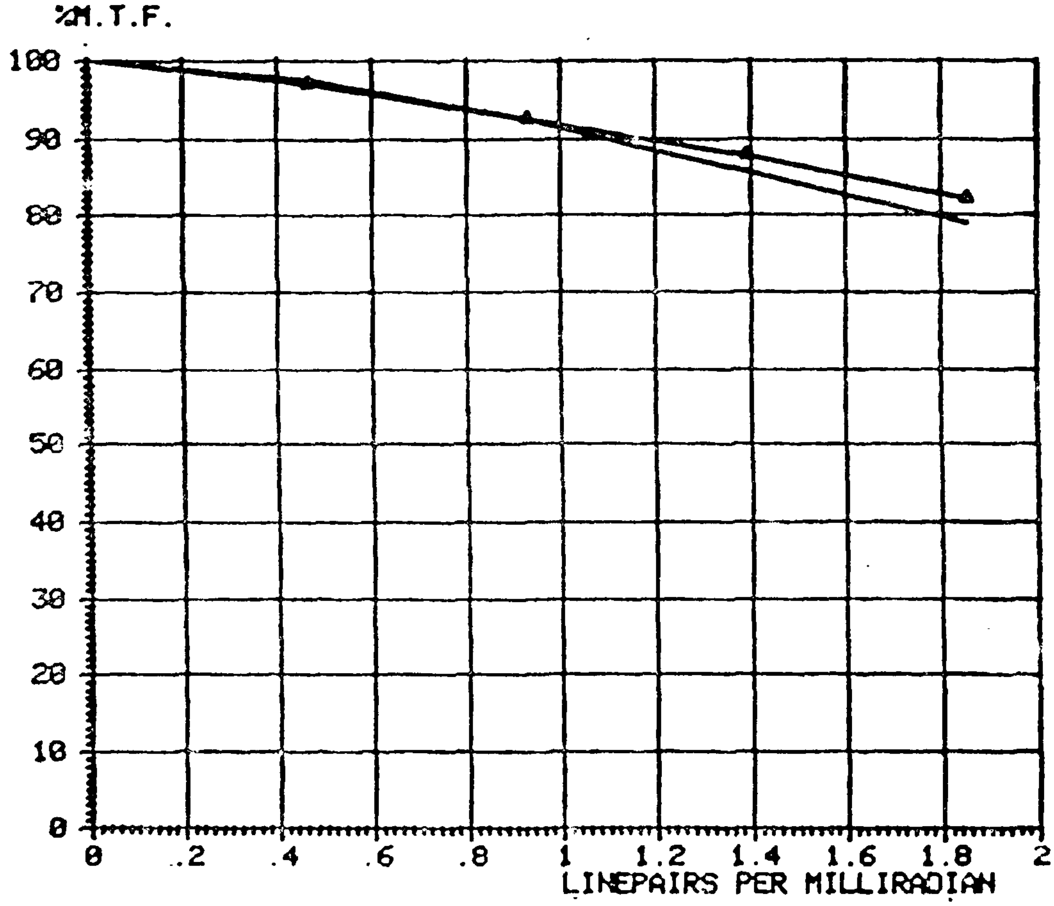


FIGURE 17

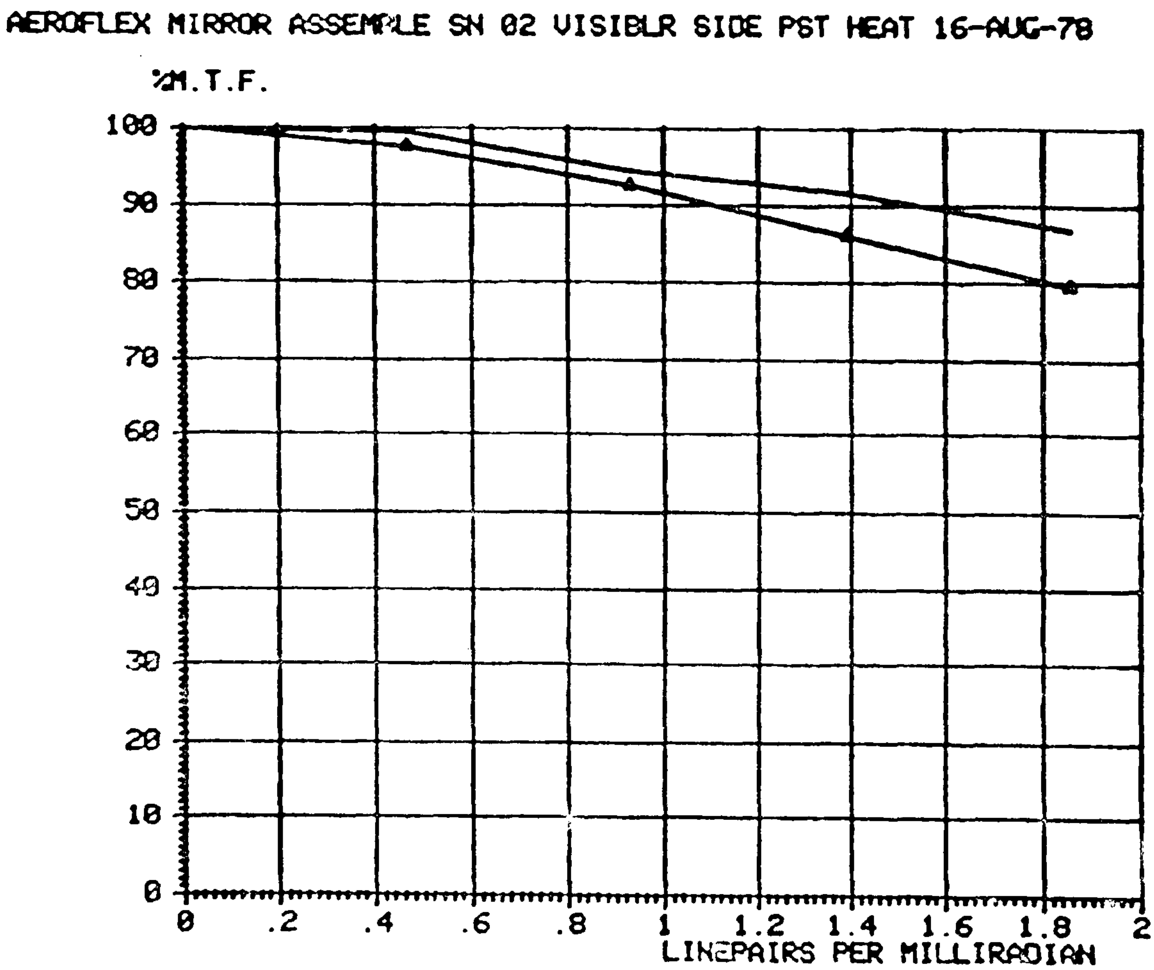

AEROFLEX MIRROR ASSEMBLE SN 02 VISIBLR SIDE PST HEAT 16-AUG-78
%M.T.F.
100
90
80
70
60
50
40
30
20
10
0
0
.2
.4
.6
.8
1
1.2
1.4
1.6
1.8
2
LINEPAIRS PER MILLIRADIAN

FIGURE 18

gap. The epoxy is then cured. After cure, the substrate is removed and the slot surfaces are sand-blasted to provide a good second surface for the final cementing operation. The finished mirror is then assembled into the metal parts using the same assembly fixture, and cemented and cured. This assembly procedure provides control over the final cement line thickness.

For the completed scanner, this thickness was held to .003 inches on each side. For the two test mirrors subjected to the static MTF, this thickness was reduced to .002 inches on each side. There was some question as to whether the mirror was centered with respect to the final slot since the interferometer patterns showed more stress on the arm return side than on the top cap side.

The results of the tests show that while the cure cycle has improved the optical performance of the mirror, the change in the cement line thickness has also contributed; what was not known is the relative contribution of each variable. During this time period it became evident that Aeroflex was pursuing a different path than others involved with mirror assembly problems. Based upon the recommendation of TWO, keeping the cement line thickness to a minimum was used as one of the basic starting points, At no time during this effort did Aeroflex temperature cycle or stress relieve the metal parts used in this assembly. There was no evidence, nor was any put forth, that this could be a contributing factor.

At this point in the test series a set of additional tests were planned to control one variable at a time and monitor the results. Each test sequence listed below involved two mirrors.

TEST PLAN

Test #2 Cure the initial epoxy hard and maintain the thickness of the final cement line on Mirror #003. Subject the mirror to a final cure cycle per NVL recommendation. Repeat for Mirror #004 but with reduced cement line.

Test #3 All other values held the same but change percent of hardener to 4.1% by weight.

Test #4 Hold all values as in Test #2 but machine metal parts to final glue line thickness and repeat tests on two mirrors.

Test #5 Select optimum values from Tests 2-4 and repeat for two additional mirrors each from two vendor sources.

Test #6 Repeat as necessary.

For Mirror Assembly #003, the initial results showed that a 6-7 fringe distortion resulted after assembly. A detailed review of the assembly procedure was held and the steps taken on Mirrors #001 and #002 were ostensibly repeated. Further investigation showed that the initial assembly had been different. In #003 assembly, the first cure cycle (after the cement was mixed) was eliminated and the mirror and its two associated parts were placed into the oven for curing within 1/2 to 1 hour after assembly. Thus the epoxy was totally uncured when subjected to the NVL temperature cycle.

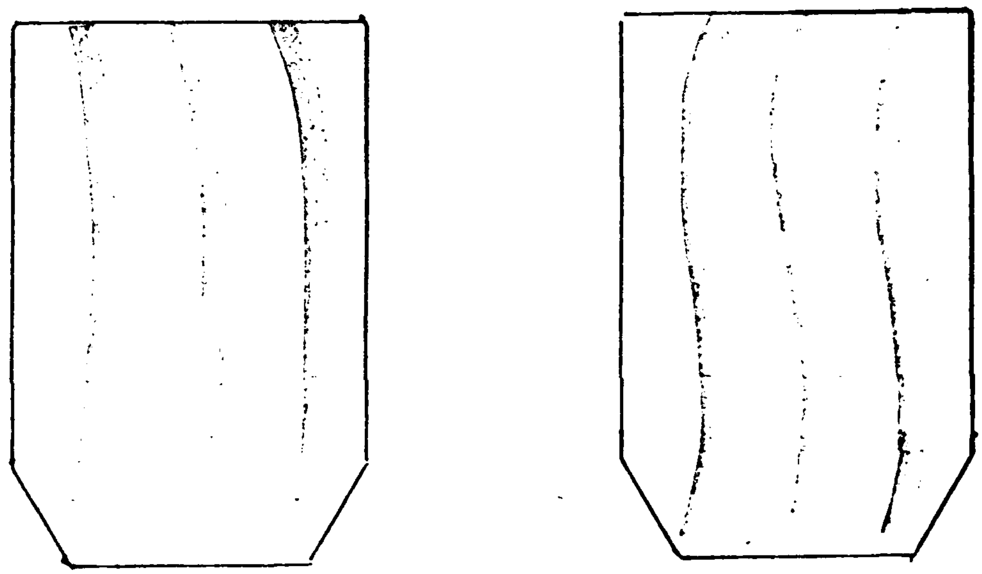
Re-examination of the #001 and #002 mirror data showed that a preliminary high (160°-170°F) temperature cycle was run. This was followed by an air cure of at least 3 hours before the NVL cure cycle was performed. This step had been eliminated from the #003 mirror assembly. The remainder of the assembly procedure was performed as closely as possible to the first two mirror cycles.

In order to determine whether a repeat of the NVL cycle had any effect, #003 mirror was resubjected to this cycle and by stages the full cycle was completed. The assembly was then re-checked for distortion. In this case, the distortion remained at 6-7 fringes with a definite saddling of the surface. The only conclusion which could be drawn from this re-test was that once the cure cycle is completed the mirror distortion is set and very little, if any, change occurs thereafter.

The #003 assembly was not considered to be good enough to pass the MTF test. It was disassembled for rework and re-assembly since the mirror surface had become badly scratched during this cure cycle processing.

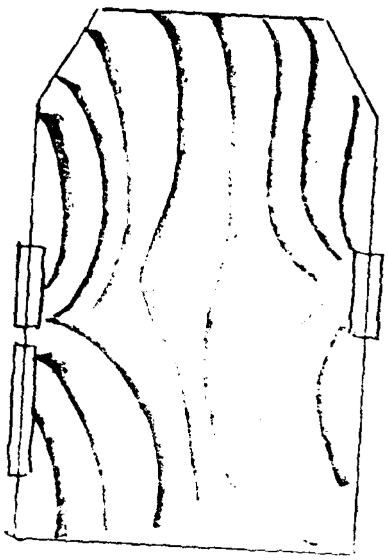
Mirror assembly #003 was then subjected to a high temperature (400°F) cycle for 10-15 minutes to break the epoxy cement bond. After removal of the top cap and arm return, the mirror was rechecked for flatness and distortion. Figure 19 is a sketch showing the fringe patterns which resulted. The significance of this test is the fact that the mirror can be restored to its original state and therefore those mirrors which do not pass MTF checks can, at least, be salvaged and re-assembled. The cost of rework would therefore not involve a completely new mirror. It should be noted however that the mirror may require repolishing and recoating.

Serial #004 was then assembled and tested after cycling through the initial and final cementing processes. In this case, there was a small improvement in the distortion over that of #003. However, the patterns show approximately 4 fringes with an irregular pattern. (See Figure 20.)



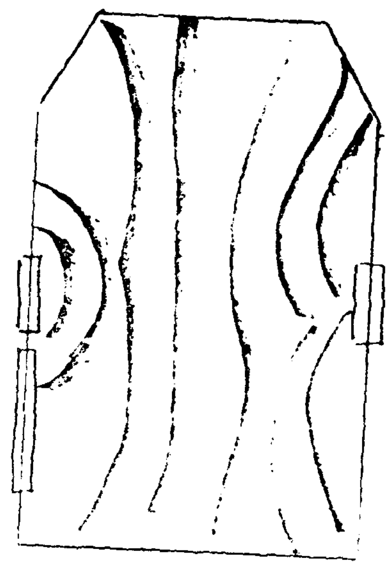
I R SIDE, 1/2 FRINGE VISIBLE, 1/2 FRINGE

FIGURE 19 FRINGE PATTERN S/N 003



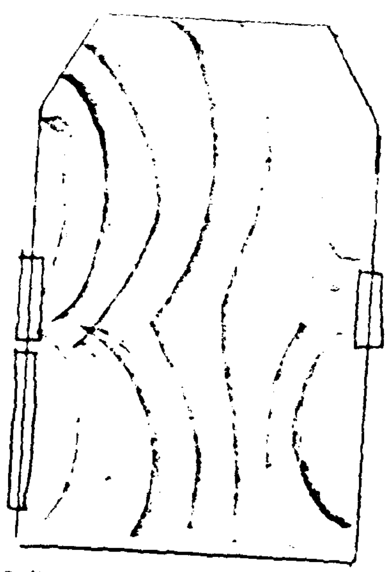
10/13/78 VISIBLE

4 FRINGE IRREG.



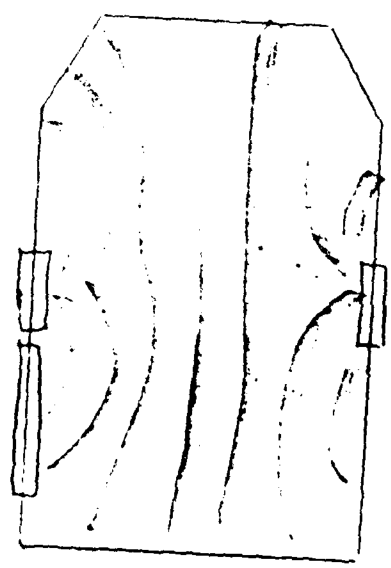
10/19/78 VISIBLE

2-3 FRINGE IRREG.



10/13/78 IR

4 FRINGE IRREG.



10/19/78 IR

2 FRINGE IRREG.

FIGURE 20 FRINGE PATTERNS S/N 004

The only conclusion which could be drawn from this result was that there were additional variables which were not identified and therefore were uncontrolled. A recheck of every step in the process used did not reveal any changes made from those used on #001 or #002.

Mirror #004 was rechecked after six days at room temperature. Figure 20 shows that some additional stress relief had occurred in this period. The reason for this could not be determined.

Since there was an obvious change in Mirror #004 stress pattern, a further check was made using an optical flat survey. Figure 21 is a representative sketch of this pattern. The optical flat survey shows some further change but it is difficult to estimate the number of fringes. It was estimated that Mirror #004 showed a fringe response which exceeded the mirror specification.

Serial #005 was assembled using an increased percentage of hardener (4.1% by weight) and the assembly was checked at each stage to determine the stress sources and to correct them.

For Mirror #005, the fringe pattern was taken (optical flat survey) after the first room temperature curing cycle. Figure 22 shows a representative pattern.

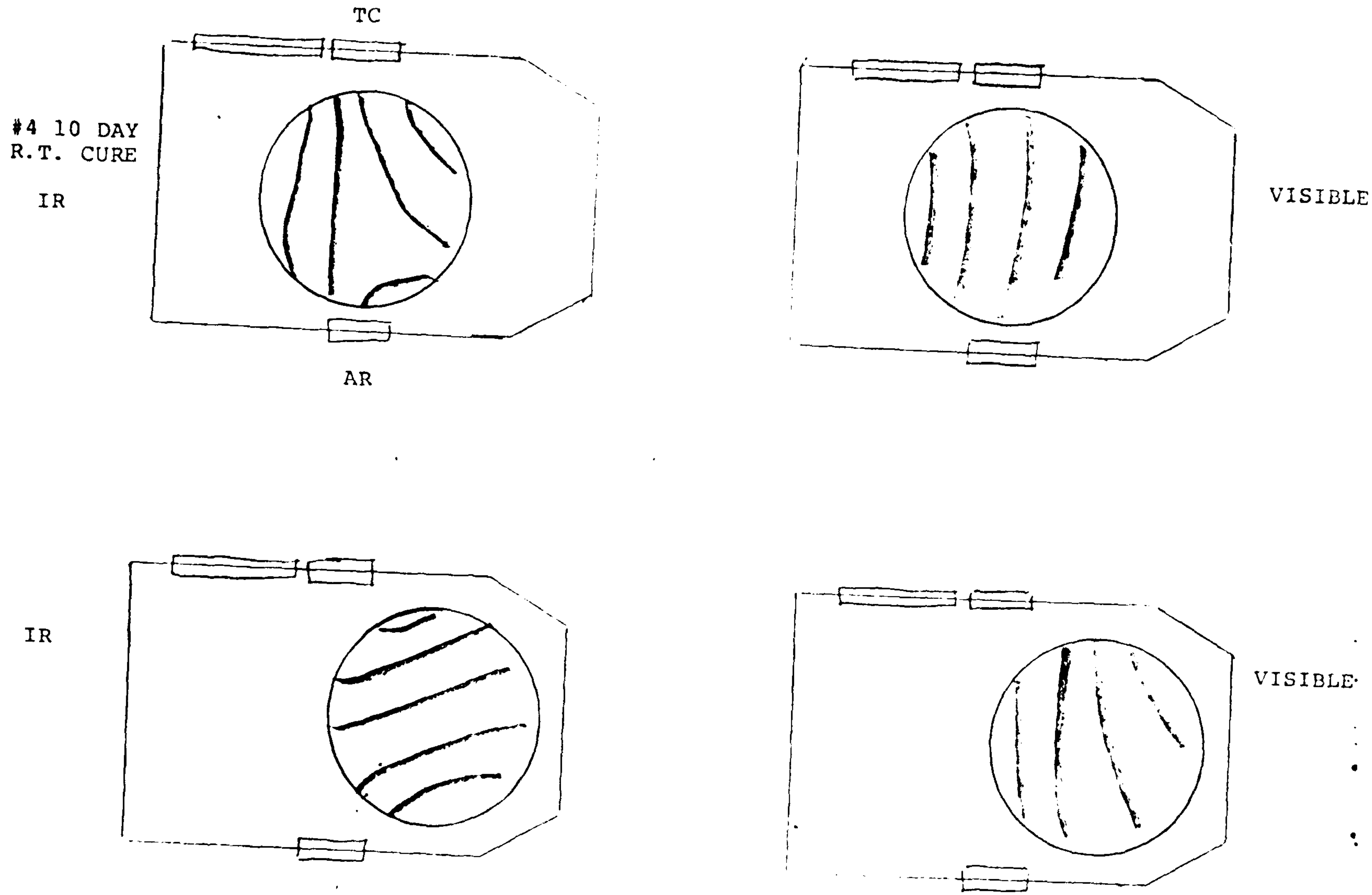


FIGURE 21. FRINGE PATTERNS S/N 004

10 DAY ROOM TEMP AFTER CURE CYCLE

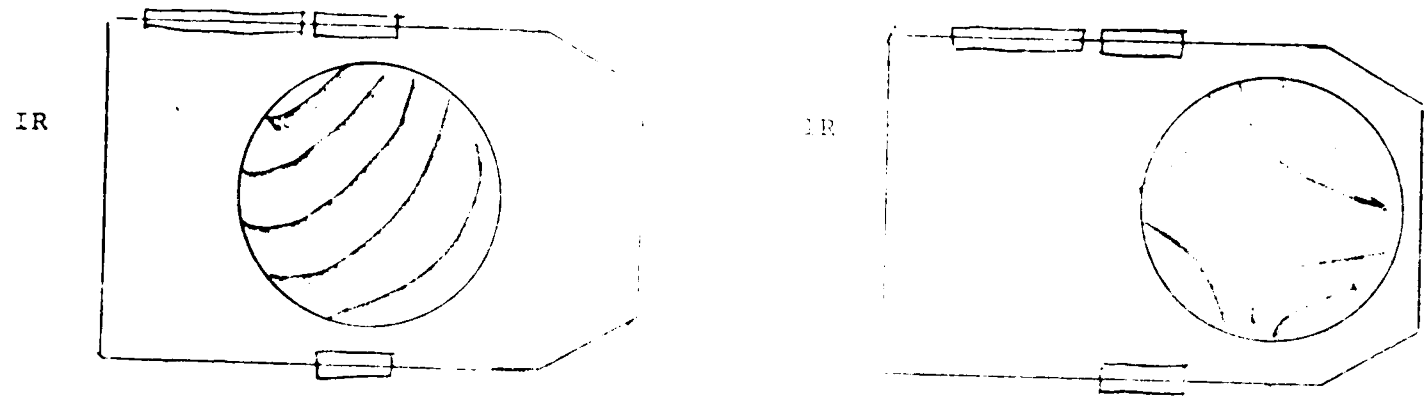


FIGURE 22· FRINGE PATTERNS S/N 005 AFTER FIRST HEAT CYCLE

24 HOURS AT ROOM TEMP.

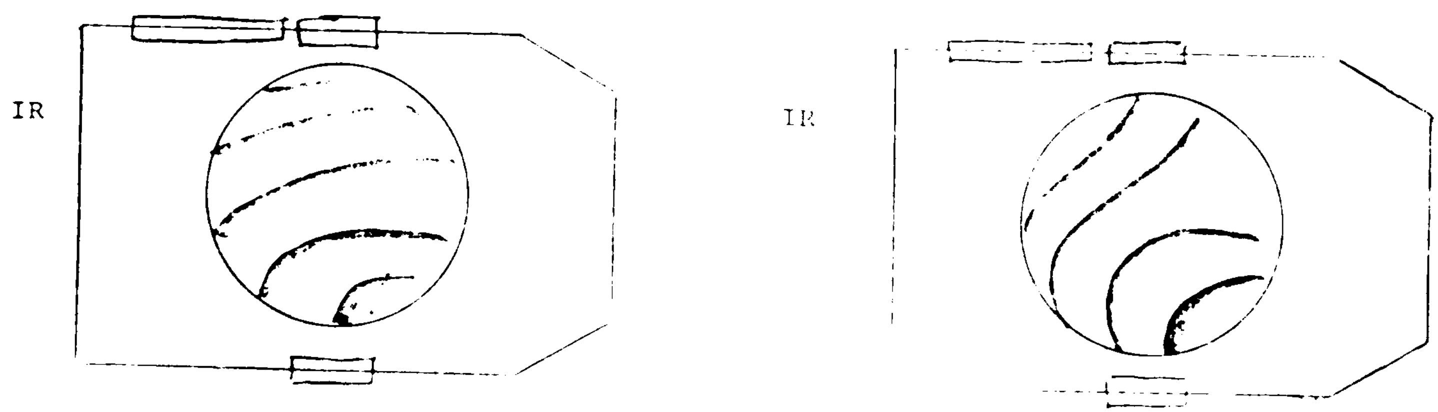


FIGURE 23. FRINGE PATTERNS S/N [illegible]

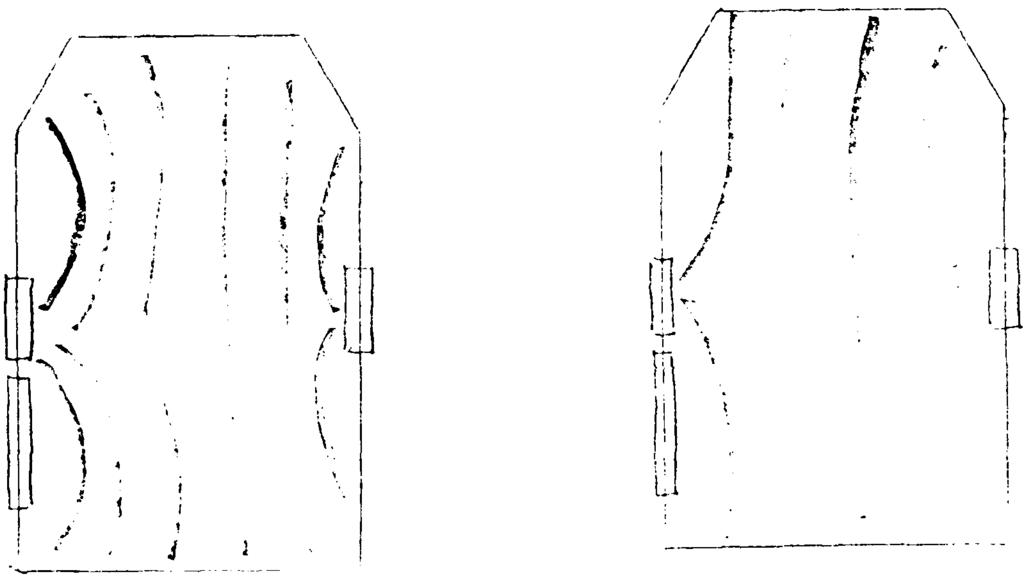
AFTER FIRST HEAT CYCLE NOT STRESS RELIEVED

On Mirror #005, the temperature cycle recommended by NVL was interrupted after the polymerization cycle and an optical flat survey was made of both sides. There was an indication of stress caused by the cement on both the top cap and the arm return. This stress showed in an irregular pattern of about 3 fringes. (Figure 23.)

The temperature cycling was then completed by going through the low temperature (-62° C) and then high (+95° C) for four hours at each temperature. Upon completion of this cycle the mirror was surveyed using an optical flat and a definite improvement in the number of fringes was observed (see Figure #24). However, there is still a basic irregularity to the mirror surface near the metal parts with a more regular area towards the center of the mirror. On this basis, the mirror was tested for MTF in order to establish a correlation between fringe patterns and MTF response. As shown in later tests, this correlation has not been found.

For Mirror assembly #005, a recheck (Figure 25) was also made using an optical flat survey once more. There are changes to these patterns but an overall fringe response could not be estimated.

IR VISIBLE



2-3 CYLINDRICAL

1-2 FRINGE IRREG.
3 ARM RETURN

FIGURE 24. FRINGE PATTERNS S/N 003
AFTER FULL CURE CYCLE

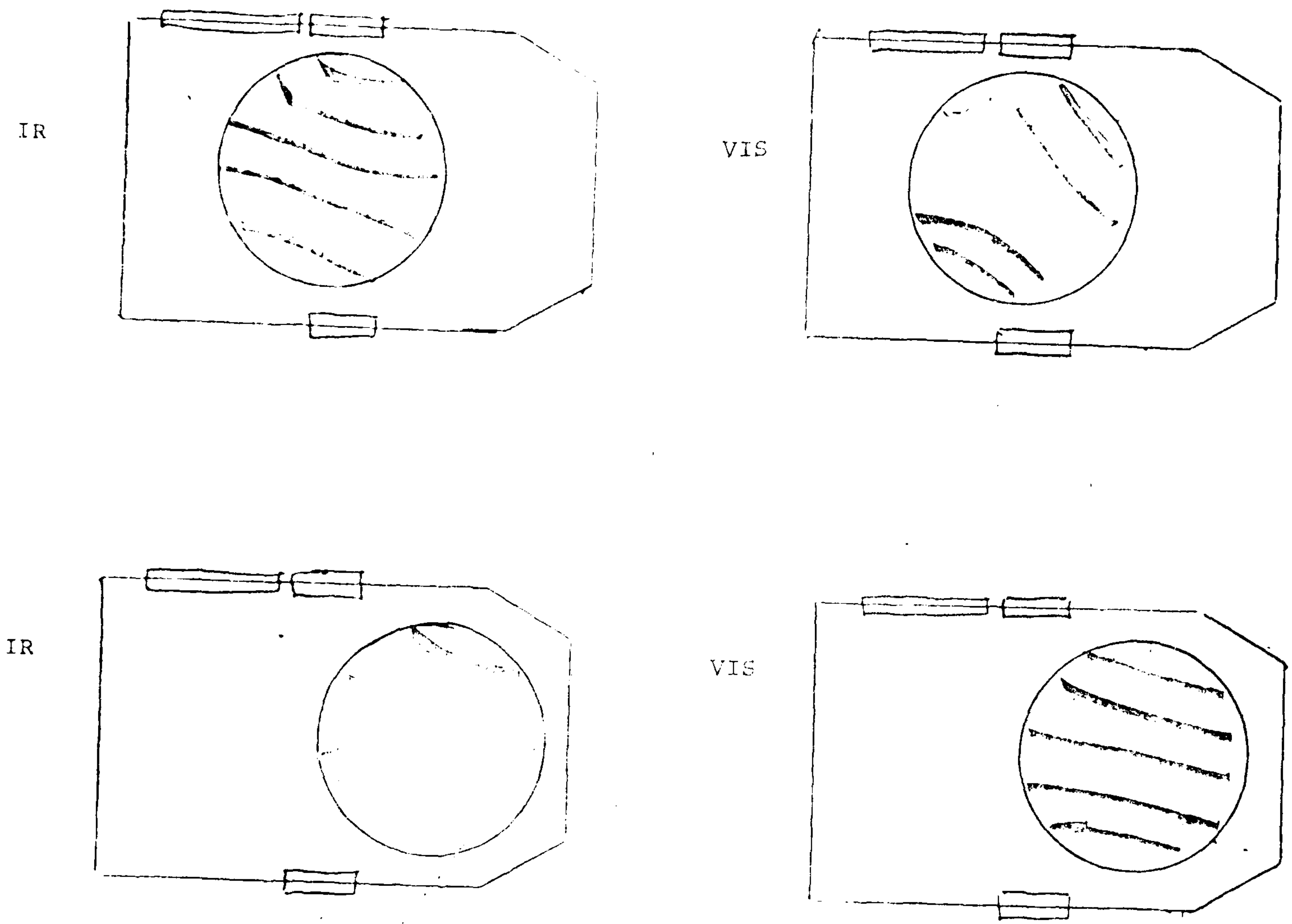


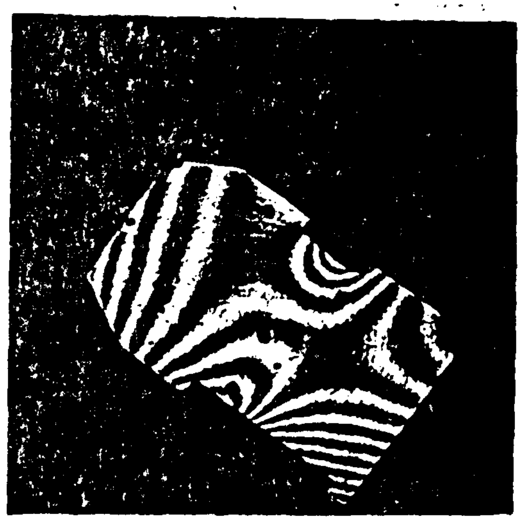
FIGURE 25. FRINGE PATTERNS S/N 005

4 DAY ROOM TEMP AFTER CURE CYCLE

MTF tests were then run on Serial #004 and #005 mirror assemblies. Figure 16 is a reproduction of interferograms of Mirror #004 and reflects the fringe patterns measured by optical flat survey. Both the IR side and the Visible side show 2-3 fringe characteristics with irregularities. The significant part of these interferograms is that the stress patterns show that the top cap introduced considerably greater stress than the arm return. This distortion in the mirror shows that in Mirror #004 there is an overall azimuthal distortion affecting the MTF in that direction. The MTF was then run on both the Visible and IR sides (see Figures 27 thru 30) to determine what MTF a pattern of this nature would yield. Figure 17 shows that the MTF of Serial #004 on the IR side has an elevation MTF which more than exceeds the required MTF. However, the azimuthal pattern shows that it just misses the required value. In view of this, a second run was taken on the same side of the mirror in which the focus was readjusted. The same basic pattern shows up in the MTF printout (Figure 18) with the elevation exceeding spec and azimuthal just missing.

Figure 28 shows very little change in the MTF characteristic described previously. The conclusion that was drawn from this set of runs on the IR side was that the number of overall fringes just exceeds the value acceptable for the mirror assembly to pass the MTF test requirements.

I R



VISIBLE

FIGURE 26. INTERFEROGRAMS, S/N 004

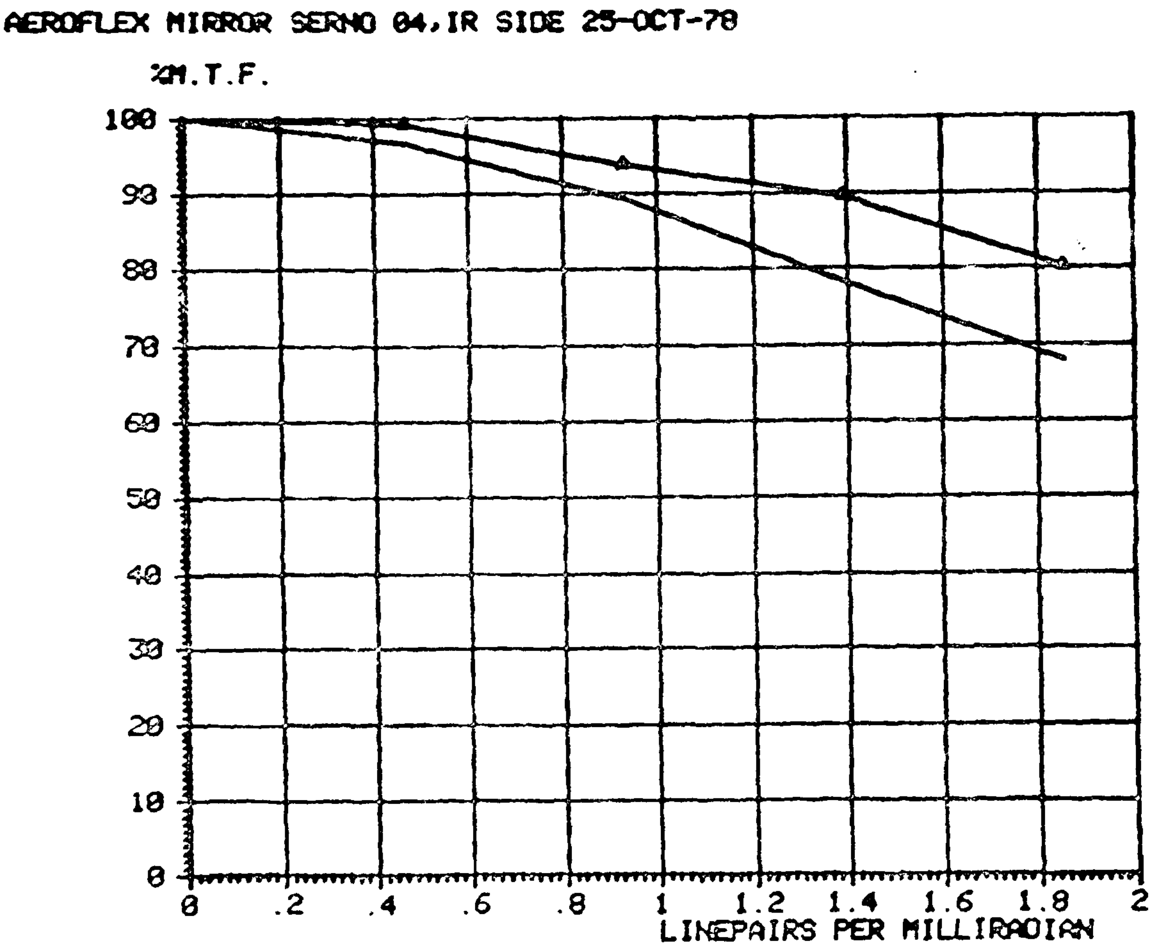


FIGURE 27. MTF RESPONSE, S/N 004, I R SIDE

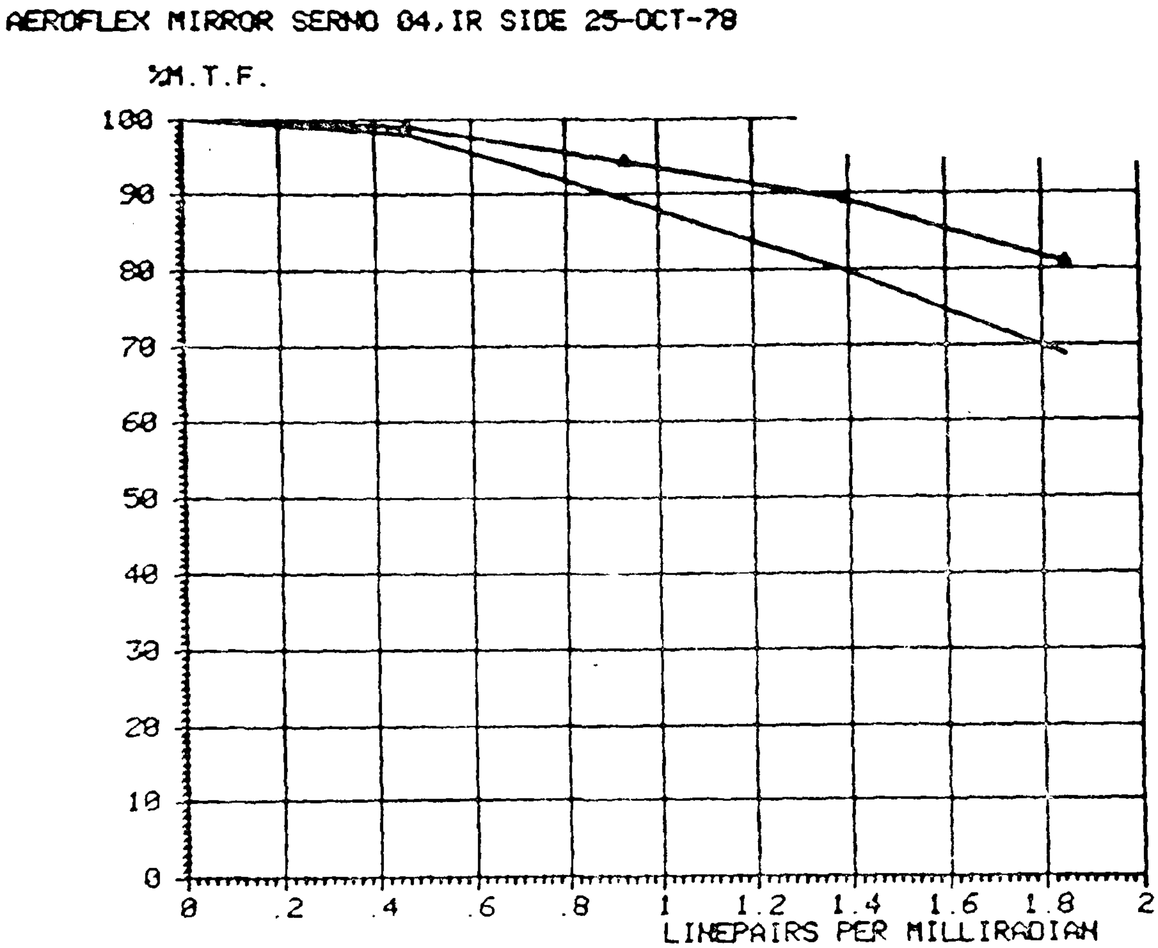


FIGURE 28. MTF RESPONSE, S/N 004, I R SIDE

A similar set of MTF runs was taken on the Visible side (Figures 29, 30) using the same procedure. Figure 26 shows the interferogram of the Visible side of the same mirror. The patterns are essentially the same as that shown for the IR side and the astigmatism in the azimuthal plane is also reflected in the MTF response. Once again the focus was readjusted and a change from the original pattern occurred. In this case, azimuthal MTF dropped from 94% to 93%. The test was then re-run adjusting the focus one more time and the elevation MTF was now affected as well.

It became apparent then with the irregularity and distortion shown on Mirror #004, and in spite of repeated adjustments in focus, the mirror missed the MTF requirements by approximately 1-2%. The data obtained on this test was considered to be valuable because a baseline number had been established for the number of fringes which are acceptable before the MTF response goes beyond the spec limits. However later tests showed enough deviation to question the validity of this once again.

Mirror #005 was also subjected to the same sequence of testing. The interferograms shown in Figure 31 show a slight reduction in the distortion patterns after the full cure cycle. Specific changes were made to the assembly procedure for Serial #005. A 4.1% hardness by weight was used

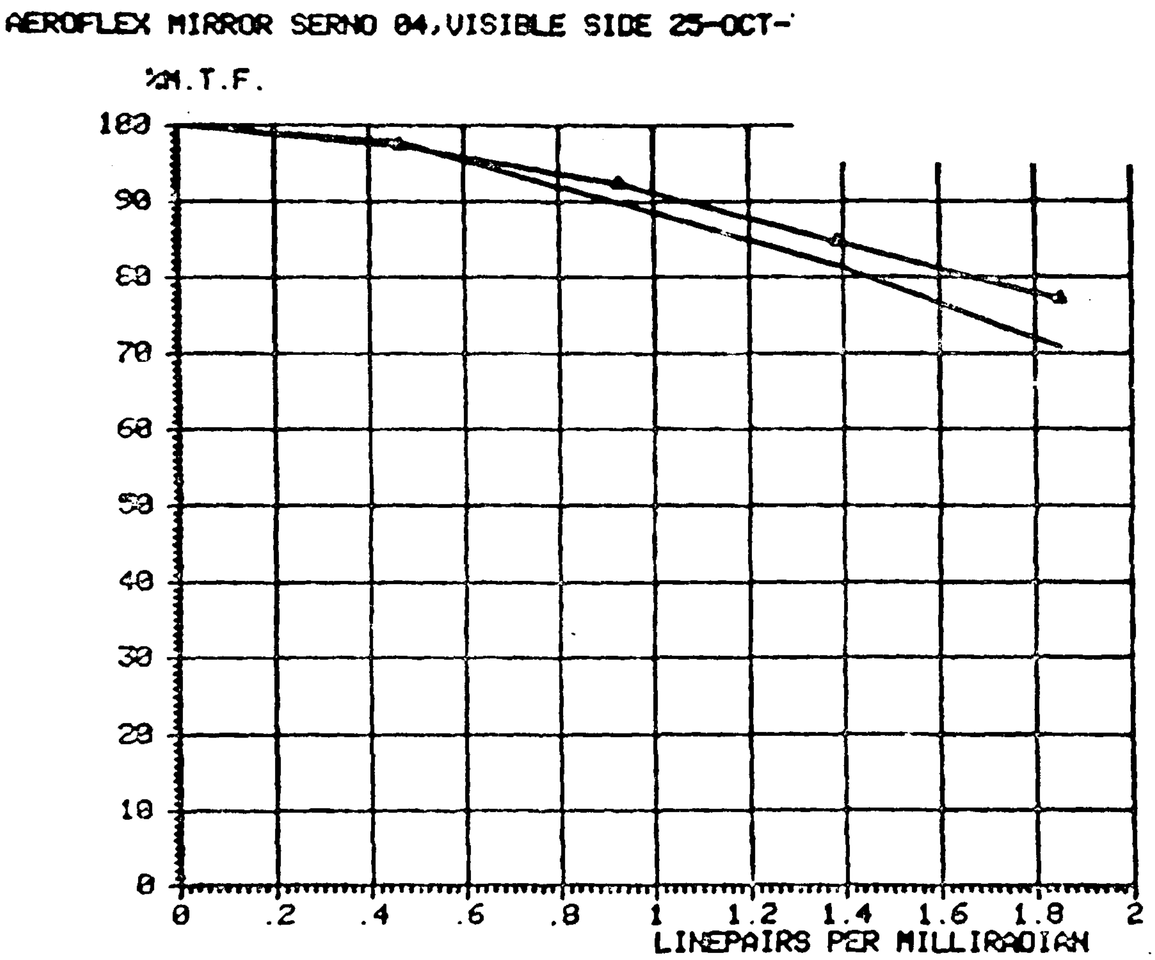


FIGURE 29. MTF RESPONSE, S/N 004, VISIBLE SIDE

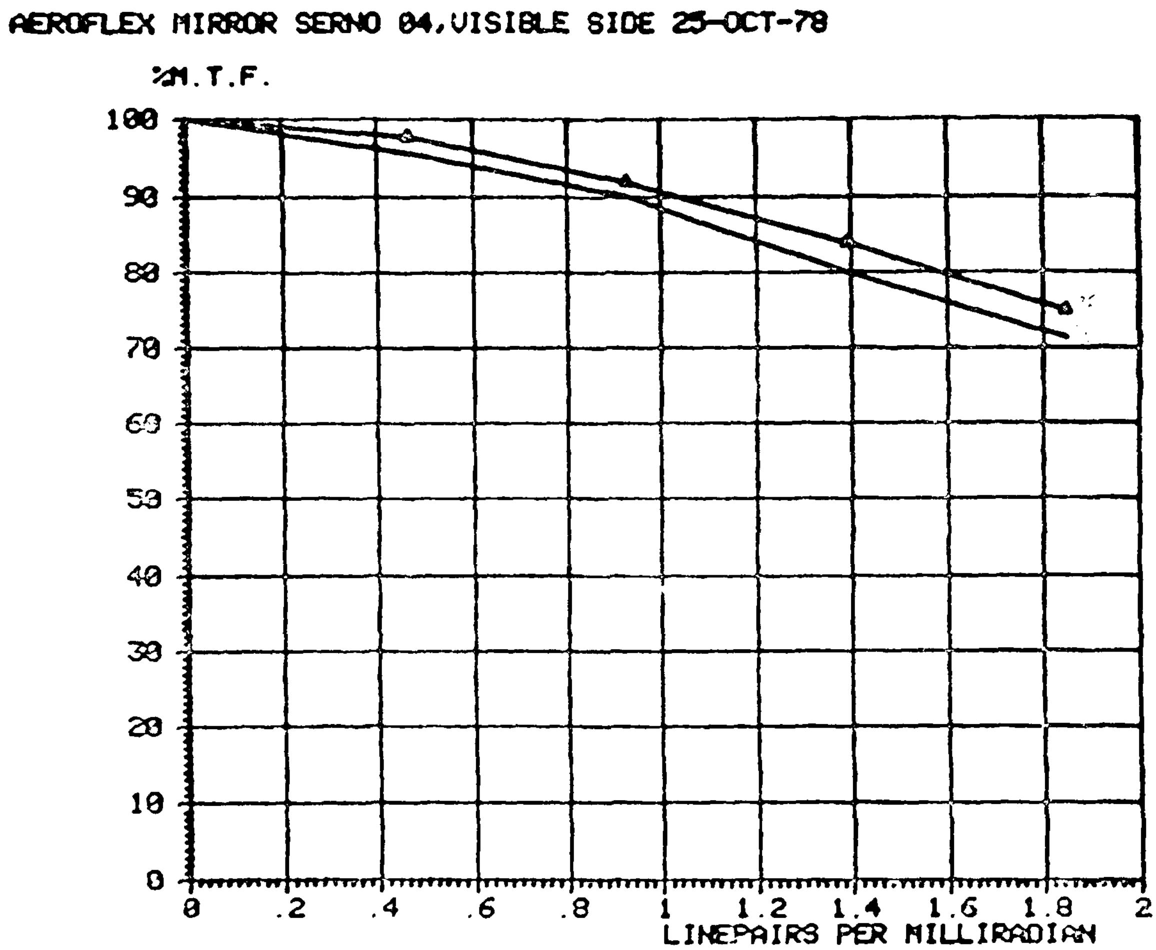
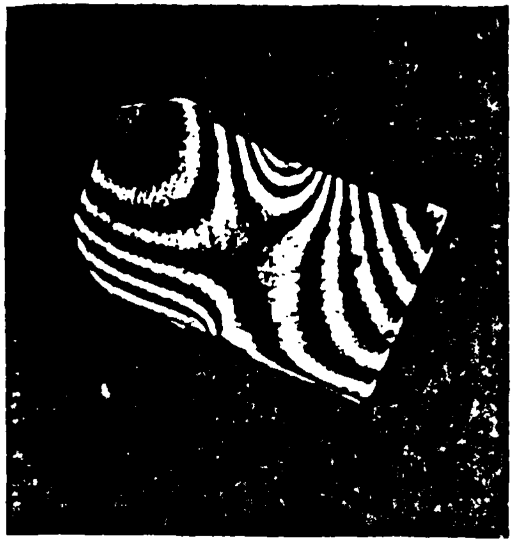


FIGURE 30. MTF RESPONSE, S/N 004, VISIBLE SIDE



I R

VISIBLE

FIGURE 31. INTERFEROGRAMS, S/N 005

and every possible source of stress in the mirror assembly was eliminated before final cementing. Figure 32 shows the MTF response of the IR side of the mirror and indicates that for both elevation and azimuthal axis the mirror has passed the MTF requirement.

More significantly, this characteristic was obtained after a number of refocusing trials were made. Figure 33 shows the net result of these retrials as the focus was readjusted. The Visible side characteristics shown in Figures 34 and 35 also indicated essentially the same characteristics as described for the IR side.

At this point in the mirror study effort, it was felt that the assembly procedures being followed had the variables under control and that a reasonable production yield could result. Of concern was the ability to repeat such tests on subsequent mirrors and, more importantly, whether the ability to obtain an optimum focus during MTF tests could be done in minimum time.

Mirror #006 assembly was also tested for MTF response. In this case, the final epoxy gap was kept to a nominal .002" and the entire assembly was subjected to the cure cycle described previously. Figure 36 is an interferogram taken for both IR and Visible sides. These interferograms

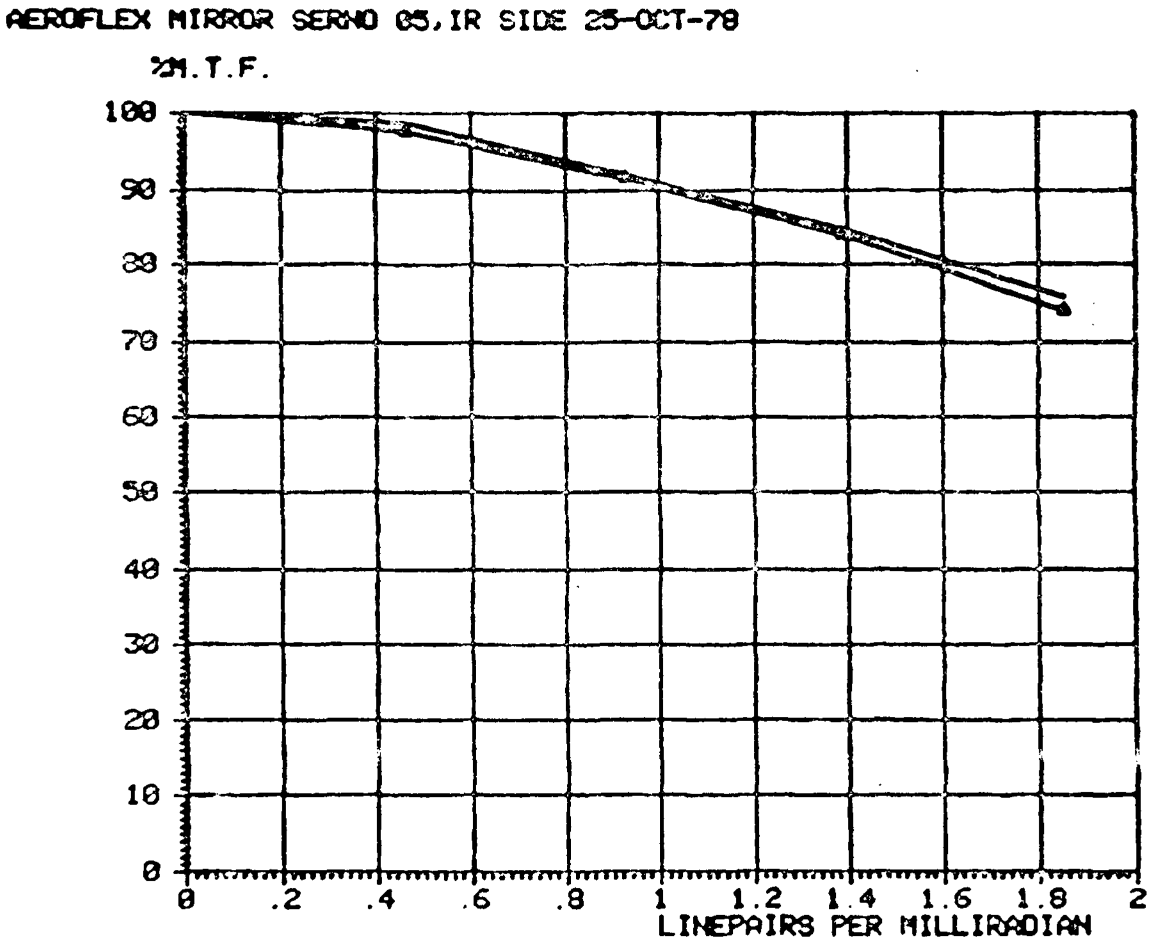


FIGURE 32. MTF RESPONSE, S/N 005, I R SIDE

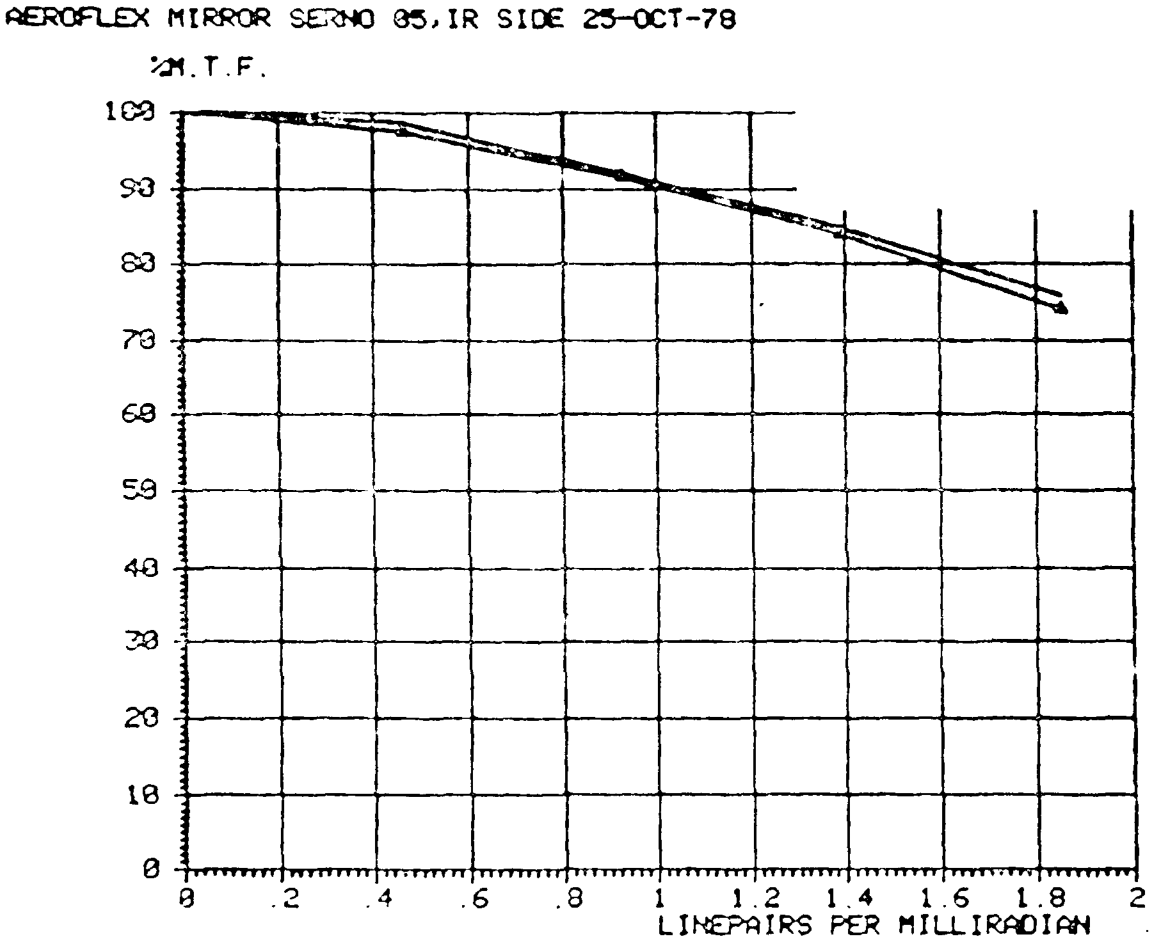


FIGURE 33. MTF RESPONSE, S/N 005, I R SIDE

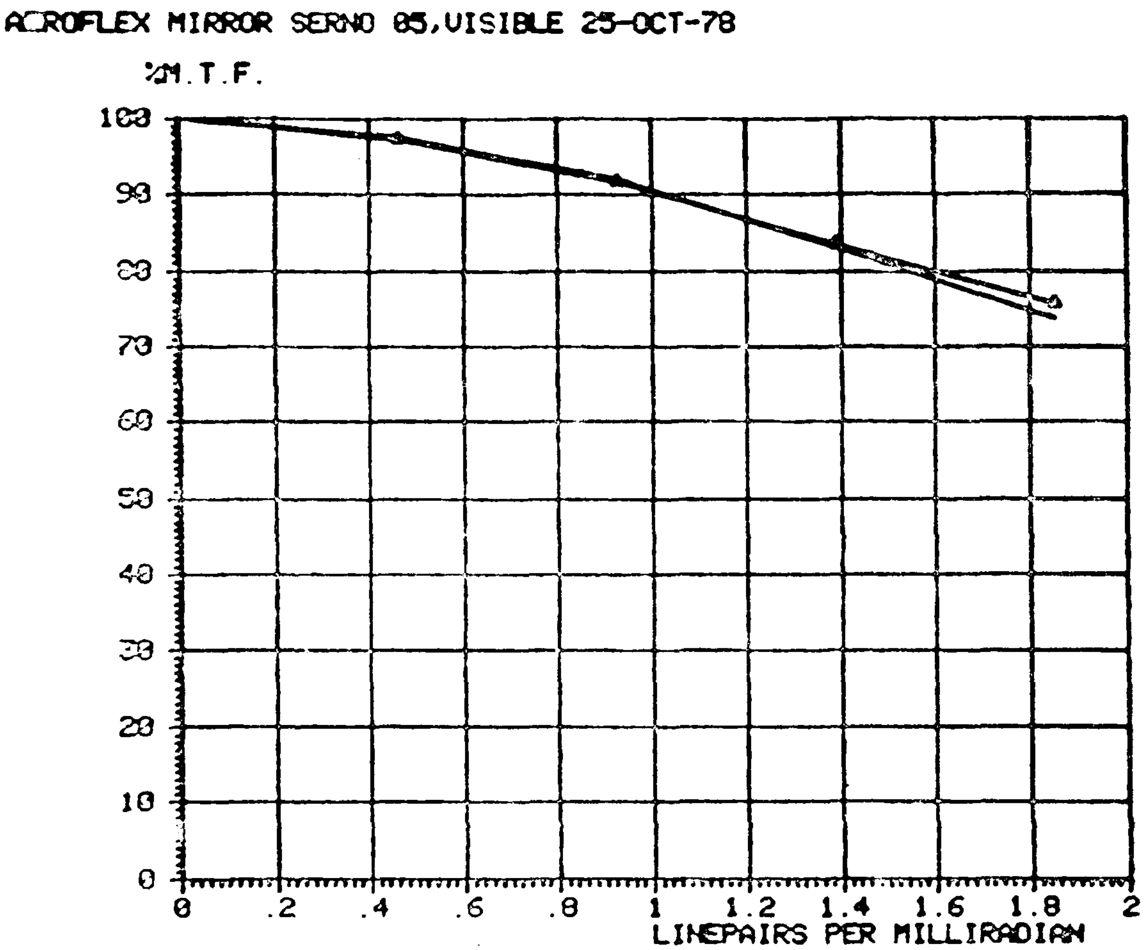


FIGURE 34. MTF RESPONSE, S/N 005, VISIBLE

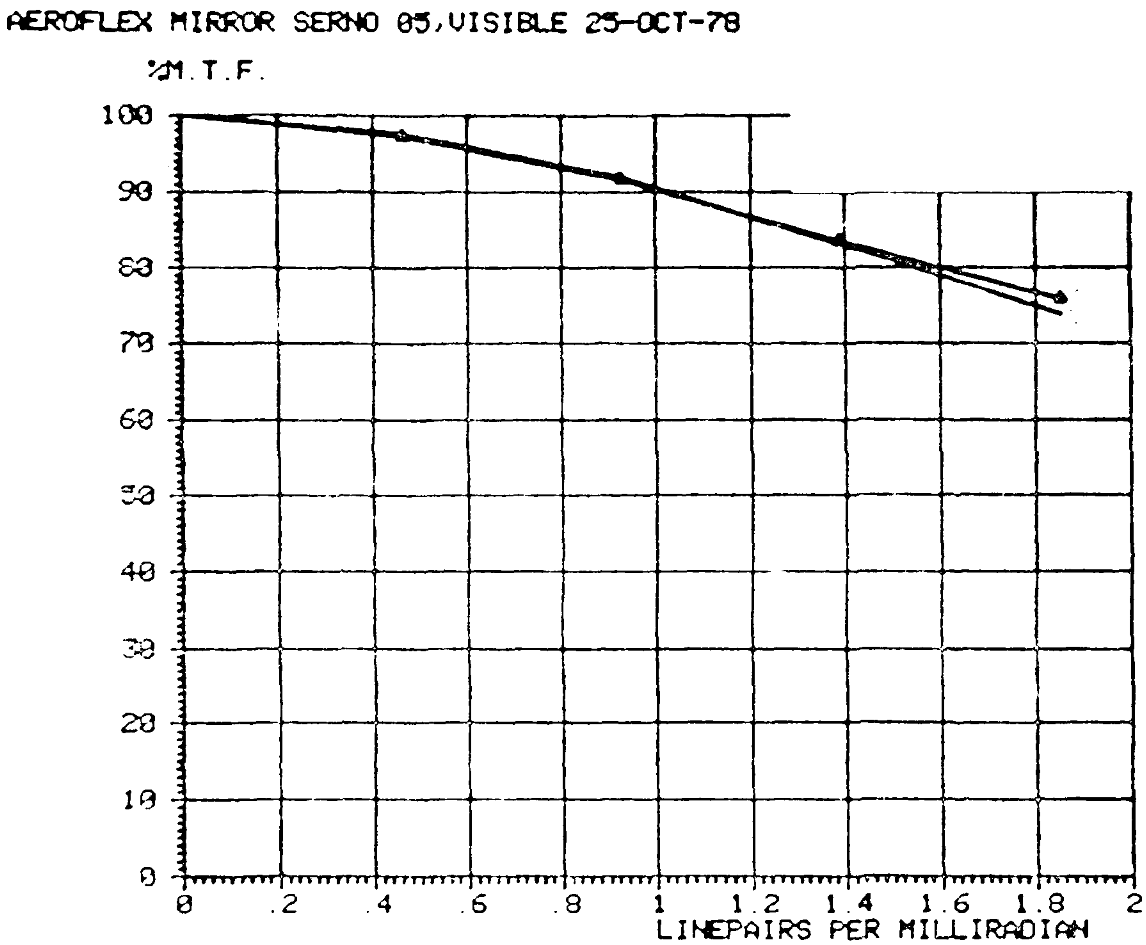
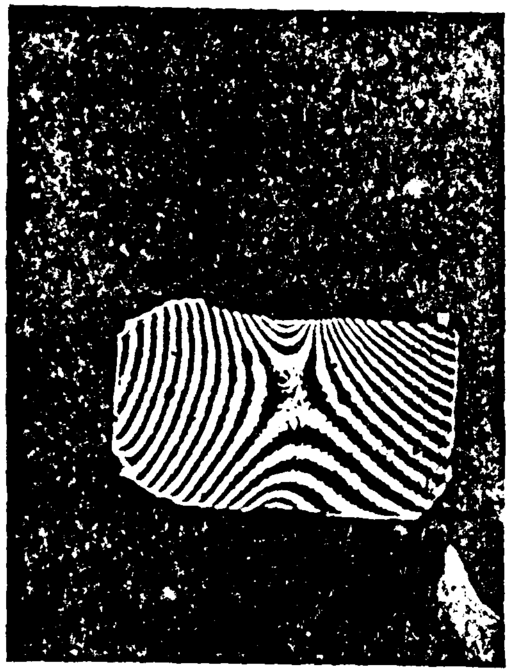
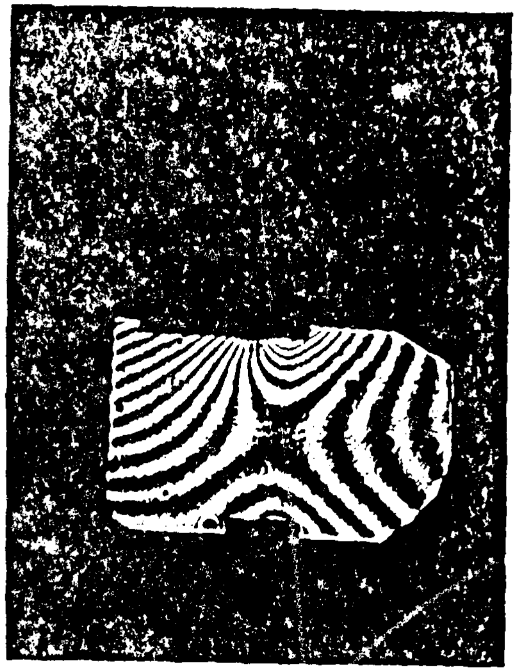


FIGURE 35. MTF RESPONSE, S/N 005 VISIBLE



I R



VISIBLE

FIGURE 36. INTERFEROGRAMS, S/N 006

show that considerable distortion had occurred on both the top cap and arm return sides of the mirror with a net effect of a saddle occurring on what was originally a 1/4 to 1/2 fringe regular mirror, Of interest in these two patterns is the fact that the arm return showed considerably more stress than the top cap side. Examination of the interferograms yields approximately a 3-fringe irregular surface for the IR side and similarly a 3-fringe irregular surface for the Visible side. The MTF test was run on this mirror, which is obviously poor, for the sake of completeness and Figure 37 shows the resultant MTF response obtained. From this, it can be seen that the saddle effect results in astigmatic characteristics which yield no more than about 75% MTF in the azimuthal plane and considerably better, but below specification, in the elevation plane.

The MTF equipment was refocused to see if a more optimum focal point could be achieved. In this case, the azimuthal and elevation planes reversed themselves with similar patterns. The MTF was then taken on the Visible side (Figure 38) and although the surface showed astigmatism, the elevation plane again failed to meet the requirement by a considerable margin and the azimuthal plane also fell below requirements. The test equipment was refocused again with the response shown in Figure 39 resulting.

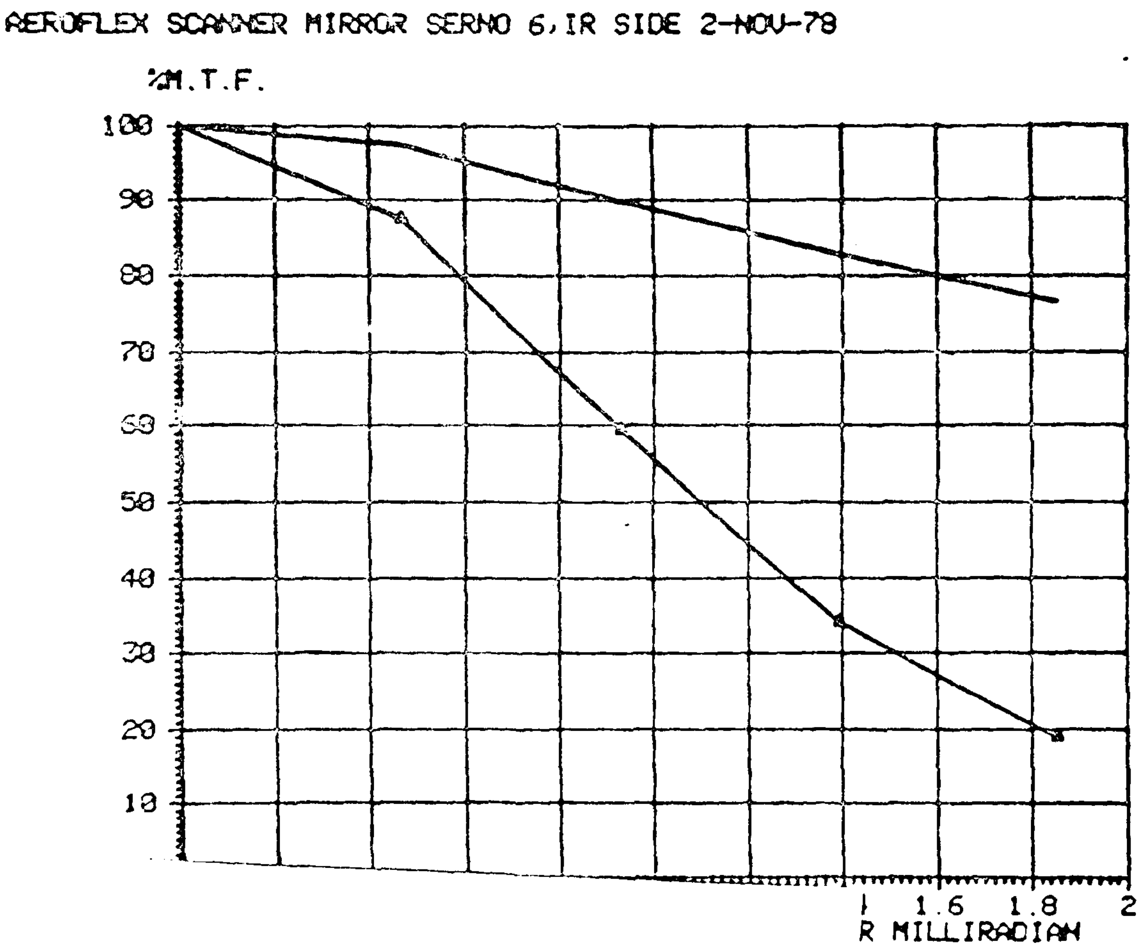


FIGURE 37. MTF RESPONSE, S/N 006, I R SIDE

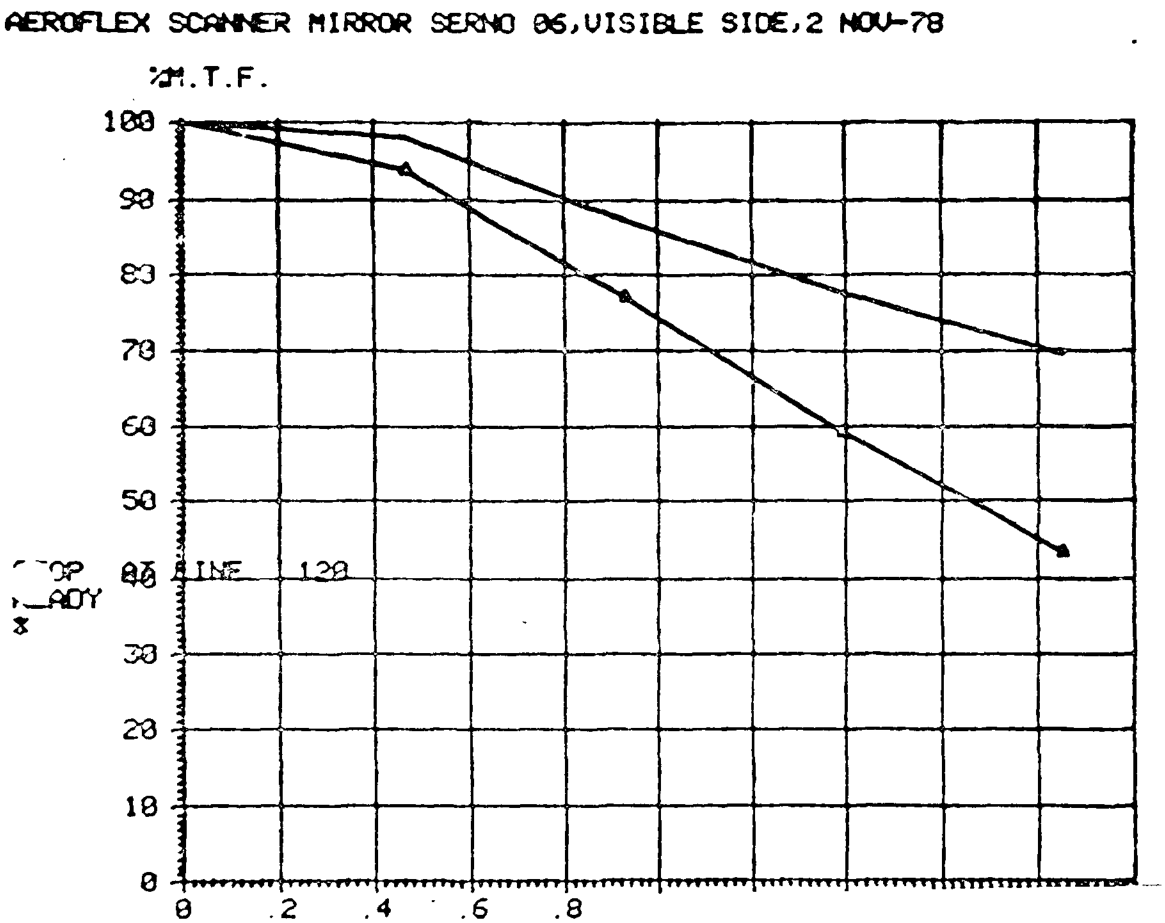


FIGURE 38. MTF RESPONSE, S/N 006, VISIBLE SIDE

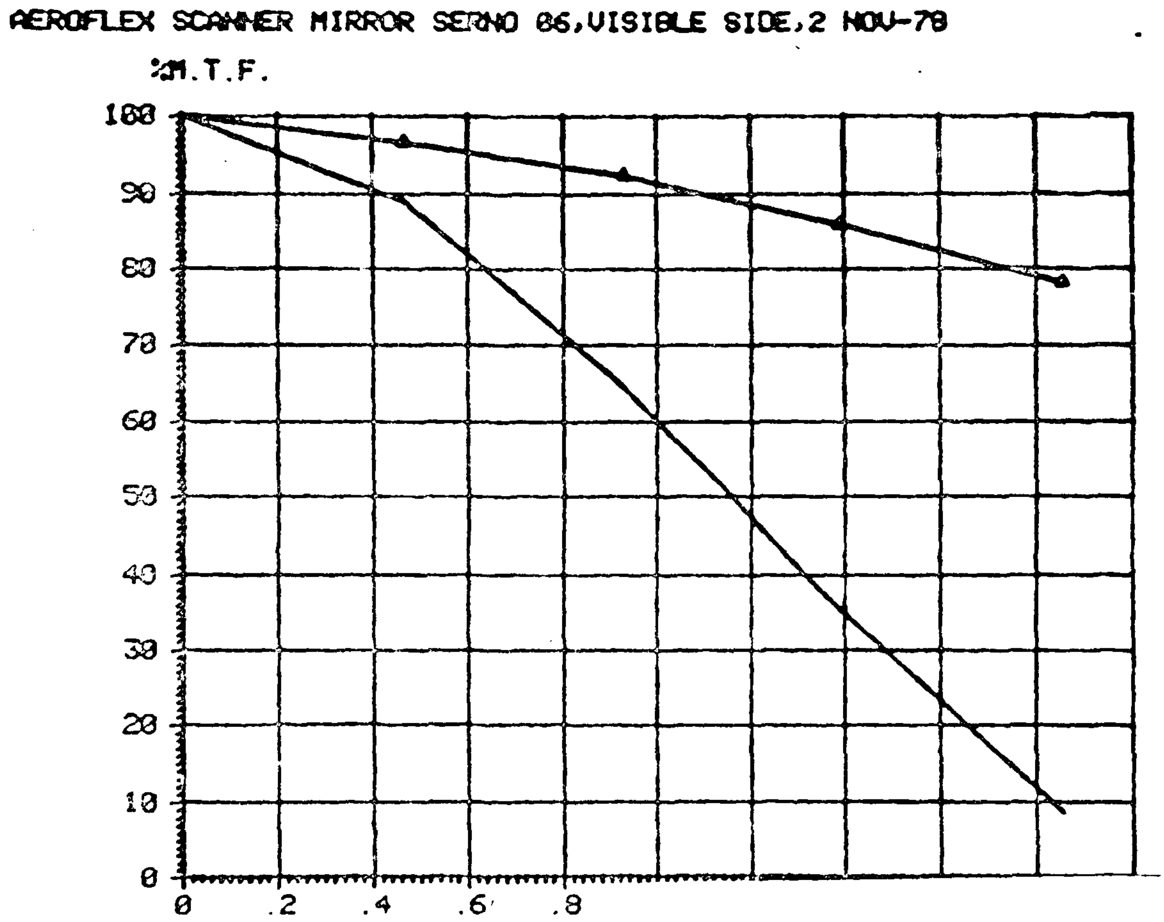


FIGURE 39. MTF RESPONSE, S/N 006, VISIBLE SIDE

At this point, the test on Serial #006 was stopped since it was obvious that no matter what focal point was chosen, the mirror was just not going to make it. As it turned out, Mirror #006 proved to be of great value in the study in that the cause of such a poor response was then carefully investigated and the results of this investigation led to changes in the fixture and approach to the assembly.

During the assembly procedure on Mirror #007, a measurement was made of the fixture used for #003 through #006 on the axis defining the top cap and arm return positions in both planes. It was determined during the course of this measurement that after Mirror #002 had been assembled and subjected to a temperature cycle, condensation had formed and some oxidation had occurred on parts of the fixture. In order to remove the corrosion, the fixture had been disassembled and subsequently reassembled. This resulted in a shift in the elevation plane of top cap to arm return axis of about .0025".

Reassembly of the fixture was made and a measurement of the center line established the correct axis for the top cap and arm return. In view of the results achieved on Mirror #007, it is assumed that a large portion of the distortion shown in Mirrors #003 through #006 was, for the most part, directly attributable to the shift in this axis. In addition, it was also determined that the mounting pins used to maintain the plane of the mirror with respect to the top cap and arm return slots had also taken a slight shift. As a result of this measurement, mounting pins for the mirror were reground and rechecked for co-planarity. In addition to the above fixturing corrections, additional steps were taken to relieve, wherever possible, any further stresses on the mirror during the final cement cycle. This resulted in the removal of vlier pins against the edge of the mirror as well as all other pressure points to the top and bottom surface of the mirror.

Data was taken at each point to determine stress points and distortion in the mirror before the cementing operation took place and where possibe distortion was eliminated. The mirror was also permitted to air cure for 72 hours before the NVL cure cycle was initiated. An optical flat survey was made of the mirror both before the cementing cure and before the high temperature/low temperature cycles were initiated. The interferometric patterns showed that a 1/4 to 1/2 fringe mirror resulted in an increase in distortion of approximately 1/2 to 1 fringe regular. When the curing cycle had been completed, a further survey was made of the mirror and resulted in an optical flat survey showing 1-1½ fringes with some irregularity of the surface (Figure 40).

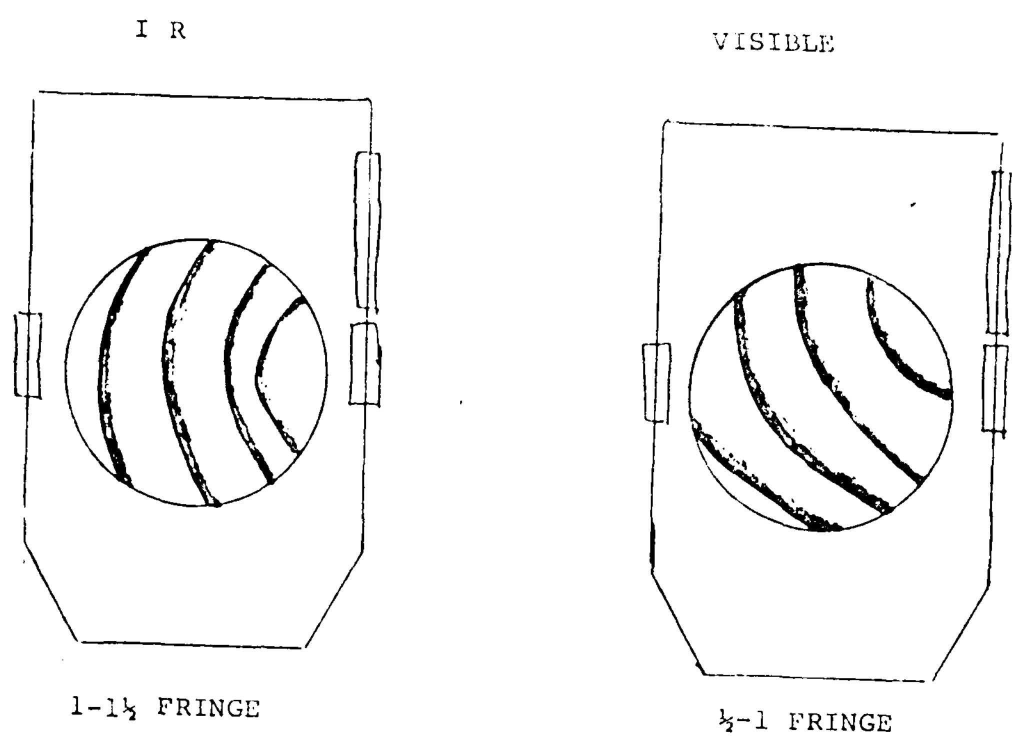


FIGURE 40. S/N 007 FRINGE PATTERNS

Figure 41 is a photograph of the interferogram taken for the IR side of Mirror #007. In this case, stress patterns are shown along the arm return side and although the interferogram shows a slight difference in the number of fringes, pattern is essentially the same on the Visual side.

Figure 42 is an interferogram of the Visual side of the mirror and shows that there are stress lines evident at the arm return/mirror assembly point. This should be highlighted since in previous assemblies the top cap button has shown similar stress concentrations and yet this mirror shows almost zero stress at the top cap button. This serves to highlight the randomness of the stress imposed by the cement (2 part epoxy 4.1%) to both parts. In this case, the final gap was set at .002" for both the top cap and arm return parts on each side of the mirror.

A plot of the MTF achieved for the IR side is shown in Figure 43. In this case, the mirror passes the MTF requirements with an indication of some astigmatism in the azimuthal plane. The focus was readjusted from the point at which the first MTF was taken and Figure 44 is a plot of the second MTF achieved. In this case, the astigmatism is more clearly defined with the mirror achieving the required MTF azimuthally but shows that adjustment of the focal point between sagital and tangential focus improved the elevation pattern. For the

FIGURE 41. INTERFEROGRAM, S/N 007, I R SIDE

S-73 [illegible] 07 VIS SIDE

FIGURE 42. INTERFEROGRAM, S/N 007, VISIBLE SIDE

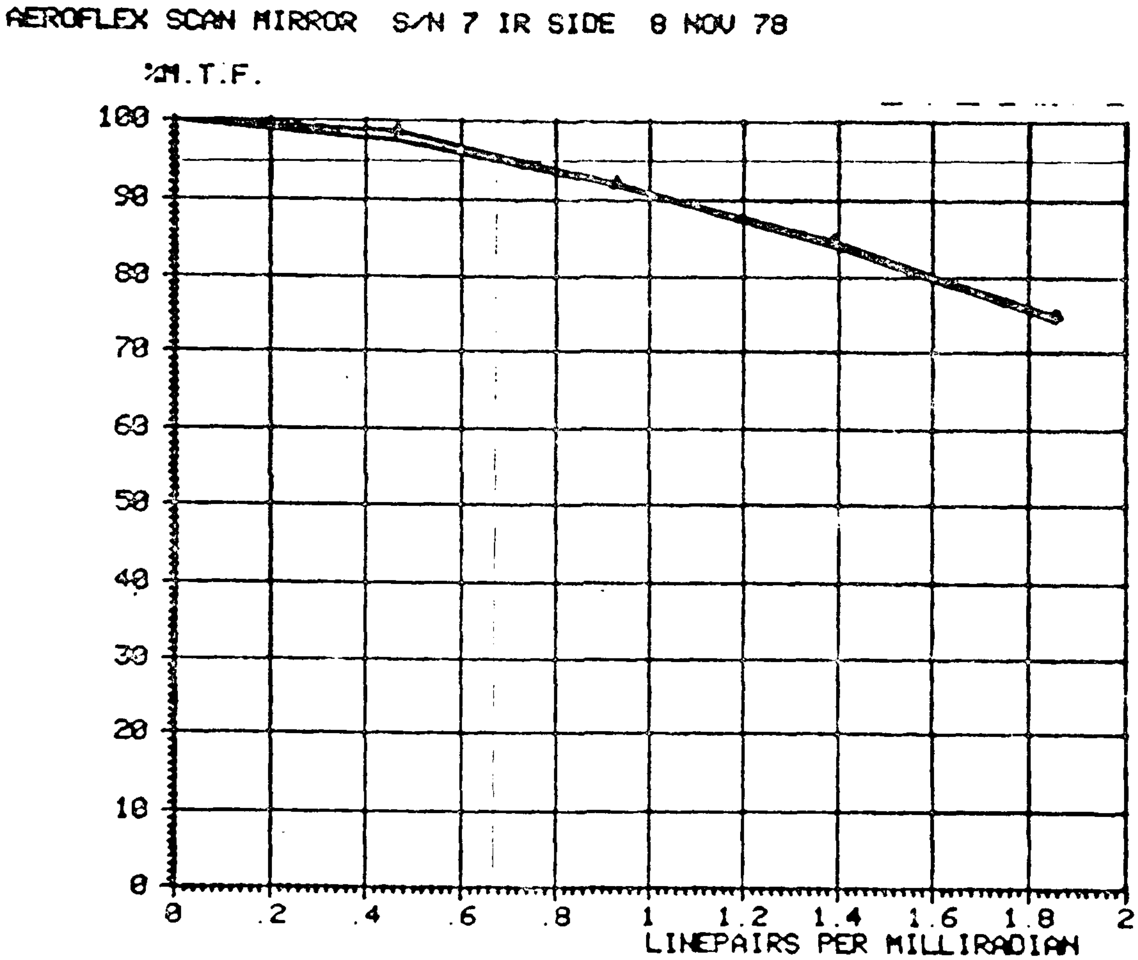


FIGURE 45. MTF RESPONSE, S/N 007, I R SIDE

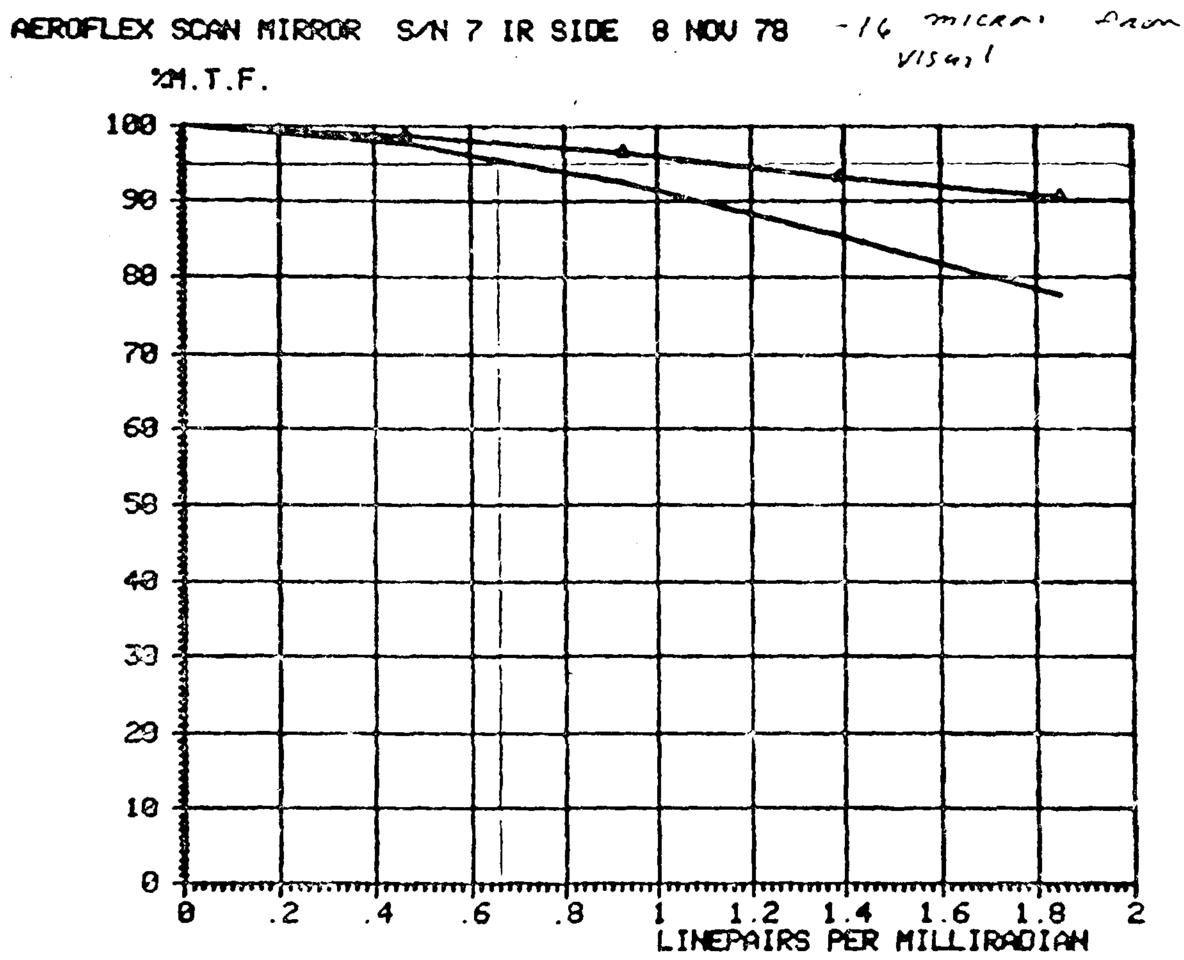


FIGURE 44. MTF RESPONSE, S/N 007, I R SIDE

purposes of completeness, this test was rerun by moving the focal point one more time with the same basic pattern resulting. The conclusion drawn from these results was that, depending upon the effective astigmatism in the mounted mirror and the focal point chosen, a rather significant variation in the MTF response (for both planes) can be arrived at. It is a moot point to describe whether the amount of astigmatism shown on the IR side can be calibrated against the interferometric pattern shown in Figure 41.

Figure 45 is a plot of the MTF achieved for the Visible side and shows that the specification has been met in spite of arm return distortion shown in Figure 42. Interestingly enough, the amount of astigmatism produced by this side of the mirror is effectively nil and the azimuthal and elevation patterns are essentially congruent and that in spite of the stress patterns evident along the arm return side, the MTF is excellent.

Mirror #008 was assembled and was carefully controlled at every point in the assembly process. As in #007, all stress points were removed and an optical check was made as the assembly was completed. Under this condition, the mirror was checked before the heat treat cycle (see Figure 46) with a resultant fringe pattern of 1/2 to 1 fringe regular being

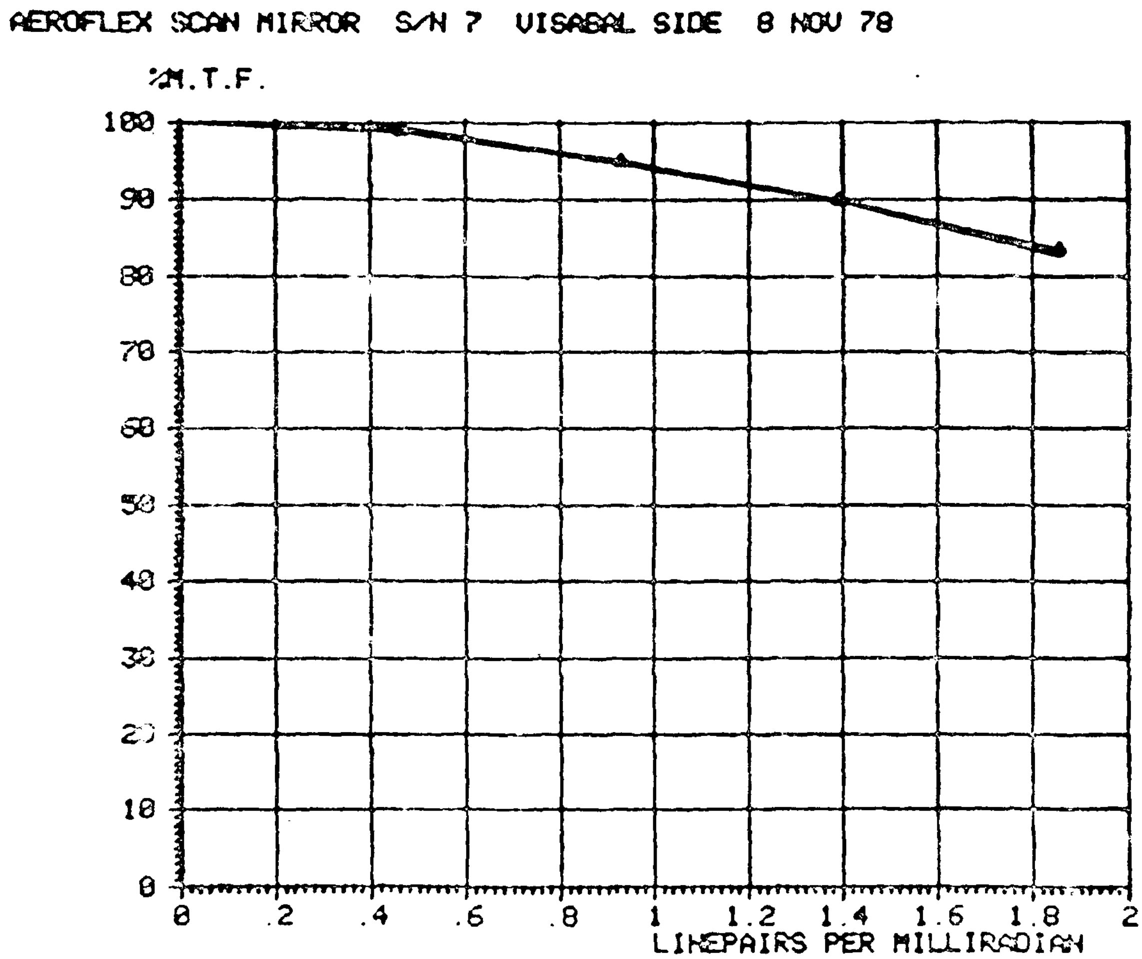
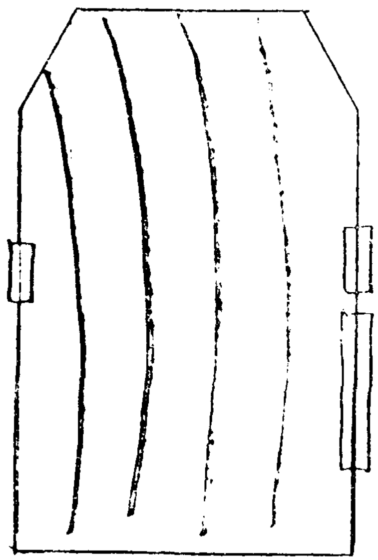
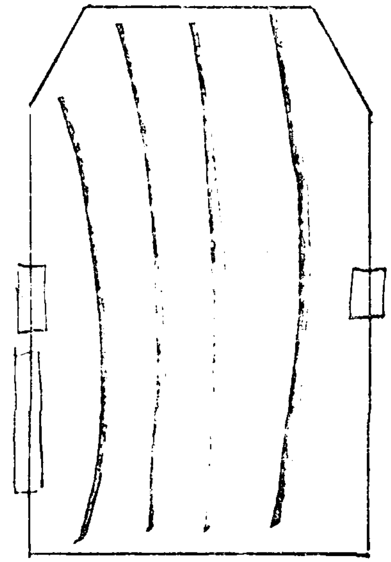


FIGURE 45, MTF RESPONSE , S/N 007, VISIBLE SIDE



I R SIDE

½-1 FRINGE



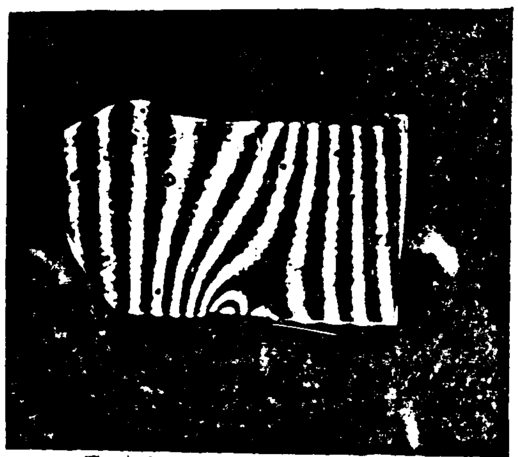
VISIBLE SIDE

½-1 FRINGE

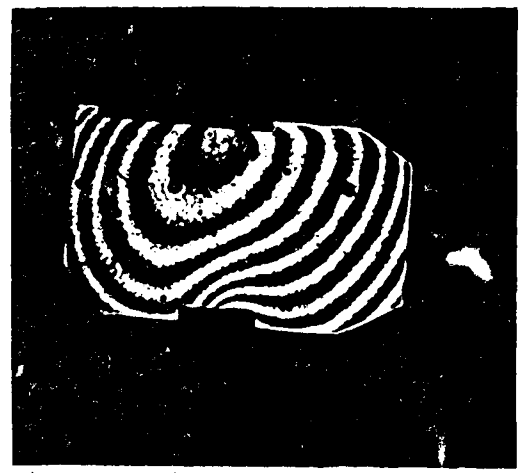
FIGURE 46. SERIAL #008 AFTER ROOM TEMPERATURE CURE

exhibited by both sides of the mirror. This unit was then subjected to the NVL temperature cycle and over the central portion showed a considerable shift from the previous pattern exhibited before temperature cycling (Figure 47). In this case, the top cap still showed distortion patterns which were greater than that shown on the arm return side. A rough estimate of the number of fringes using an optical flat surface showed approximately 2 fringes or more with some irregularity being evidenced on both sides.

The mirror was then subjected to a MTF test at the NVL facility and Figures 48 and 49 reflect the response of this mirror. The curves achieved for the MTF test indicated that the Visual side showed essentially no astigmatism with a regular elliptical surface in evidence. The IR side shows that the elevation plane response was somewhat better than that of the azimuthal response with some astigmatism involved. It is difficult to interpret the interferogram shown on Figure 47 to determine that this astigmatism is there. However, it becomes evident that the response of the mirror from an interferogram point of view can be misinterpreted to a considerable degree, especially to an inexperienced eye.



I R



VISIBLE

FIGURE 47. INTERFEROGRAMS, S/N 008

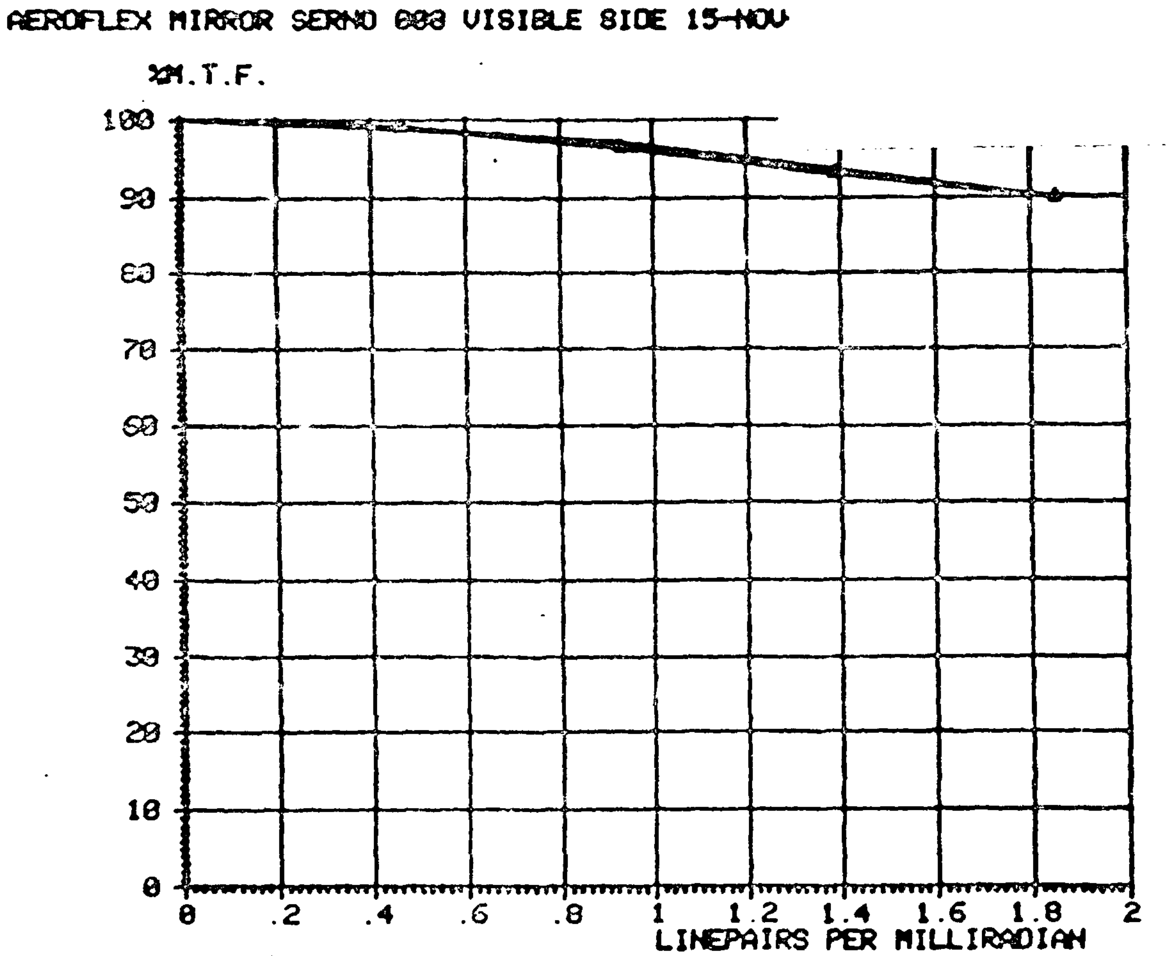


FIGURE 48. MTF RESPONSE , S/N 008, VISIBLE SIDE

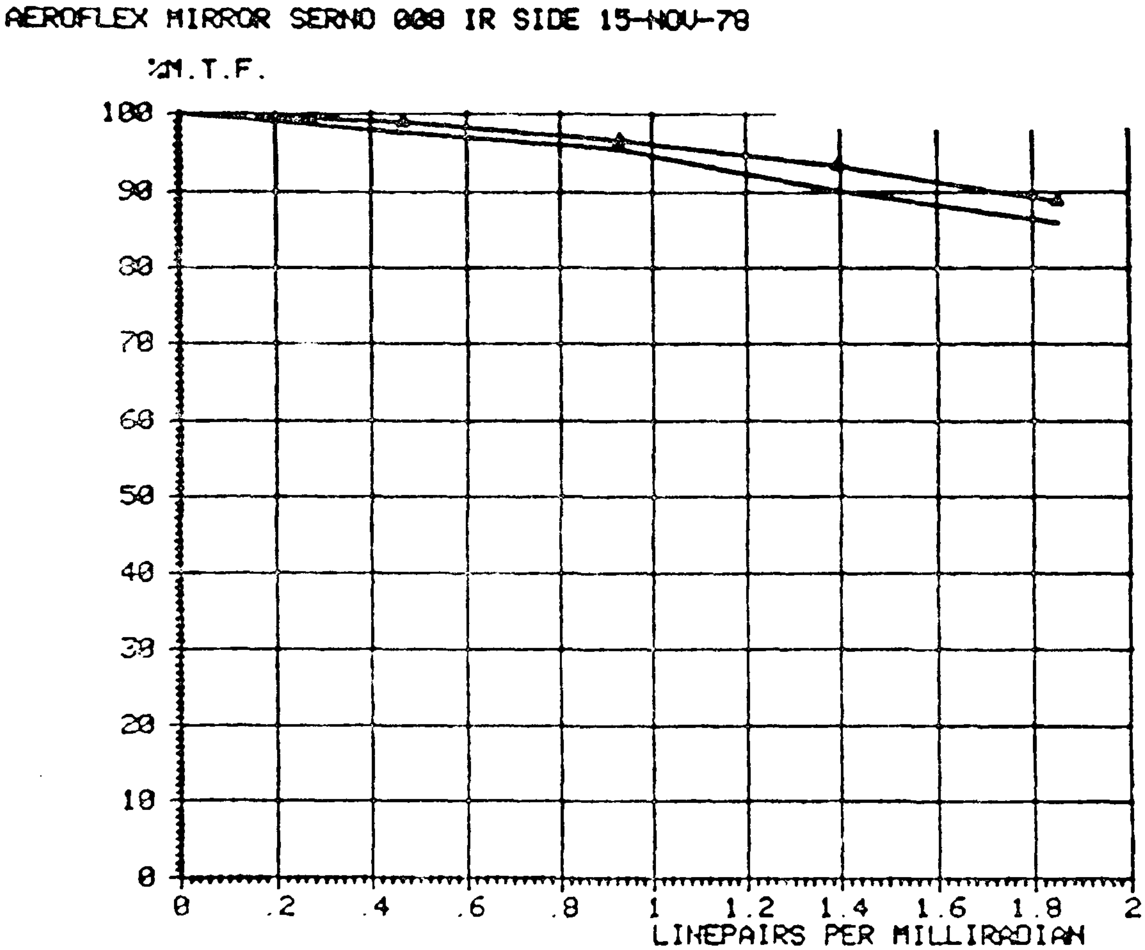


FIGURE 49. MTF RESPONSE, S/N 008, I R SIDE

The results of the MTF tests for Mirror #008 show excellent responses and it more than adequately met the MTF requirement. However, the amount of care in assembly at this state of the effort is far in excess of anything that could be expended during production run. Additional effort would be required to bring the fixturing to a point where the stress can be immediately seen and relieved before the cement has had any time to set. Mirror #008 was left at room temperature for at least 72 hours before the temperature cycle was initiated. The conclusion drawn at this time was that the epoxy itself was causing the prime stress and distortion in the mirror surface for both sides. In addition for Mirrors #004, #005 and #006, the number of lines shown on the interferogram were approximately the same as shown on Mirrors #007 and $008, but showed irregularity in the final surface achieved. Therefore, irregularity appeared to be the prime indicator of possible failure in the MTF tests.

Tests were also run on Mirror #008A which consisted of a different substrate (glass) to isolate the results for two different materials and the same cement (Stycast). The interferograms shown in Figure 50 are self explanatory. The distortion at the top cap and the arm return have not been controlled as in Mirror #008 in spite of every precaution being taken during the assembly process.

NOV 15 75 8A VIS SIDE

NOV 15 75 8A IR SIDE

FIGURE 50. INTERFEROGRAMS, S/N 008A

The MTF response for the IR side shows that the astigmatism resulting after cycling has caused this mirror to fail the MTF requirements. Figure 51 indicates that the astigmatism is in the elevation plane and review of the interferogram could yield such a conclusion but only to an expert eye.

The Visible side MTF (Figure 52) shows a better response than the IR but also misses the required MTF at .667 Lp/mr. Here the interferogram shows more regularity in the pattern but the saddling has affected the overall MTF response.

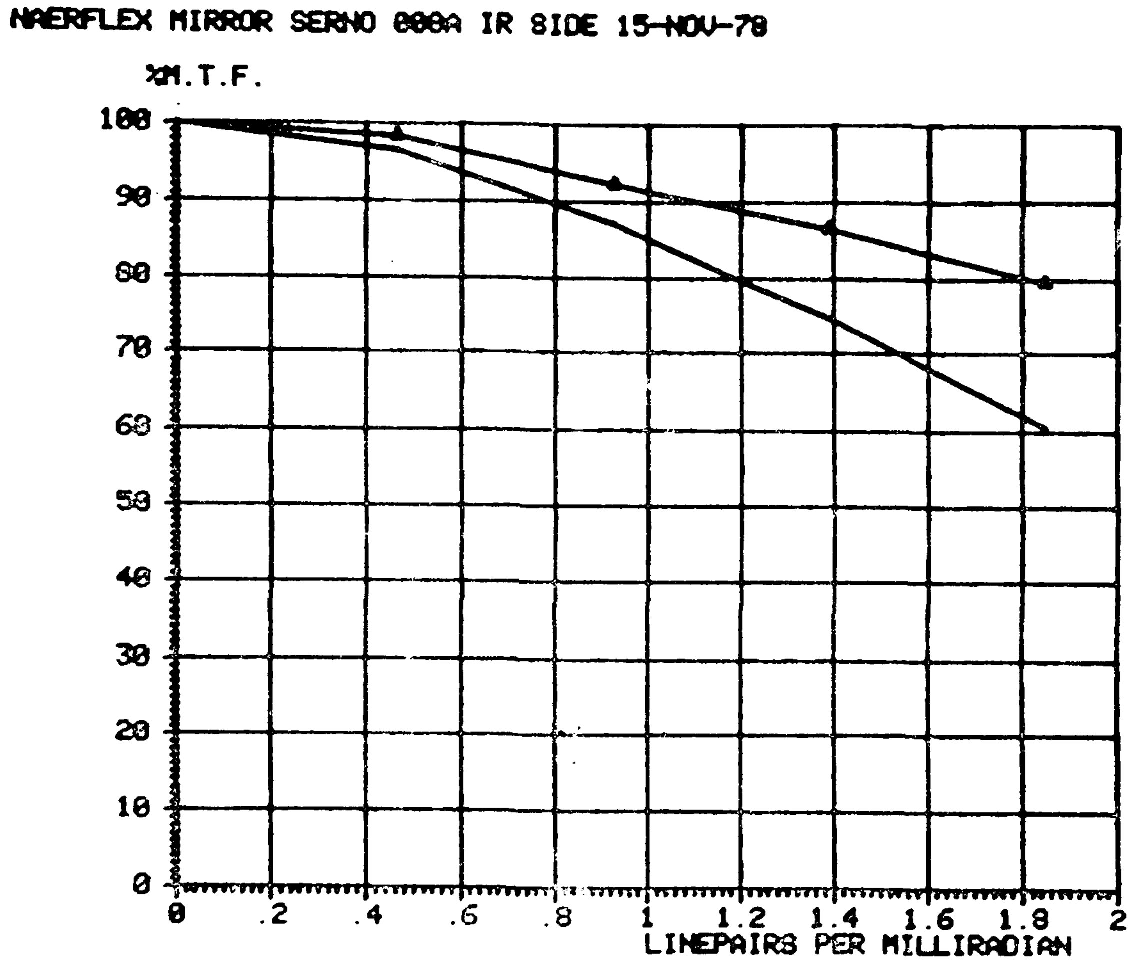


FIGURE 51. MTF RESPONSE, I R SIDE, S/N 008A

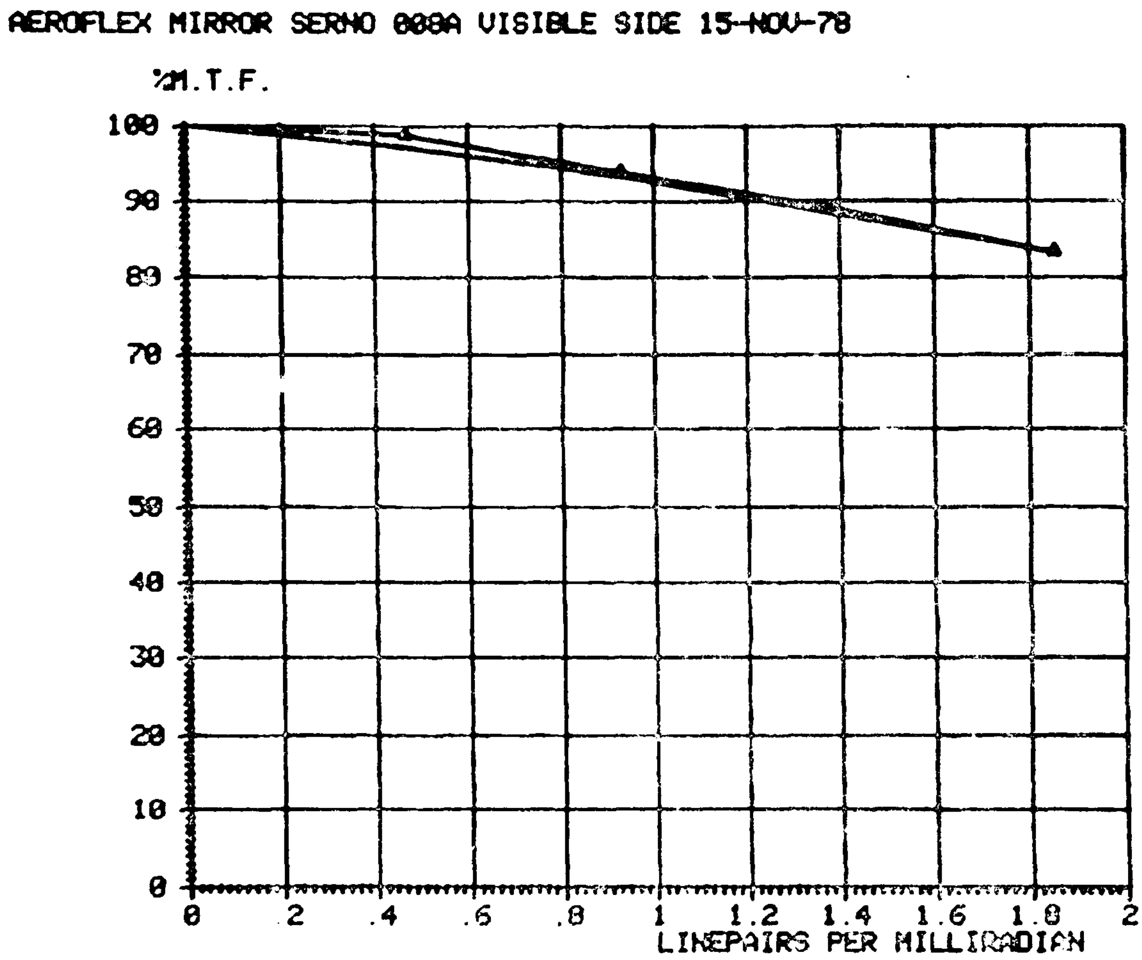
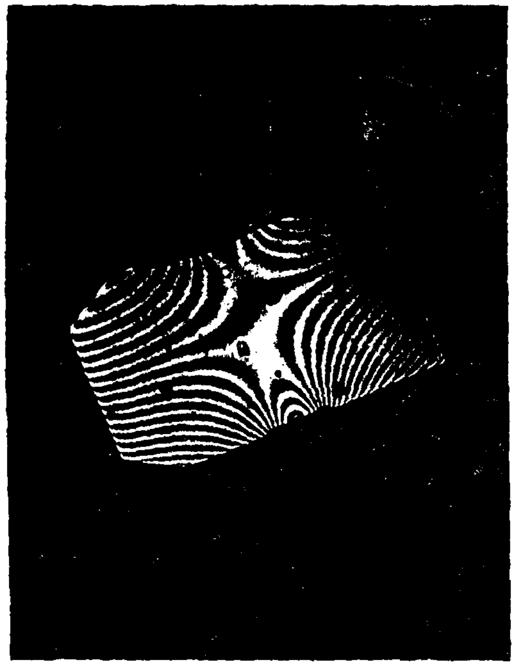


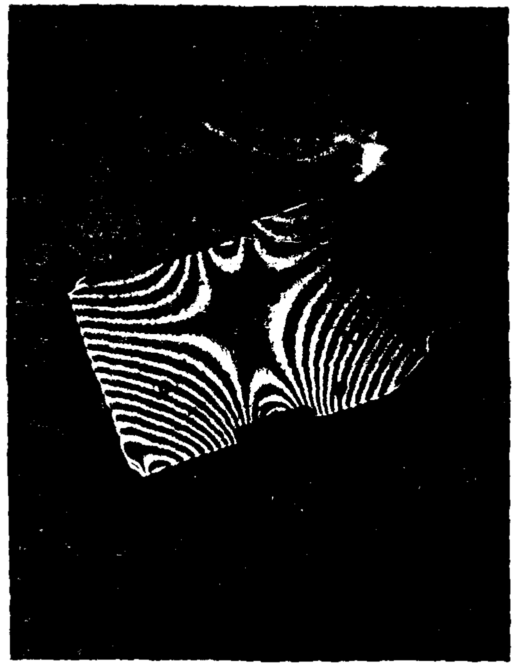
FIGURE 52. MTF RESPONSE, VISIBLE SIDE, S/N 008A

Mirror #009 was assembled and the results achieved on this and subsequent mirrors showed that there were still many variables involved with the use of the Stycast epoxy which are uncontrolled or uncontrollable. Figure 53 is a set of interferograms for both the IR and Visible sides and shows considerable saddling at the mounting points for both the arm return and top cap parts. It should be borne in mind that this mirror was assembled using the same fixture with all of the stress points relieved before and during initial cementing. In spite of this, a 1/4 to 1/2 fringe mirror ended up with the distortion shown in Figure 53. Prior to the temperature cycle and after at least 24 hours of air cure, this mirror showed practically no distortion on either side.

Figure 54 is a plot of the MTF response achieved and shows a very poor performance. This was to be expected considering the interferogram shown on Figure 53, but the quantitative degradation in MTF could not be predicted.

Figure 55 is a plot of the MTF response achieved for the Visible side of the same mirror and shows some improvement from the IR side but is still below specification.





I R

VISIBLE

FIGURE 53. INTERFEROGRAMS, IR & VISIBLE SIDES, S/N 009

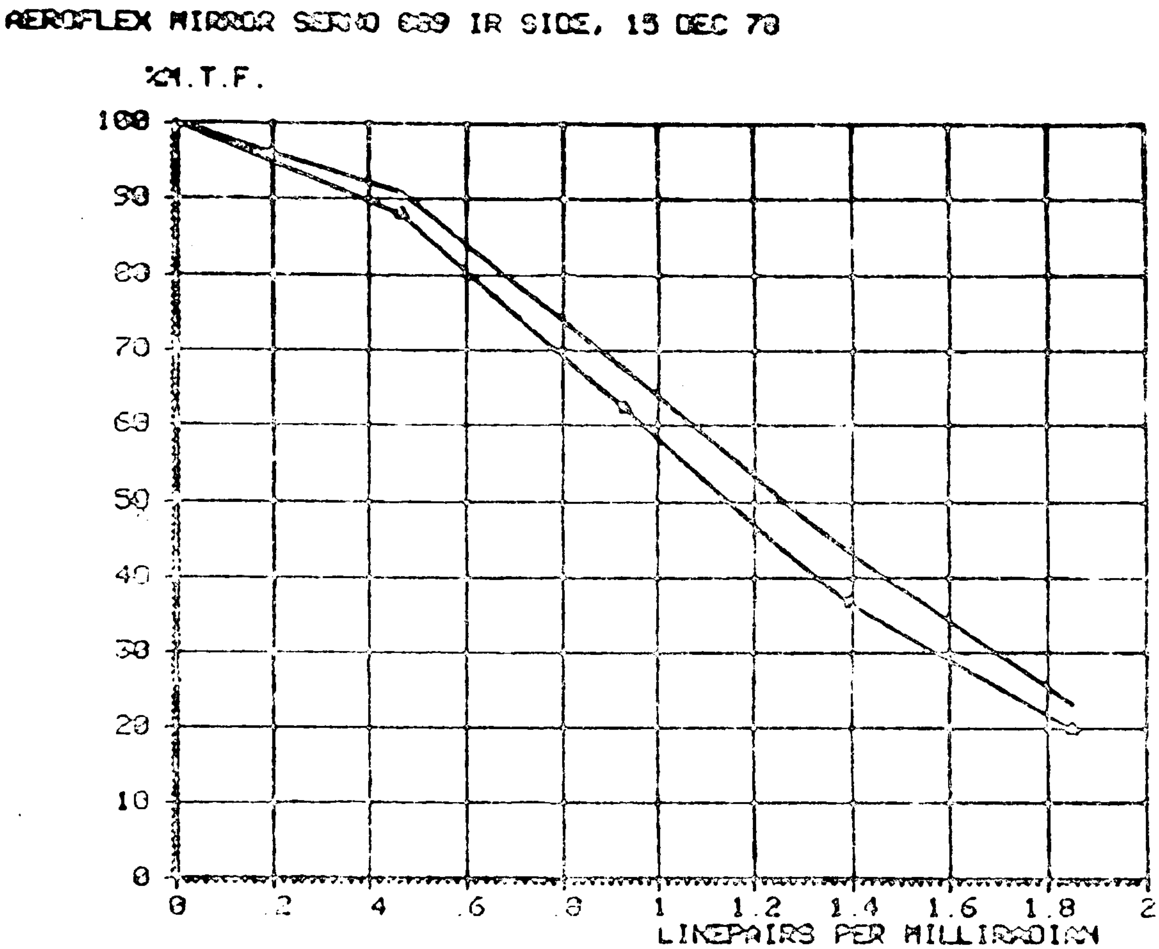


FIGURE 54. MTF RESPONSE, IR SIDE, S/N 009

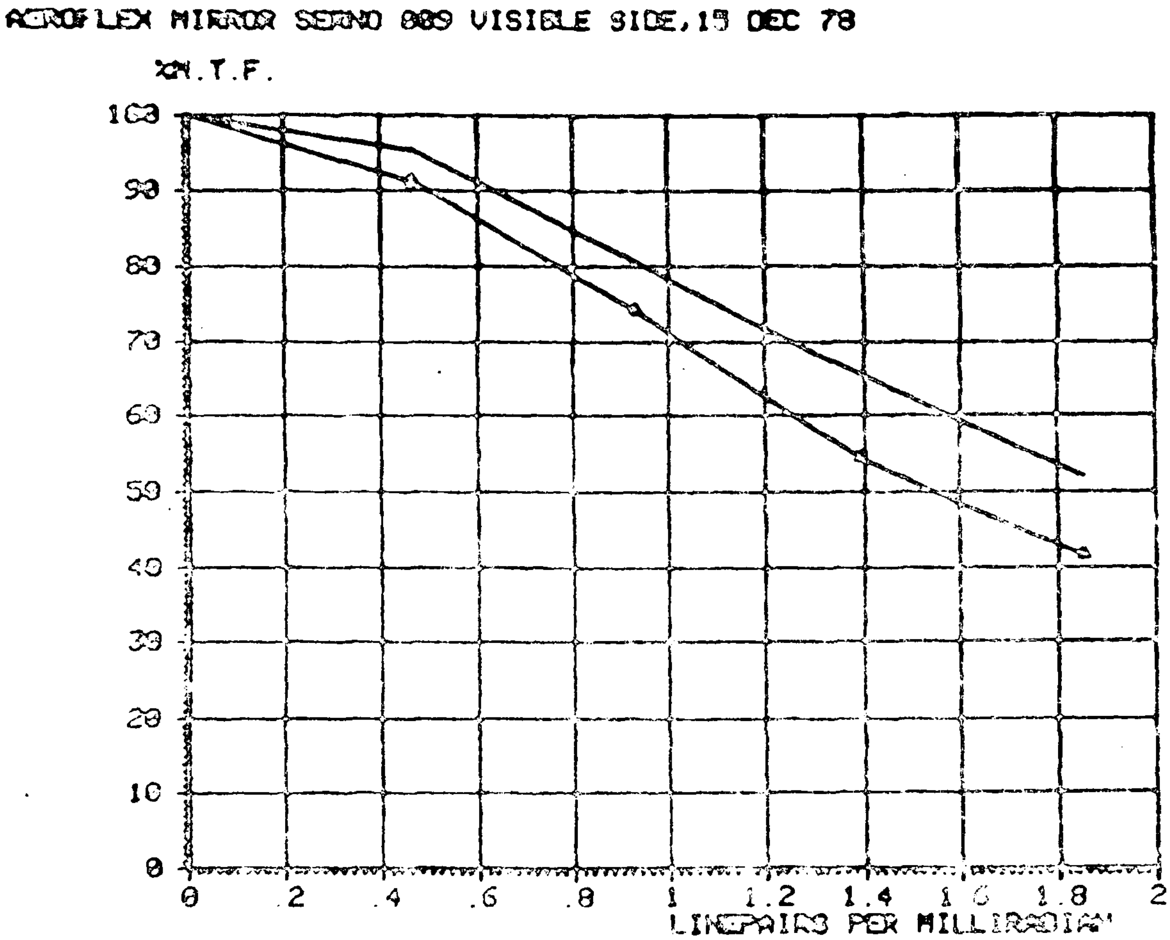


FIGURE 55. MTF RESPONSE, VISIBLE SIDE, S/N 009

AD-A087 843 AEROFLEX LABS INC PLAINVIEW NY F/G 11/9
EVALUATION OF EPOXIES TO PROVIDE STRESS-FREE BONDING OF PYROCER--ETC(U)
MAR 79 DAAK70-77-C-0186

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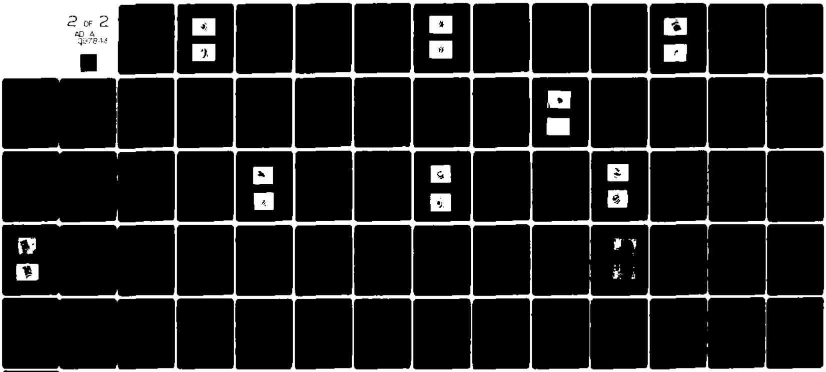

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Mirror #009 used a pyroceram substrate and a cement gap of .002 inches. Thus it seems that all of the efforts in controlling gap width, freshness of cement materials, stress relief and other identifiable variables have little if any effect when compared to the stress distortion imposed by the temperature cycling of the Stycast epoxy.

The next mirror (S/N 009A) assembled used pyroceram substrate but the cement was changed to a glass-to-metal epoxy cement (MilBond) recommended for military applications (MIL-A-48611MU). In this case, all conditions were kept identical to those used for Mirror #009. All stress points on the fixture were relieved and optical flat survey was made of the mirror before and during the cementing process and after initial curing a check was made of the distortion in the mirror. After temperature cycling, the mirror showed between 1/4 and 1/2 fringe flatness with a considerably improved regularity compared to Mirror #009. Although the manufacturer specification indicated that the cure temperature of this cement was 71°C, the MilBond cement was subjected to the full NVL temperature cycle. Figure 56 shows a set of interferograms for both the IR and Visible side of this mirror after curing. The results are self-evident.

Figure 57 is a plot of the MTF response of the IR side of this mirror. As can be seen from the plot, the results were excellent to say the very least.

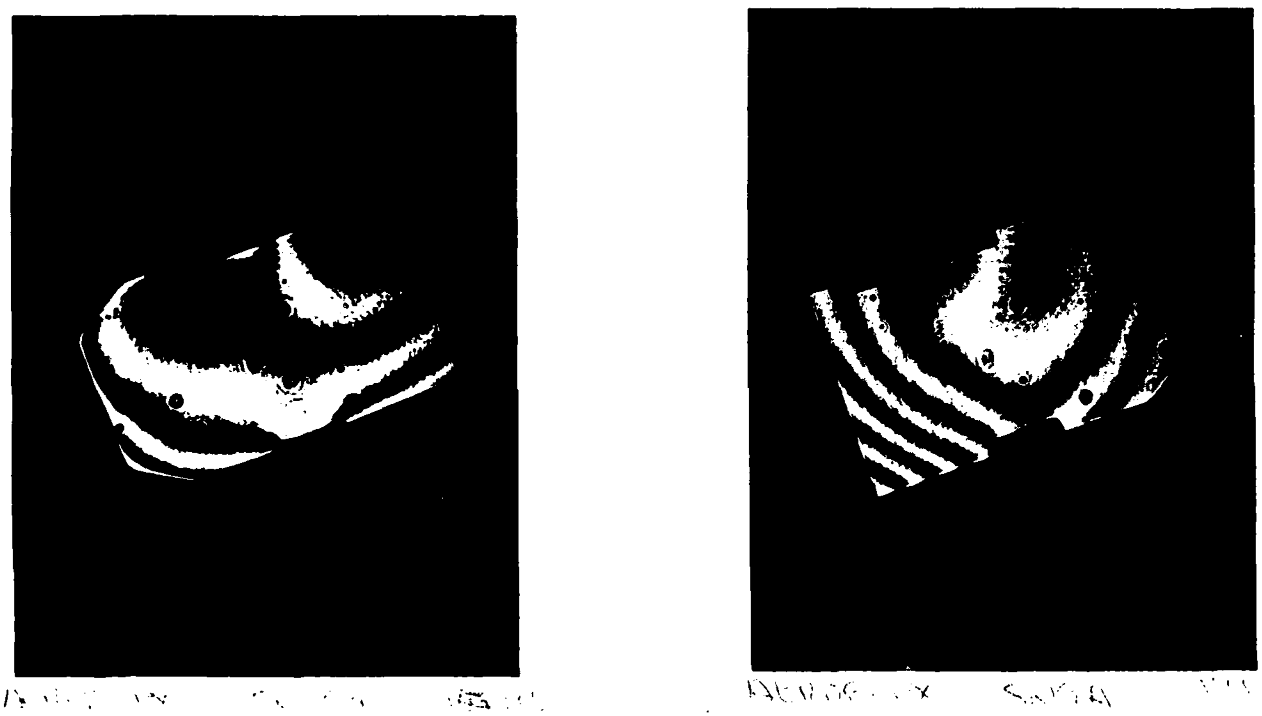


FIGURE 56. INTERFEROGRAMS, IR & VISIBLE SIDE, S/N 009A

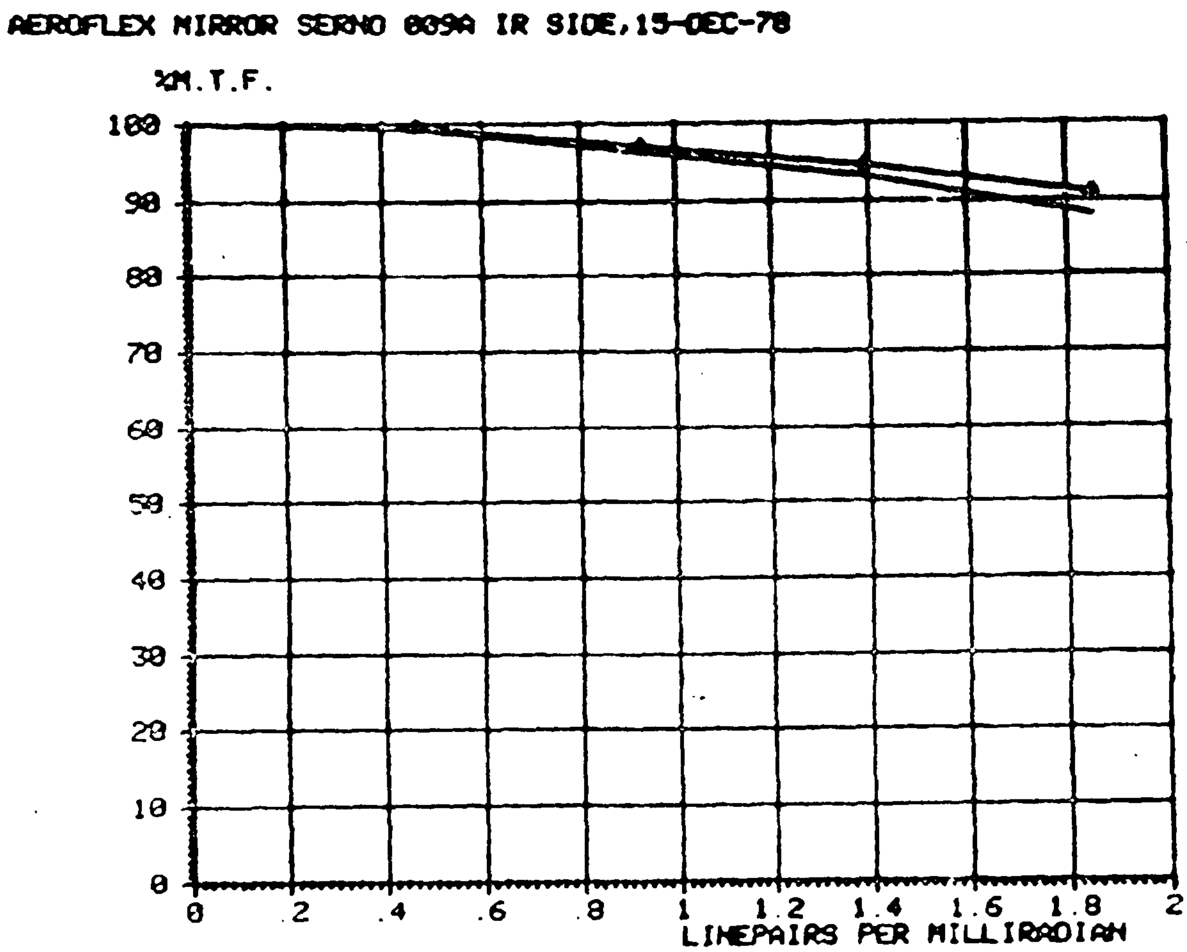


FIGURE 57. MTF RESPONSE, IR SIDE, S/N 009A

Figure 58 is a plot of the MTF response of the Visible side. This side has more than exceeded the specification requirements and in general the results are dramatic compared to Mirror #009, using exactly the same assembly techniques and procedures.

During this assembly series, Mirror #010 was assembled with Stycast and cured. From an optical flat survey of the surface it was obvious that it could not pass the MTF test; distortion was even more severe than in Mirror #009. In the attempt to salvage Mirror #010 for further testing while removing the metal parts, the mirror cracked, much to the chagrin of all involved.

Figure 59 shows a set of interferograms taken on Mirror #011 using the Stycast epoxy and a single bond line. Stress inputs were carefully controlled and after 24 hours of air cure this mirror showed essentially the same results as Mirror #009 before temperature cycling.

Figure 59 now shows the end result of curing the Stycast once again. In this case, somewhat less saddling has resulted. It was impossible to determine what caused this distortion over and above that imposed by the cement curing. The only conclusion drawn was that the stress shown on these assemblies is strictly due to the Stycast epoxy.

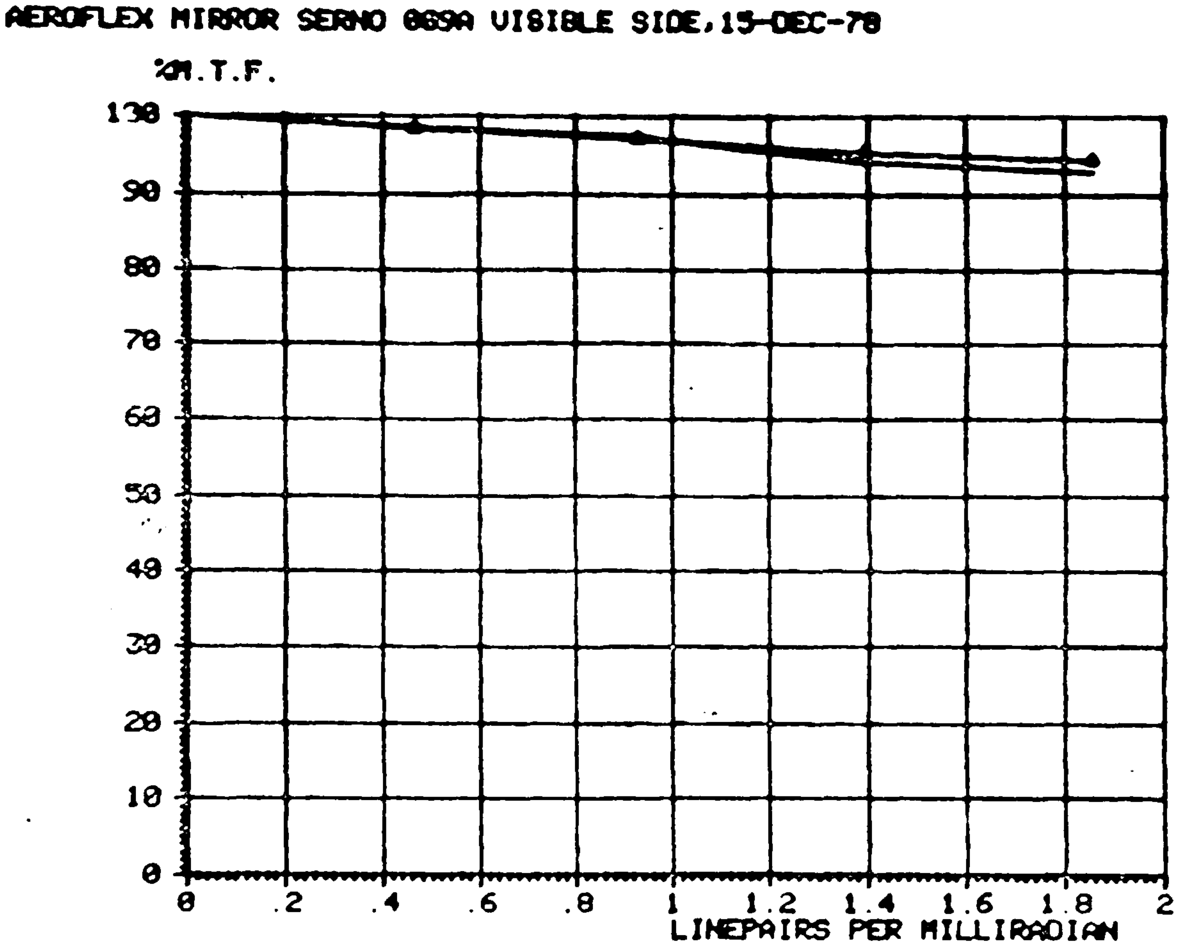
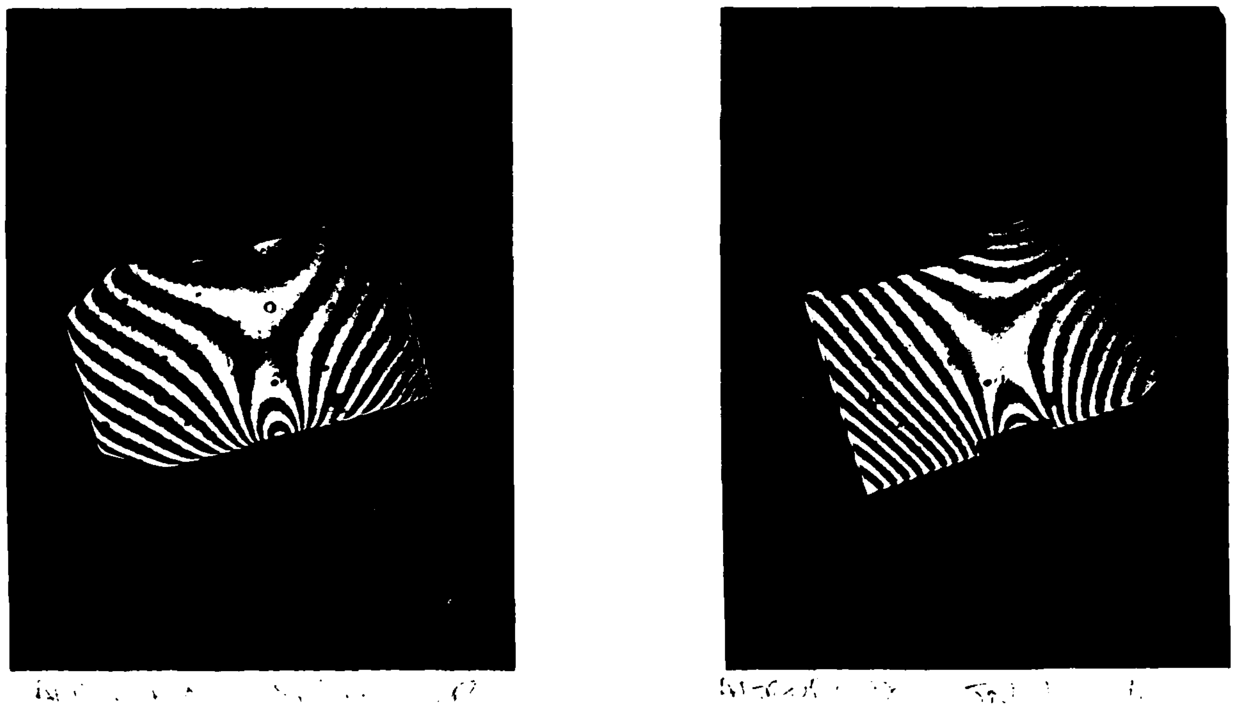


FIGURE 58. MTF RESPONSE, VISIBLE SIDE, S/N 009A



I R

VISIBLE

FIGURE 59. INTERFEROGRAMS, IR & VISIBLE SIDE, S/N 011

Figure 60 is a plot of the MTF response of Mirror #011 and while it is improved from Mirror #009, it still shows sufficient astigmatism and droop to consider it as having failed the MTF test requirement. Figure 61 is a plot of the Visible side with essentially the same results.

Mirror #011A was then assembled using a different substrate in order to determine whether the substrate was affected by the single bond line or whether the materials were affected in any way. In this case, the MilBond was applied on a single bond line as in Mirror #009A. As can be seen from the interferogram, Figure 62, the results are even better than those of Mirror #009A. Substantiating this are Figures 63 and 64 which show the MTF responses achieved.

When the use of this glass-to-metal bonding epoxy was brought to the attention of the NVL, insufficient data existed to determine the physical characteristics of the cement under dynamic and environmental conditions. For example, the coefficient of expansion, tensile and compressive strength, the maximum and minimum temperature limits have not been published or are not immediately available. MIL-A-48611 indicates that this cement is meant for the mounting of periscope prisms in tank applications and meets a rather severe shock requirement (400 g). There was not enough information to confirm that this cement could survive the

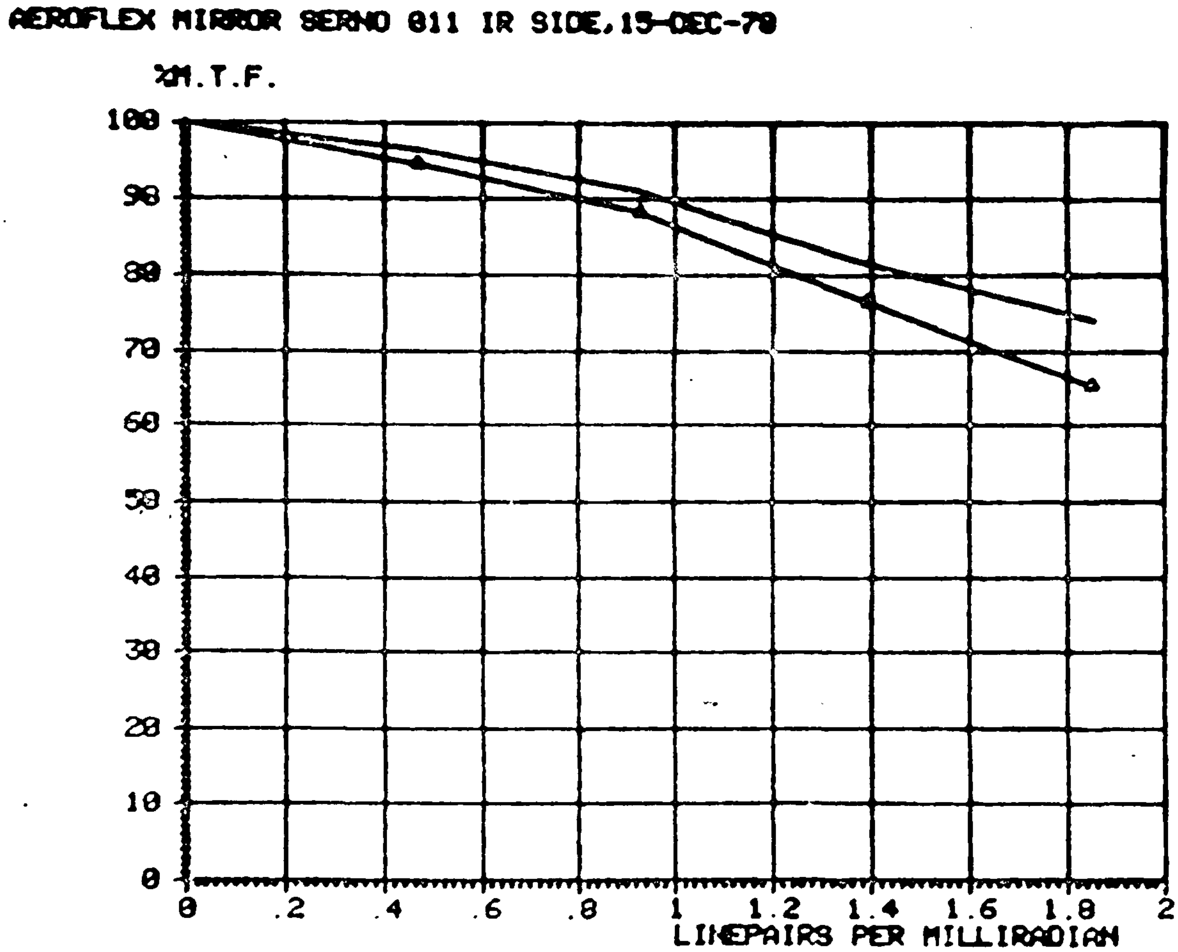


FIGURE 60. MTF RESPONSE, IR SIDE, S/N 011

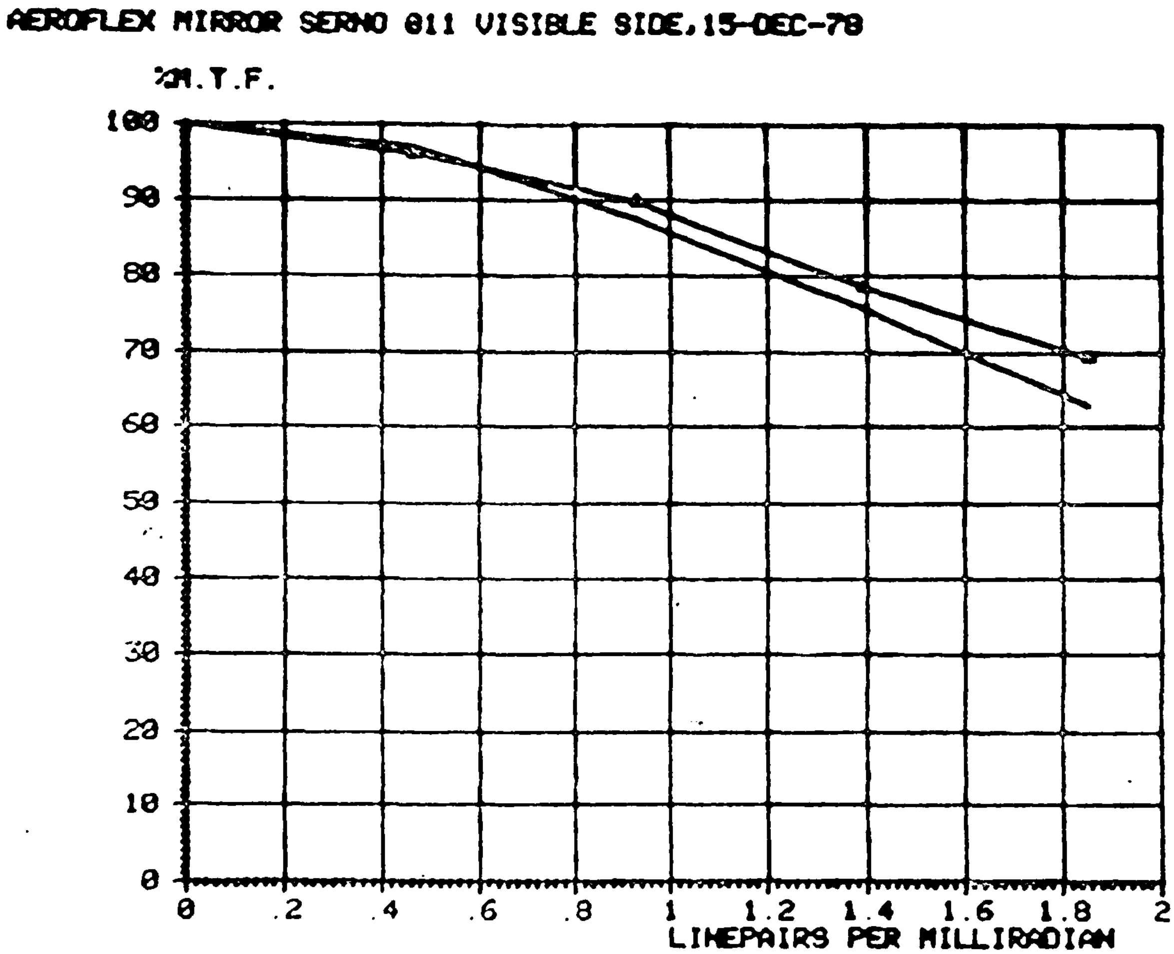
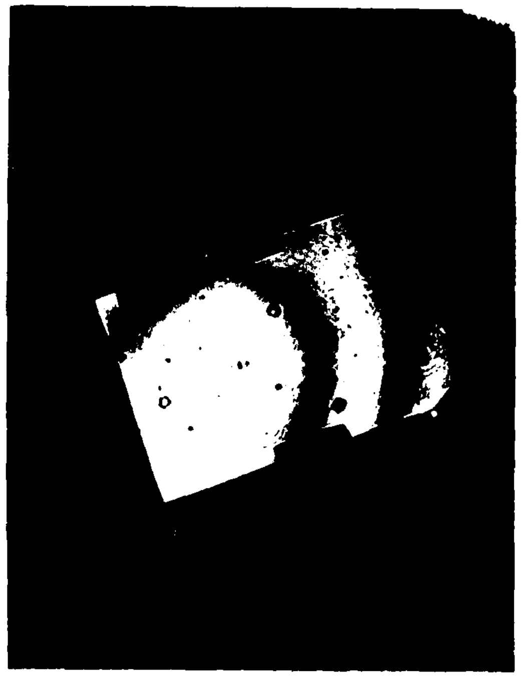


FIGURE 61. MTF RESPONSE, VISIBLE SIDE, S/N 011

I R



VISIBLE

FIGURE 62. INTERFEROGRAMS, IR & VISIBLE SIDE, S/N 011A

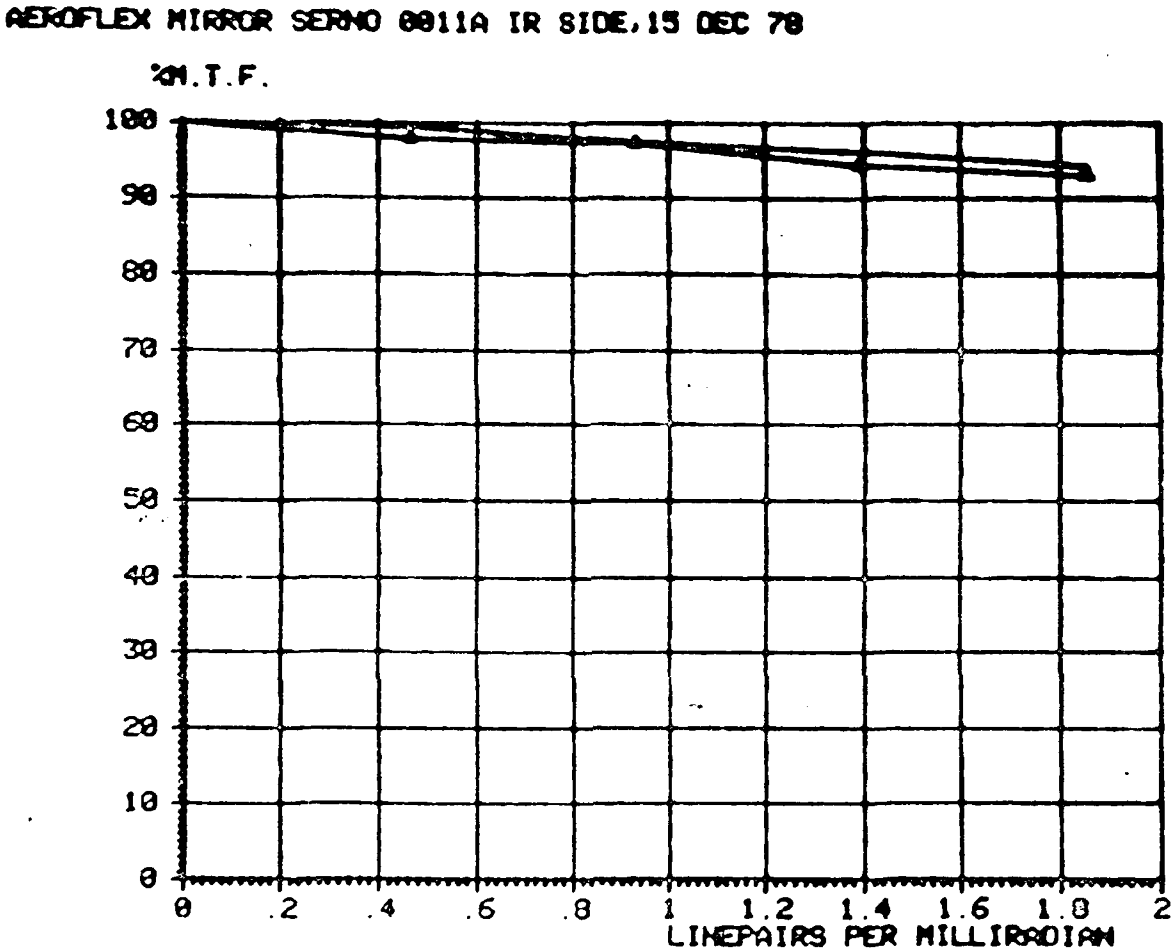


FIGURE 63. MTF RESPONSE, IR SIDE, S/N 011A

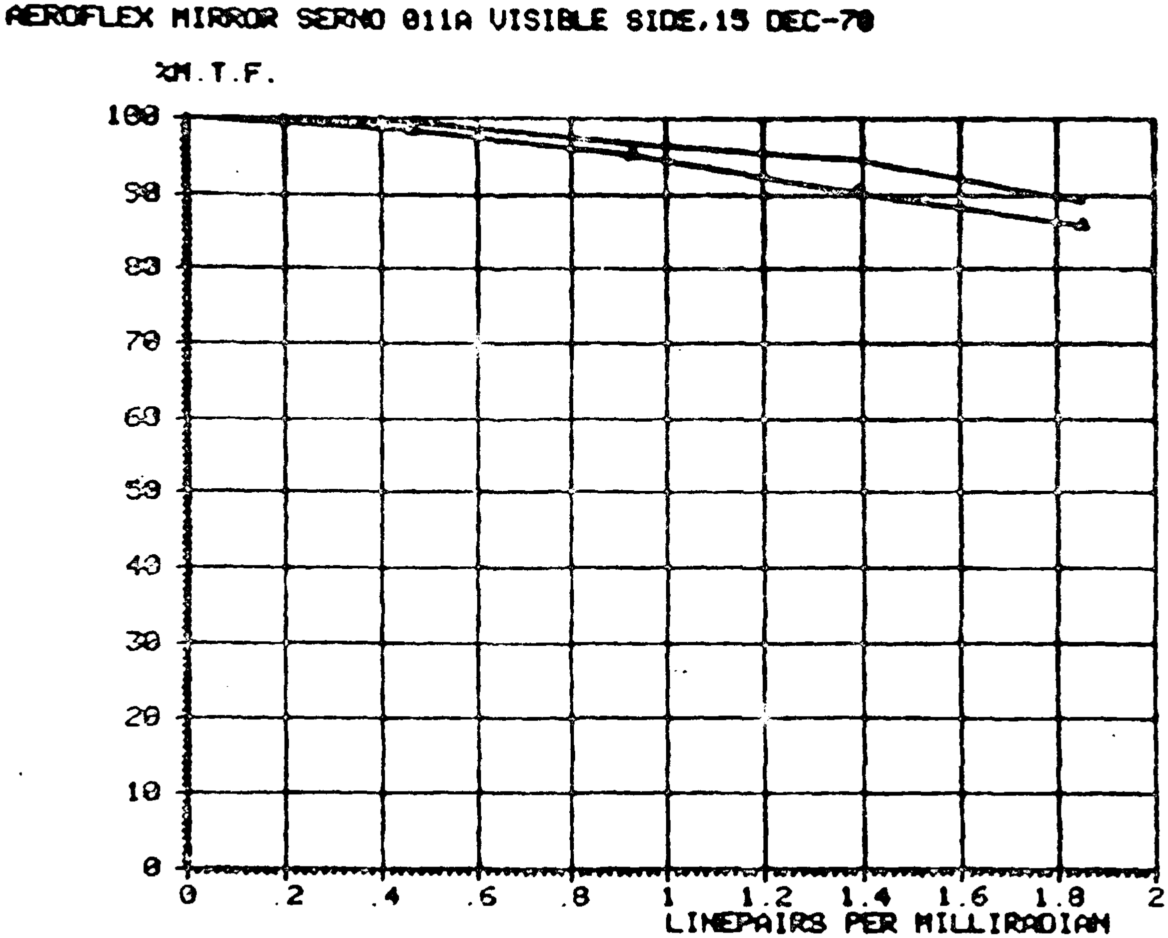


FIGURE 64. MTF RESPONSE, VISIBLE SIDE, S/N 011A

scanner environment. As a result of this, contact was made with Picatinny Arsenal to determine if further information was available. Aeroflex obtained a copy of this report to determine this material could be used as an alternate to the present Stycast epoxy.

During the visit to NVL during which the test results on Mirror #009 were obtained, a meeting was held with NVL personnel to establish what data would be necessary to provide confidence in the MilBond as a mirror cementing material. It was agreed that the first step to be taken was to assemble a mirror using the MilBond, assemble a complete scanner and check the optical performance under static and dynamic MTF testing. As part of this mirror study, Aeroflex provided such a scanner to determine the dynamic characteristics of the MilBond assembly. The results of this test are described later on in this section.

The mirror study effort continued with the assembly of Mirror #009B. This mirror was taken from the completed assembly reported as Serial #009. The mirror was disassembled from its associated mounting parts and rechecked for "free-state" distortion. Using an optical flat, this was determined as 1/4 to 1/2 fringe maximum for both sides. It was also noted that there was no evidence of "power" on either side and the patterns were regular.

The mirror (#009) was then re-assembled using the same metal parts into a fresh assembly, but the cement was changed to MilBond. In this case, the identical gap, fixturing and temperature cycling was repeated as in Mirror #009. At this point, after cure, the assembly was designated as #009B for identification purposes.

After temperature cycling to +95°C (4 hours) and -62°C (4 hours) the assembly was checked (with an optical flat) for distortion. There was no discernable change in the 1/4-1/2 fringe pattern achieved before cycling.

The assembly was then placed into a scanner and the scanner was aligned and tested to the ATP. Subsequent to the ATP, the scanner was taken to NVL for both static and dynamic MTF tests. Figure 65 is a plot of the IR side static MTF test results. To say the very least, the same mirror which failed using Stycast has now passed the required MTF limit admirably. Figure 66 is a plot of the Visible side MTF with equally dramatic results.

In view of these results, the tests were then continued and the scanner was operated (without interlace) so that dynamic MTF response could be measured. Figure 67 is a plot of the dynamic MTF response for the IR side. The curvature of this (continued)

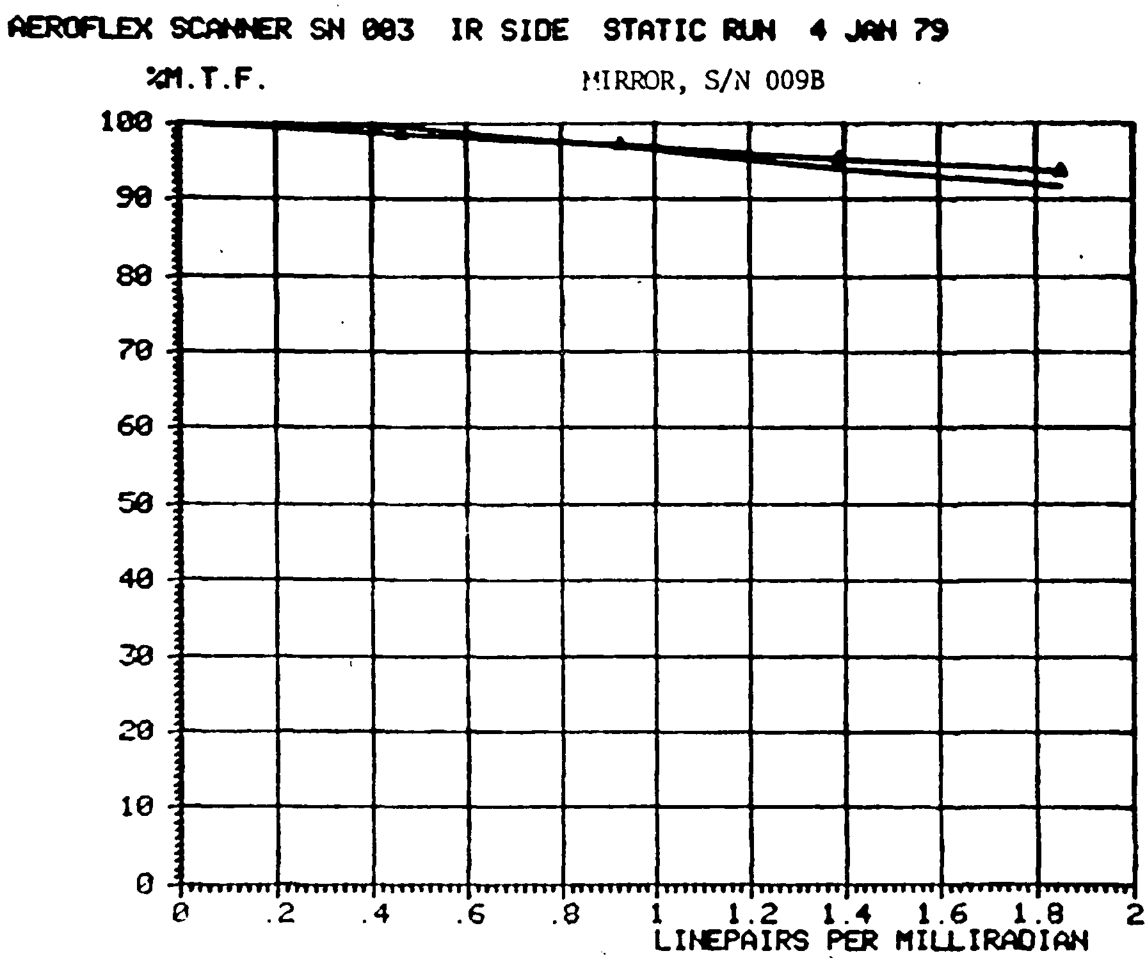


FIGURE 65. MTF RESPONSE, IR SIDE, S/N 009B

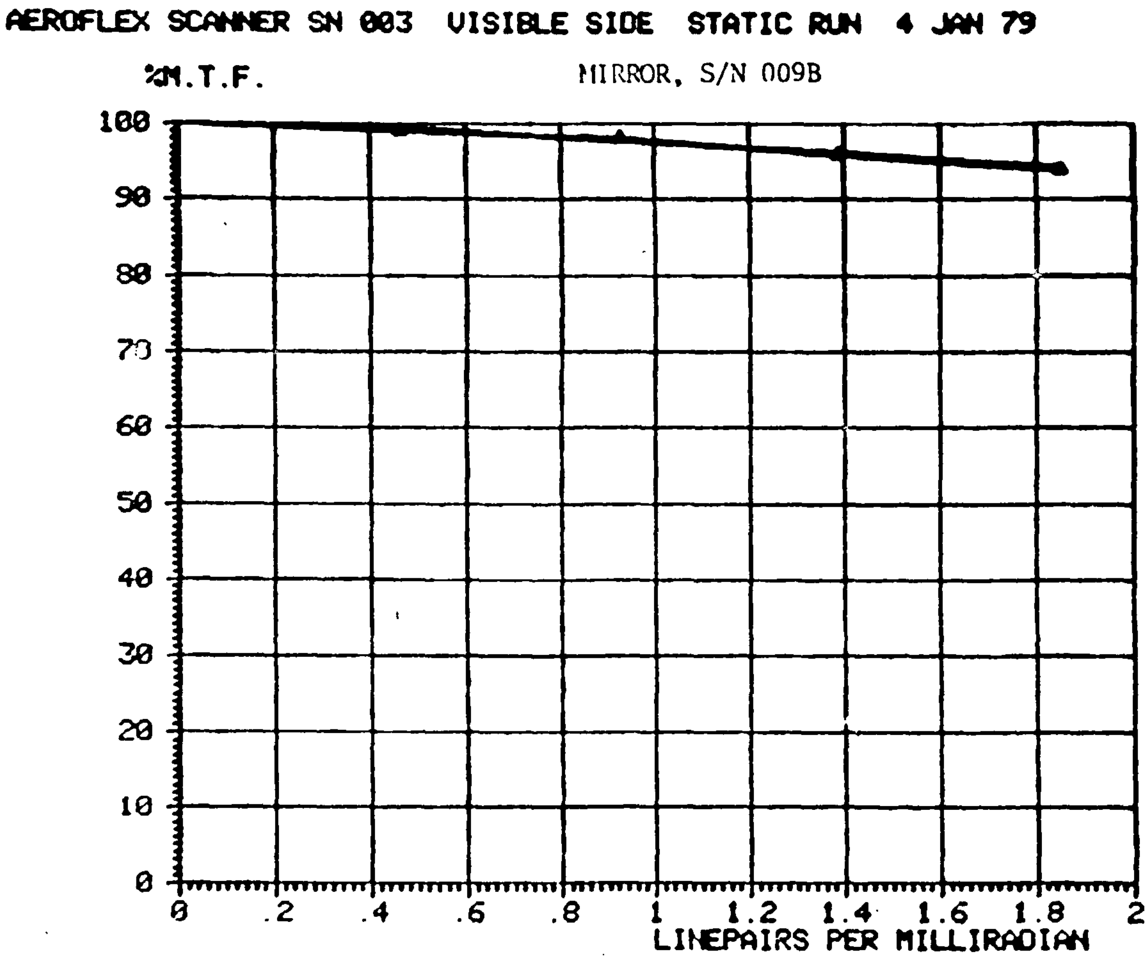


FIGURE 66. MTF RESPONSE, VISIBLE SIDE, S/N 009B

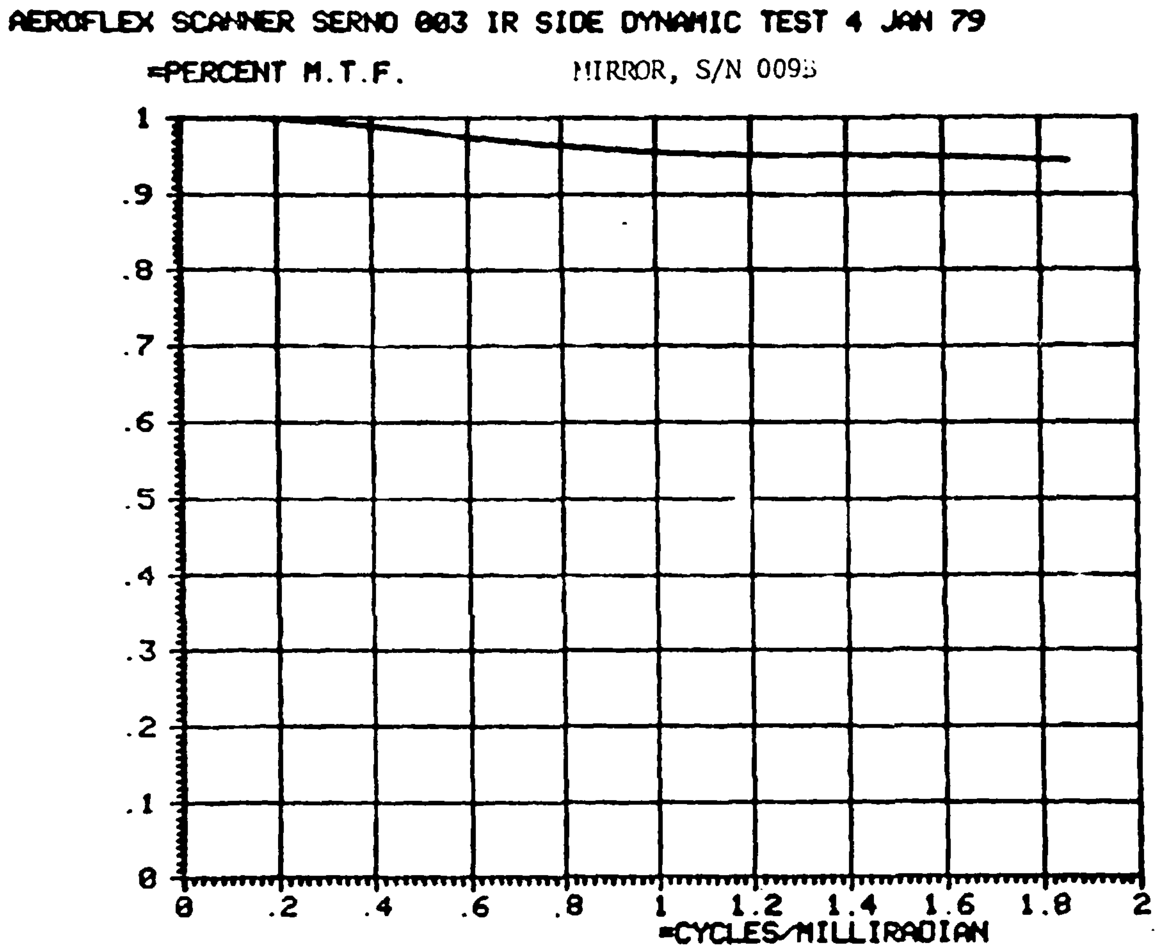


FIGURE 67. DYNAMIC MTF RESPONSE, IR SIDE, S/N 009B

plot is attributed to system noise in the test set up. Figure 68 is a plot of the Visible side with an identical curvature shown. For the sake of completeness, the dynamic test was re-run and the resulting MTF response is shown in Figure 69. Here the positive slope indicates noise in the channel and is somewhat different than the two previous curves. In any event, the dynamic response is good and more than meets the requirements.

Probably the most significant change resulting from the use of MILBOND is that the static MTF shows a 95% response to almost 1.3 LP/mr.

As a result of the excellent MTF responses achieved on Mirror #009B, it was agreed that maximum effort would be taken by NVL and Aeroflex to determine the physical characteristics of MILBOND at elevated temperatures. For all intents and purposes, Mirror #009B demonstrated that the Stycast is the source of the distortion in this optical assembly. In addition, this mirror was the third in this test series which exhibited this lack of distortion with MILBOND cement. Considering the difficulties experienced with the Stycast, this yield was significant but not the final proof. In view of this, it was agreed that at least 5 more mirrors would be assembled using MILBOND to determine MTF response vs yield.

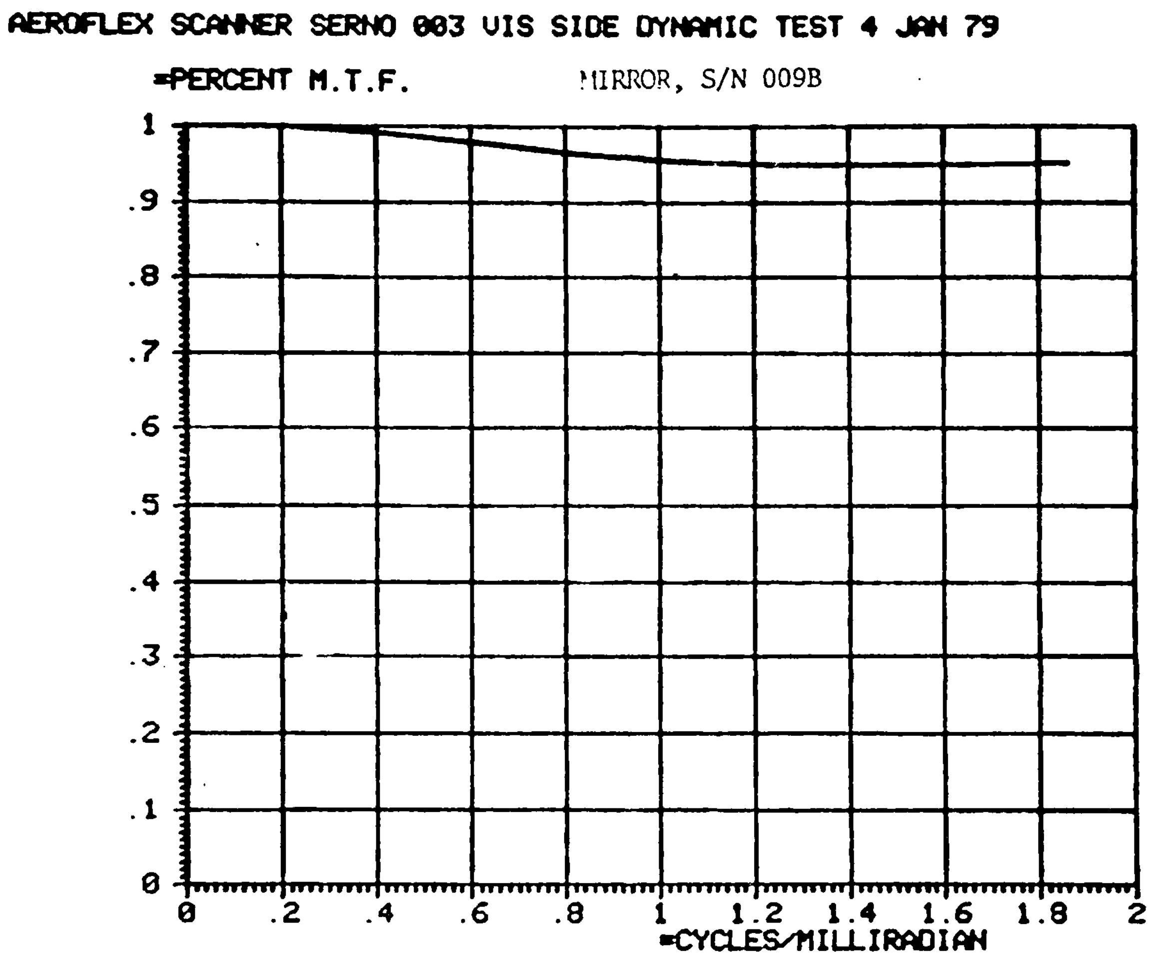


FIGURE 68. DYNAMIC MTF RESPONSE, VISIBLE SIDE, S/N 009B

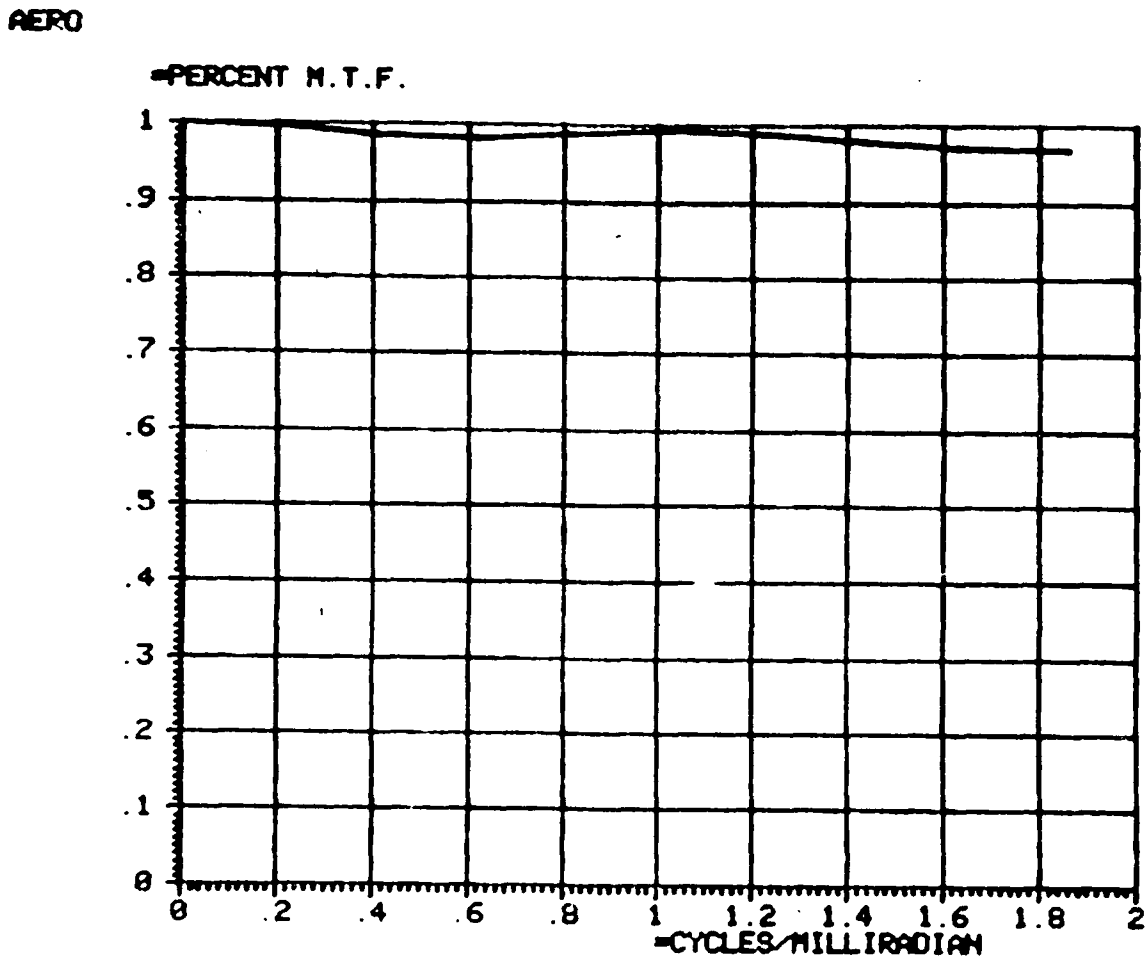


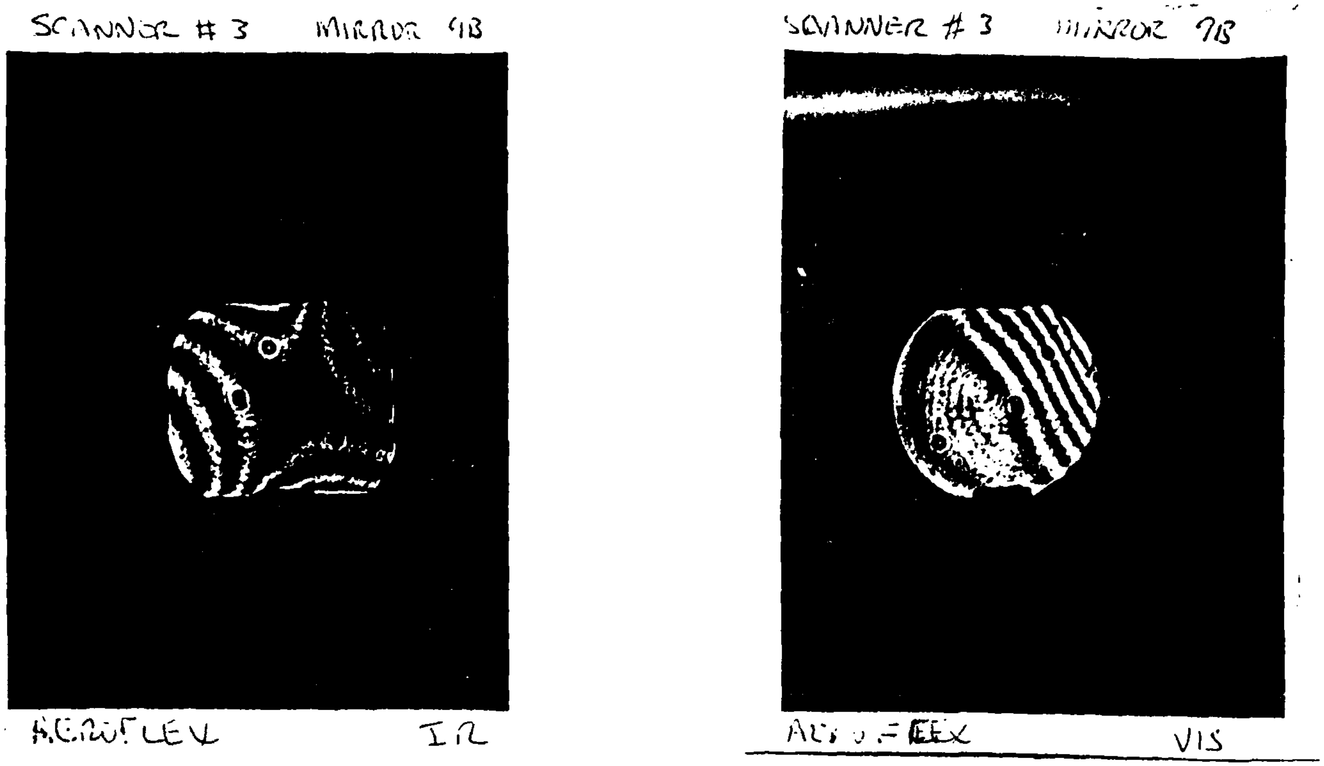
FIGURE 69. DYNAMIC MTF RESPONSE, VISIBLE SIDE, S/N 009B

Scanner #003 with Mirror #009B was then subjected to an operational test at high temperature. The performance of the scanner was monitored by the scope measurements of the scan and interlace waveforms as well as the AGC voltage. The test was run at an actual temperature of 98°C for about 1 hour with no apparent change in the monitored waveforms. The unit was then shut down and immediately removed from the chamber for a visual inspection of the mirror bond. Inspection of the bond showed no deterioration in the surface or any apparent defects in the bond itself.

The scanner was allowed to return to room temperature for several hours and the test was repeated with a running time of 2-1/2 hours. This test was witnessed by NVL personnel with the following results. There was no apparent degradation of the bond for both the arm return and the top cap. The surface of the epoxy showed a slight change in smoothness or "shine" but exhibited no pitting, flow, or cracks. The final 2-1/2 hours of testing was witnessed by NVL personnel. A copy of the test data is included in the appendix to this report.

A series of tests were then run on Mirror #009B assembled into Scanner #003 after the high temperature operation. These tests were performed at NVL using the MTF test equipment at that facility.

Figure 70 shows the interferograms taken of the



I R SIDE

VISIBLE SIDE

FIGURE 70. INTERFEROGRAMS, MIRROR #009B AFTER 4 HOUR OPERATION @ 98°C

mirror surfaces using a laser interferometer. The infra red side shows a saddling pattern and was cause for considerable concern. However, re-examination of the interferogram indicated that although the surface is saddled, the depth of the saddle is small (approximately 1 fringe or about 5×10^{-6} in). This depth or variation from a true surface is insufficient to cause a significant change in the MTF response. As it turns out, the MTF response was quite good (to the relief of all concerned). Once again a casual examination of the interferogram was misleading. The visible side showed a small change from the original fringe pattern but is still regular. Closer examination of the pattern shows that the surface is cylindrical and would result in slight astigmatism. The MTF response reflects this.

A dynamic MTF test was then run on this mirror. Figure 71 is the calibration curve obtained during this test. Figure 72 is a plot of the IR side MTF response. The response is certainly well within the specified limits and but for the depth of the saddle would not reflect what would be expected with the interferogram shown in Figure 73. All that could be said at this stage was that the mirror performance was far superior to that anticipated for this type of interferogram.

The Visible side response is shown in Figure 71. Here the dynamic response is almost identical to the IR side in spite of the difference in fringe patterns.

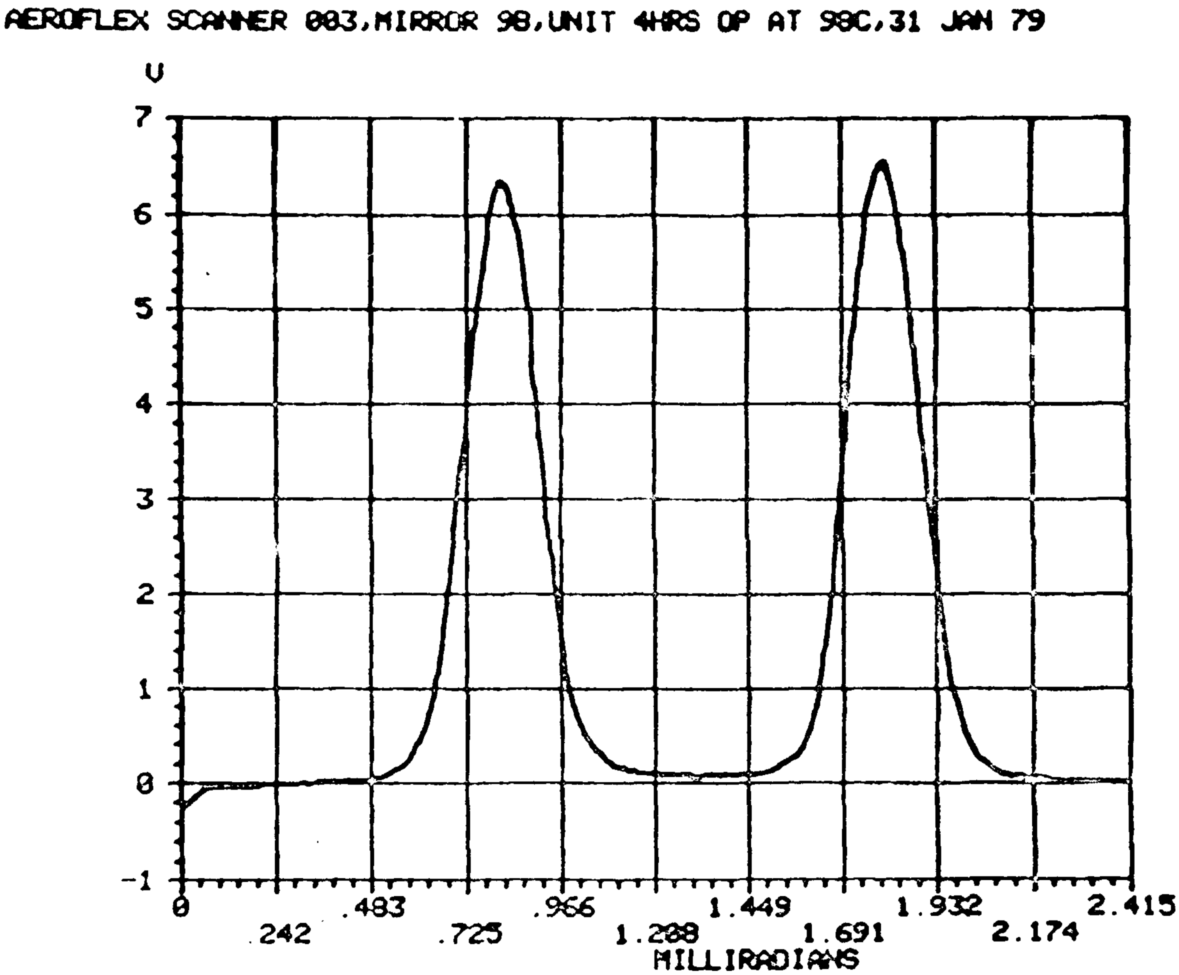


FIGURE 71. CALIBRATION CURVE, DYNAMIC MTF, SCANNER #003, MIRROR #009B

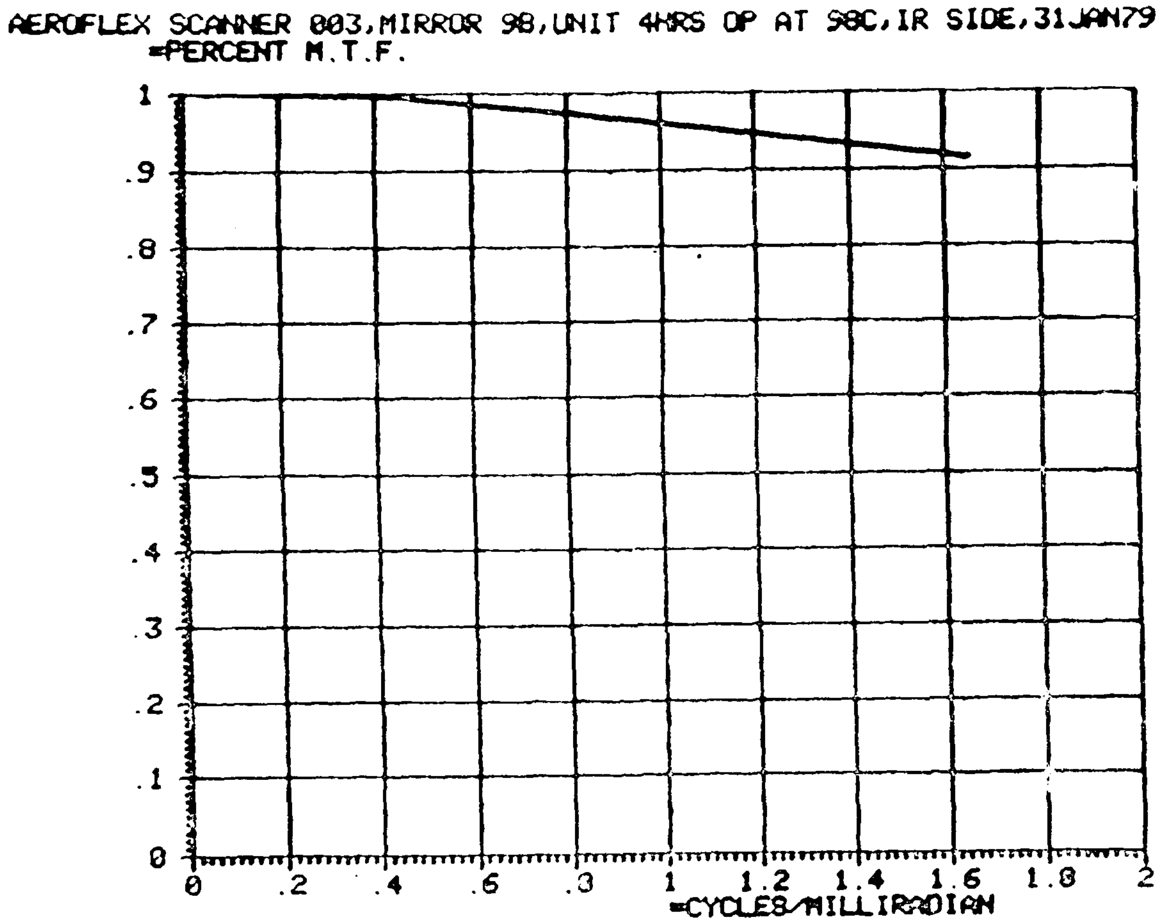


FIGURE 72. DYNAMIC MTF RESPONSE, IR SIDE,
SCANNER #003, MIRROR #009B

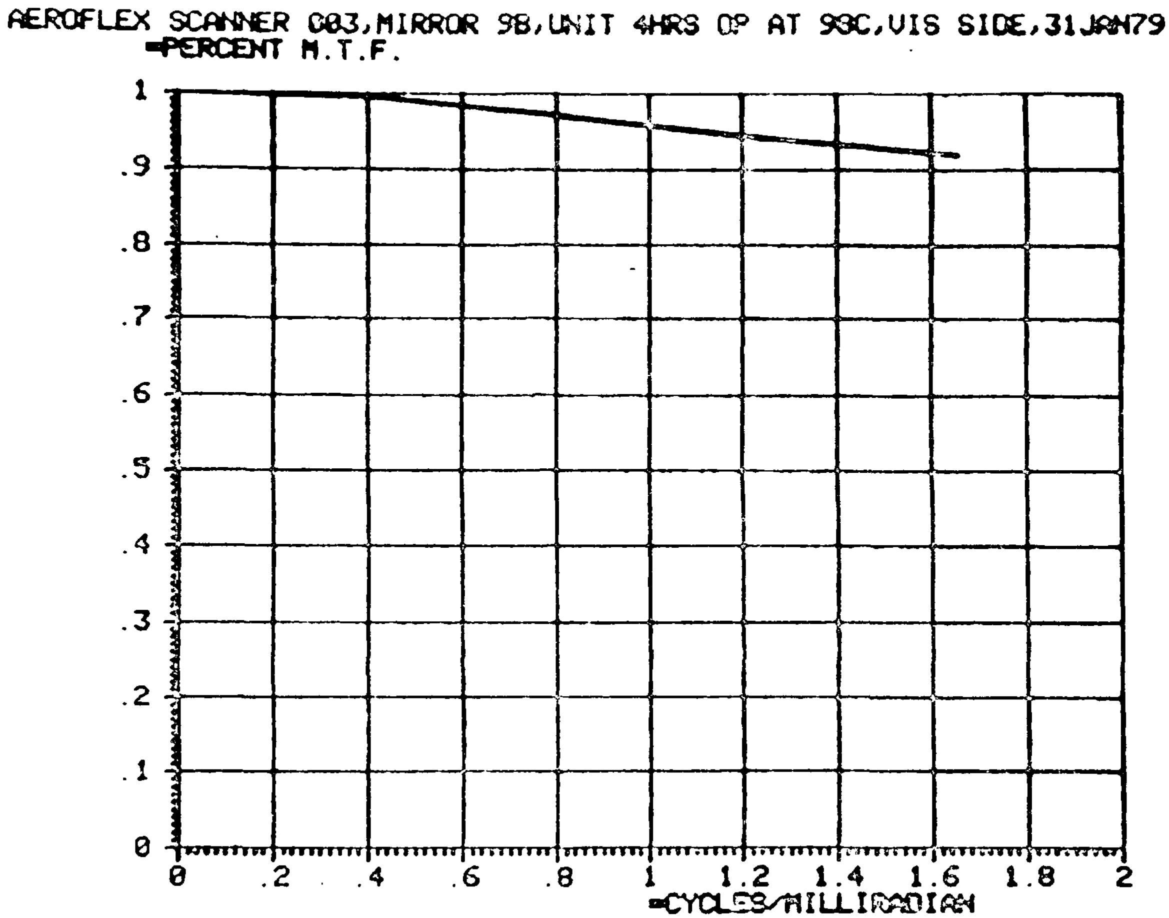


FIGURE 73. DYNAMIC MTF RESPONSE, VISIBLE SIDE, SCANNER #003, MIRROR #009B

The net result of the dynamic test is that there was no measureable degradation in the dynamic characteristics of the mirror assembly using the MILBOND cement after a 4-hour operating cycle at 98° C. The fact that the data repeated indicates that there was no movement of the mirror in the cement bond during the elevated temperature operating cycle.

Upon completion of the dynamic tests, the scanner was turned off and static MTF tests were run on the mirror as well. Figure 74 shows the IR static response and as can be seen, the astigmatism is virtually zero for this side. This again apparently conflicts with the interferogram shown in Figure 70 for this side. While the dynamic response effectively gives the MTF for the azimuthal plane and would eliminate any elevational astigmatism, the static response is designed to show this difference. Figure 74 indicates that the depth of the saddle can be no more than one fringe.

The MTF response for the Visible side (Figure 75) shows some minor astigmatic change (as expected) but this side more than adequately meets the requirements for MTF.

In general the conclusion drawn from this scanner test was that up to 98°C the MILBOND is adequate for this application.

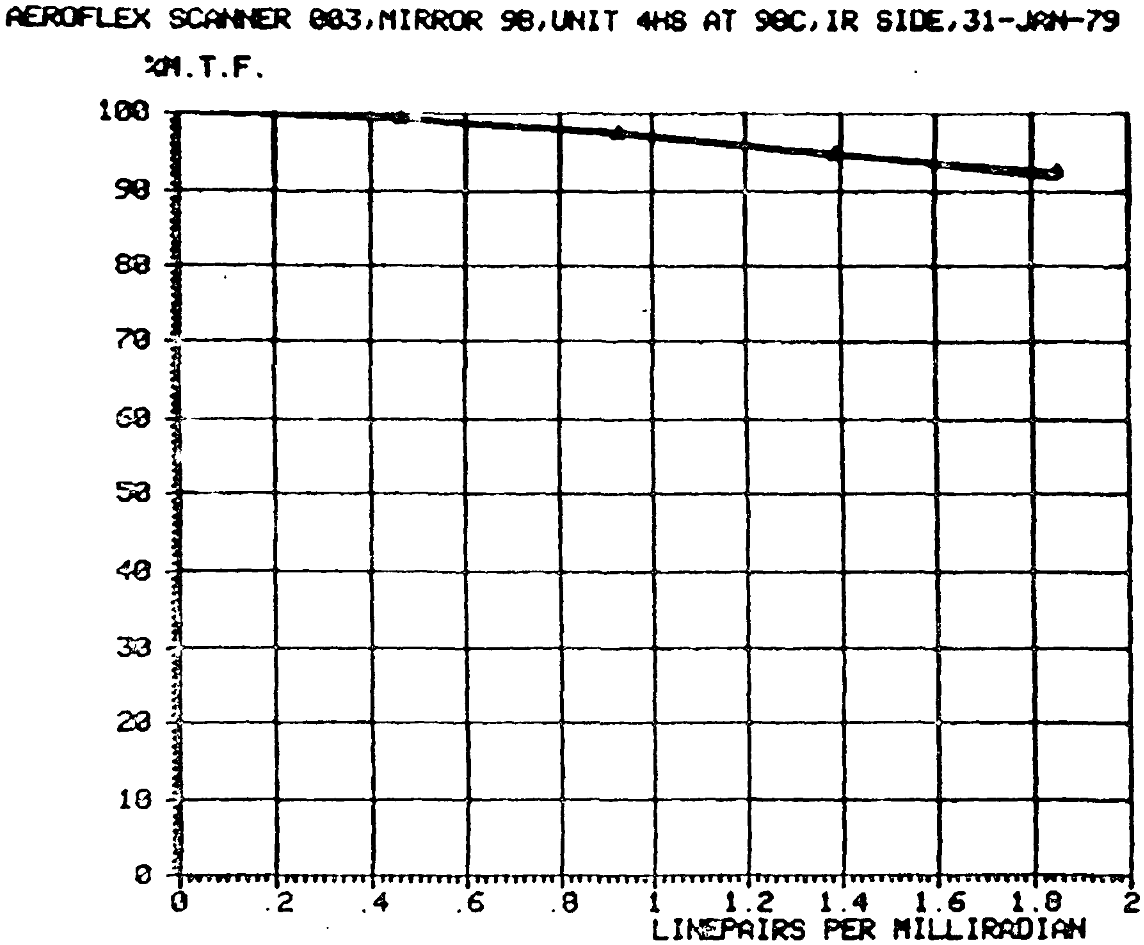


FIGURE 74. STATIC MTF RESPONSE, IR SIDE

SCANNER #003, MIRROR #009B

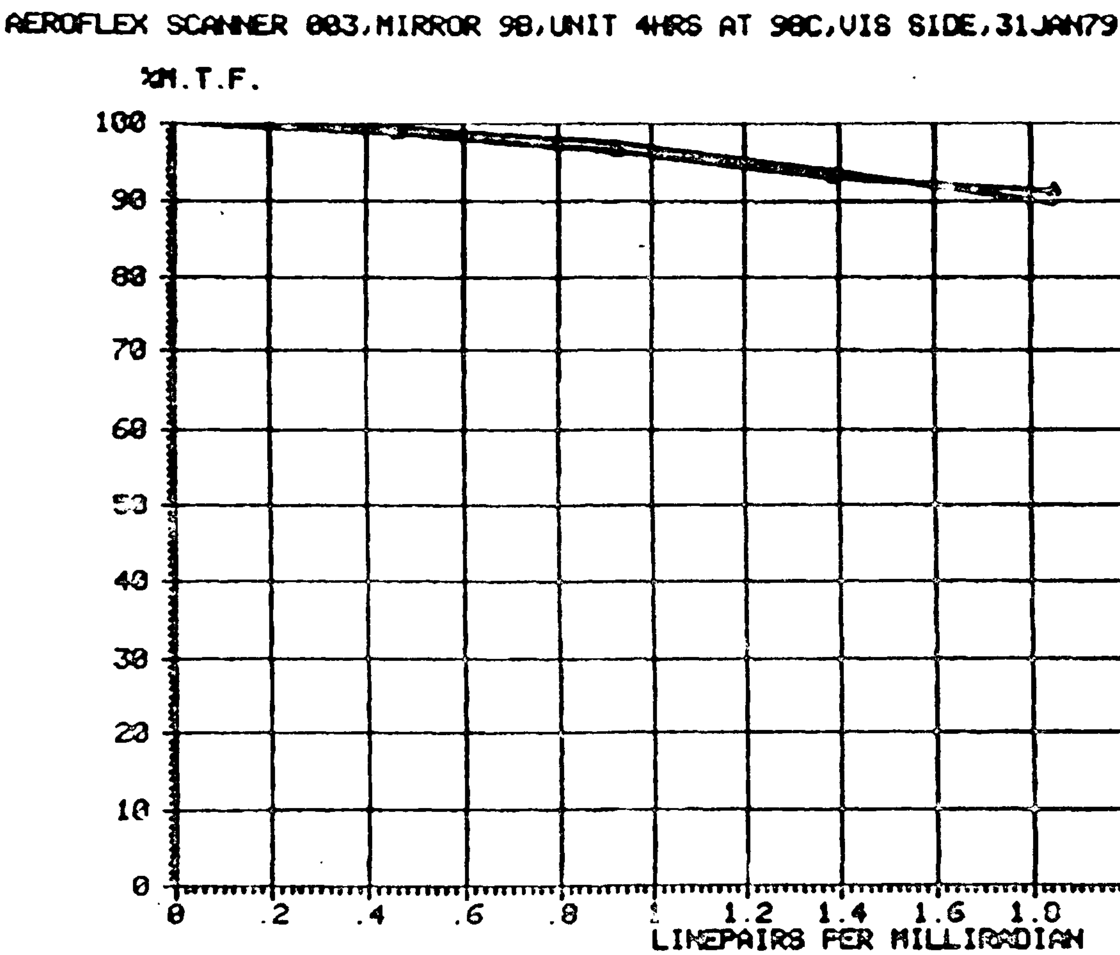


FIGURE 75. STATIC MTF RESPONSE, VISIBLE SIDE, SCANNER #003, MIRROR #009B

A set of 4 additional mirrors were tested for static MTF response. These mirrors were assembled using MILBOND and were subjected to the temperature cycle suggested by NVL.

Figure 76 shows the interferogram taken on Mirror #013. Both sides show no distortion of the surface at the top cam and arm return mounting points. The resultant MTF responses are shown in Figures 77 and 78. Needless to say, the responses are excellent and in this case reflect the response expected with the interferograms shown.

Figure 79 shows the interferograms taken on Mirror #014. Once again the surfaces show no distortion as a result of the assembly of the metal parts. In this mirror, however, the visible side shows some ellipticity and associated "power" in the fringe pattern.

The MTF responses shown in Figures 80 and 81 show that the mirrors met the requirements. Moreover in this case the Visible side shows an attendant astigmatism which is consistent with the ellipticity shown in Figure 79.

Figure 82 shows the interferograms taken on Mirror #015. In this case, the IR side shows some power (cylindrical). The Visible side shows an absence of any regular pattern but is still quite flat. In both cases, the metal parts have not affected the surface. Figures 83 and 84 are the static MTF

IR SIDE

VISIBLE SIDE

FIGURE 76. INTERFEROGRAMS, MIRROR S/N 013

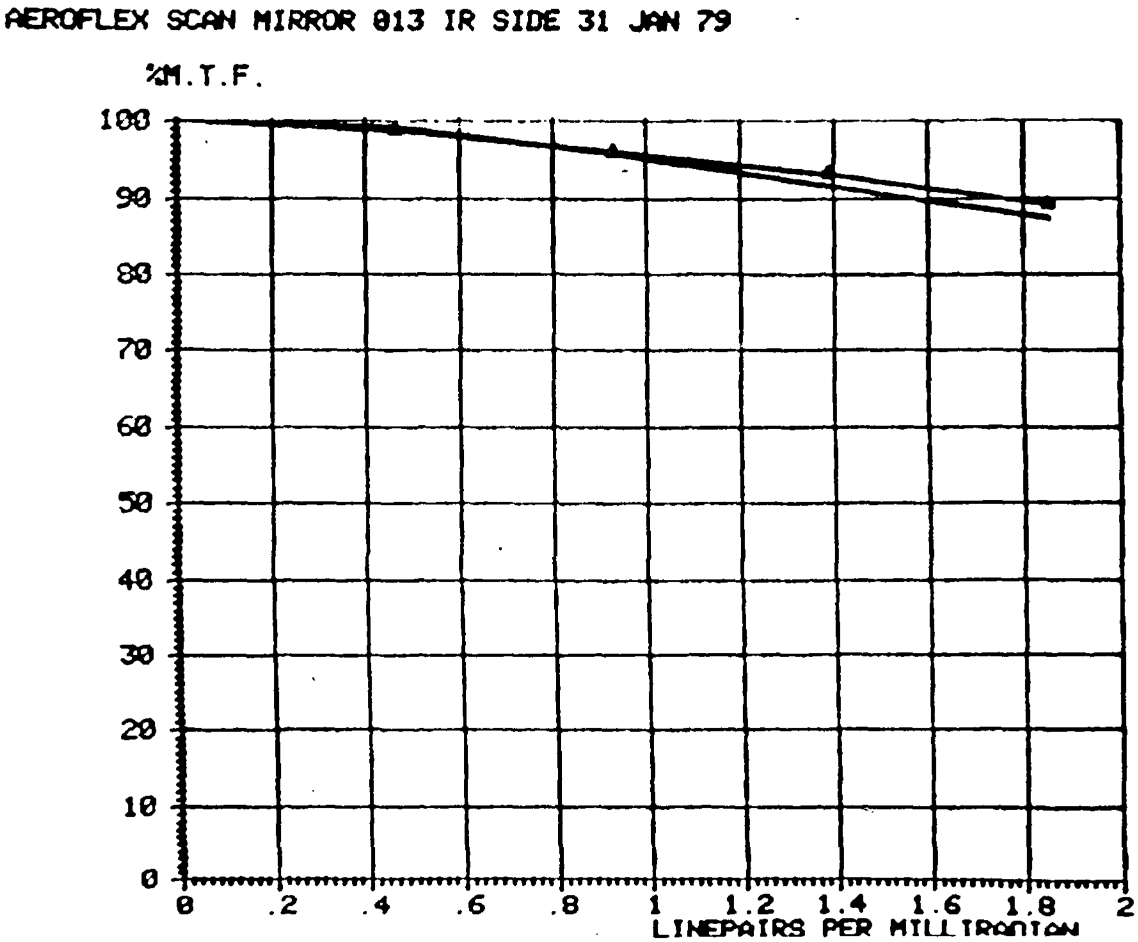


FIGURE 77. MTF RESPONSE, STATIC, S/N 013

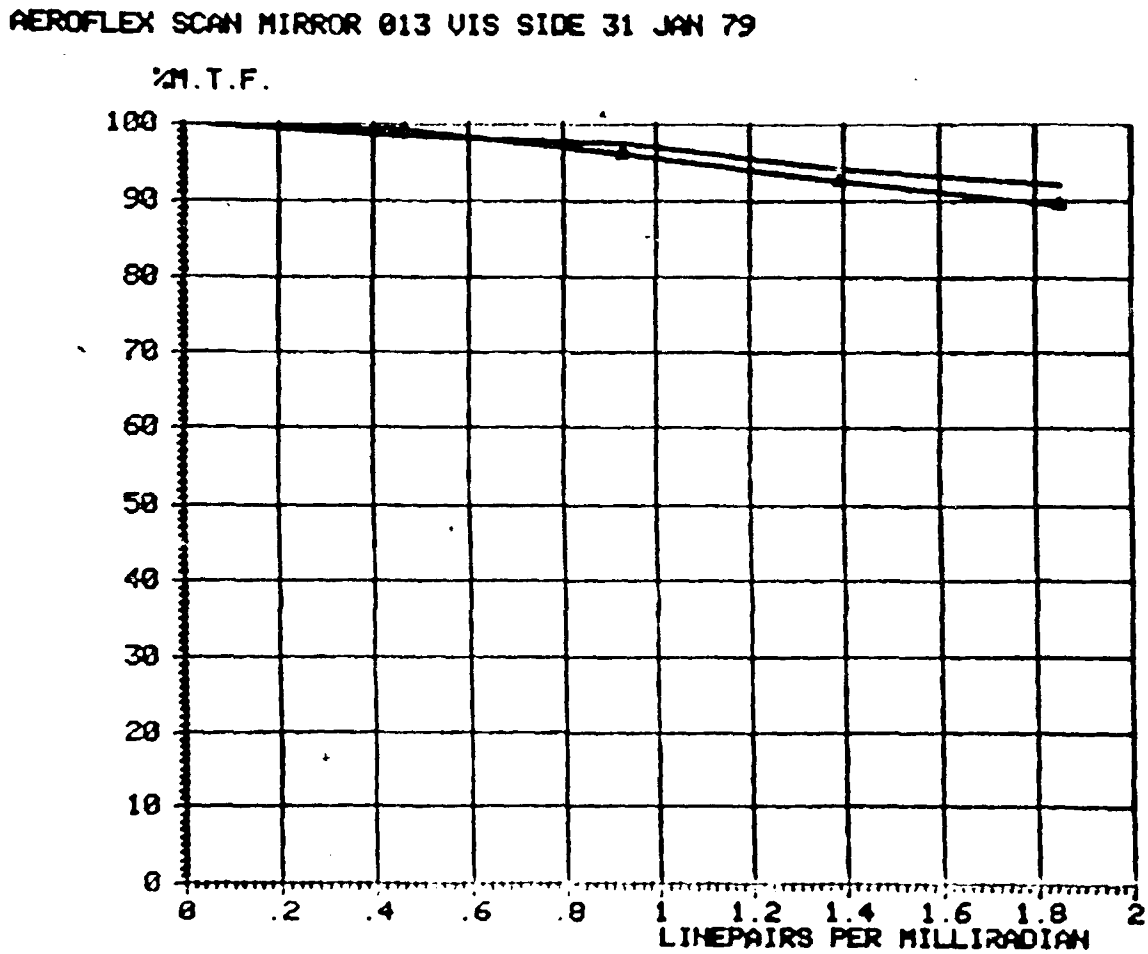


FIGURE 78. MTF RESPONSE, STATIC, S/N 013

IR SIDE

VISIBLE SIDE

FIGURE 79. INTERFEROGRAMS, MIRROR #014

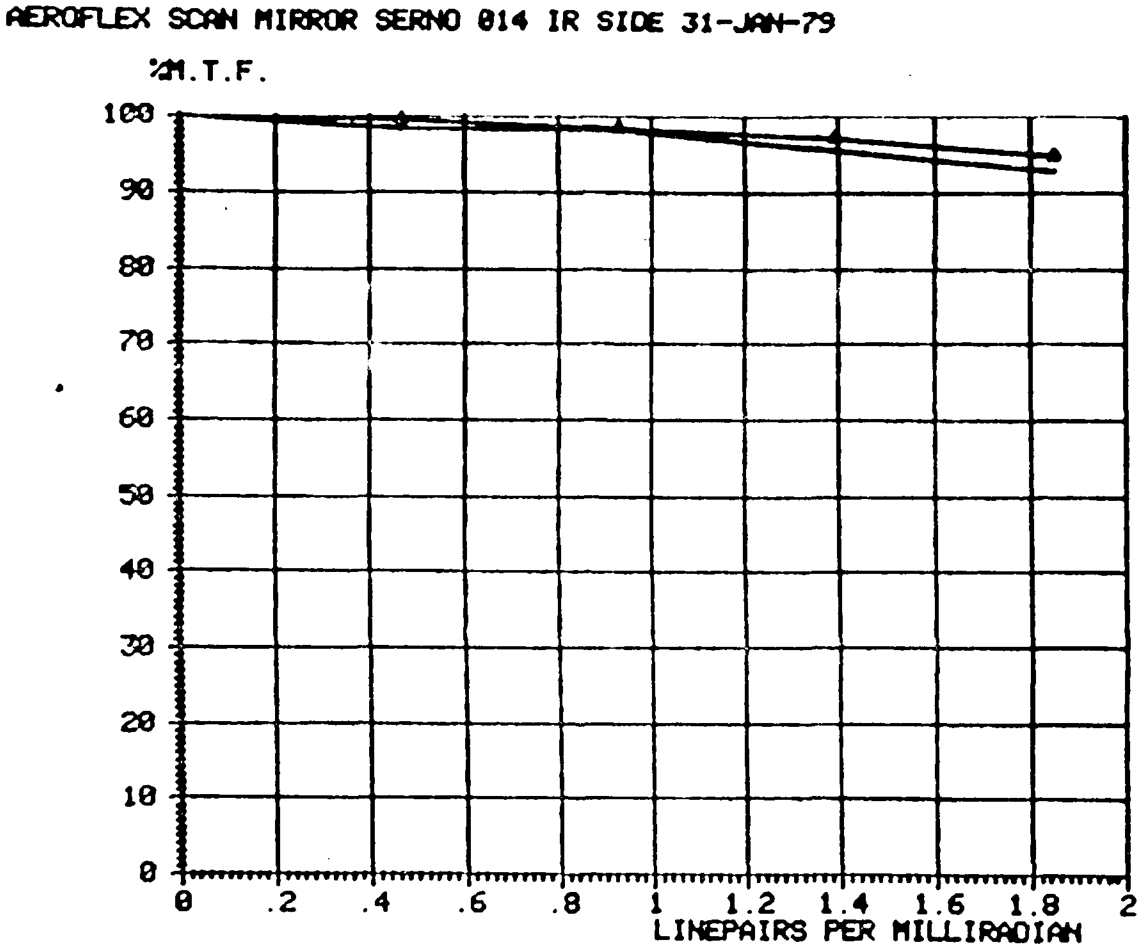


FIGURE 80. MTF RESPONSE, IR SIDE, MIRROR #014

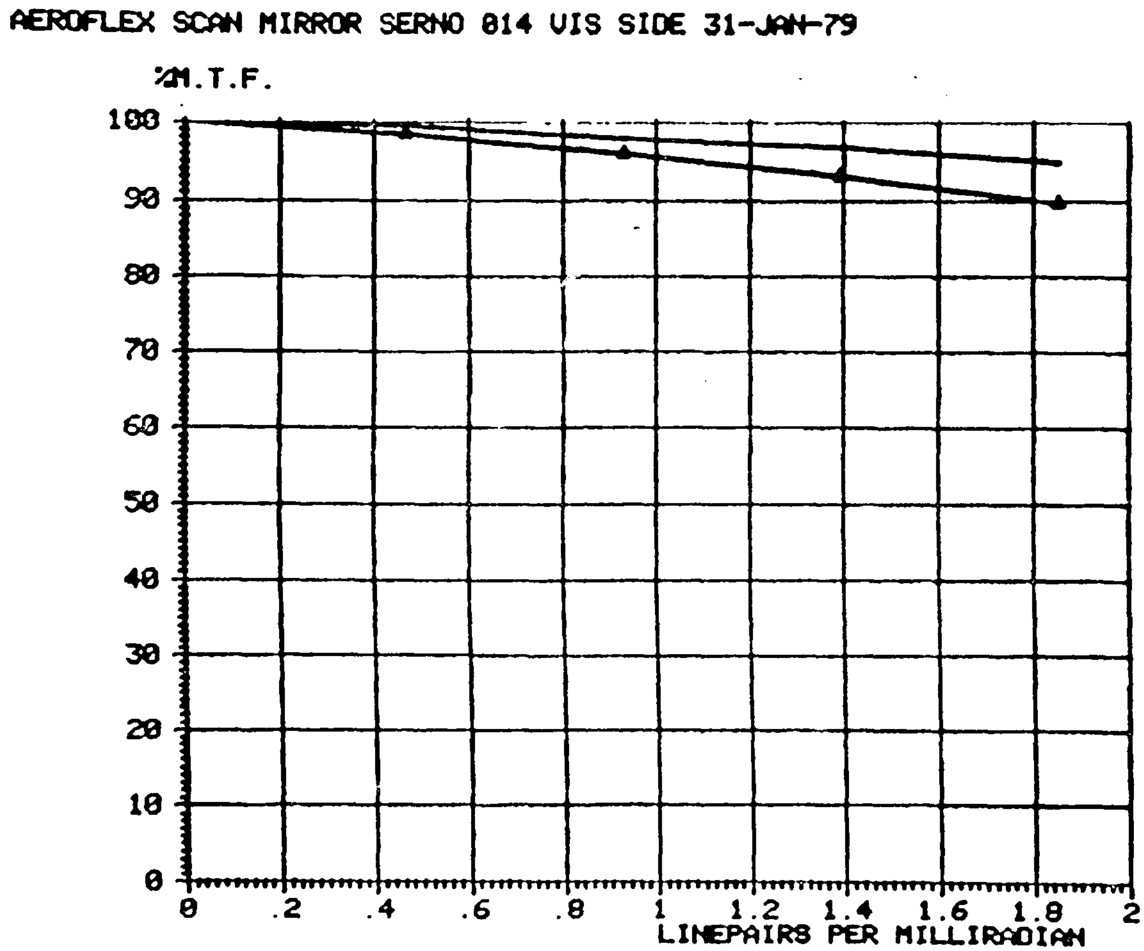
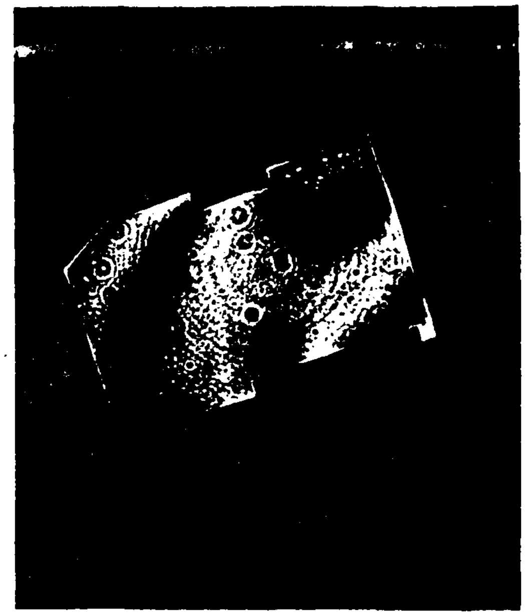


FIGURE 81. MTF RESPONSE, VISIBLE SIDE, MIRROR #014

AEROFLEX SN 15 IR

IR SIDE



AEROFLEX SN 15 VIS

VISIBLE SIDE

FIGURE 82. INTERFEROGRAMS, MIRROR #015

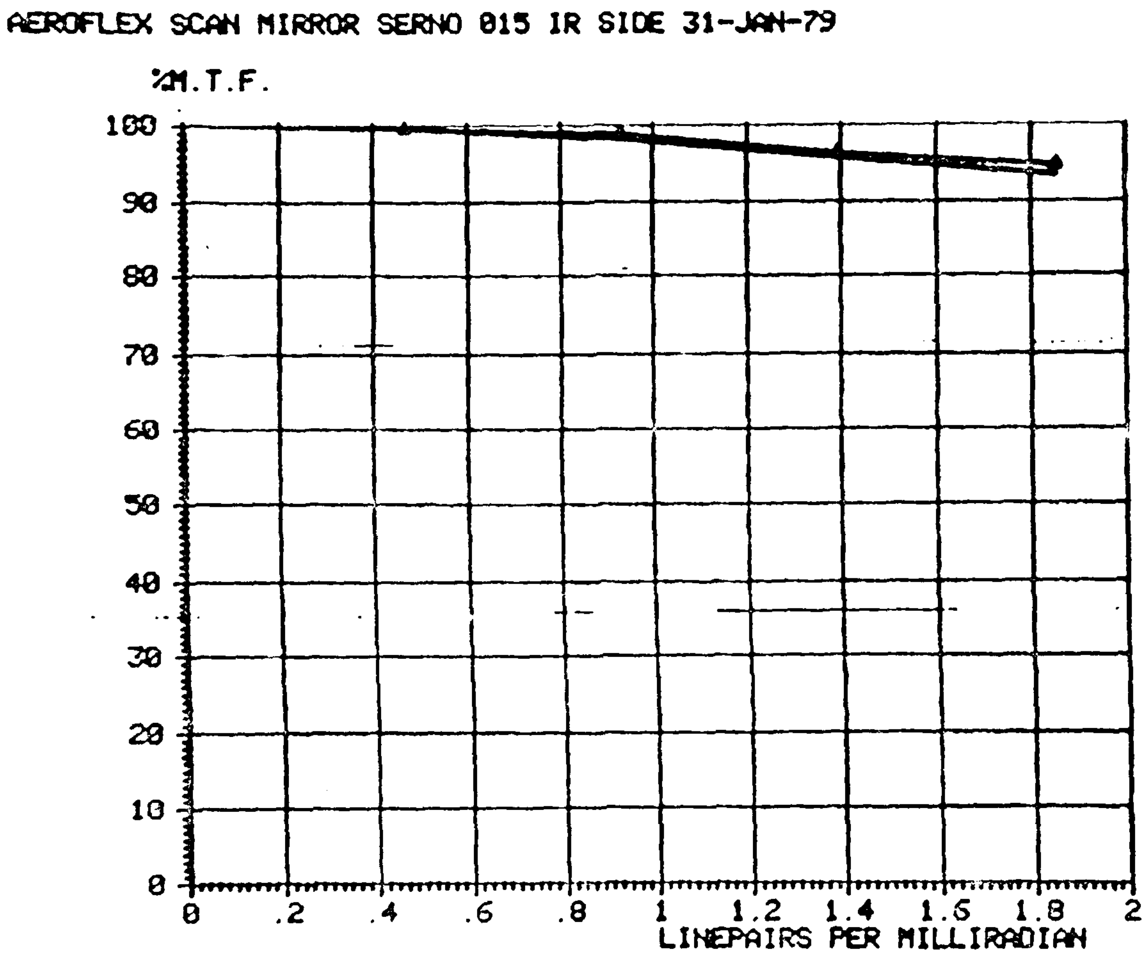


FIGURE 83. MTF RESPONSE, IR SIDE, MIRROR #015

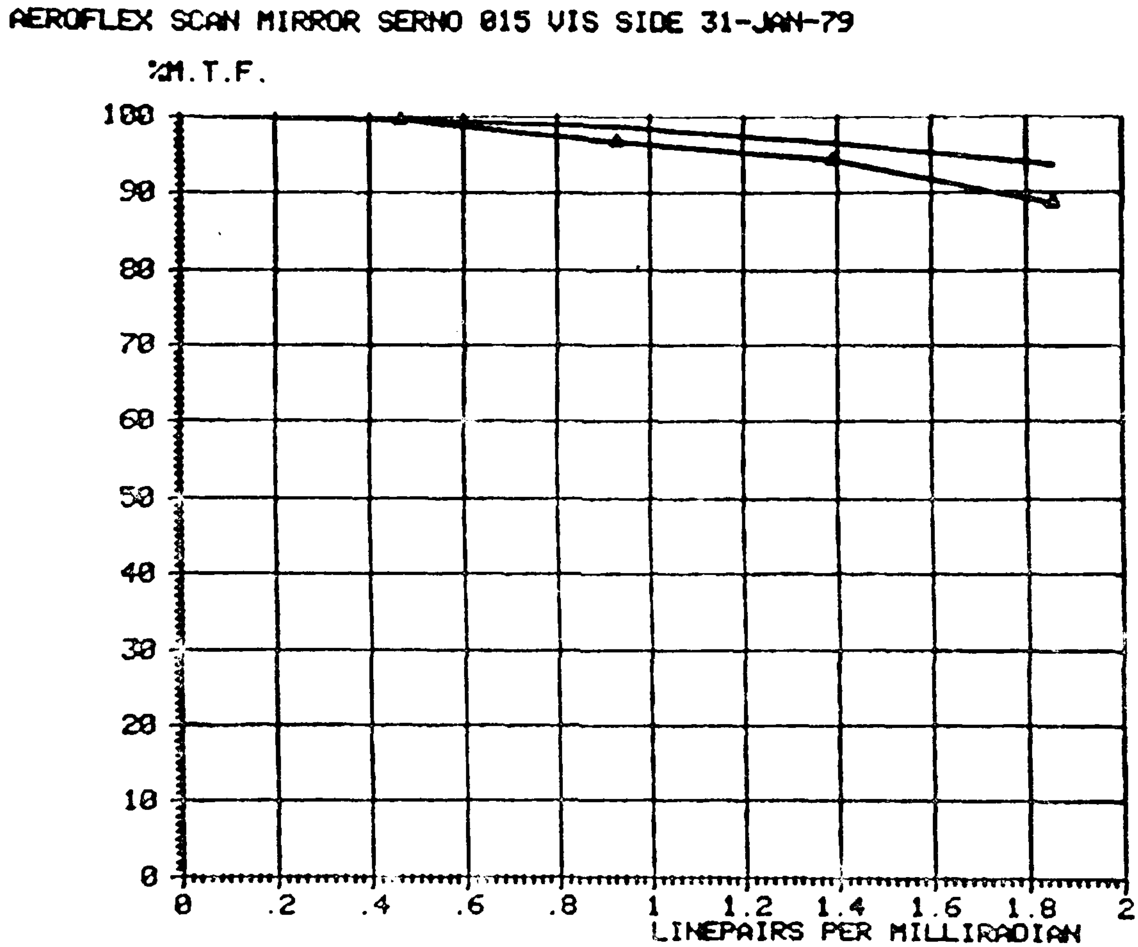


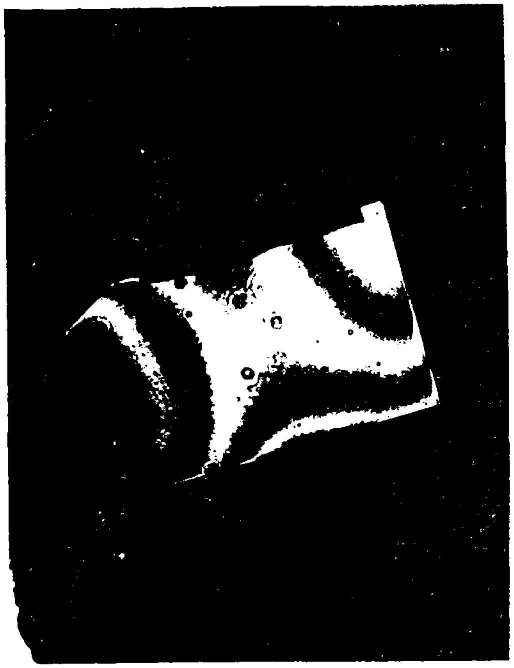
FIGURE 84. MTF RESPONSE, IR SIDE, MIRROR #015

responses taken for each side of the mirror. The Visible side shows some astigmatism in the elevation plane and correlation of this with the interferogram is extremely difficult. This astigmatism is minor because both sides of the mirror passed the MTF test requirement with a good margin.

Figure 85 shows the interferograms taken on Mirror #016. In this case, the Visible side shows some elliptical power but is regular. Both sides do not reflect any distortion due to the metal parts.

Figure 86 is a plot of the MTF response of the IR side and shows some astigmatism. However, the MTF at .667 Lp/mr is well above the required .95 and is therefore acceptable. Figure 87 is the MTF response for the Visible side of the mirror. The response is flat enough to meet the .95 requirement to about 1-5 Lp/mr which is excellent.

For the record, Mirrors #013 and #015 of this series were manufactured by Broomer Manufacturing, and #014 and #016 were manufactured by Trans World Optics. The two sets of mirrors were used to eliminate any correlation between mirror manufacturer and MTF. This is particularly true in this case because two different manufacturing techniques are employed.



IR SIDE

VISIBLE SIDE

FIGURE 85. INTERFEROGRAMS, MIRROR #016

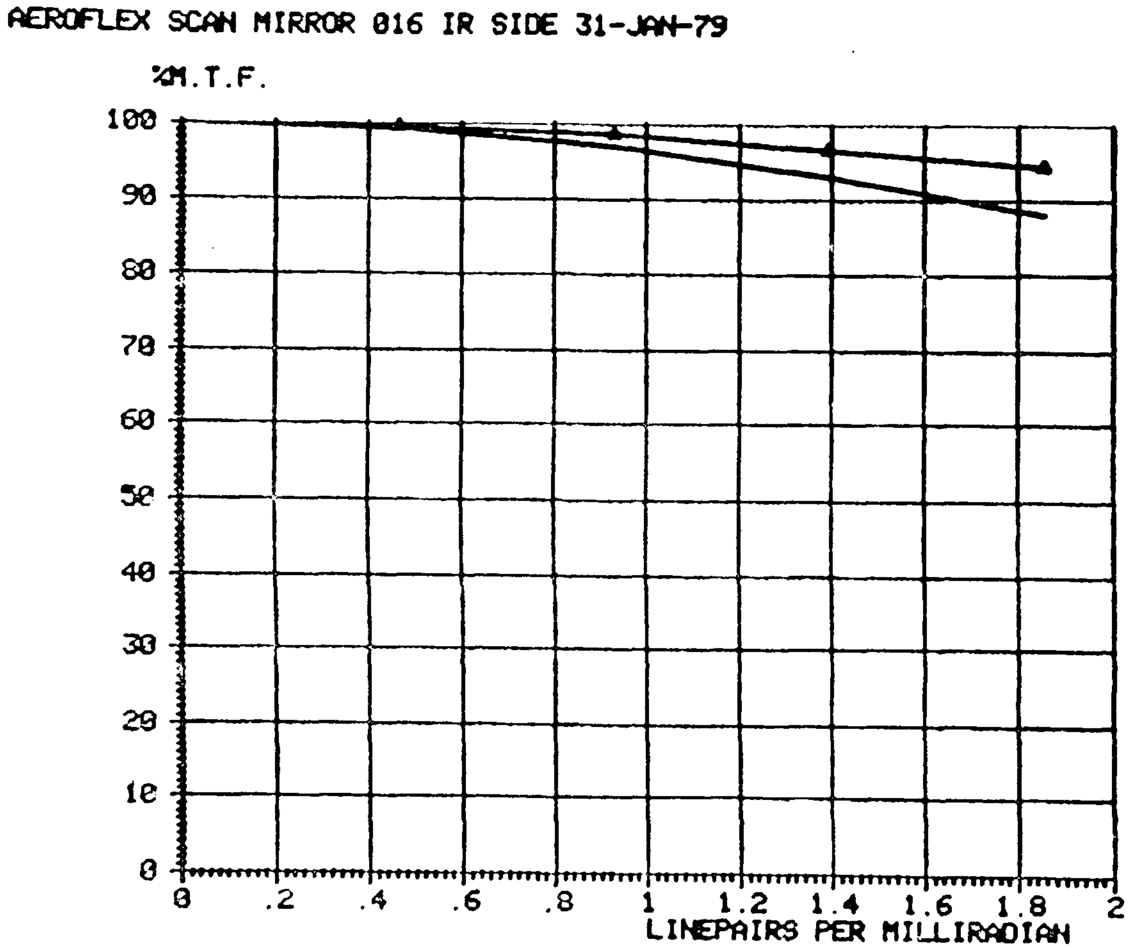


FIGURE 86. MTF RESPONSE, IR SIDE, MIRROR #016

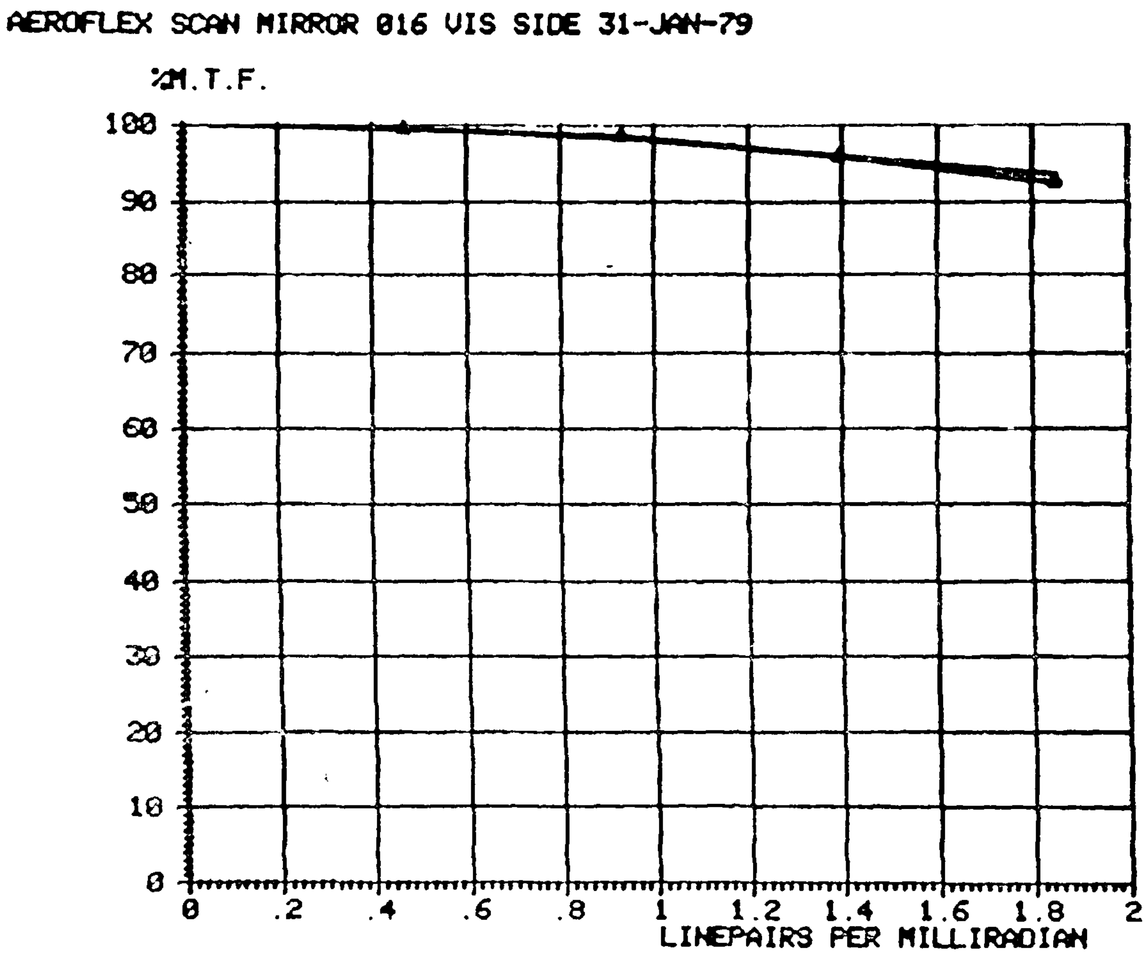


FIGURE 87. MTF RESPONSE, VISIBLE SIDE, MIRROR #016

As part of the study effort, arrangements were made to test the MIL-BOND epoxy at New York Testing Labs, Westbury, New York.

Two sets of tests were performed on five samples each. The tests are described below.

(a) Tensile-Shear. This test used the pyroceram substrate sandwiched between two standard aluminum strips and utilized the MIL-BOND as the adhesive. The samples were temperature cycled before the test and used two different cement thicknesses. The first was the manufacturer's recommended .014" gap and the second the .002-.003 gap presently used in the mirror assembly. This test was run at 95°C.

(b) Tension (Flat-wise). This test also utilized the MIL-BOND in two cement thicknesses and was temperature cycled before testing. In this test, the pyroceram was sandwiched between two 1" x 1" x 1" blocks and yields a value for the tensile characteristics of the bond. This test was also run at 95°C.

MILBOND TEMPERATURE TESTS

The test samples were made up according to MIL-A-48611 (MU) and in accordance with the ASTM Standards (see Figures 88 and 89 for flat-wise and tension test samples). The samples contained a 1" square of pyroceram and were polished to the same surface flatness as in the final mirror application. After the samples were made, the entire set of 10 units was subjected to the recommended NVL temperature cycle (Figure 90).

The high temperature tests were then run on the MILBOND samples at New York Testing Labs, Westbury, New York. Table I shows the various samples tested for both Tensile Shear and Tensile (Flat-wise) limits. One sample of each was run at room temperature for checking purposes.

TABLE I - TENSILE STRENGTH TESTS

			MILBOND Thickness (Both Sides)	Time @ 95°C Before Test	Stress Limit PSI
I	Flatwise	001	.014	4 hrs	1060
		002	.014	4 hrs	800
		003	.004	4 hrs	1042
		004	.004	4 hrs	1182
		005	.004	Rm	1750
II	Tension	001	.014	4 hrs	916
		002	.014	4 hrs	777
		003	.004	4 hrs	1028
		004	.004	4 hrs	1214
		005	.004	Rm	1600

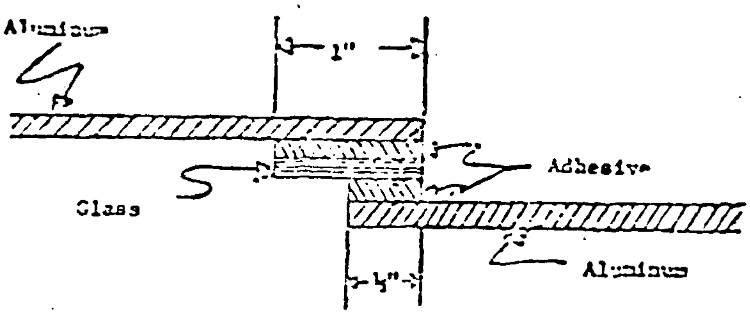


FIGURE 88. ASSEMBLY OF SHEAR SPECIMENS
(per MIL-A-48611(MU)

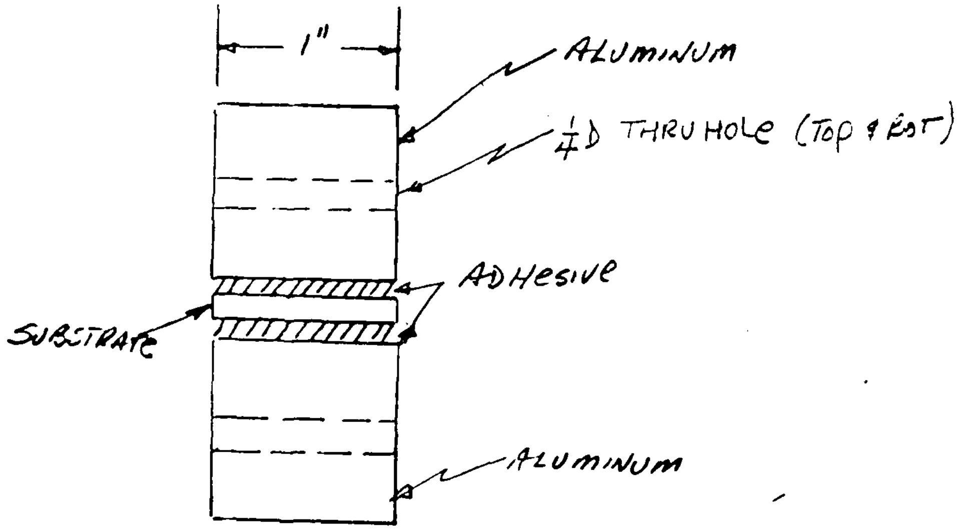
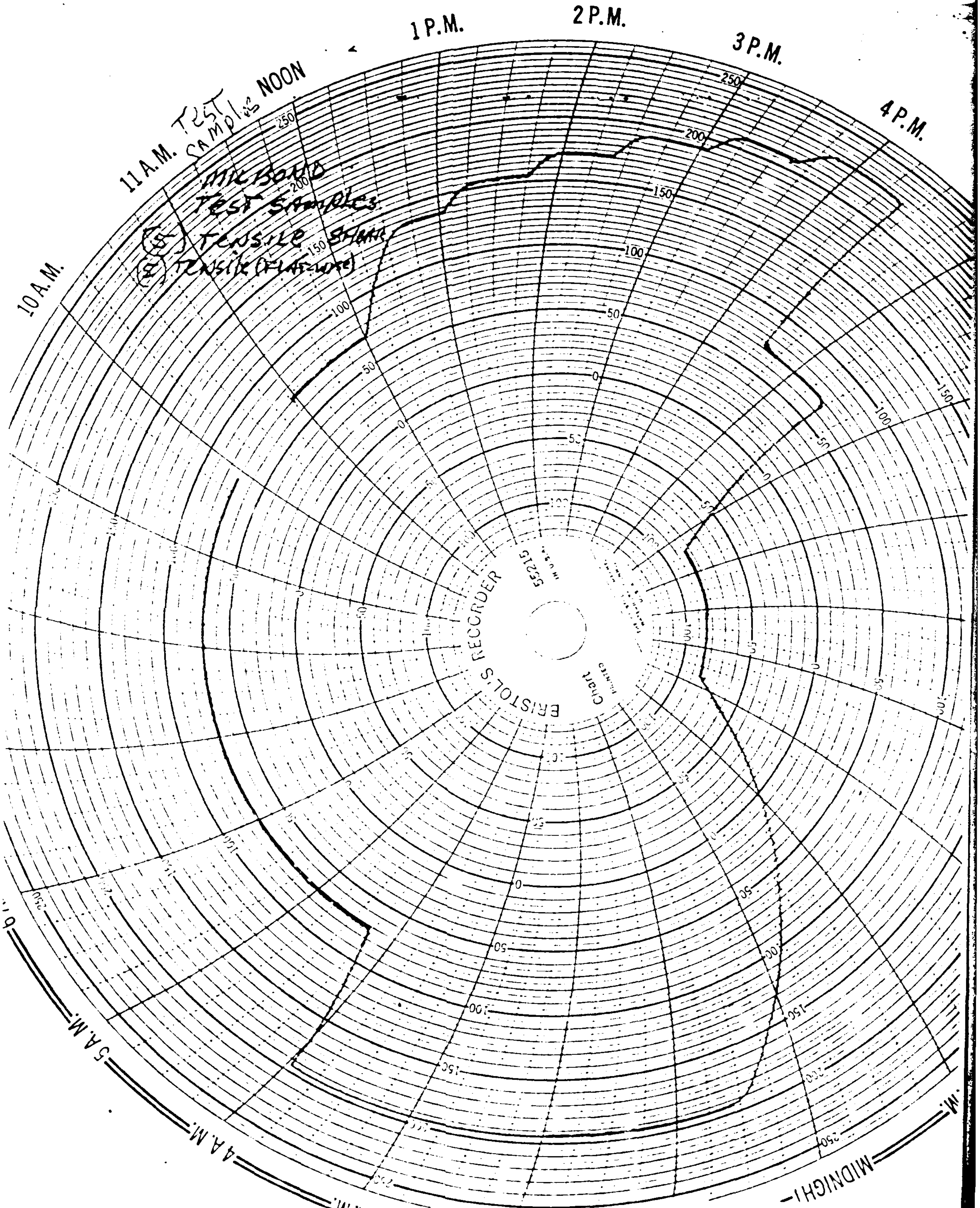


FIGURE 89. ASSEMBLY OF TENSION SPECIMEN



NOON
1 P.M.
2 P.M.
3 P.M.
4 P.M.
11 A.M.
10 A.M.
5 A.M.
4 A.M.
MIDNIGHT
TEST SAMPLES
MICBOND
TEST SAMPLES
(5) TENSILE SHEAR
(4) TENSILE (FLATWISE)
BRISTOL'S RECORDER
Chart
5215

FIGURE 90.

The average was taken for the two gap widths for each test and plotted against the original Milbond results obtained at Frankford Arsenal. These are shown in Figure 91. The temperature cycling (per NVL) has apparently reduced the low temperature strength by about 30% but has improved the high temperature strength by at least 75%. When the surface area of the mirror bond is examined, the total area (per side) is equal to .0945 in^2 for the arm return and .04095 in^2 for the minimum surface on the top cap. When the yield strength in tension for the 004" gap (1100 psi) is applied, the pull strength is 45# for the top cap. The worst case condition of 777 psi applied to the top cap yields a pull strength of 31.8 lbs @ 95°C. This is considered to be satisfactory.

Aeroflex contacted New York Testing Labs to determine whether their laboratory can perform the necessary tests to provide sufficient data to substantiate the use of this cement in the scanners. These tests were performed with the following results:

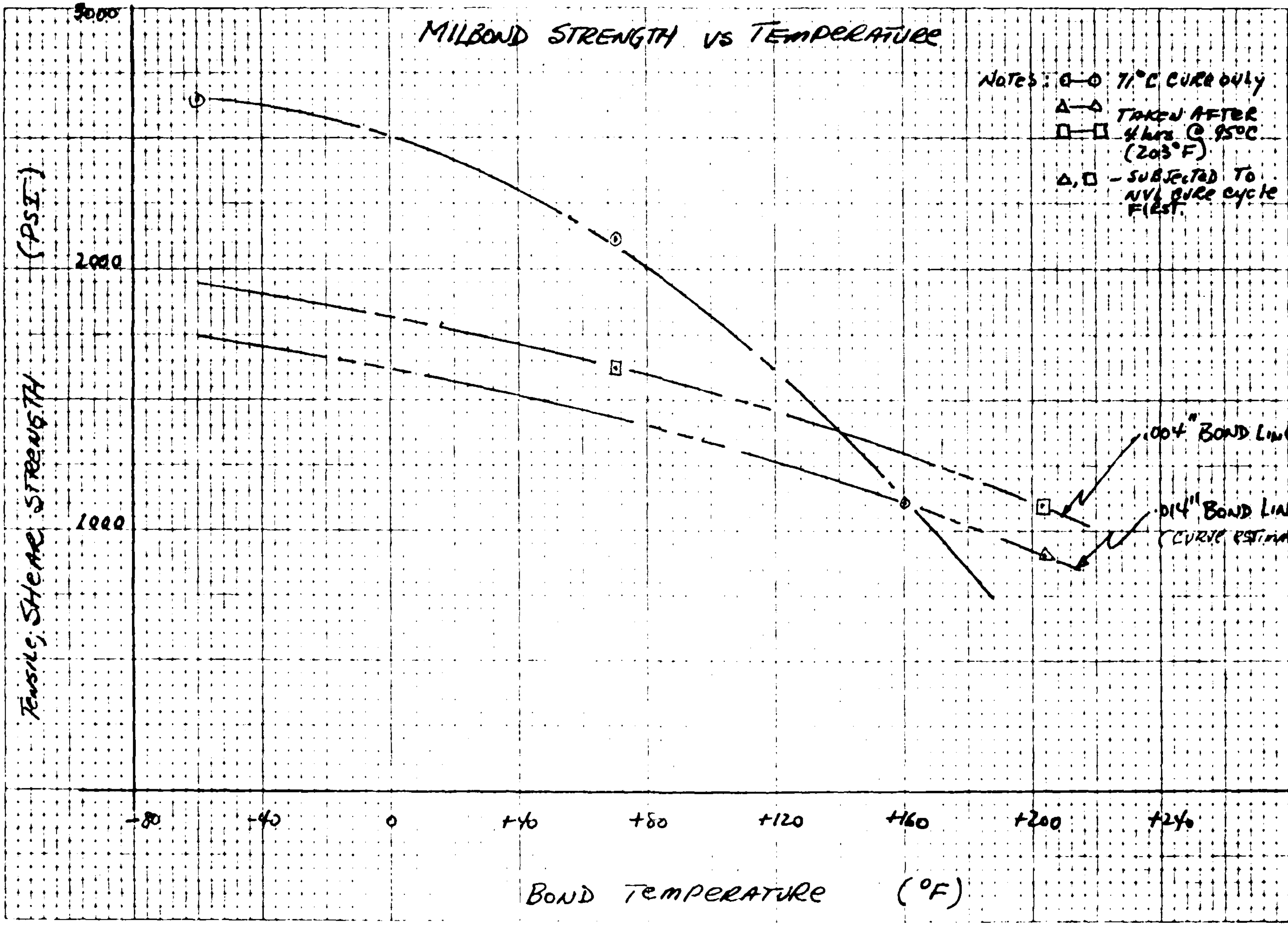


FIGURE 91. MILBOND STRENGTH VS TEMPERATURE

Two additional mirror assemblies were fabricated and tested and are discussed below.

Figure 92 is a set of interferograms taken on Mirror #017 after the NVL heat-treat cycle. This mirror was assembled using MilBond cement. As shown, the mirror exhibits a regular but somewhat spherical surface. The IR side shows about 1-1/2 fringes and the Visible about 1 fringe after heat cycling.

The resultant MTF responses are excellent. Figure 93 is a plot of the IR side response with an MTF of .95 or better at 1.6 Lp/mr with no astigmatism. Figure 94 is a plot of the Visible side with an MTF of .95 to about 1.55 Lp/mr and mirror astigmatism.

Figure 95 is a set of interferograms taken on Mirror #018. In this case, both sides are regular and spherical. The IR side shows about 2 fringes. The Visible side shows about 1-1/2 fringes worst case.

The resultant MTF responses are also excellent. Figure 96 is a plot of the IR side response. Here the MTF passes .95 at 1/8 Lp/mr with no apparent astigmatism.

VISIBLE

IR

FIGURE 92. INTERFEROGRAMS, S/N 017

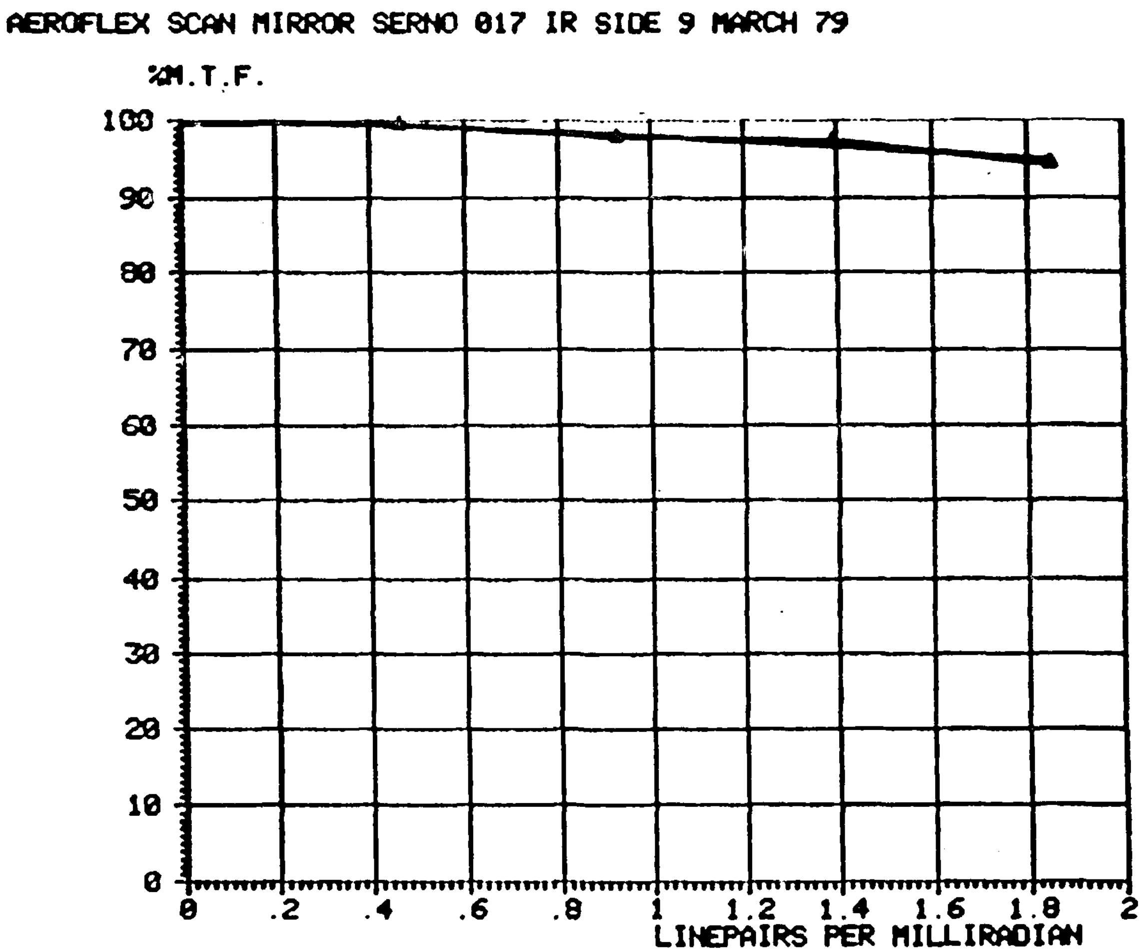


FIGURE 93. MTF RESPONSE, IR SIDE S/N 017

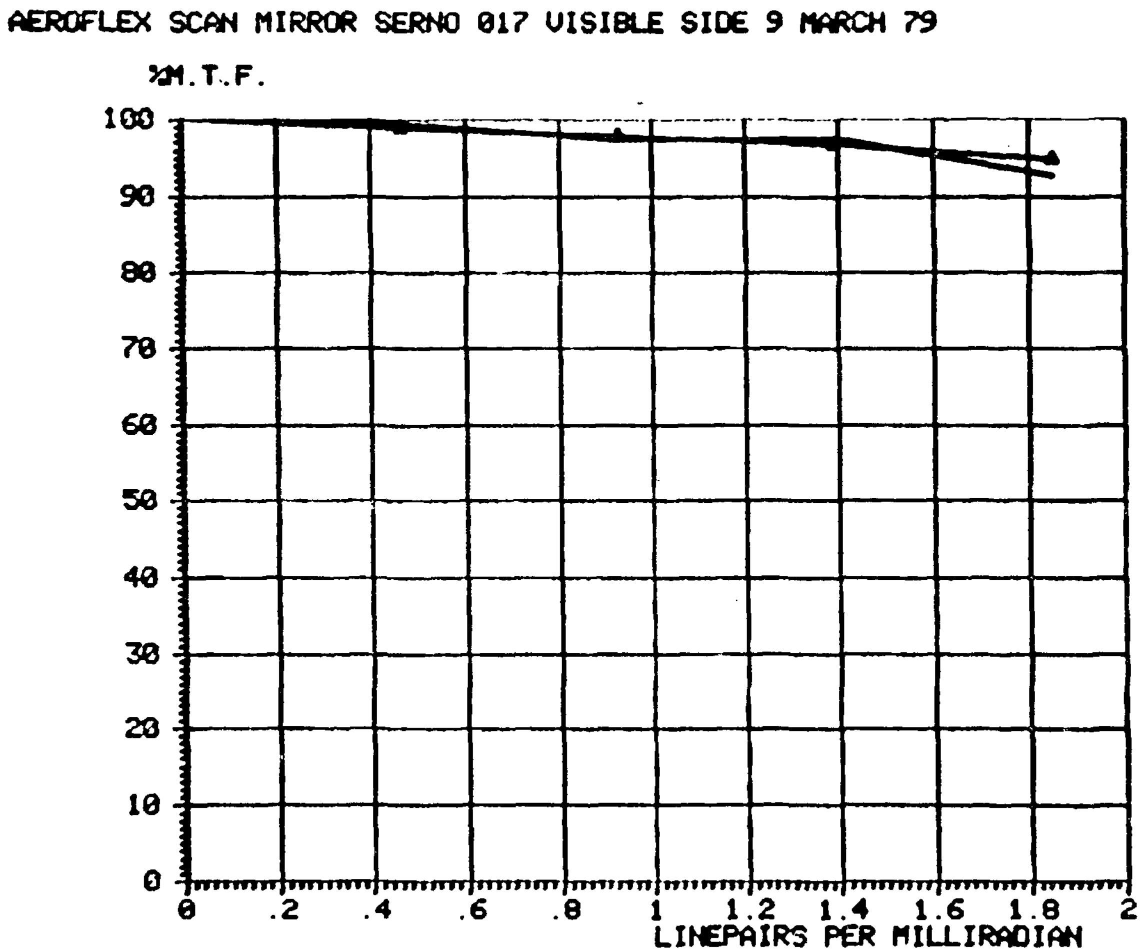


FIGURE 94. MTF RESPONSE, VISIBLE SIDE, S/N 017

VISIBLE

IR

FIGURE 95. INTERFEROGRAMS, S/N 018

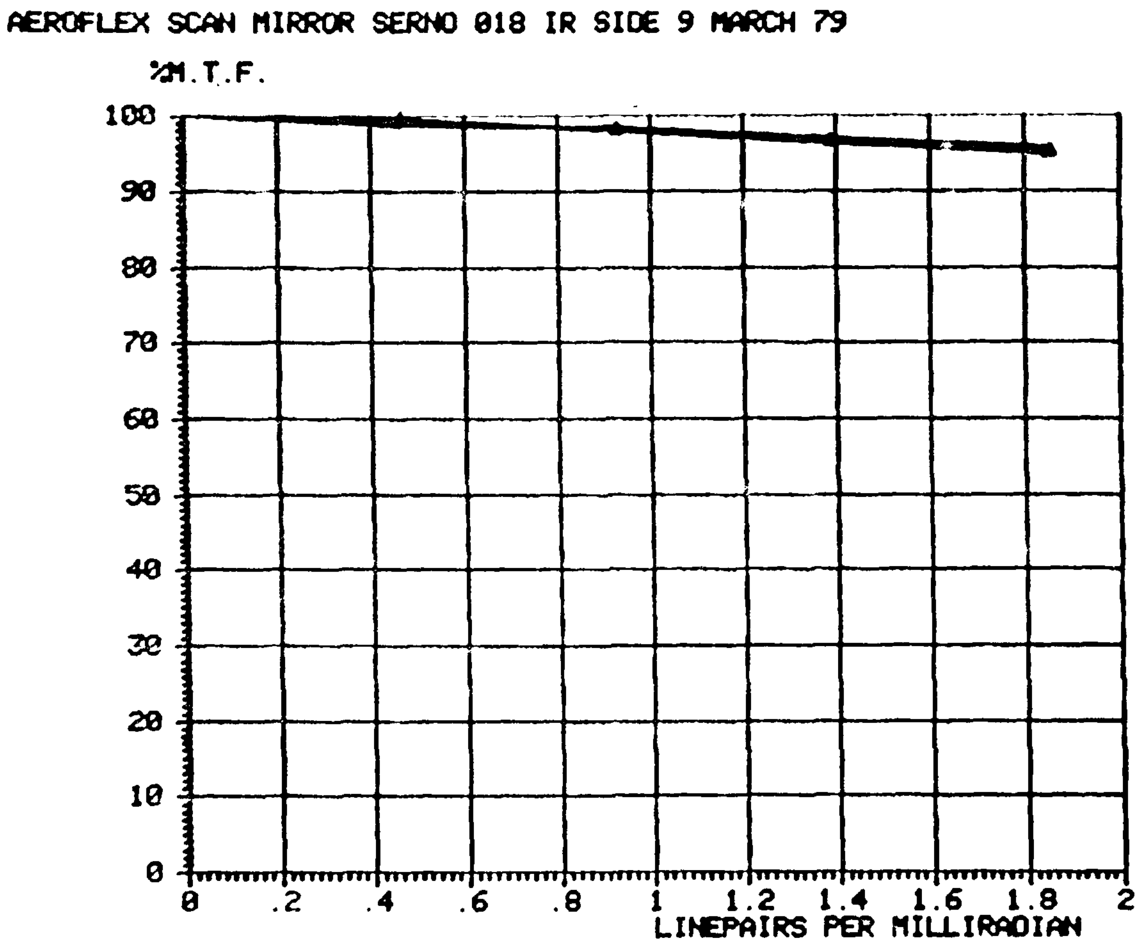


FIGURE 96. MTF RESPONSE, IR SIDE, S/N 018

Similarly, Figure 97 shows that the Visible side has an MTF of .95 to at least 1.8 Lp/mr.

With these mirrors, a total of 9 mirrors out of 9 assembled have passed the required MTF test with outstanding results. These results speak for themselves.

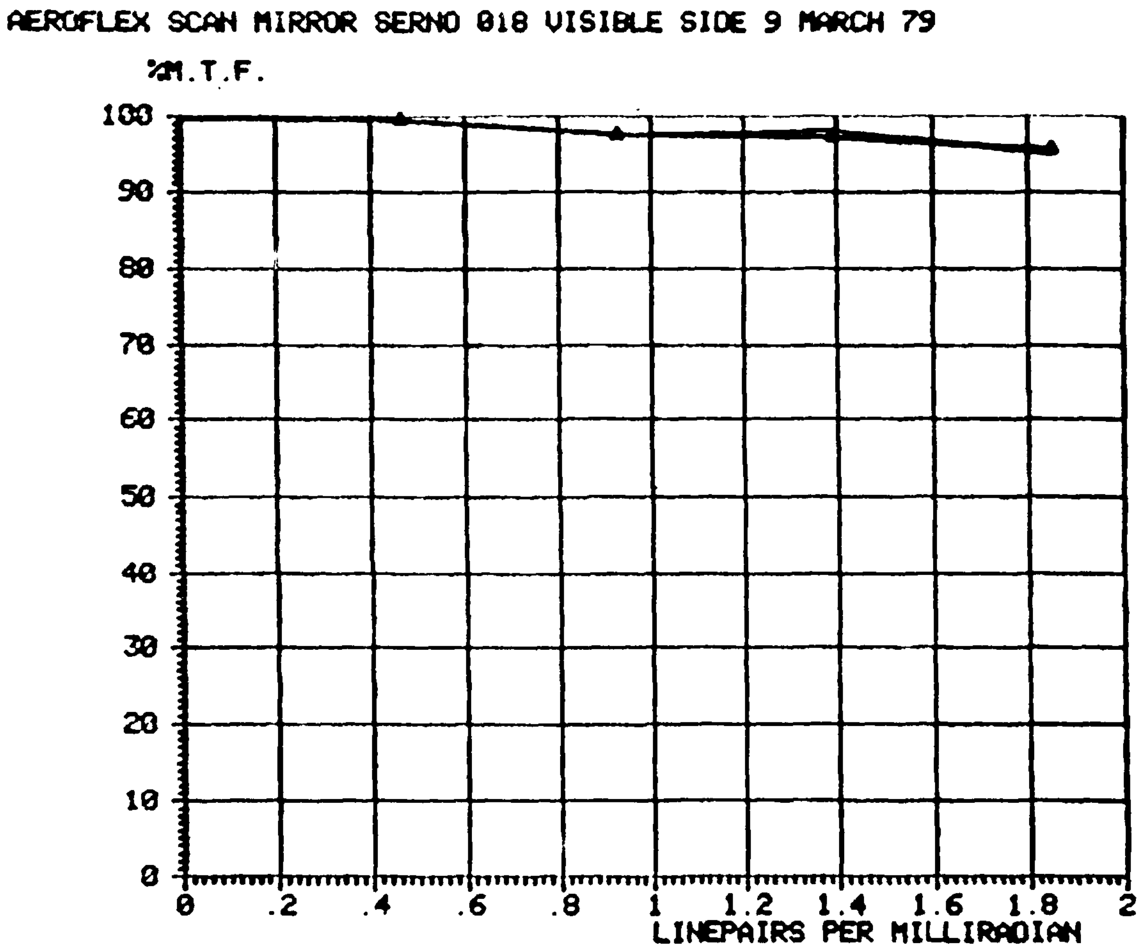


FIGURE 97. MTF RESPONSE, IR SIDE, S/N 018

CONCLUSIONS

The conclusions drawn from the results of this mirror study fall into two separate categories. The first are those derived from the use of the Stycast resin as the bonding material. The second category concerns the use of Milbond as an alternate cementing material.

I Stycast Cement

The conclusions which have been drawn with respect to the Stycast epoxy resin are listed below and each is discussed in some detail.

Temperature Coefficient. The choice of the Stycast cement with respect to temperature coefficient was originally a compromise between three diverse metals. These were Steel (top cap), Beryllium (substrate) and Aluminum (arm return). Although data is not available to the contrary, it is assumed that the cement met the environmental requirement for bonding these metals and holding under all conditions. However, during the course of the scanner program the mirror material was changed to a glass-ceramic (Pyroceram). It is apparent that even though the substrate material was changed, no tests were made to determine if the cement had any deleterious effects on the mirror quality at that time.

Temperature Coefficient (continued).

In addition, no hard data exists as to whether this cement is still a good compromise from a temperature coefficient viewpoint. As is shown below, the temperature coefficient is satisfactory but is the least of the problems generated by the use of this cementing material.

Optical Performance Effects

1. Since the overall optical performance rests, in the final analysis, upon the scan mirror, the effects of the assembly process upon the optical quality of the mirror can be attributed to the cement. While there have been parallel efforts to relieve some of the stresses in the mirror assembly parts, the primary conclusion is that the cement is the major contributor to poor mirror assembly optical performance.

2. Stress relief in the assembly procedure still results in mirror distortion. The amount of distortion is random.

3. While mirror assemblies have been made which pass the required MTF tests, the results have not been repeatable with any consistency.

4. The mirror specification allowing up to four fringes is not consistent with the final assembly distortion limits. Any additional distortion due to the assembly will put the mirror out of the MTF spec requirements.

5. The recommended temperature cycle (per NVL) for Stycast polymerization helps but given an initial distortion will not relieve that distortion by any significant amount.

6. The mirror substrate does not affect the overall distortion to the extent that the cement does. Recycling the mirror to its original state repeats the initial optical performance.

7. The thinner band line increases the cement strength and contributes to a lowering of the assembly distortion. It is overwhelmed by the cement in the final distortion of the assembly.

8. Stress relief in the metal parts (top cap and arm return) probably alleviates the situation but it is a time consuming and costly process.

II Milbond Cement

The following conclusions have been drawn with respect to the Milbond cement as an alternate mirror assembly material.

1. The stress imposed by the cement after air cure or cure at 71°C or after the recommended NVL temperature cycle is minimal.

2. The temperature coefficient of this cement is compatible with the metal parts and the substrate.

3. The cement has survived operation at elevated temperature (98°C) and has shown no intrinsic change in its characteristics.

4. The thinner band line yields a higher strength at elevated temperatures than the recommended gap.

5. The cement is suitable for use as an alternate to the Stycast epoxy resin. Of the seven mirrors assembled with this cement, all have passed the MTF test. All were tested statically with excellent results. One dynamic test (after elevated temperature test) was made with excellent performance achieved.

III General Conclusions

The following conclusions apply to the mirror assembly and are independent of the cement or assembly technique used.

1. The correlation between the interferogram and the resulting MTF performance is difficult if not impossible to establish by eye. If the patterns shown on the interferogram are regular and can be shown to be less than 2 fringes, the assembly will probably pass. An irregular surface (saddled or other irregularity) will probably not pass since the resultant astigmatism is difficult to establish by eye.

2. The total number of fringes shown on a test interferogram are less important than the regularity of the surface. That is, a 3 fringe spherical surface may have a better MTF response than a 2 fringe saddled surface.

3. Once the mirror in the assembly is distorted and astigmatism is present, a significant variation in MTF response can result. With this distortion, the optimum focus between sagital and tangential can be found but the MTF will be poorer than a mirror with a

III General Conclusions (continued)

regular surface. Moreover, depending upon the focus chosen, there can be a reversal in the MTF response between the elevation and azimuthal axes. This will occur only during the statis MTF testing.

RECOMMENDATIONS

As a result of this mirror study results, the following recommendations are made.

1. Pending determination of the operation of the mirror assembly under vibration and at elevated temperature, the Milbond cement should be approved as an alternate cement.

2. It is recommended that NVL assist in determining whether this material is satisfactory or not and to come to a rapid conclusion as to its suitability for production usage.

3. It is recommended that additional tests be made on Milbond to determine additional physical characteristics so that final approval can be substantiated.

4. It is recommended that additional work be undertaken to find other cements as suitable for this application for back-up purposes in production.

APPENDIXES

MIRROR SECURED WITH MILBOND ADHESIVE MIL-A-48611(MU)

Unit Subjected to +98°C as noted below on Scanner S/N 003, Mirror 009B

AGC Volts

1.88	at start		
2.12	at +95°C	08:30 hrs	5.05 Watts
2.30	+96°C	08:40 hrs	
2.36	+97°C	08:50 hrs	
2.41	+98°C	09:00 hrs	
2.47	+98°C	09:10 hrs	
2.51	+98°C	09:20 hrs	5.37 Watts
2.54	+98°C	09:30 hrs	

Shut down for visual inspection at 09:30 hrs. No visible signs of bond failure.

Test continued 2:00 pm. Chamber raised to +95°C and Scanner turned on.

2.21	at +98°C	14:20 hrs	
2.40	+98°C	14.40 hrs	
2.68	+98°C	15:40 hrs	
2.74	+98°C	16:00 hrs	
2.78	+98°C	16:20 hrs	
2.78	+98°C	16:25 hrs	Test Stopped.

No apparent degradation of bond.
Slight change in surface "shine".
No pitting, flow or cracks for either arm return or top cap.

Witnessed by M. Halpern, 1/16/79

Verified by C. Creech, NV&EOL, 1/16/79

Lab No: 79-55018

Date: February 8, 1979

NEW YORK TESTING LABORATORIES, INC.

P.O. BOX 484, 81 URBAN AVENUE, WESTBURY, L.I., N.Y. 11590 • (516) 334-7770 • (212) 297-1449

REPORT OF TESTS

Client	—	79-55018 - Aeroflex Laboratories, Inc.
Material	—	Ten (10) Milbond Resin Samples
Client's Order No.	—	C-25295
Identification	—	As Indicated Below
Submitted for	—	Tension Tests

PROCEDURE

The submitted samples were tested in a Tinius Olsen Universal Testing Machine.

Four (4) samples from each group were heated at 95°C for four (4) hours and while still at that temperature they were tested.

One (1) sample from each group were tested at room temperature (23°C).

RESULTS

See the following page.

Type of Test	Serial No.	Test Temperature °C	Gap inches	Area sq. in.	Maximum Load lbs.	Tensile Strength PSI
Tension Flat-Wise	001	95	0.014	1.0	1,060	1,060
	002	95	0.014	1.0	800	800
	003	95	0.004	1.0	1,042	1,042
	004	95	0.004	1.0	1,132	1,182
	005	23	0.004	1.0	1,750	1,750
Tension Shear	001	95	0.014	0.5	458	916
	002	95	0.014	0.5	388	776
	003	95	0.004	0.5	514	1,028
	004	95	0.004	0.5	607	1,214
	005	23	0.004	0.5	800	1,600

We certify that this report is a true report of results obtained from our tests of this material.

Respectfully submitted,

NEW YORK TESTING LABORATORIES, INC.

G. J. Harvey, President

To:

Aeroflex Laboratories, Inc.
South Service Road
Plainview, New York 11803

Att: Mr. M. Halpern

mg

DATE

FILME