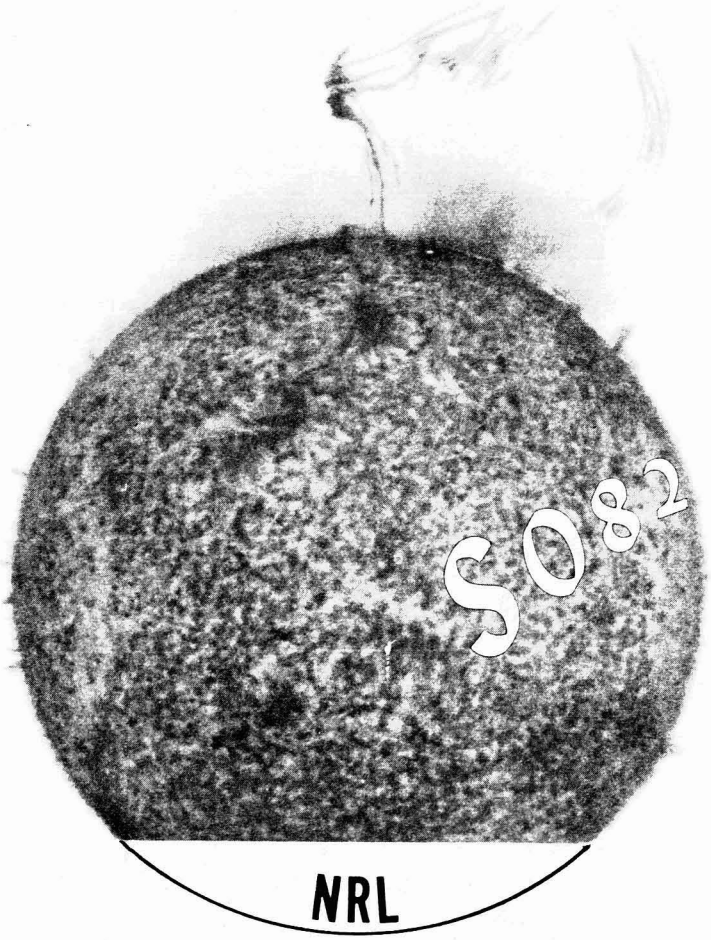
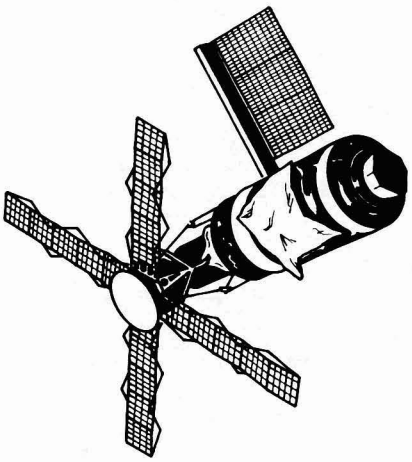
NRL/ATM
THERMAL DISTORTION PERFORMANCE
for
S082A AND S082B INSTRUMENTS





VOLUME I
THERMAL DISTORTION
PROGRAM DESCRIPTION

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BALL BROTHERS RESEARCH CORPORATION
SUBSIDIARY OF BALL CORPORATION
BOULDER, COLORADO

BALL BROTHERS RESEARCH CORPORATION

BOULDER, COLORADO

NRL/ATM
Thermal Distortion Performance
for
S082A and S082B Instruments

620-238 1 May 1974

Contract No. N00014-67-C-0470
Contract Modification
P00055

PREPARED

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NRL/ATM Program Manager

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Volume I
Thermal Distortion Program Description

NRL/ATM
THERMAL DISTORTION PERFORMANCE
FOR
S082A and S082B Instruments

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FOREWORD

This report summarizes the Thermal Distortion Program for the S082 Instruments during the Skylab Missions. This document consists of five (5) volumes and was prepared by Ball Brothers Research Corporation, Boulder, Colorado, for the Naval Research Laboratory, Washington, DC, under Contract No. N00014-67-C-0470. The authority for this document is BBRC Proposal C-474 which was added to the contract by Contract Modification P00055.

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Volume IV	SO82B Thermal Distortion Plots: SL-4 Mission DOY332 to DOY 362
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Section 1

INTRODUCTION

The purpose of this report is to describe the development and use of the thermal distortion computer programs used to analyze the thermal performance of the Naval Research Laboratory S-082A and S-082B Instruments during the Skylab missions.

The programs were developed for the purpose of providing near real-time thermal distortion data from which scientific data acquisition decisions could be made during the Skylab missions. In addition, the thermal distortion data generated during the missions would be useful for post-mission scientific data analysis.

Section 2

THERMAL PROGRAM DESCRIPTION

2.1 SUMMARY

The thermal distortion programs for S082A and B were developed for the purpose of providing near real-time thermal distortion data from which data acquisition decisions could be made during the Skylab/ATM missions. In addition, the distortion data generated during the missions would be useful for post mission scientific data analysis.

The first purpose was not totally realized because the required Skylab telemetry data tapes were normally not available for use until 5 to 6 days after the data acquisition date. In addition, during the Skylab SL-1/SL-2 mission no thermal distortion program runs from Skylab tape were made because of program problems caused or aggravated by data format changes, tape read routine changes, missing data and noise on the tapes. Several computer runs were made using data from the real-time or MDRS consoles at Johnson Space Center. The data was transmitted to MSFC, hand punched on cards and input to the thermal distortion program. The results of these runs are included in Appendix A; A-1 and A-2.

All program problems were solved during the period between Skylab SL-1/SL-2 and the early part of the SL-3 mission. Thirteen thermal distortion runs were made for each instrument during the SL-3 mission. A run list and data summary are included in Appendix A; A-3.

Ten thermal distortion program runs were made to analyze the thermal performance of the S082A instrument during the SL-4 mission. Run times and a data summary are included in Appendix A, A-4.

Forty-nine S082B thermal distortion computer program runs were made during the SL-4 mission. The runs included 27 orbits during the Comet Kohoutek observations and seven orbits during the full sunlit orbits. The run times and a data summary are included in Appendix A, A-4.

The thermal distortion parameter plots are contained in Volume II, III, IV, and V. Volume II contains plots for all Skylab missions for S082A. Volume III contains plots for Skylab SL-3 mission DOY 219 through DOY 251 for S082B. Volume IV and V contain plots for SL-4 for S082B.

2.2 DISCUSSION

Figures 1 and 2 provide a block diagram and flow chart of the thermal distortion program. The basic building blocks of the program are the thermal analytical models used in the thermal design analyses and the structural models used for stress and dynamics analyses. The thermal model node breakdown for S082A is depicted in Figures 3 through 10. The S082A structural model is shown in Figure 11. The S082B thermal model node breakdown is given in Figures 12 through 22 and the S082B structural model is shown in Figure 23.

The thermal and structural models were updated to the flight hardware configuration and the thermal analytical predictions compared with data from the flight unit tests run at Johnson Space Center. Appendix B provides a description of the tasks performed in developing the structural part of the thermal distortion program. Thermal input to the program consists of node temperatures for each node describing the instrument thermal model.

The adequacy of the thermal model to predict instrument temperatures was checked by comparing calculated instrument temperatures computed using the thermal model and environmental temperatures from the flight unit tests with corresponding instrument probe temperatures measured during the test.

The model was updated by modifying the radiation exchange factors, conductances etc. until the calculated mean case temperatures agreed with the case temperature computed by averaging the temperature probe data from the flight unit tests. The criteria for agreement was approximately 0.2^{o}F for the two tests run a JSC. This 0.2^{o}F corresponds to 10 percent of the allowable defocus for the S082B and about 2.5 percent of the allowable defocus for S082A. This error was reduced in the flight analyses because in the analytical development previously described, all instrument case temperatures were calculated for an input environmental temperature distribution, whereas in the flight analyses, the measured instrument temperatures were also input as specified temperatures. Twelve of the 64 instrument case node temperatures for S082A and 25 of the 84 instrument case node temperatures for S082B were flight measurements.

The total thermal models consisted of 215 nodes for S082A and 344 nodes for S082B. Forty-three probe temperatures for S082A and 119 probe temperatures for S082B, including quadrant environmental temperatures were read from Skylab tape at 0.025 hour (1.5 minute) intervals during each orbit. These data were input to the transient thermal analysis program as time dependent specified temperature tables. The output of this transient thermal analyses program is the thermal model node temperature/time array, T_t, of Figure 2. The temperature/time array T_t, for each output time interval, normally 0.05 hour (3 minute) is input to the optical distortion matrix multiplication program (Figure 2) which generates the instrument optical distortion parameters at each time interval. The optical thermal distortion parameters are output in both

tabulated and plotted format. The thermal distortion parameter plots for all S082A and S082B program runs made during the Skylab missions are included in Volumes II through V of this report. The tabulated data is stored in the S082 project files.

The thermal distortion sign convention, and maximum allowable thermal distortions are shown in Figures 24 and 25 and Table 1 for S082A and in Figures 26 and 27 and Tables 2 and 3 for S082B.

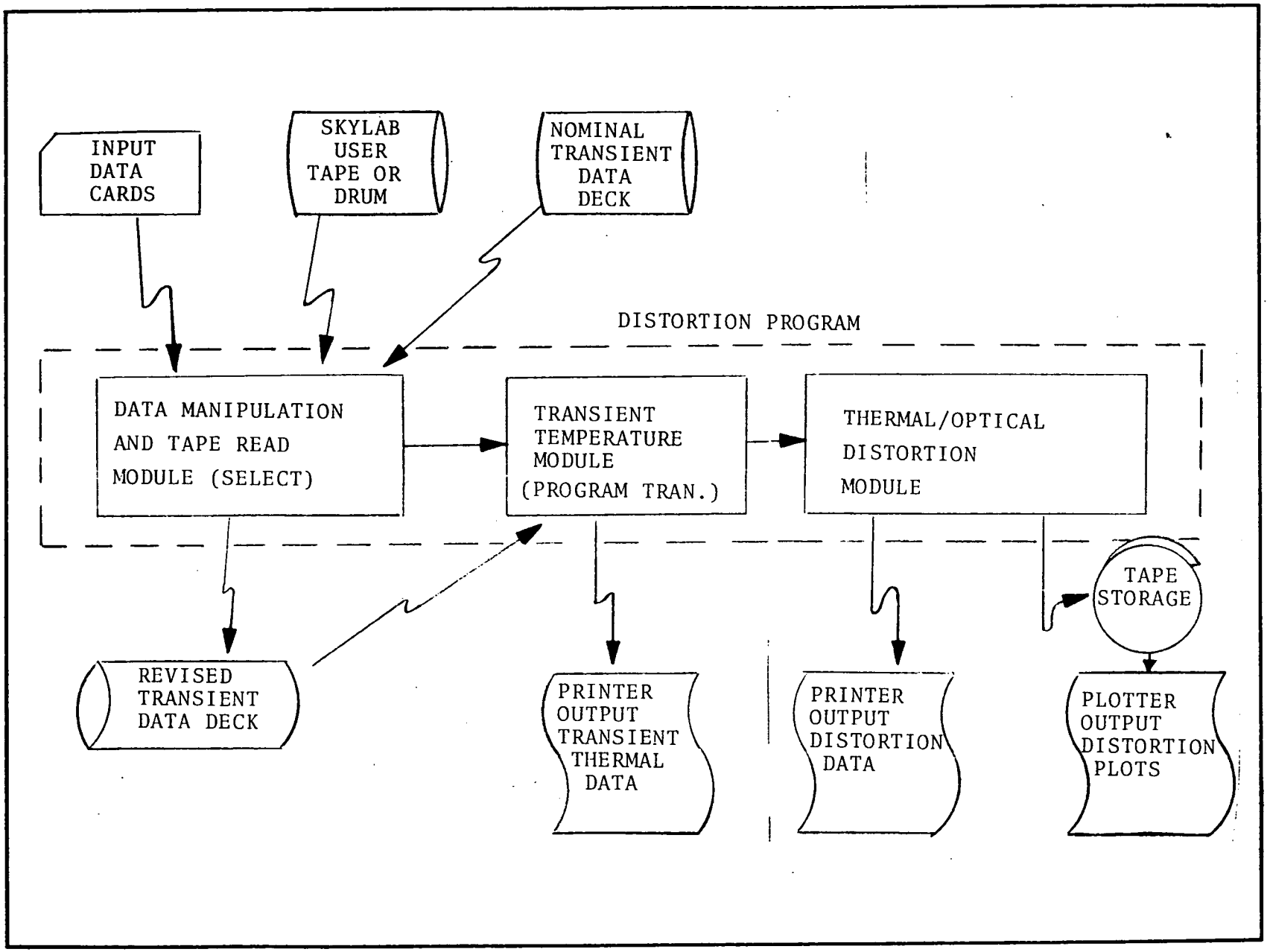


Figure 1 Thermal Distortion Program

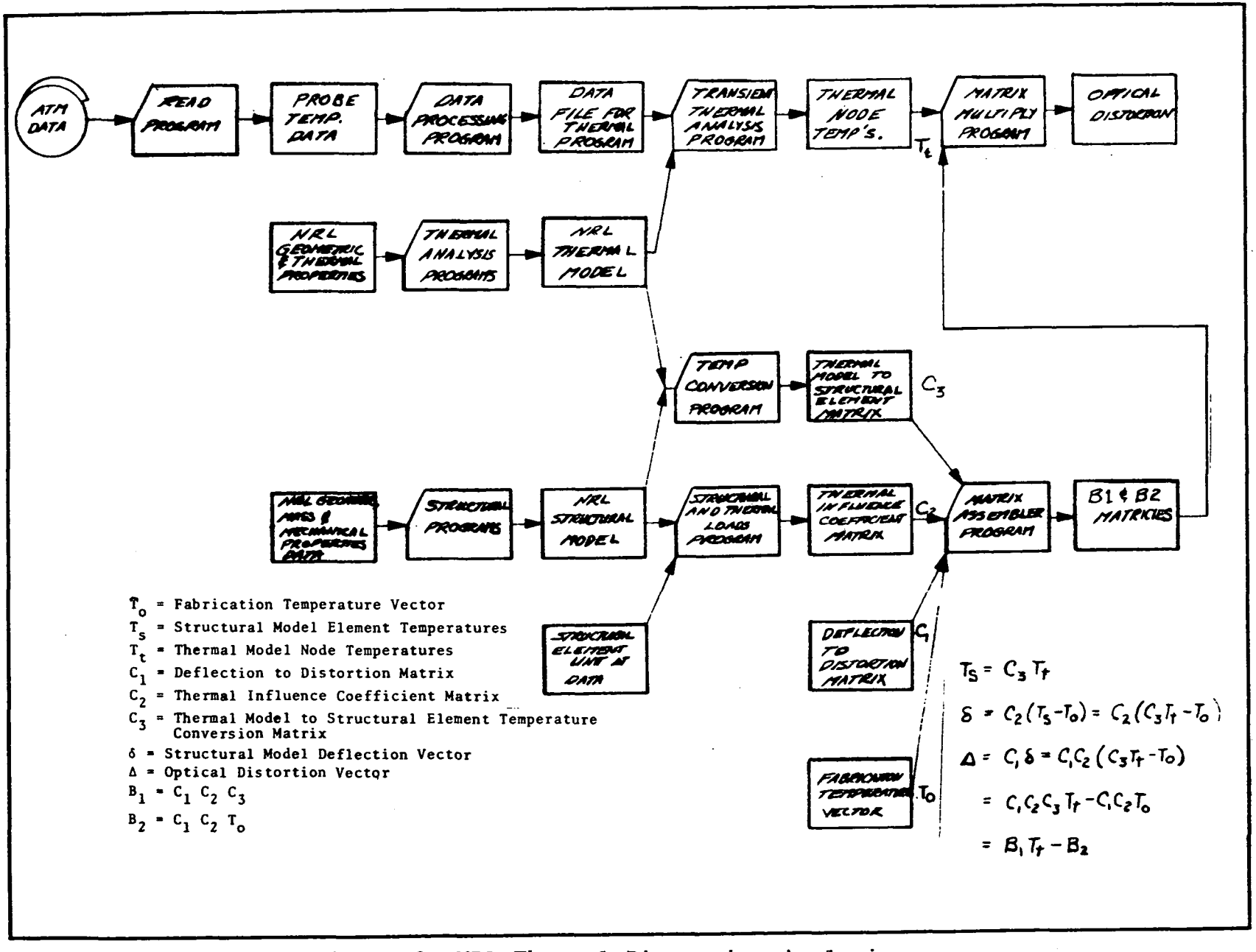


Figure 2 NRL Thermal Distortion Analysis

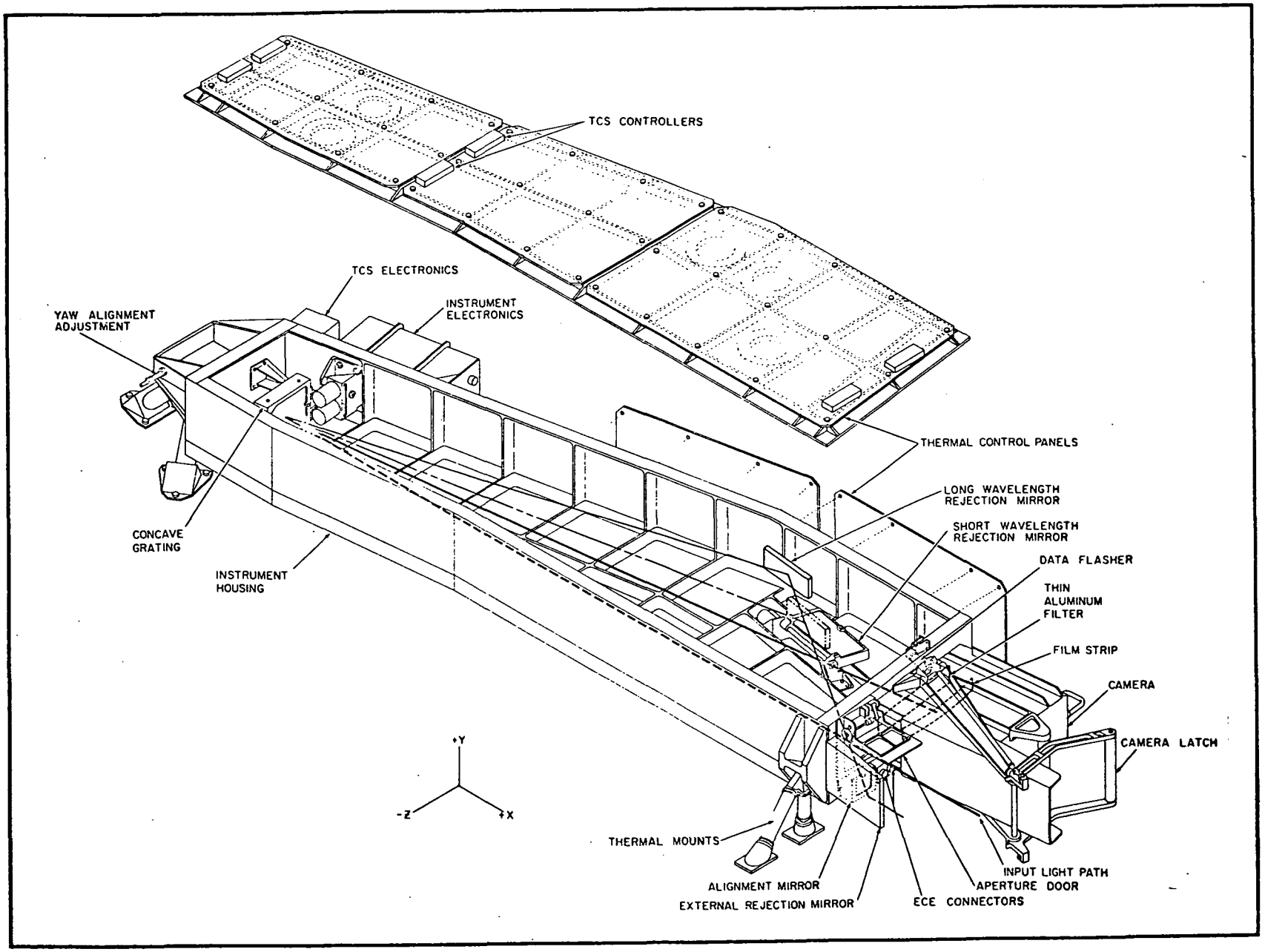


Figure 3 NRL ATM Experiment "A" Spectroheliograph

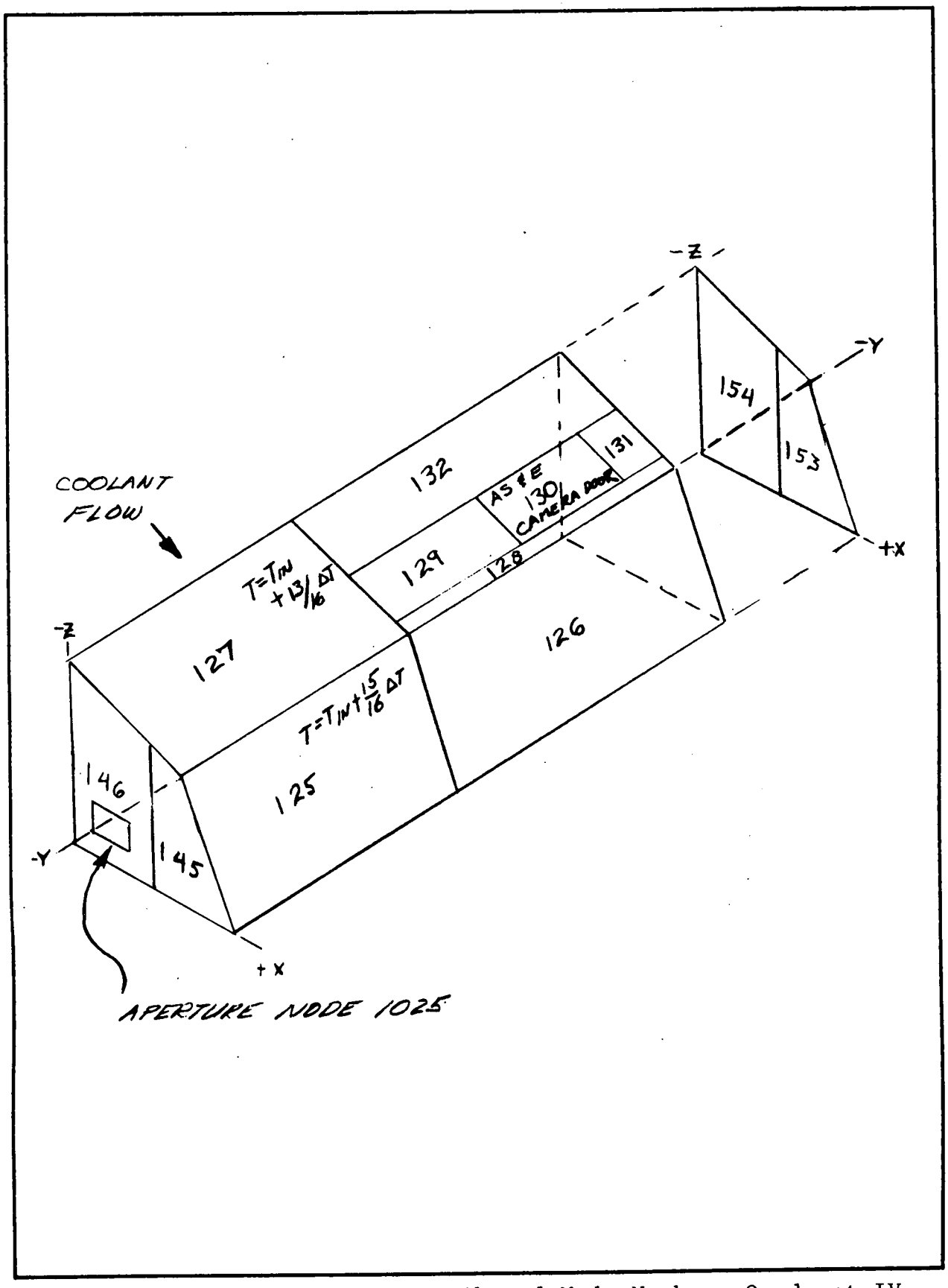


Figure 4 Skylab/ATM Canister Shroud Node Numbers Quadrant IV

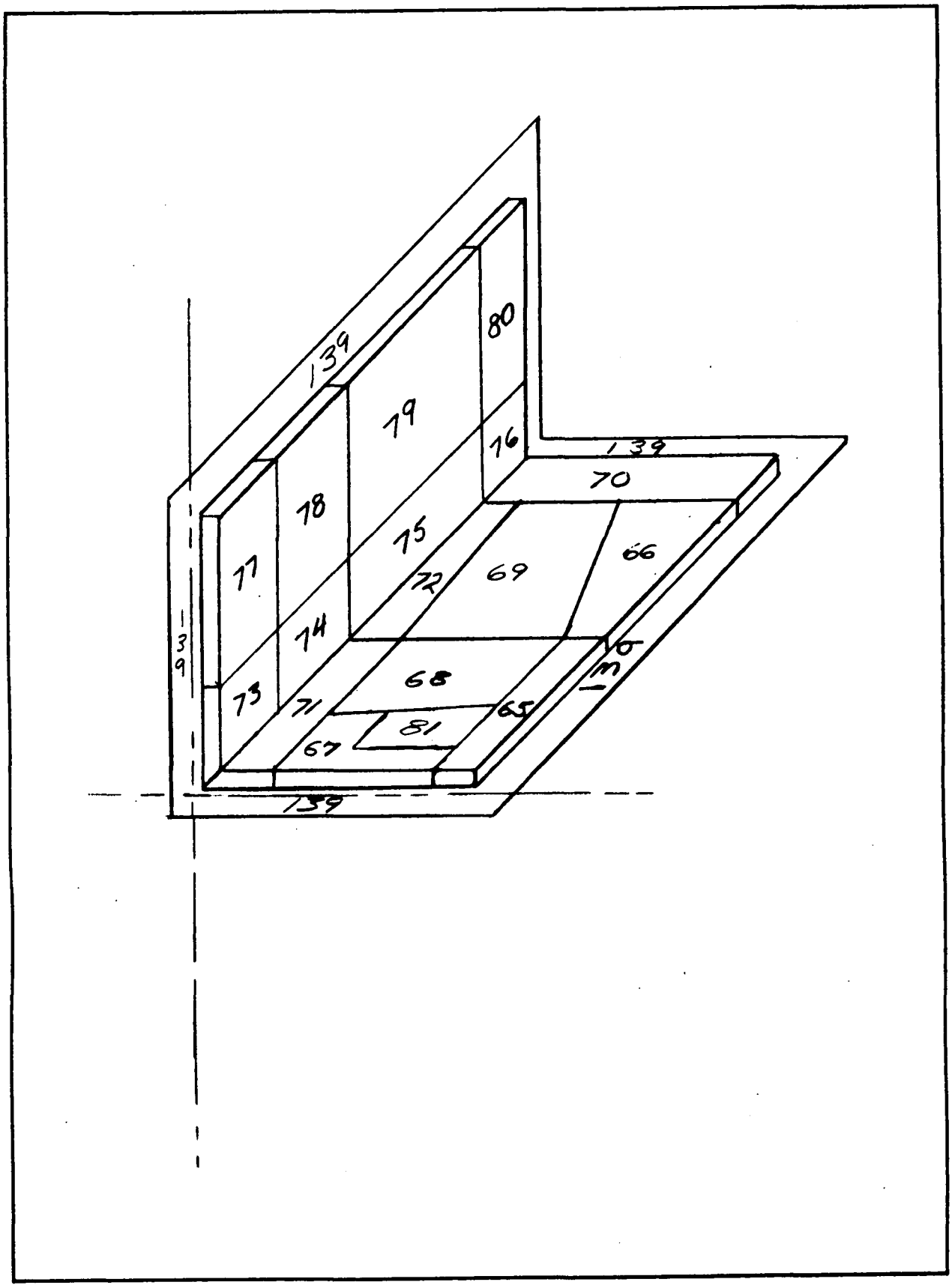


Figure 5 Skylab/ATM Cruciform Spar Insulation Nodes
Quadrant IV

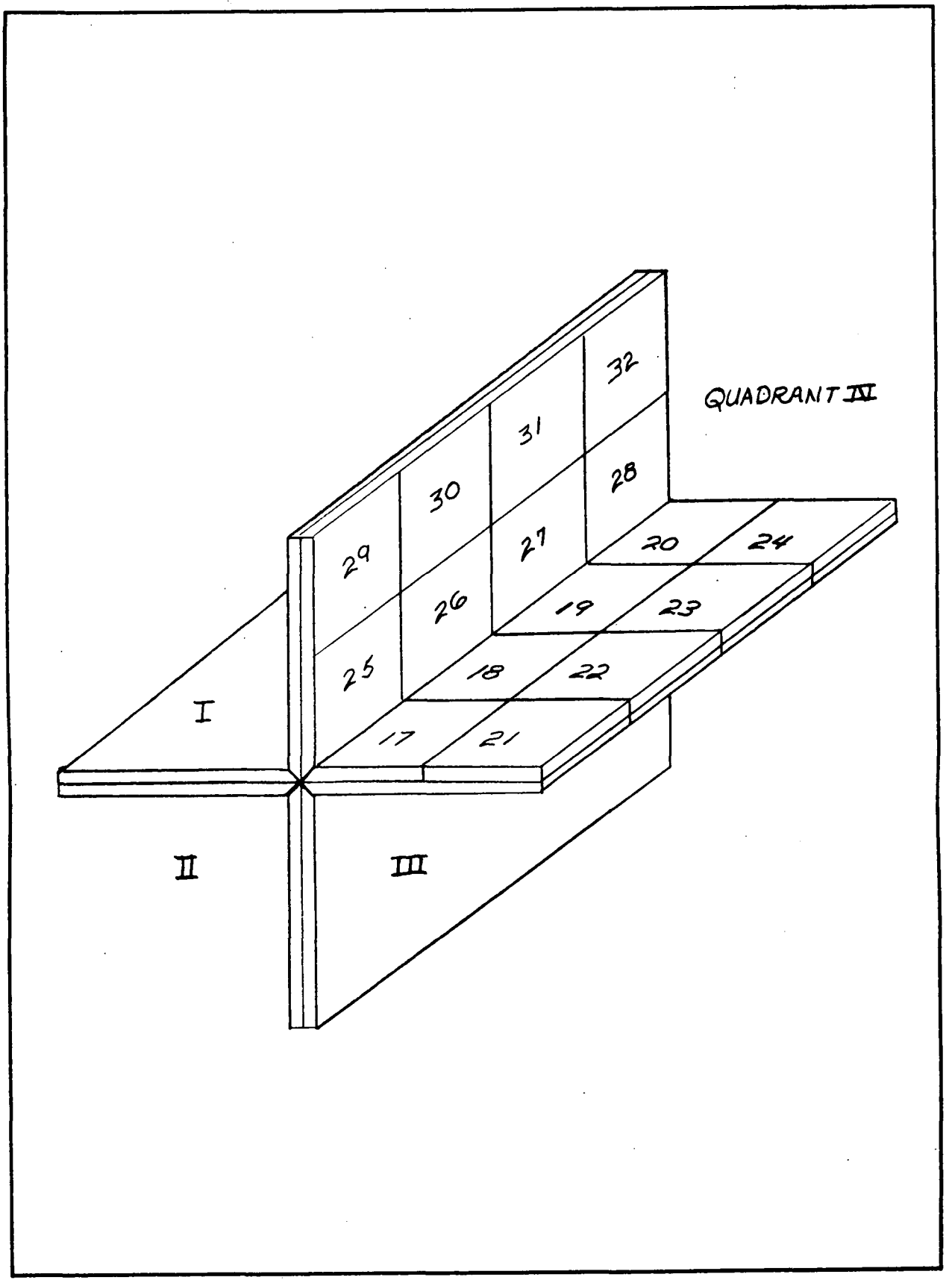


Figure 6 Skylab/ATM Cruciform (Spar), Quadrant IV Node Numbers

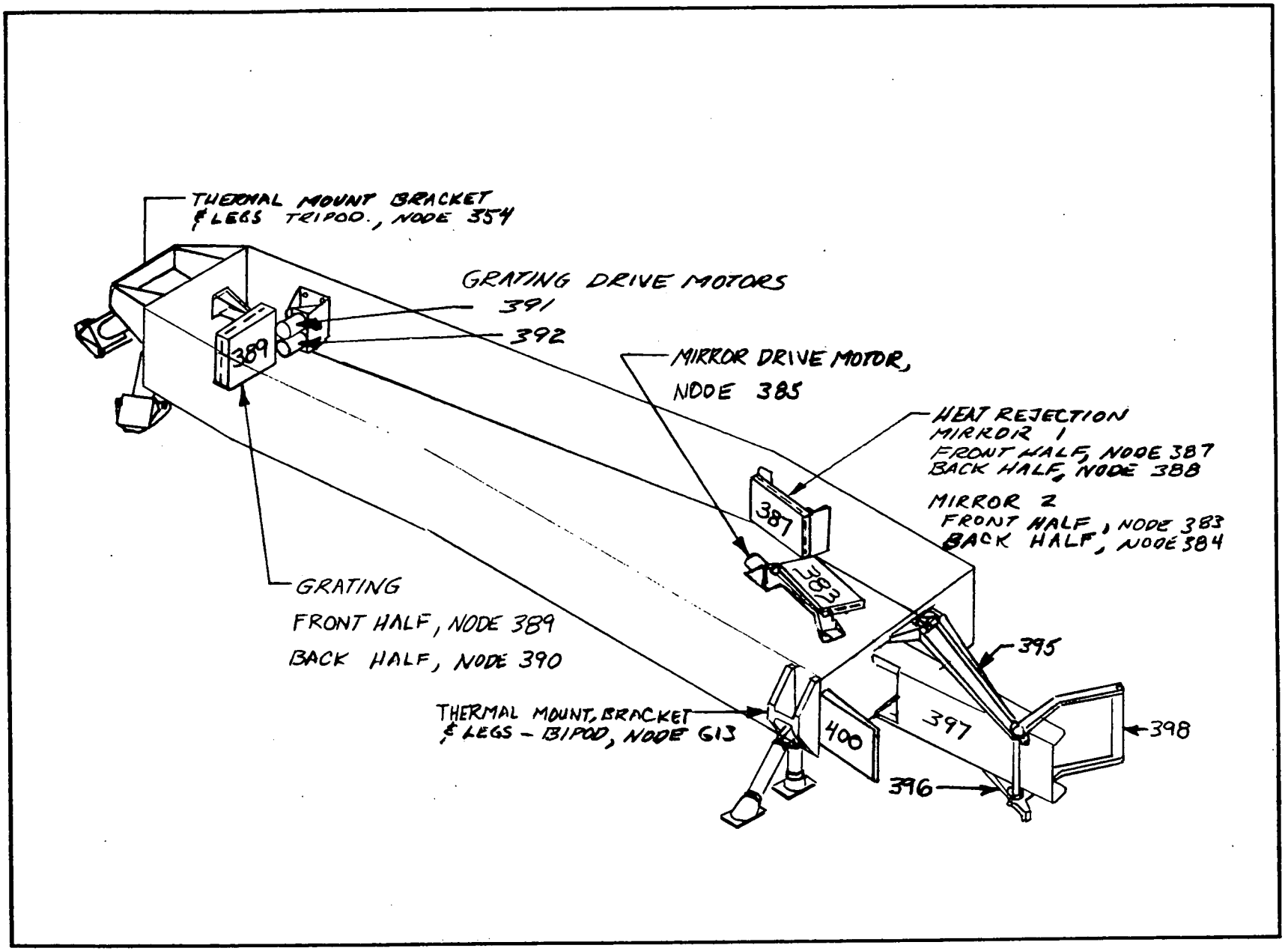


Figure 7 NRL-A Spectroheliograph Node Numbers

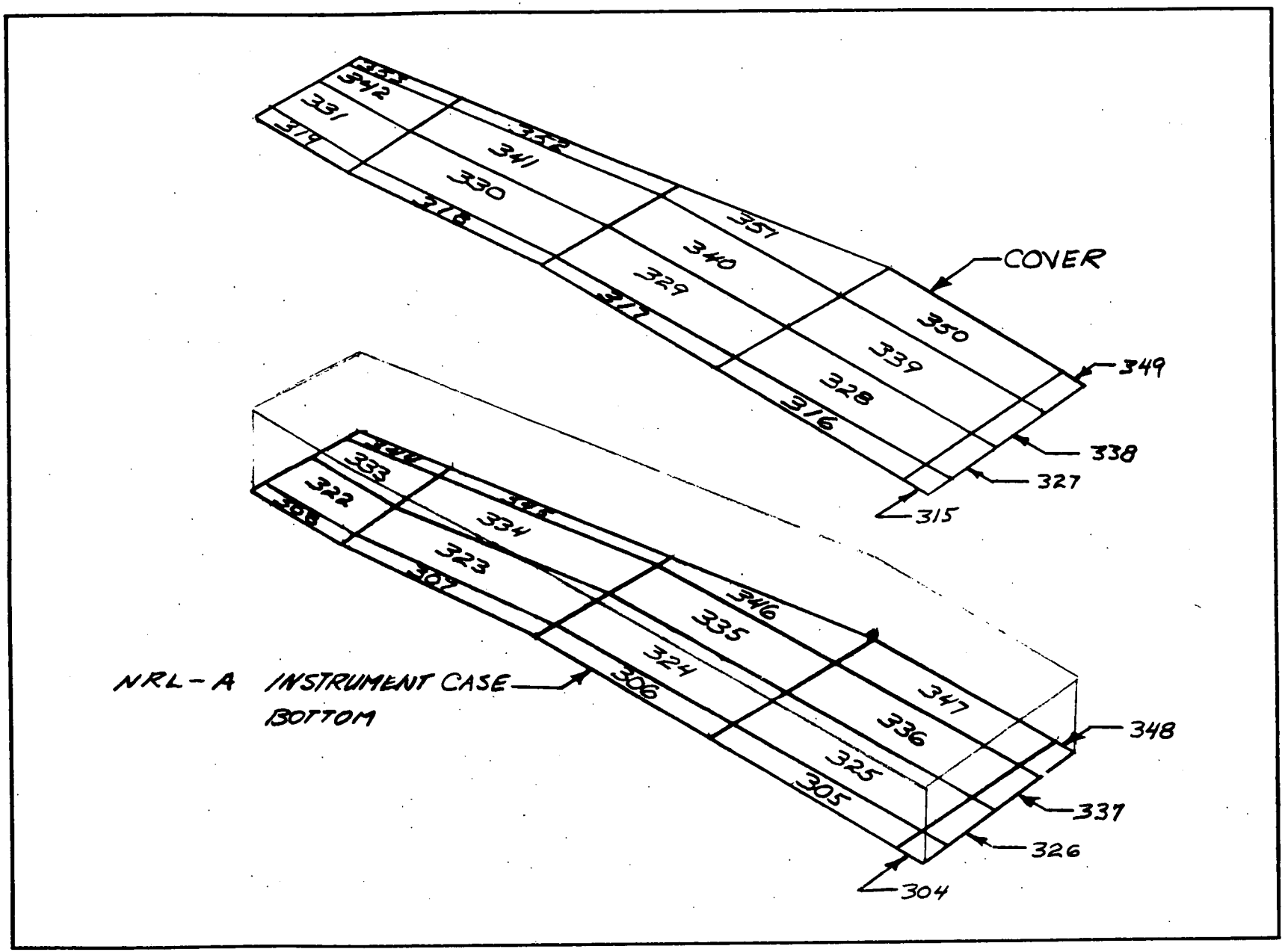


Figure 8 NRL-A Spectroheliograph Node Numbers Cover and Bottom

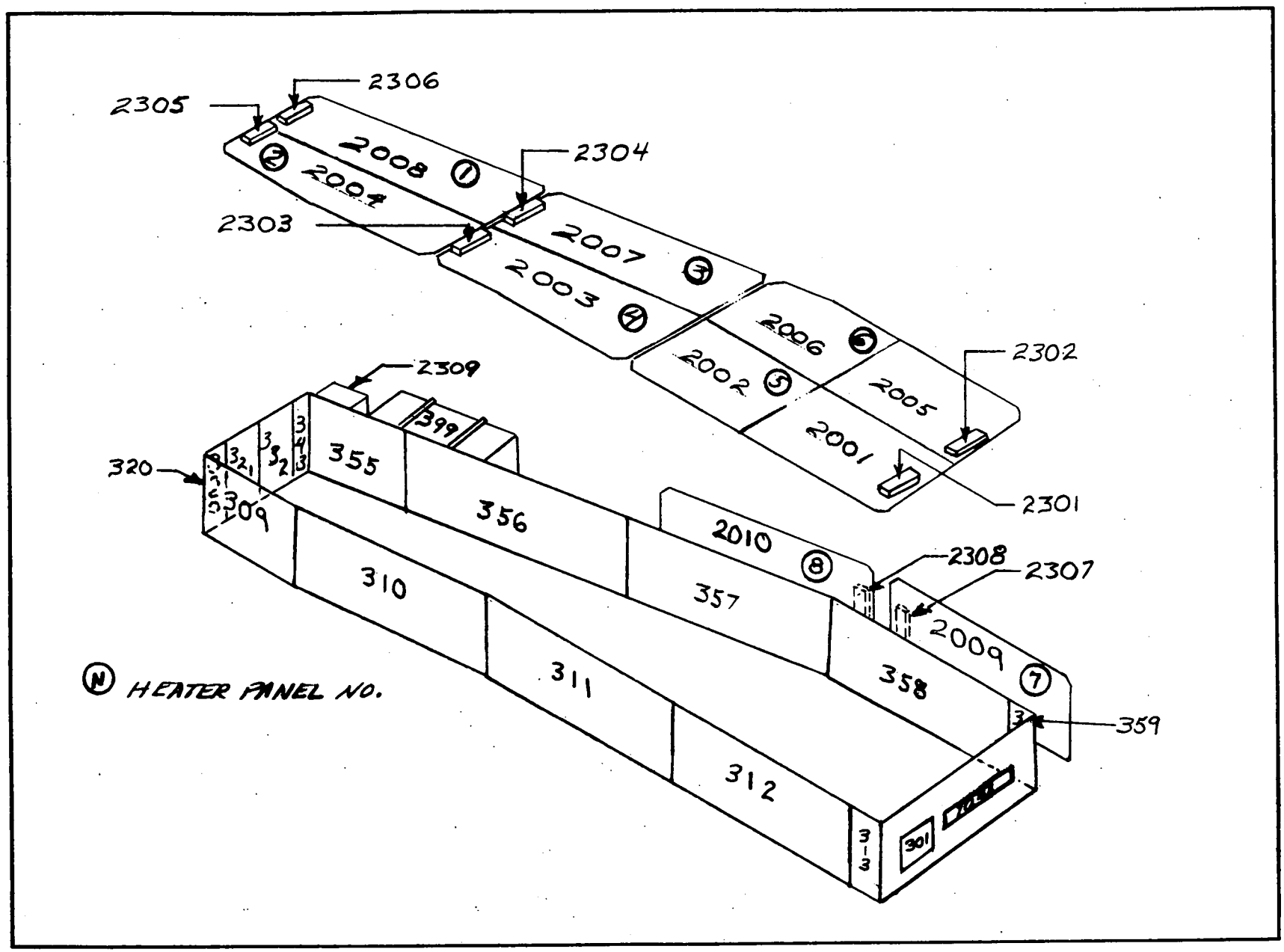


Figure 9 NRL-A Spectroheliograph Node Numbers

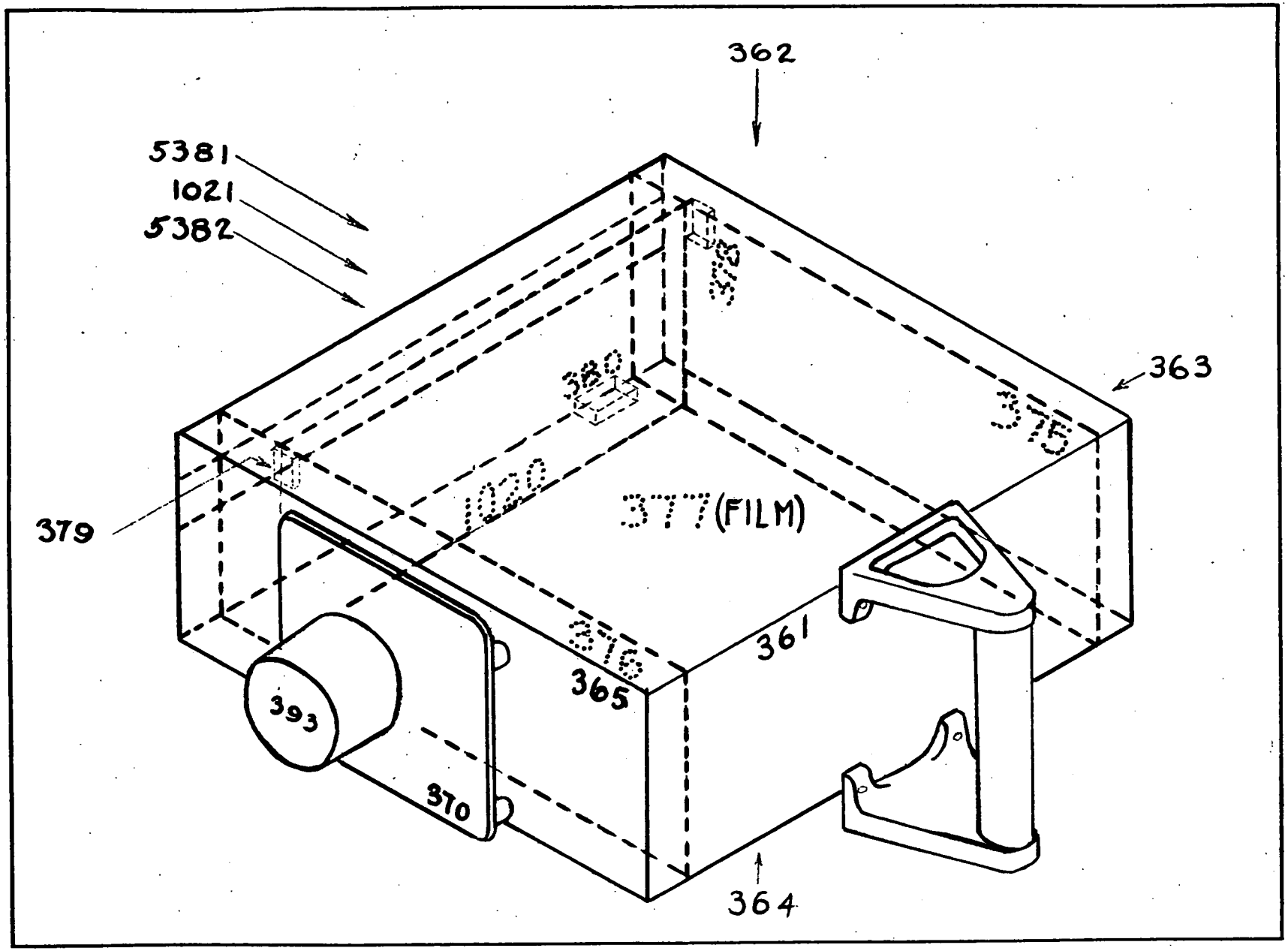


Figure 10 NRL-A Spectroheliograph Camera Node Numbers

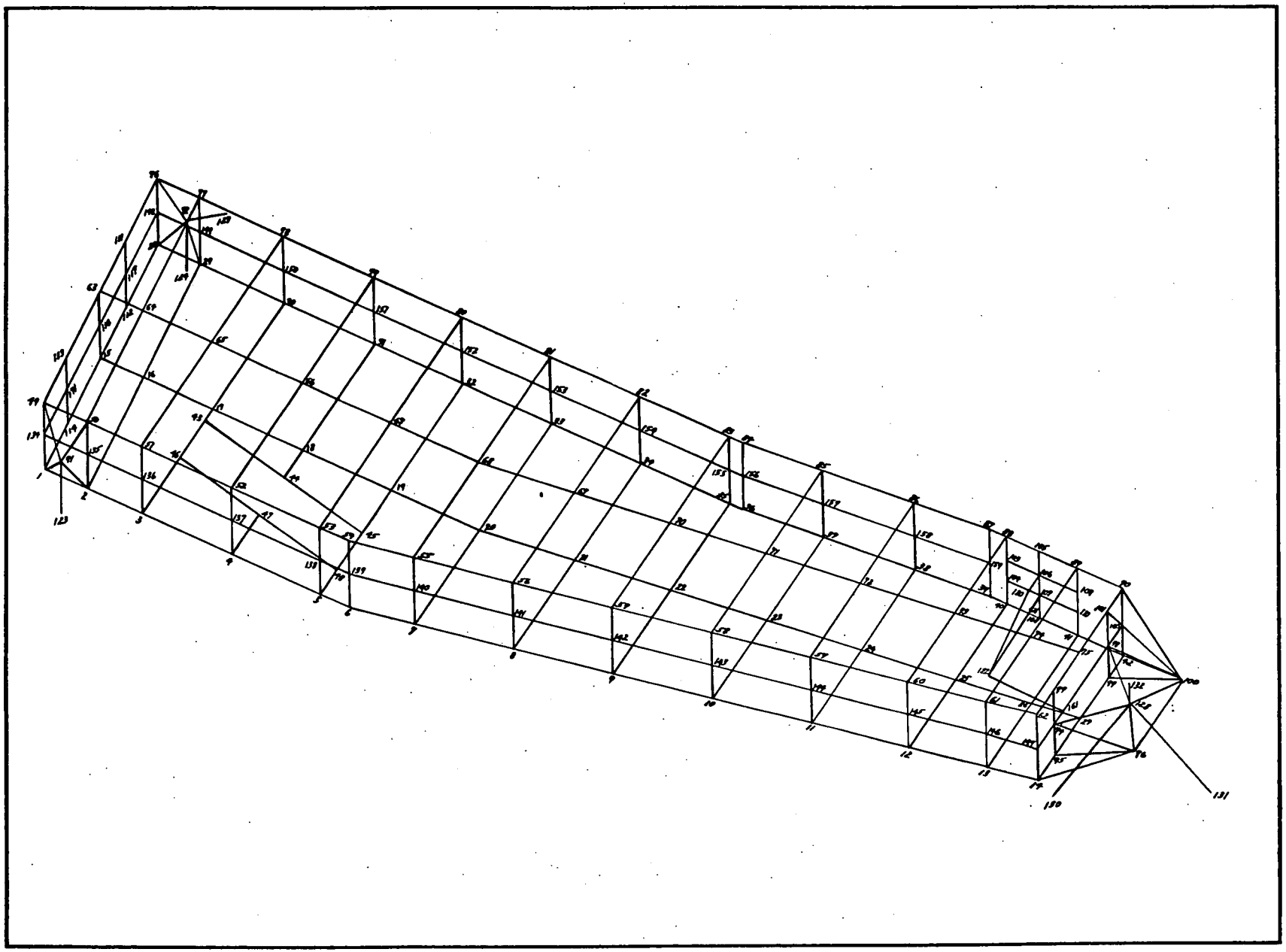


Figure 11 SO82A Structural Model

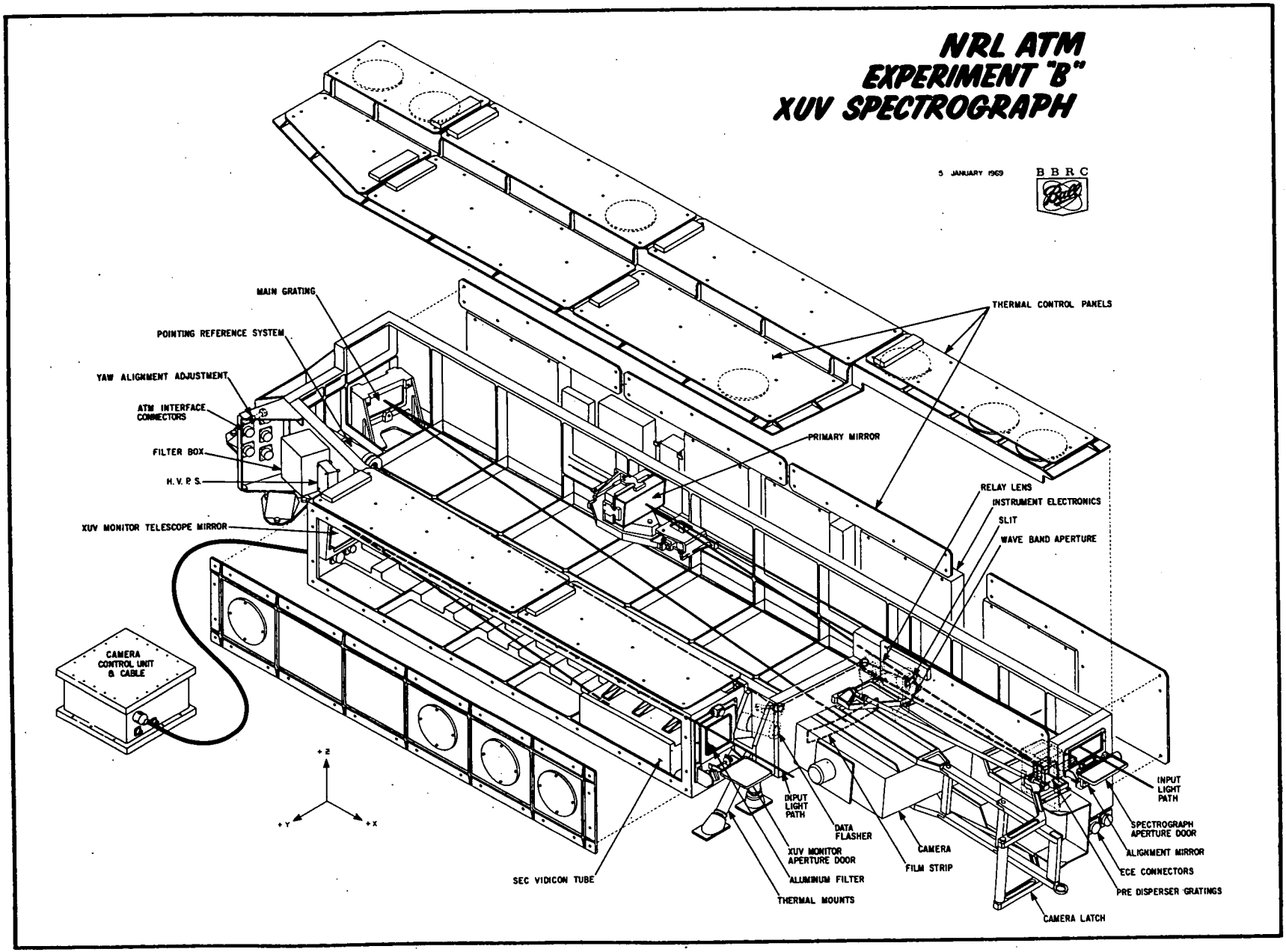


Figure 12 NRL ATM Experiment "B" XUV Spectrograph

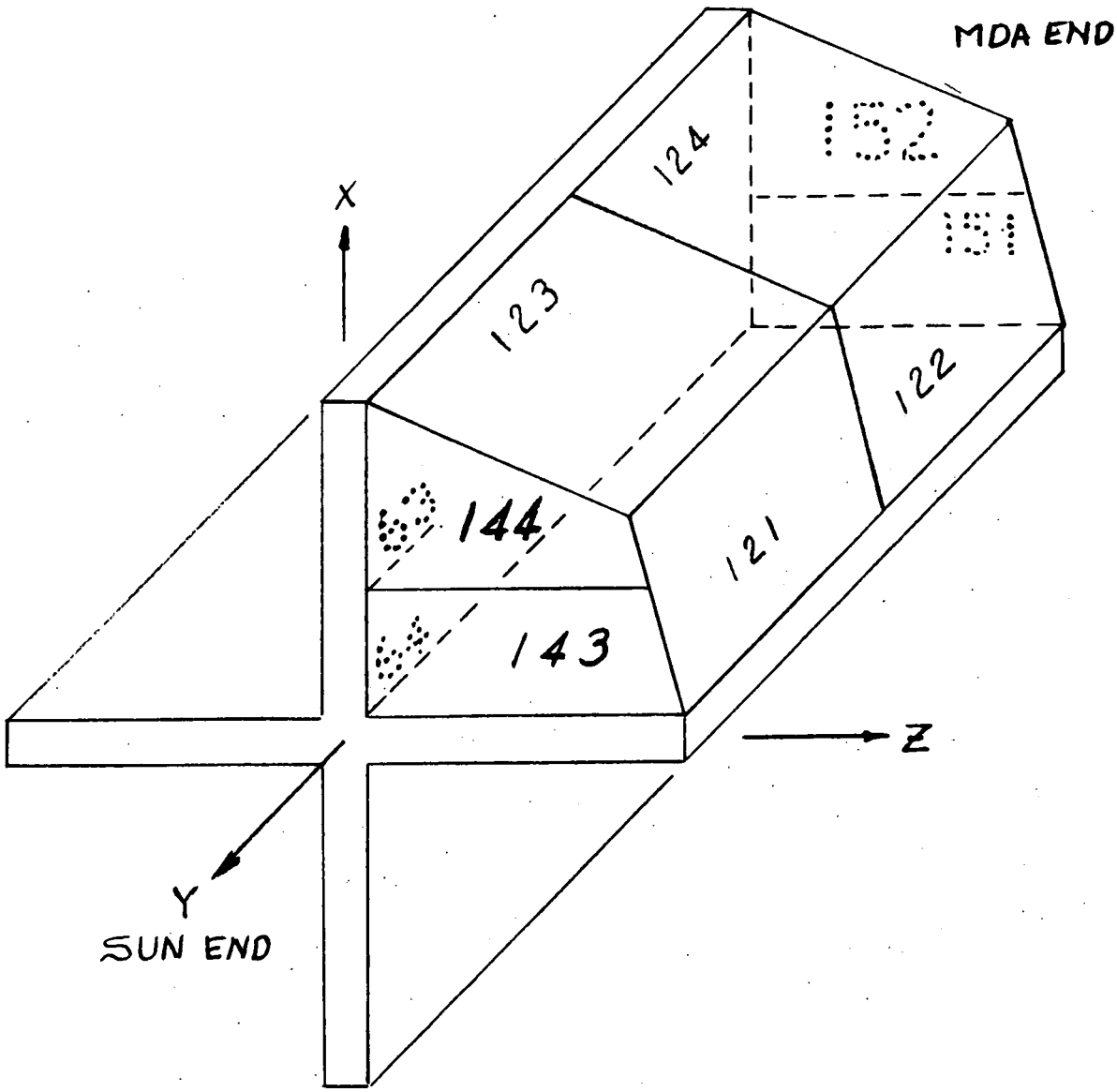


Figure 13 ATM Canister Nodes, Quadrant III

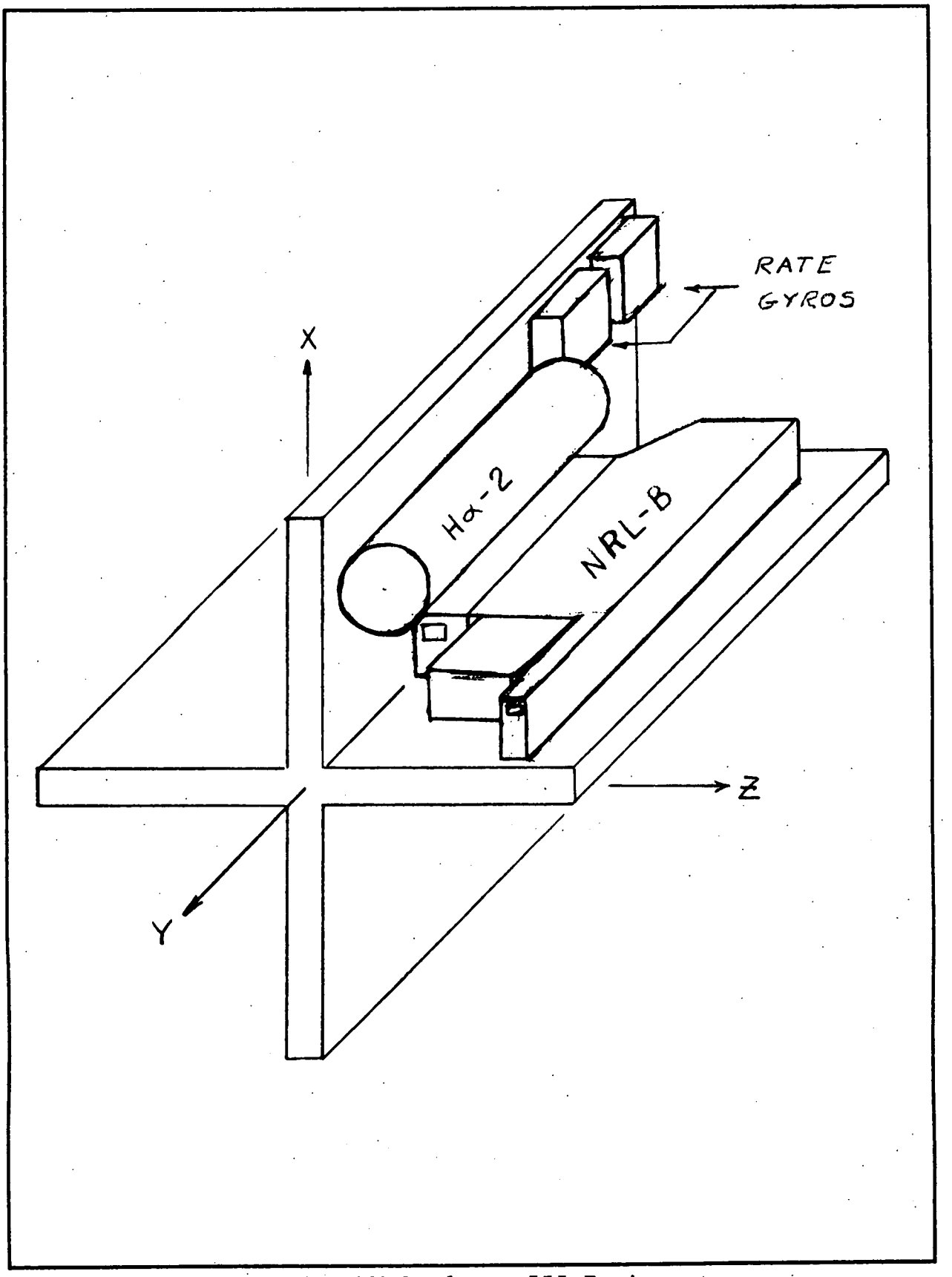


Figure 14 ATM Quadrant III Equipment

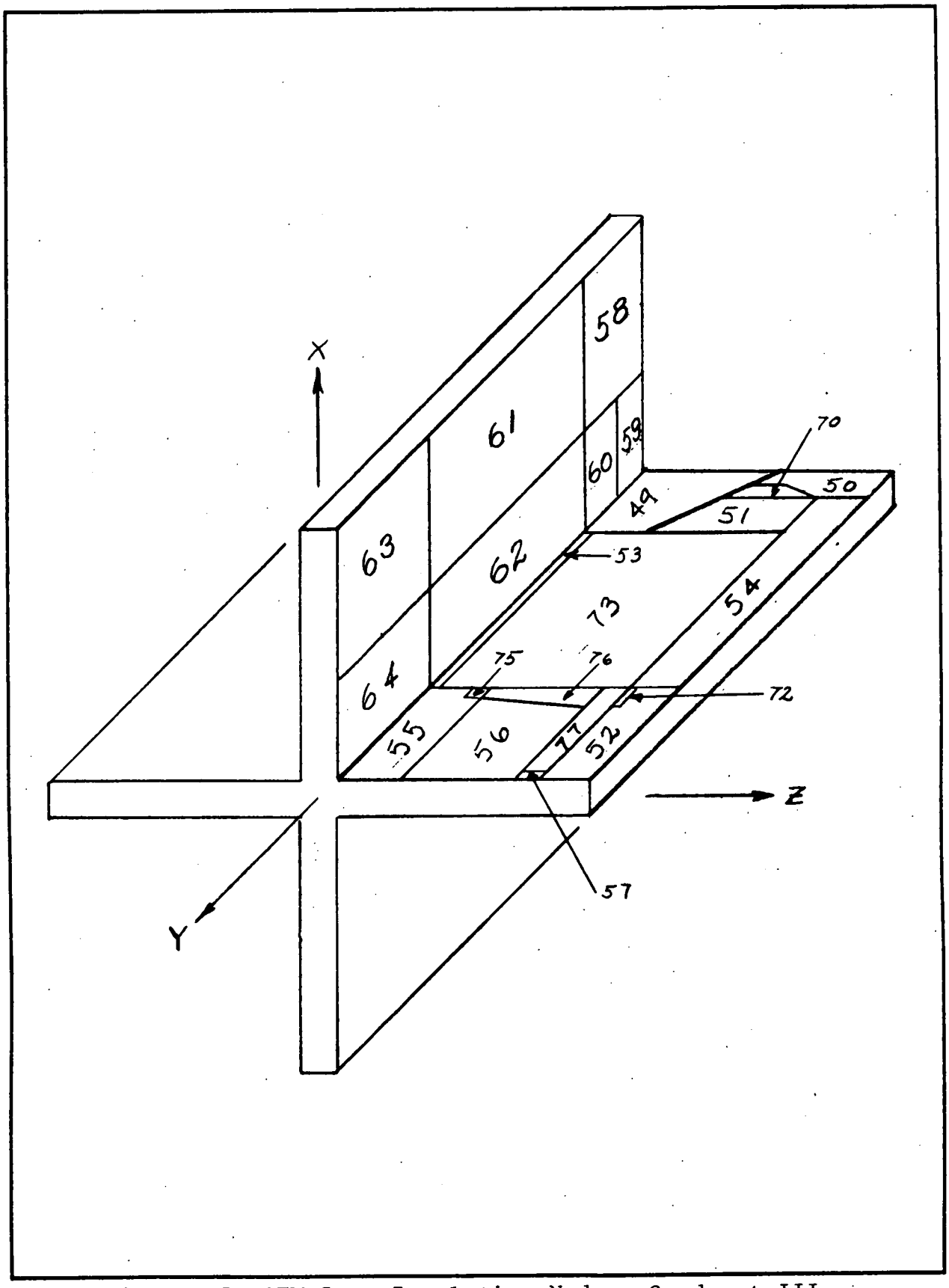


Figure 15 ATM Spar Insulation Nodes, Quadrant III

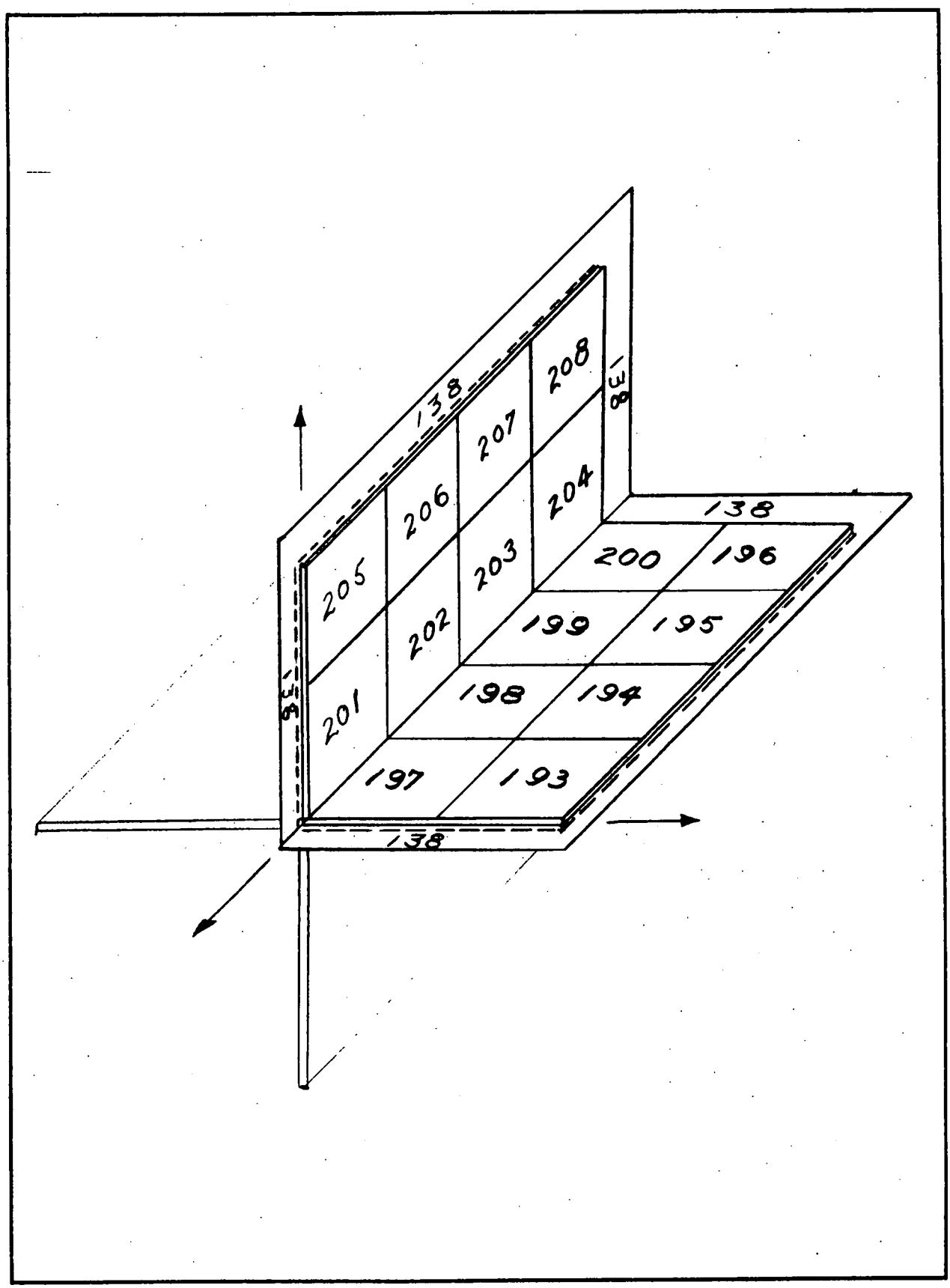


Figure 16 ATM Spar Nodes, Quadrant III

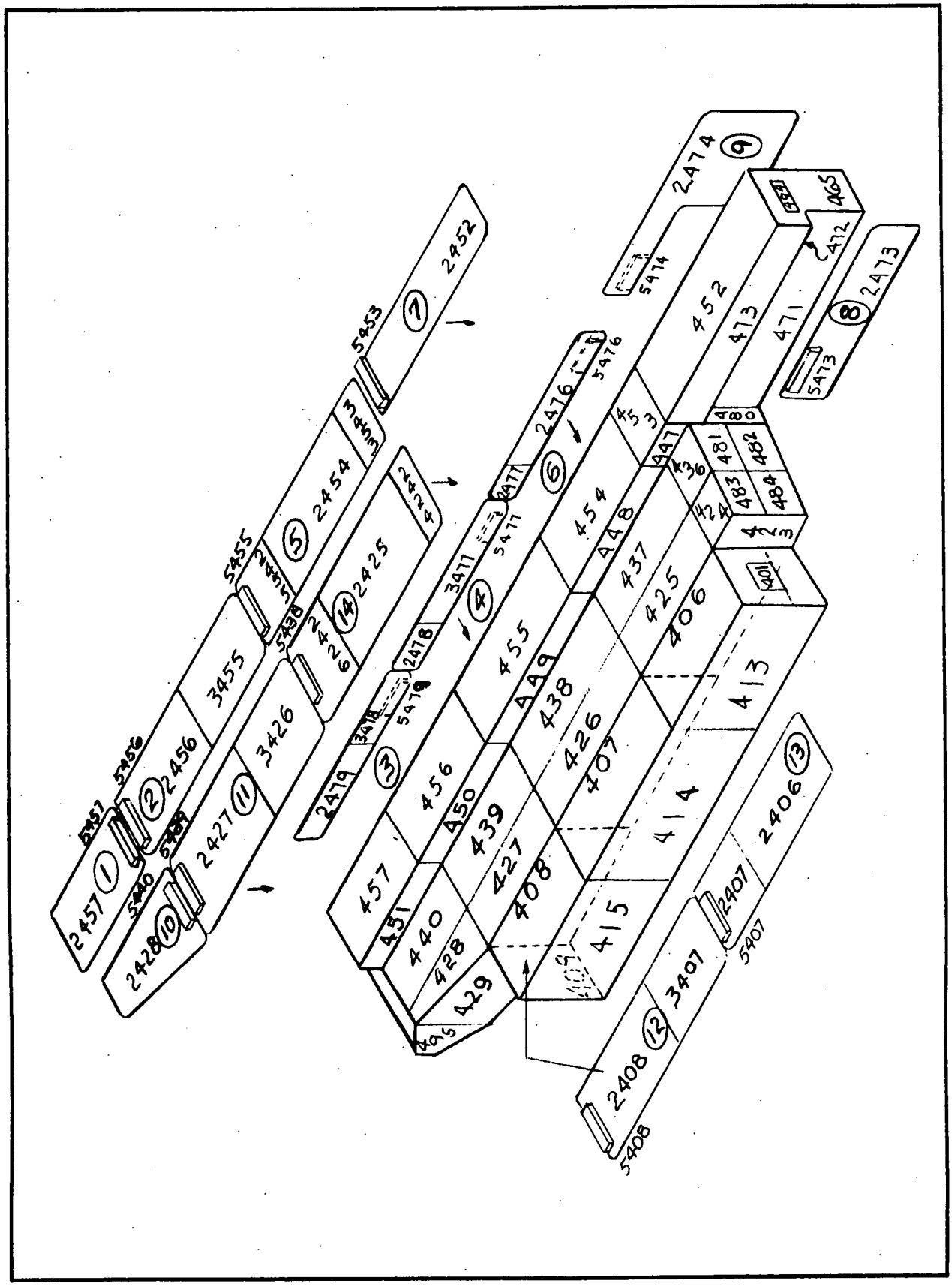


Figure 17. NRL B Spectrograph and XUV Monitor Nodes

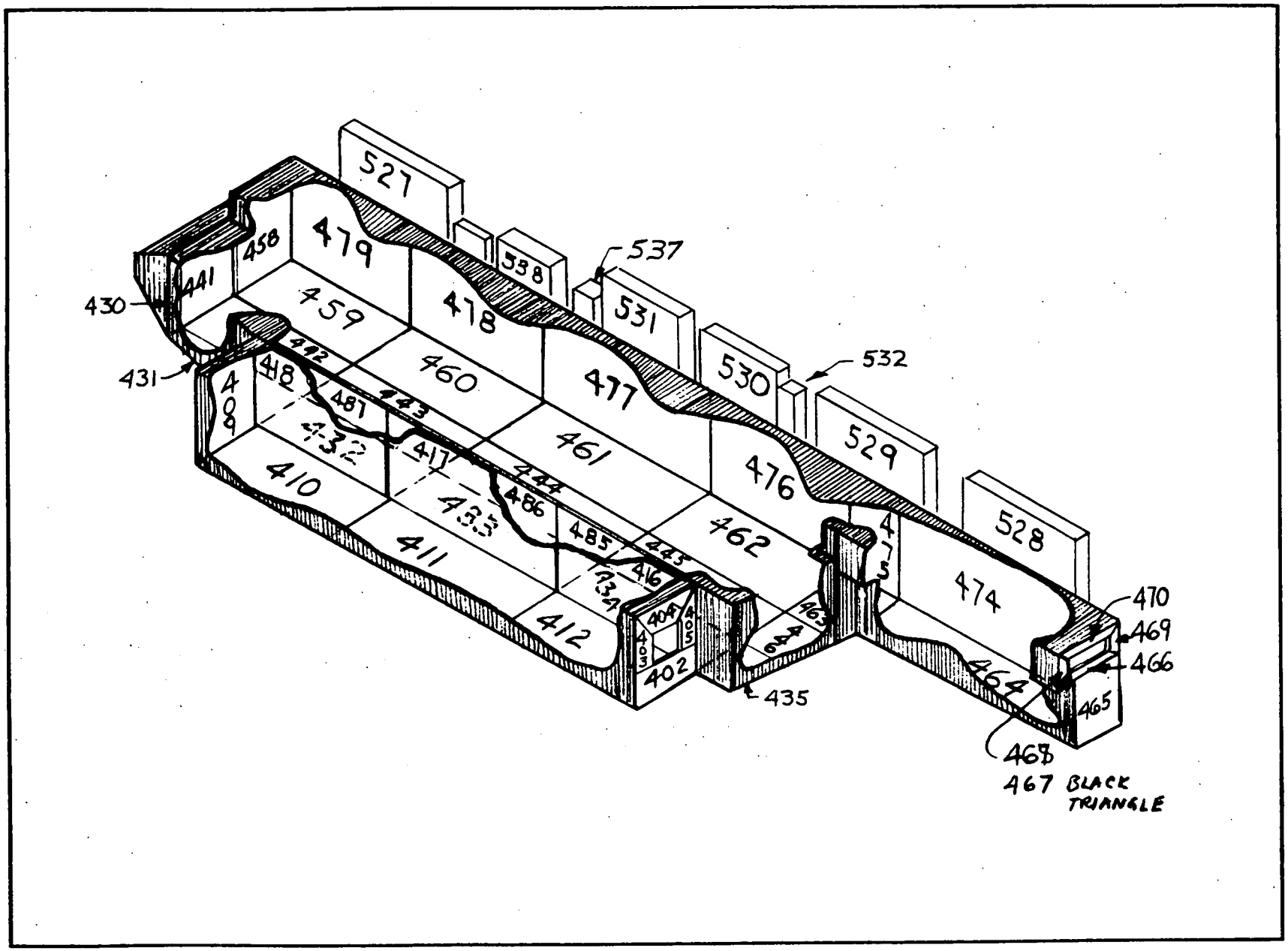


Figure 18 NRL B Spectrograph and XUV Monitor-Interior Nodes

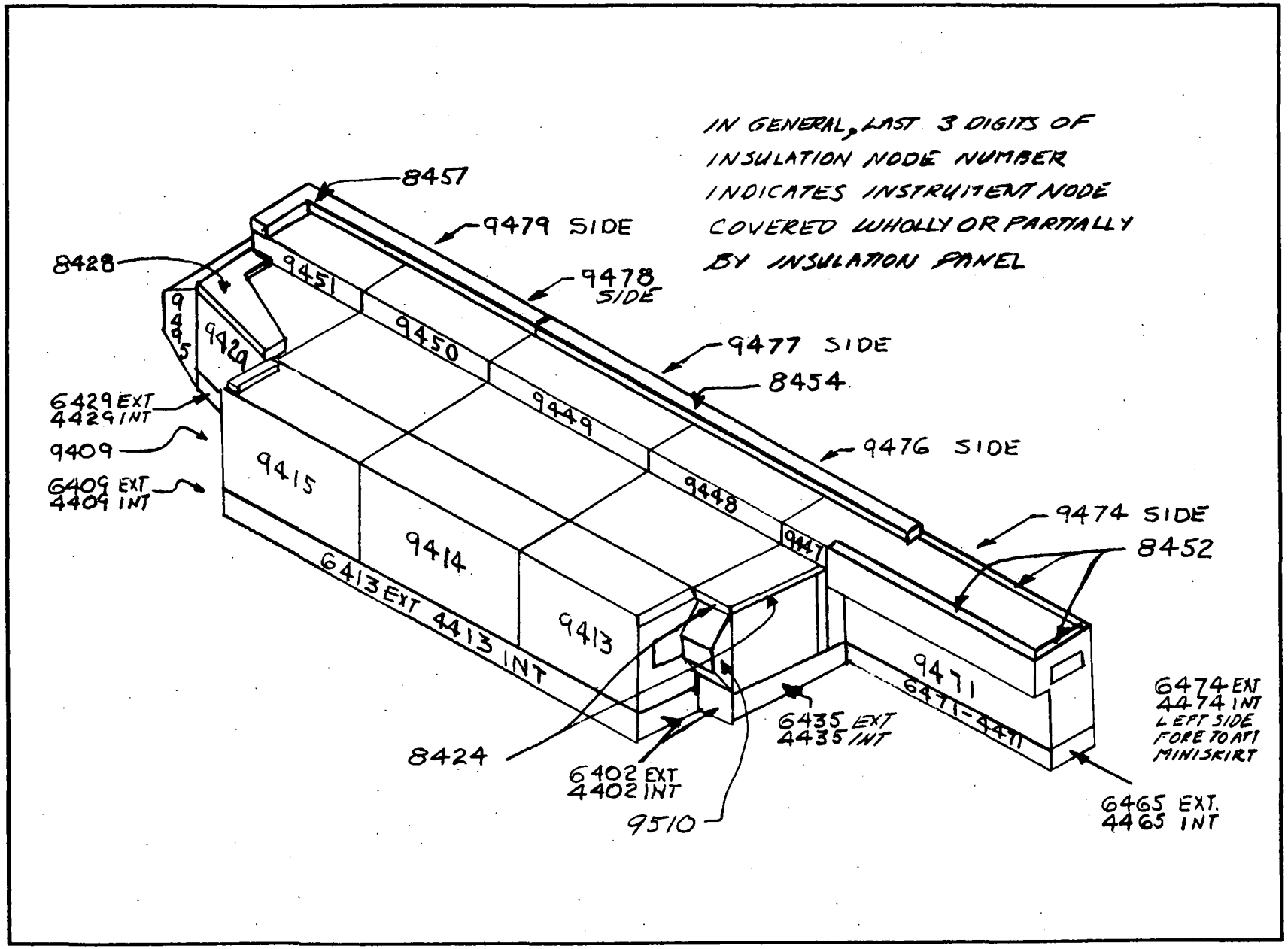


Figure 19 NRL B Spectrograph and XUV Monitor Insulation Nodes

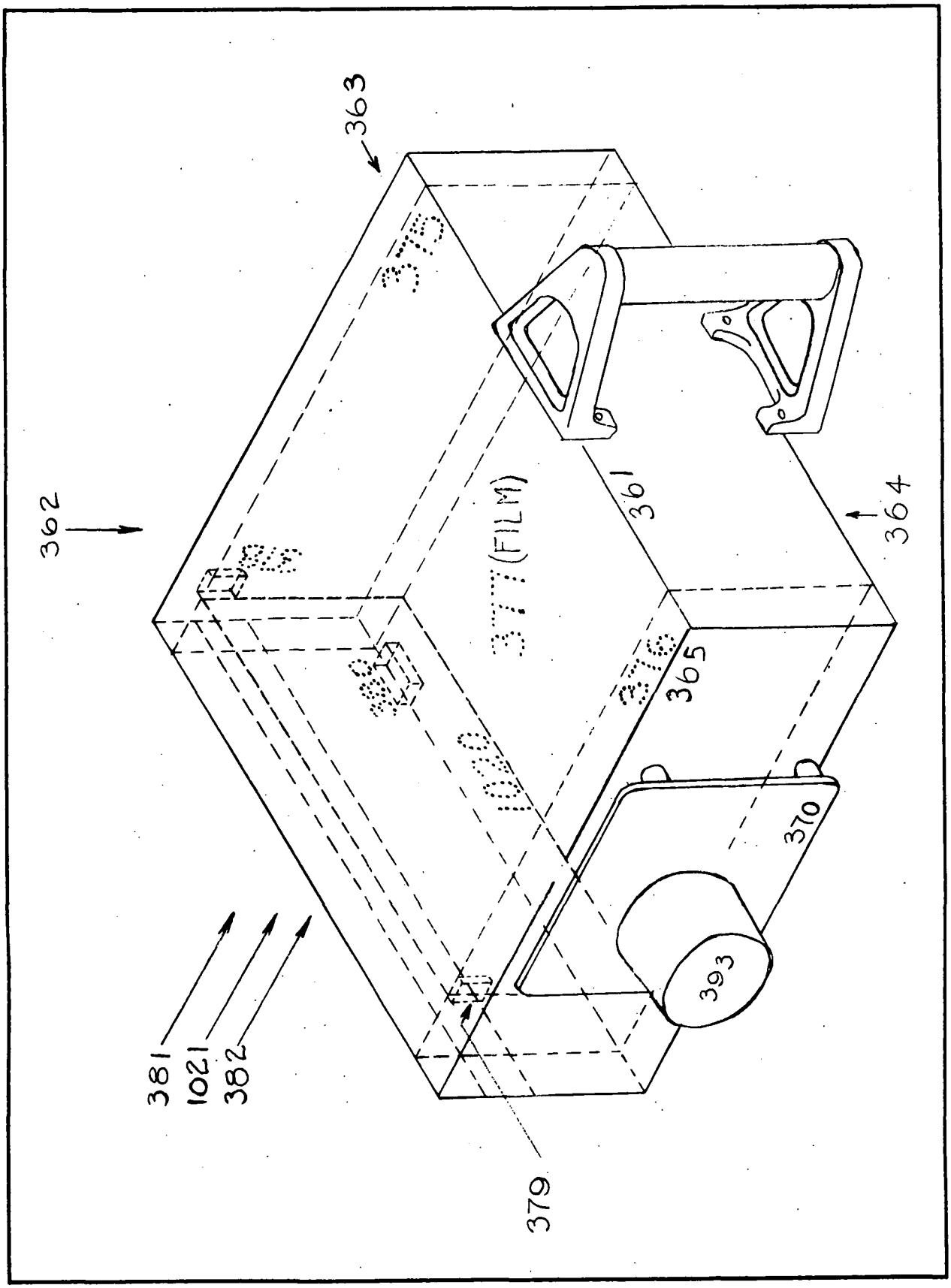


Figure 20 NRL B Spectrograph Camera Nodes

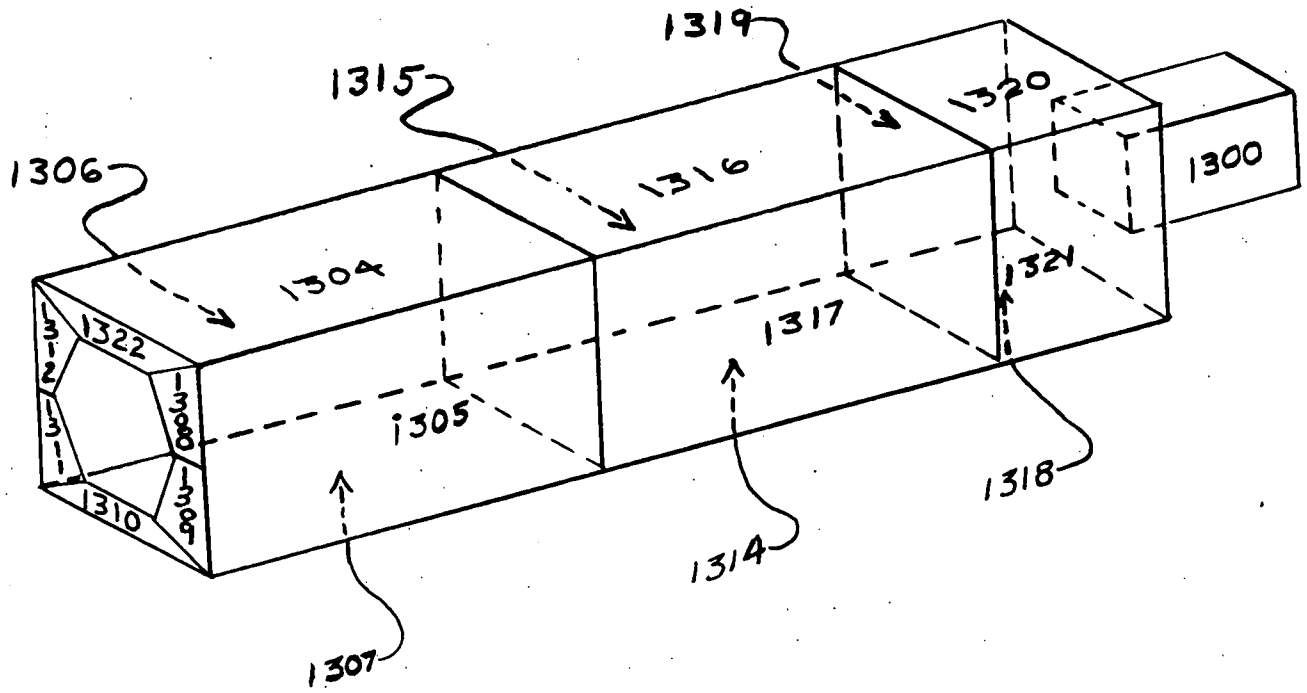


Figure 21 ATM Hα Experiment Nodes

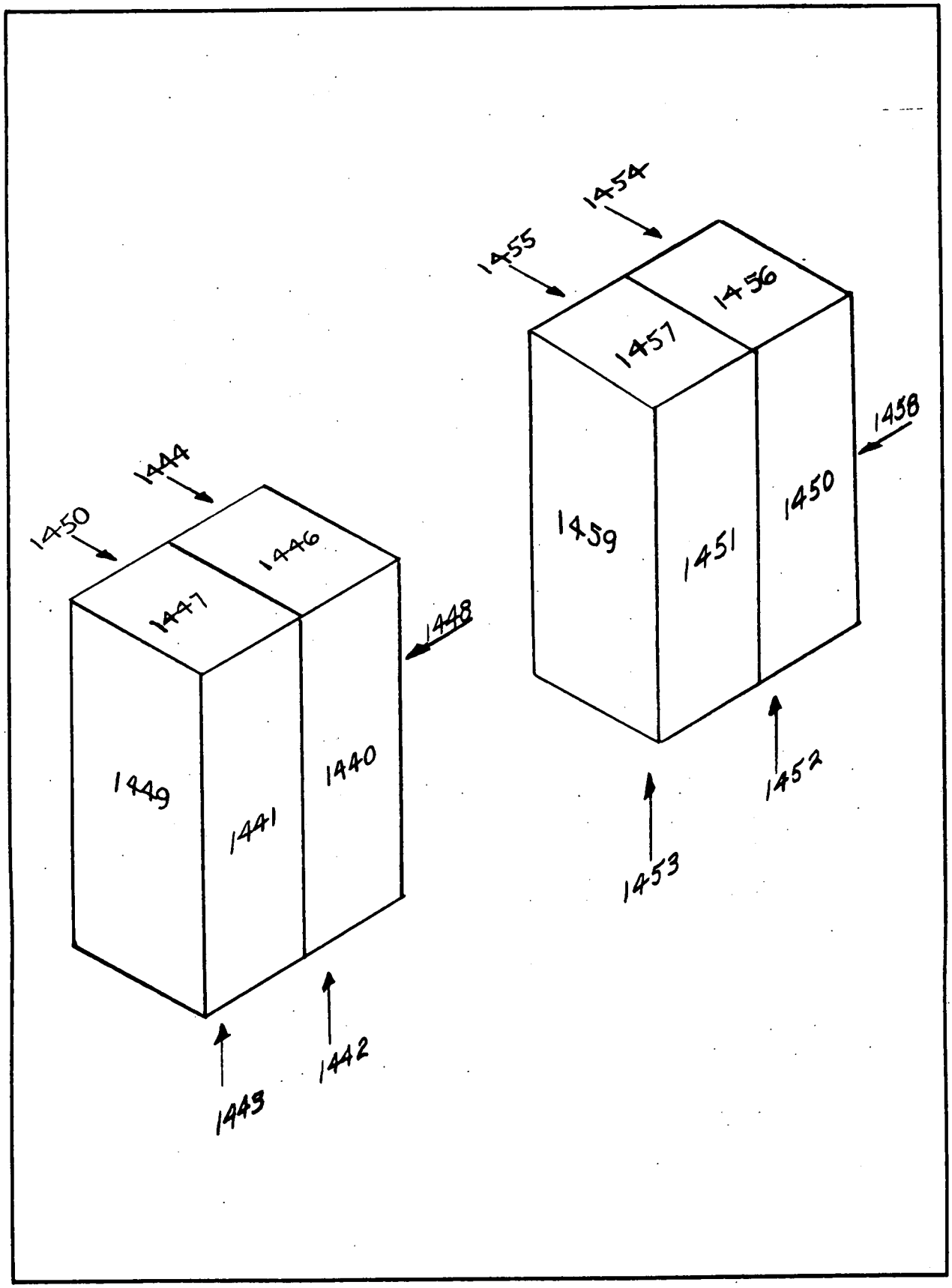


Figure 22 ATM Rate Gyro Nodes

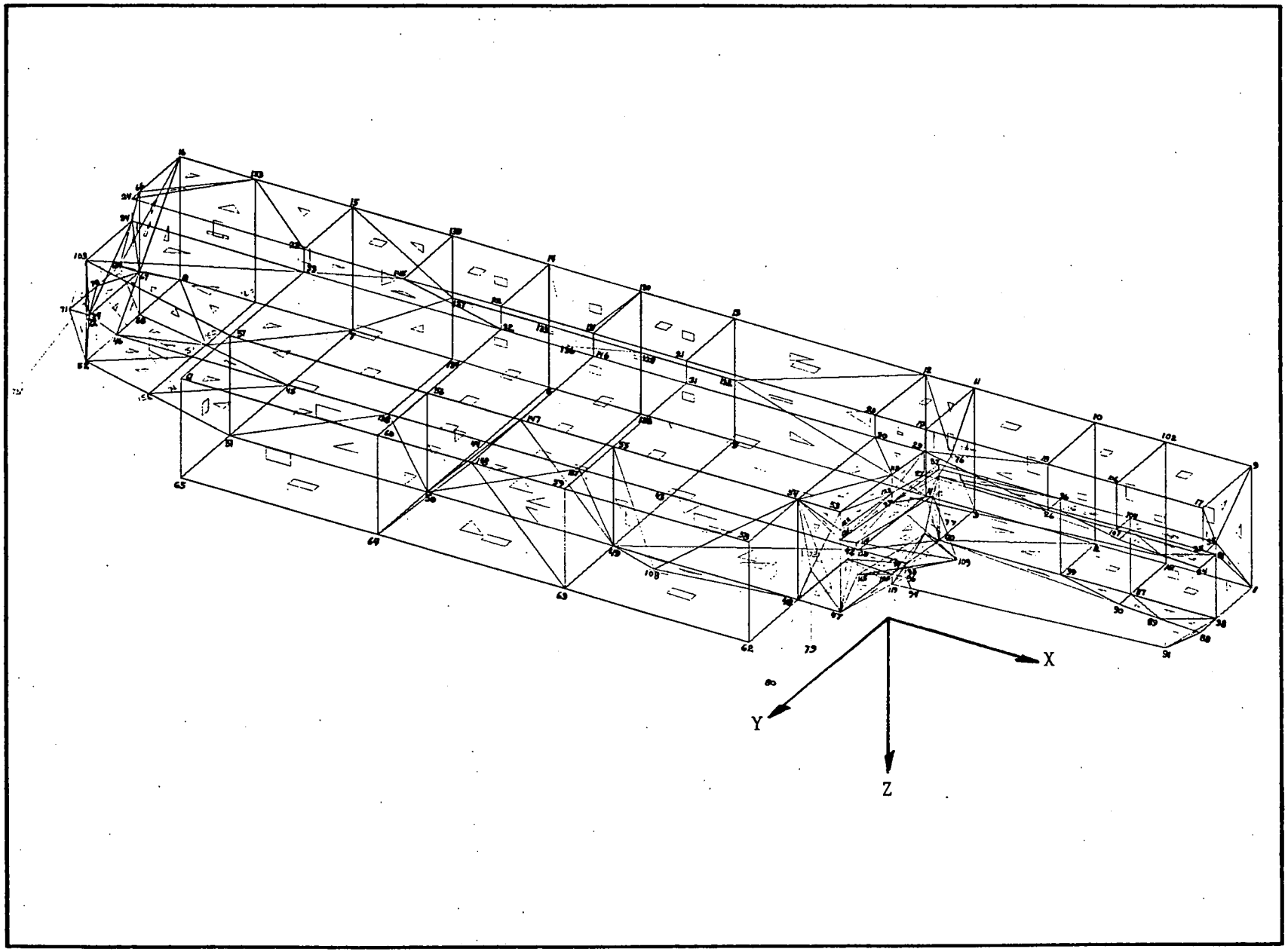
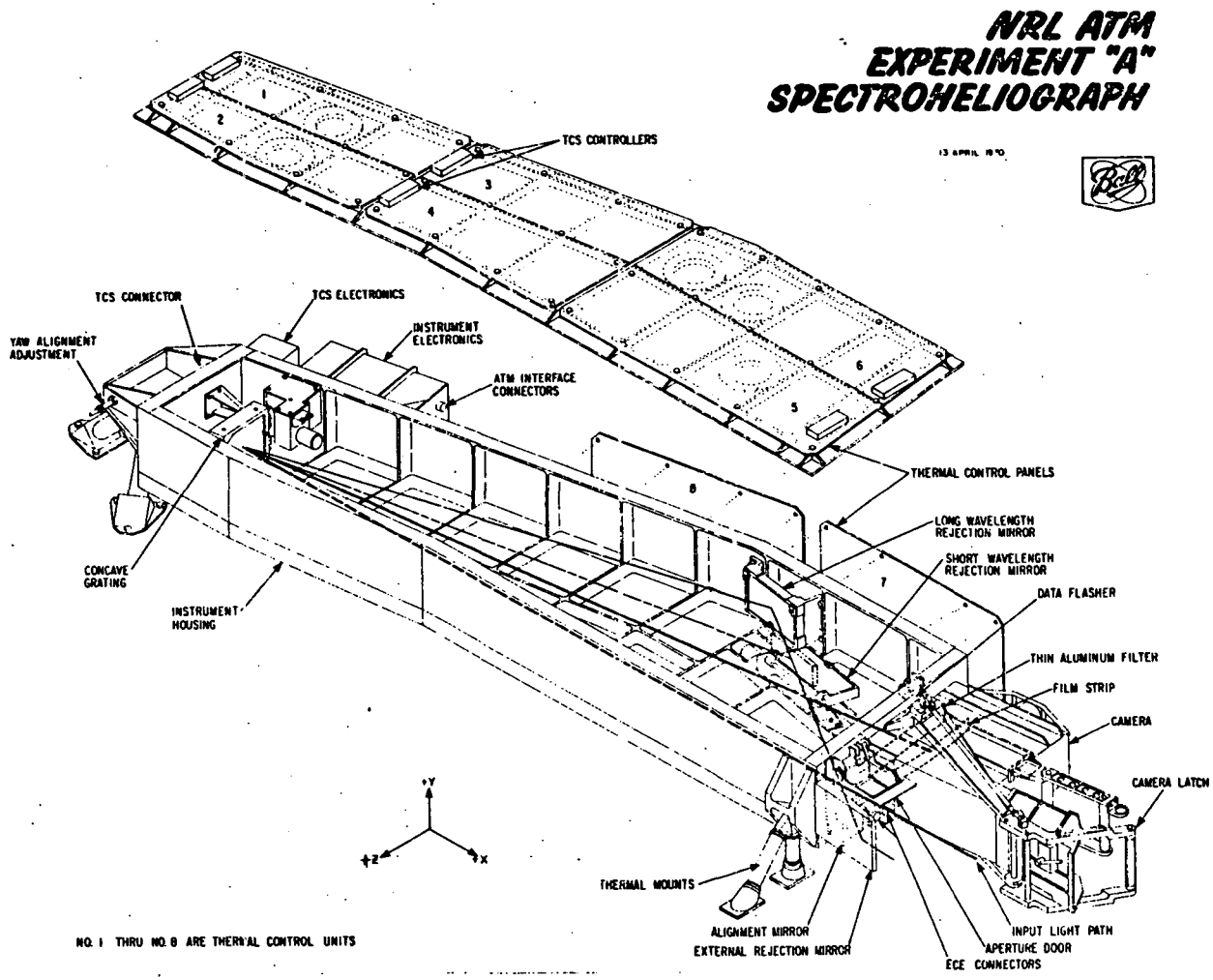


Figure 23 NRL-B Spectrograph and XUV Monitor Structural Model



Focal Distance - Positive No. indicates distance image is in front of film.
Negative No. indicates distance image is behind film.

Vertical Movement - Positive No. indicates image movement in the +Y direction relative to the film plane.

Horizontal Movement - Positive No. indicates image movement in the +Z direction relative to the film plane.

Figure 24 Distortion Sign Convention

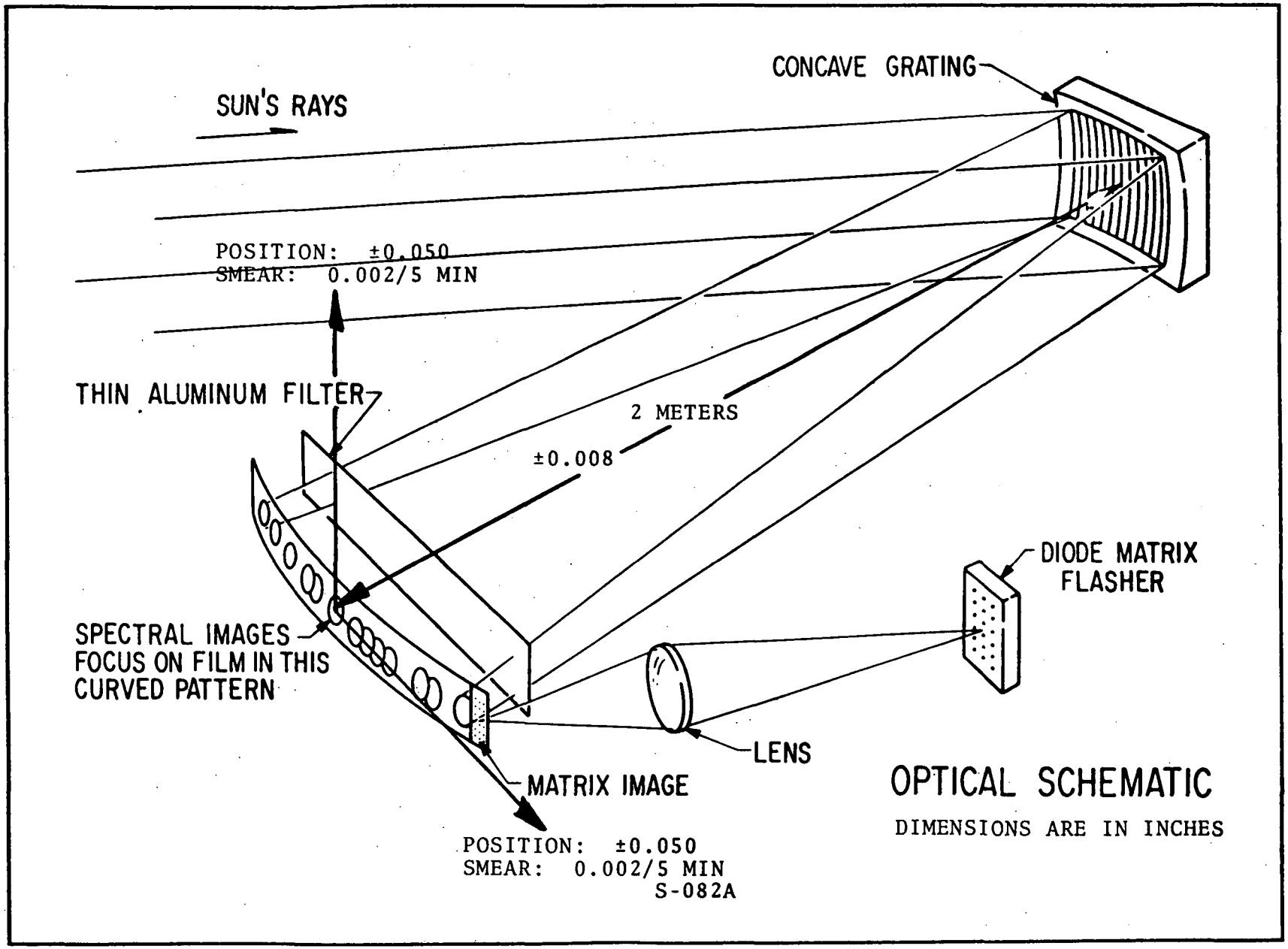


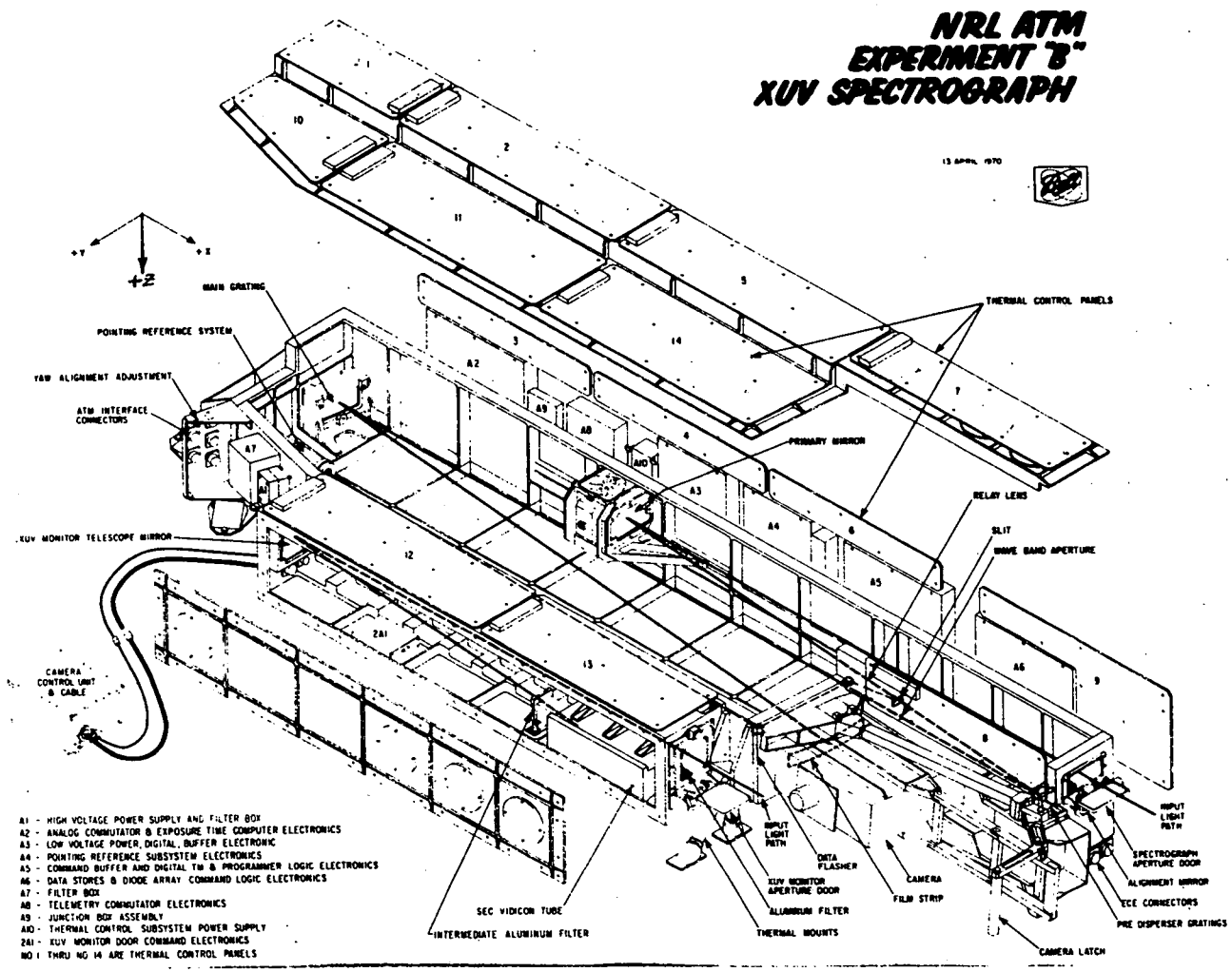
Figure 25 SO82A Spectroheliograph, Maximum Allowable Thermal Distortions

Table 1
S082A SPECTROHELIOGRAPH
OPTICAL IMAGE TOLERANCES FOR THERMAL DISTORTION

Solar Image on Film

		$(X-X_o)$ Image on Film				$T-T_o$*	Basis
Focus							
Tolerance		±0.20	mm	±0.008	inch	±8.0°F	D&PS
Accuracy		±0.05		±0.002		±2.0°F	
Horiz. Position		$(Z-Z_o)$ Image on Film				ΔT Hor.	
Tolerance	2 arc-seconds Solar Image	±1.25	mm	±0.050	inch	±13.0°F	Estimate
Accuracy							
Vert. Position		$(Y-Y_o)$ Image on Film				ΔT Vert.	
Tolerance	2 arc-seconds Solar Image	±1.25	mm	±0.050	inch	± 5.5°F	Estimate
Accuracy							
Horiz. Smear		$\Delta(Z-Z_o)$ in 5 Minutes				ΔΔT/5 Min.	
Tolerance	5 arc-seconds/5 Minutes	0.05	mm	0.002	inch	0.5°F	D&PS
Accuracy		±0.012		±0.0005		± 0.12°F	
Vert. Smear		$\Delta(Y-Y_o)$ in 5 Minutes				ΔΔT/5 Min.	
Tolerance	5 arc-seconds/5 Minutes	0.05	mm	0.002	inch	0.22°F	D&PS
Accuracy		±0.012		±0.0005		± 0.05°F	

*T_o = Calibration Temperature = °F



Focal Distance - Positive No. indicates distance image is in front of slit or film.
Negative No. indicates distance image is behind slit or film.

Horizontal Movement - Positive No. indicates image movement in the +Y direction relative to the slit or film plane.

Vertical Movement - Positive No. indicates image movement in the +Z direction relative to the slit or film plane.

Figure 26 Distortion Sign Convention

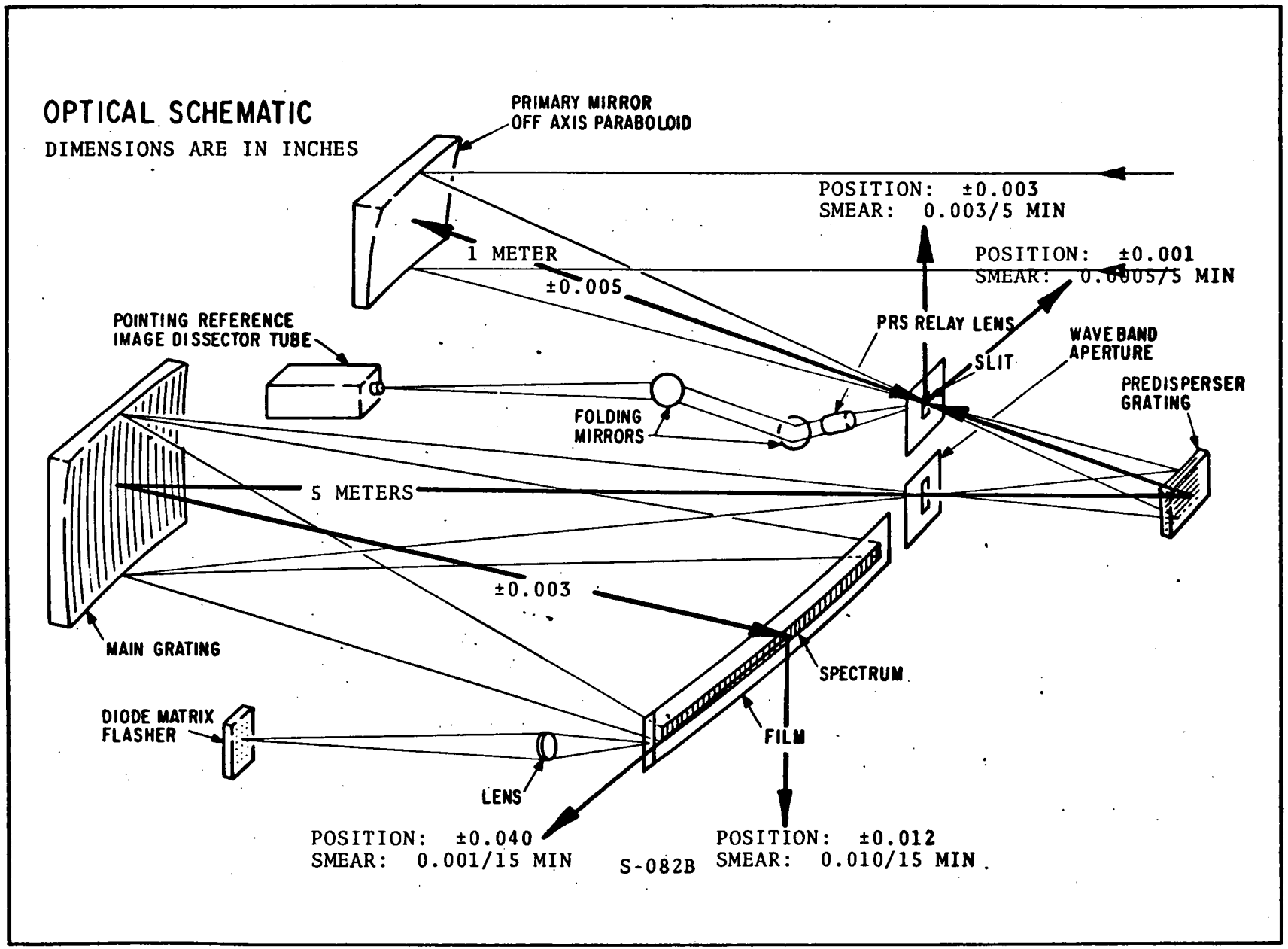


Figure 27 S082B Spectrograph, Maximum Allowable Thermal Distortions

Table 2
S082B Spectrograph and XUV Monitor
Optical Image Tolerances for Thermal Distortion

Sun Image on Slit Plate

Focus		$(X-X_o)$ Sun Image			$T-T_o$*	Basis
Tolerance	2.5 arc-sec Image Blur	±0.126 mm	±0.005	inch	±9.6°F	D&PS
Accuracy		±0.025	±0.001		±2.0°F	
Horiz. Position		$(Y-Y_o)$ Sun Image			ΔT Hor.	
Tolerance	±5 arc-sec on Solar Image	±0.025 mm	±0.001	inch	±2.5°F	Co-Align
Accuracy		±0.010	±0.0004		± 1°F	HCO
Vert. Position		$(Z-Z_o)$ Sun Image			ΔT Vert.	
Tolerance	±15 arc-sec on Solar Image	±0.075 mm	±0.003	inch	±2.5°F	Co-Align
Accuracy		±0.030	±0.0012		± 1°F	HCO
Horiz. Smear		$\Delta(Y-Y_o)$ in 5 Minutes			$\Delta\Delta T$/5 Min.	
Tolerance	2.5 arc-sec/5 Minutes	0.0125 mm	0.0005	inch	±1.25°F	D&PS
Accuracy		±0.005	±0.0002		±0.5°F	
Vert. Smear		$\Delta(Z-Z_o)$ in 5 Minutes			$\Delta\Delta T$/5 Min.	
Tolerance	15 arc-sec/5 Minutes	0.075 mm	0.003	inch	2.5°F	Est.
Accuracy		±0.025	±0.001		±0.8°F	

* T_o = Calibration temperature = 69.8°F

Table 3
NRL-B Optical Image Tolerances for Thermal Distortion

Slit Image on Film

		$(X-X_o)$ Image on Film		$T-T_o$*	Basis
Focus					
Tolerance	6 μ Image Blur	±0.076 mm	±0.003 inch	±1.2°F	D&PS
Accuracy		±0.025	±0.001	±0.4°F	
Horiz. Position		$(Y-Y_o)$ Image on Film		ΔT Hor.	
Tolerance		±1.0 mm	±0.04 inch	± 13°F	Estimate
Accuracy		±0.25	±0.01	± 3°F	(Conservative)
Vert. Position		$(Z-Z_o)$ Image on Film		ΔT Vert.	
Tolerance		±0.3 mm	±0.012 inch	±1.3°F	Estimate
Accuracy		±0.1	±0.004	±0.4°F	
Horiz. Smear		$\Delta(Y-Y_o)$ Image on Film/15 Min		ΔΔT/15 Min.	
Tolerance	25 μ/15 Minutes	0.025 mm	0.001 inch	0.33°F	D&PS
Accuracy		±0.005	±0.0002	±0.07°F	
Vert. Smear		$\Delta(Z-Z_o)$ Image on Film/15 Min		ΔΔT/15 Min.	
Tolerance	250 μ/15 Minutes	0.25 mm	0.010 inch	1.1°F	D&PS
Accuracy		±0.05	±0.002	±0.2°F	

* T = Calibration temperature = 69.8°F

Appendix A

A-1 Memo Report - No B5502 73.026 Skylab 1/2
THERMAL DISTORTION ANALYSIS, S082A and B.

A-2 Memo Report - No B5502 73.028 S082A and B
THERMAL PERFORMANCE SUMMARY SKYLAB 1/2 MISSION

A-3 Memo Report - No B5502 73.036 S082 A and B
THERMAL PERFORMANCE REPORT SKYLAB 3 MISSION

A-4 Memo Report - No B5502 74.002 S082A and B
THERMAL PERFORMANCE REPORTS -- SKYLAB 4 MISSION

620-238
Vol. I

INTEROFFICE MEMORANDUM

TO:	M. W. Frank	NO:	B5502 73.026
FROM:	R. R. Anderson	DATE:	26 June 1973
SUBJECT:	SKYLAB 1/2 THERMAL DISTORTION ANALYSIS, SO82A & B	cc:	See Distribution

---

The attached report was written at the conclusion of the Skylab 1/2 mission. The report describes the work accomplished during the mission and the status of the thermal distortion programs at mission end--June 22, 1973.

R. R. Risinger has informed me that since June 22 he has made the necessary revisions to the tape read logic so that the thermal distortion programs can be run from either fixed format or compressed format Engineering Unit Conversion tapes or user tapes. However, a run using the compressed data tape indicates that negative noise spikes were sufficient in number to cause problems in the data smoothing routine. Additional logic had to be added to the program to eliminate negative going noise spikes from the data. Logic to eliminate positive spikes and to delete the 1×10^6 values inserted by the MSFC programs in place of missing data previously had been added to the program. The necessary program changes have been made and checkout runs will be run this week. The program run time using compressed data tapes is approximately twice that required for fixed format tapes, i.e. ~10 minutes for SO82A and ~18 minutes for SO82B per orbit. Normally fixed format tapes will be used during the mission. In addition, Risinger is continuing the effort to check out the thermal distortion program plotting routine.

Because of the necessity of adding a data smoothing routine to the tape read program--to eliminate noise spikes and missing data--it may never be possible to read aperture open and close data and PRS operating times from tapes. These data are needed to properly input the experiment heat fluxes that are functions of aperture and PRS operation. Manual input of aperture open and close times and PRS operation by punched card will be substituted.

We anticipate that all programs will be checked out and available for use at HOSC and Slidell during the Skylab 3 mission.

R. R. Anderson
R. R. Anderson
Senior Member Technical Staff

pcb

Attachment

Distribution: J. E. Butler
D. W. Ferguson
L. Frobom
J. H. Guy
R. E. Hassig
C. E. Noble
R. R. Risinger
L. L. Schlagel
W. R. Sidle
P. A. Slingsby
R. H. Grunz

THERMAL DISTORTION ANALYSIS
SKYLAB 1/2 REPORT

Thermal distortion analysis of the S082A and B experiments during the Skylab 1/2 mission has been plagued by program problems caused or aggravated by data format and tape read routine changes, missing data and noise on the tape.

Correction of these problems requiring program changes has been hampered by the HOSC computer overload. Priority to run program checkout required negotiation with the data manager for each run. Computer turn-around time for checkout or production runs varied from a few minutes to 36 hours. The average turn-around time was 10 - 12 hours. (generally overnight). This problem has lessened since June 19th and computer priority has been granted on request with a turn-around time average of about four (4) hours.

At this point in time, the thermal distortion analyses programs cannot be run from tape - with a notable exception that on June 20, an NRL-A Thermal distortion analysis was run from a Engineering Unit Conversion (EUC) fixed format tape. This run used the tape for Day 147-4. Attempts to run using identical type EUC tapes from Days 161 and 165 have failed although we have been assured that no tape format changes have been made. R. R. Risinger will work this problem beginning June 21, 1973.

The computer programs were able to read the fixed format users tapes from the Flight unit tests at JSC. All programs were checked out at HOSC using these tapes prior to the Skylab 1/2 mission. A partial listing of the checkout runs is attached.

Capability to read the Skylab 1/2 users tapes required that several program changes be made. The major program problems were caused or aggravated by data format and tape read routine changes missing data and noise spikes on the tapes. The solutions to these basic problems have been found as indicated by the successful NRL-A run - but other problems exist since the program will not read an identical type tape for a different day.

Completion of program checkout requires that sufficient computer time be made available to run several (4-5) runs per day until the errors are found and eliminated. The program debug time is a direct function of computer availability since stepwise isolation of program faults is normal procedure.

When the EUC tape read programs are operational, we plan to continue the programming effort to develope the thermal distortion parameter plotting routines and capability to run thermal distortion and parameter plotting from the NRL User tapes (compressed data format).

Thermal distortion analyses during the first Skylab mission (SL 1/2) were limited to manual runs wherin data from the real time or MDRS consoles was recorded at JSC and transmitted to MSFC by facsimile. Several runs were made using either fixed (single time) input data (which simulates steady state operation) or several points spread over a one orbit period (Transient operation). Distortion data from these runs was plotted or tabalated and transmitted to Bill Sidle at JSC. A listing of the runs made is attached. In addition to the thermal distortion runs listed, frequent reviews of the experiment thermal data available in Data Book Six (6) were done to assess the day to day thermal condition of the experiments. NRL-A has run consistantly colder than expected but within the mean temperature tolerance. NRL-B although in general colder than expected has consistantly been within 0.2 F of the temperature at alignment 69.8 F. A few typical mean temperatures are listed in the table below.

SKYLAB 1/2	NRL-B (S082B) TEMP			NRL-~~B~~ A (S082A) TEMP		
DAY	MEAN	ALIGN	Δ T	MEAN	ALIGN	Δ T
148		69.8		68.09	70.0	-1.91
150	69.76	69.8	-0.04	69.79	70.0	-1.21
154	69.87	69.8	+0.07	68.71	70.0	-1.29
156	69.61	69.8	-0.19	68.36	70.0	-1.64
ALL TEMPERATURES F						

Mean temperatures and the allowable variation from the mean temperatures at alignment for the experiments are as follows:

S082A	70 F ± 8 F	FOCUS, SUN IMAGE ON FILM
S082B	69.8 F ± 1.2 F	FOCUS, SLIT IMAGE ON FILM
	69.8 F ± 9.6 F	FOCUS, SUN IMAGE ON SLIT

Thermal distortion analyses were run in support of A.R. 52 updated, wherin cyclic operation of the canister Thermal control system was proposed as part of the early mission power management solution. Six runs (orbits) were made for NRL-A and four runs were made for NRL-B. The results of these analysis are available in the BBRC Skylab thermal files and are described in the response to AR 52/AR 52 updated.

Thermal Distortion analysis program checkout runs at HOSC (only successful runs listed).

All the following runs were made using the JSC Flight unit test users tape for Day 213 #25012 and 25110

DATE	RUN IDENTIFICATION	COMMENT
5-2-73	NRL B Checkout.run #1	Manual input combining Houston test data and SIM data for 4-24-73 SIM,1 orbit
5-2-73	NRL B Checkout Run #2	Checks system capability to read Skylab users tape from Houston test data day 213 with 61 entry flux and specified temp tables. 1 orbit
5-3-73	NRL B Check Run #3	Checks program capability to delete selected probe data from tape input. Simulate probe failure also checks heater (TCS) failure.
5-3-73	NRL B check run #4	Checks program failed heater probe function with heater not failed.
5-4-73	NRL B check run #5 A and 5 B	Checks program manual input of add on positive and negative heat flux tables.
5-4-73	NRL B run #6	Checks program manual input of add-on fluxes and deletion of nominal data deck fluxes. Checks capability to simulate failure of an electronic box or other heat producing component without disturbing nominal data deck setup.

DATE	RUN IDENTIFICATION	COMMENT
5-4-73	NRL B check run #7	Checks program function which replaces nominal data deck initial temperatures file with a card input file.
5-7-73	NRL A check run	Checks program manual input of add-on flux deleting nominal data deck tables.
RUNS LISTED BELOW USE MANUAL DATA INPUT/NO DATA TAPE		
5-28-73	NRL B ATM TCS Power Management Thermal Distortion Analysis Orbit 4	Re-run at HOSC to check program tape #33106
5-28-73	NRL A ATM TCS Power Management Thermal Distortion Analysis Orbit 6	Re-run at HOSC to check program tape #33106
6-1-73	NRL B ATM TCS Power Management Thermal Distortion Analysis Orbit 4	Re-run at Slidel to check capability to run and to check program tape #99998
6-1-73	NRL A ATM TCS Power Management Thermal Distortion Analysis Orbit 6	Re-run at Slidel to check capability to run and to check program tape #99998.

Production Runs SL 1/2 Mission Support

DATE	RUN IDENTIFICATION	COMMENT
5-25-73 thru 5-27-73	NRL A ATM TCS Power Management Thermal Distortion Analysis Orbit 1 thru 6	6 runs in support of AR 52/ AR 52 updated.
5-26-73 thru 5-27-73	NRL B ATM TCS Power Management Thermal Distortion Analysis Orbit 1 thru 4	4 runs in support of AR 52/ AR 52 updated

PRODUCTION RUNS: SL 1/2 MISSION SUPPORT (ONLY SUCCESSFUL RUNS LISTED)

5-31-73	NRL A Fixed Point Thermal Distortion Day 150	Manual input from data supplied by Sidle results transmitted to Sidle.
5-31-73	NRL B Fixed Point Thermal Distortion Analysis, Day 150	Same as above.
6-3-73	NRL A Fixed Point Thermal Distortion Analysis Day 154:3:1:42	Manual input from data supplied by Sidle - Results transmitted to Sidle.
6-3-73	NRL B Fixed Point Thermal Distortion Analysis Day 154:3:1:42	Same as above.
6-7-73	NRL A Transient Thermal Distortion Analysis; Day 156:6:43:44	Manual 8 point input table supplied by Sidle - Results plotted and transmitted to Sidle.
6-7-73	NRL B Transient Thermal Distortion Analysis; Day 156:6:43:44	Same as above.
6-15-73	NRL A Transient Thermal Distortion Analysis; Day 156:6:43:44 Revised Flux Tables	Similar to "A" run on 6-7-73 - Heat Flux tables corrected. Used to check out program at Slidell.

INTEROFFICE MEMORANDUM

TO: M. W. Frank

NO: B5502 73.028

FROM: R. R. Anderson X4221

DATE: 2 July 1973

SUBJECT: SO82A & B THERMAL PERFORMANCE SUMMARY SKYLAB 1/2 MISSION

cc: J. E. Butler
R. H. Grunz
C. E. Noble
W. R. Sidle
H. L. Valentine

The attached tables and curves summarize the thermal performance of the SO82A and B experiments during the Skylab 1/2 mission.

Thermal distortion analyses during this mission were limited to manual runs wherein data from the real time or MDRS consoles was recorded at JSC and transmitted to MSFC by facsimile. Several runs were made using either fixed point (single time) input data (which simulates steady state operation) or several data points spread over a one orbit period. Distortion data from these runs were tabulated, for steady state, or plotted for transient operation. The tabulations and plots are attached.

Thermal distortion analyses were run in support of AR52/AR52 updated, wherein cyclic operation of the canister thermal control system was proposed as part of the early mission power management solution. Six runs (orbits) were made for NRL-A and four runs were made for NRL-B. The plotted results of the first and last orbits of each set are attached.

These results together with frequent reviews of real time temperature data (not tabulated) indicated that at no time during the mission did the experiments exceed the image focus or smear requirements.

R. R. Anderson

R. R. Anderson
Senior Member Technical Staff

Attachments

S082A - Skylab 1/2
FIXED POINT THERMAL DISTORTION
(Steady State)

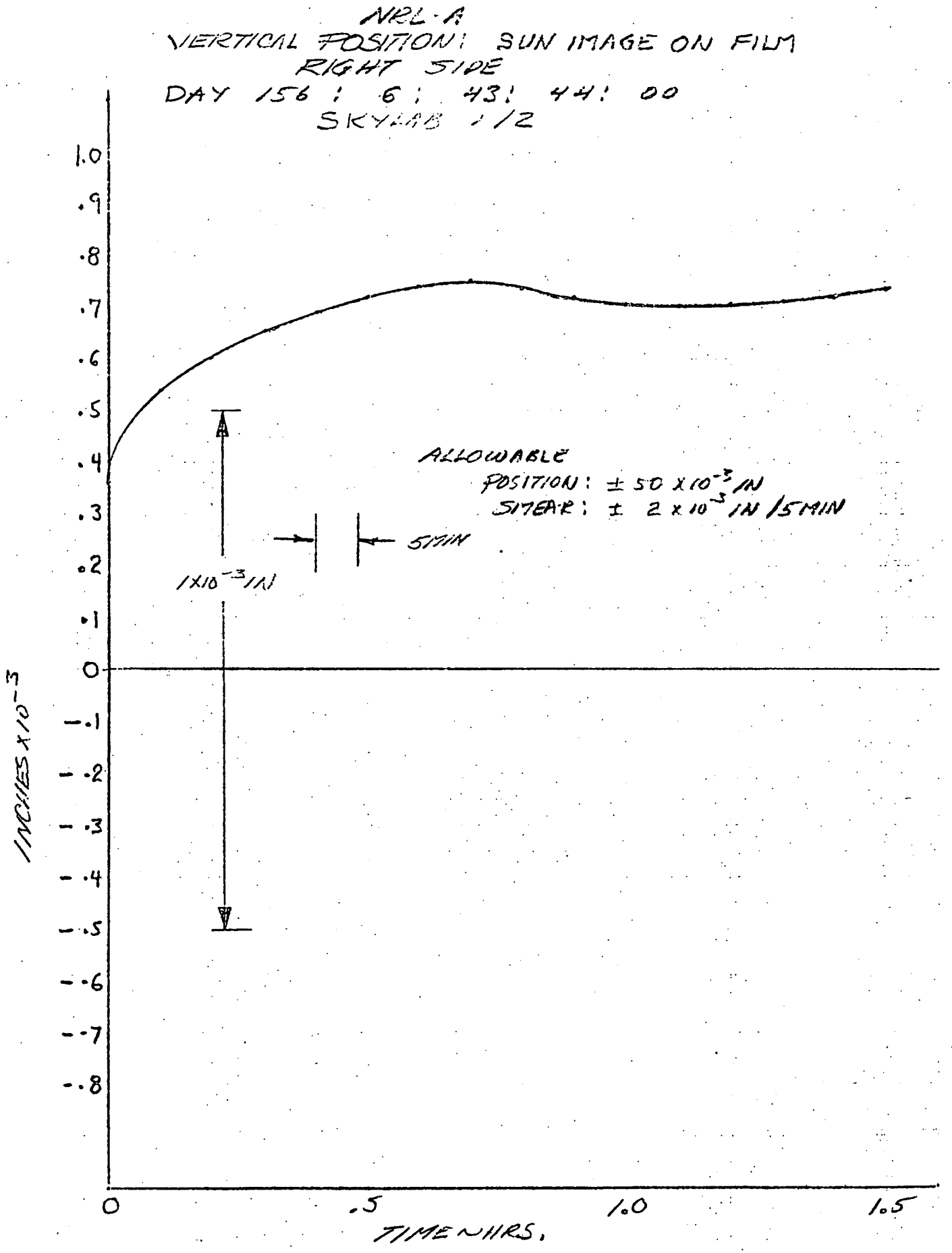
	Orbit Day 150	Orbit Day 154	Allowable
1. Focus Sun Image on Film			
Right	-1.49×10^{-3}	-1.57×10^{-3}	$\pm 8 \times 10^{-3}$
Left	-1.63×10^{-3}	1.72×10^{-3}	$\pm 8 \times 10^{-3}$
2. Horizontal Position: Sun Image on Film			
Right	-7.69×10^{-3}	-7.63×10^{-3}	$\pm 50 \times 10^{-3}$
Left	-7.94×10^{-3}	-7.88×10^{-3}	$\pm 50 \times 10^{-3}$
3. Vertical Position: Sun Image on Film			
Right	-0.008×10^{-3}	0.28×10^{-3}	$\pm 50 \times 10^{-3}$
Left	-0.050×10^{-3}	0.24×10^{-3}	$\pm 50 \times 10^{-3}$

All Dimensions Inches

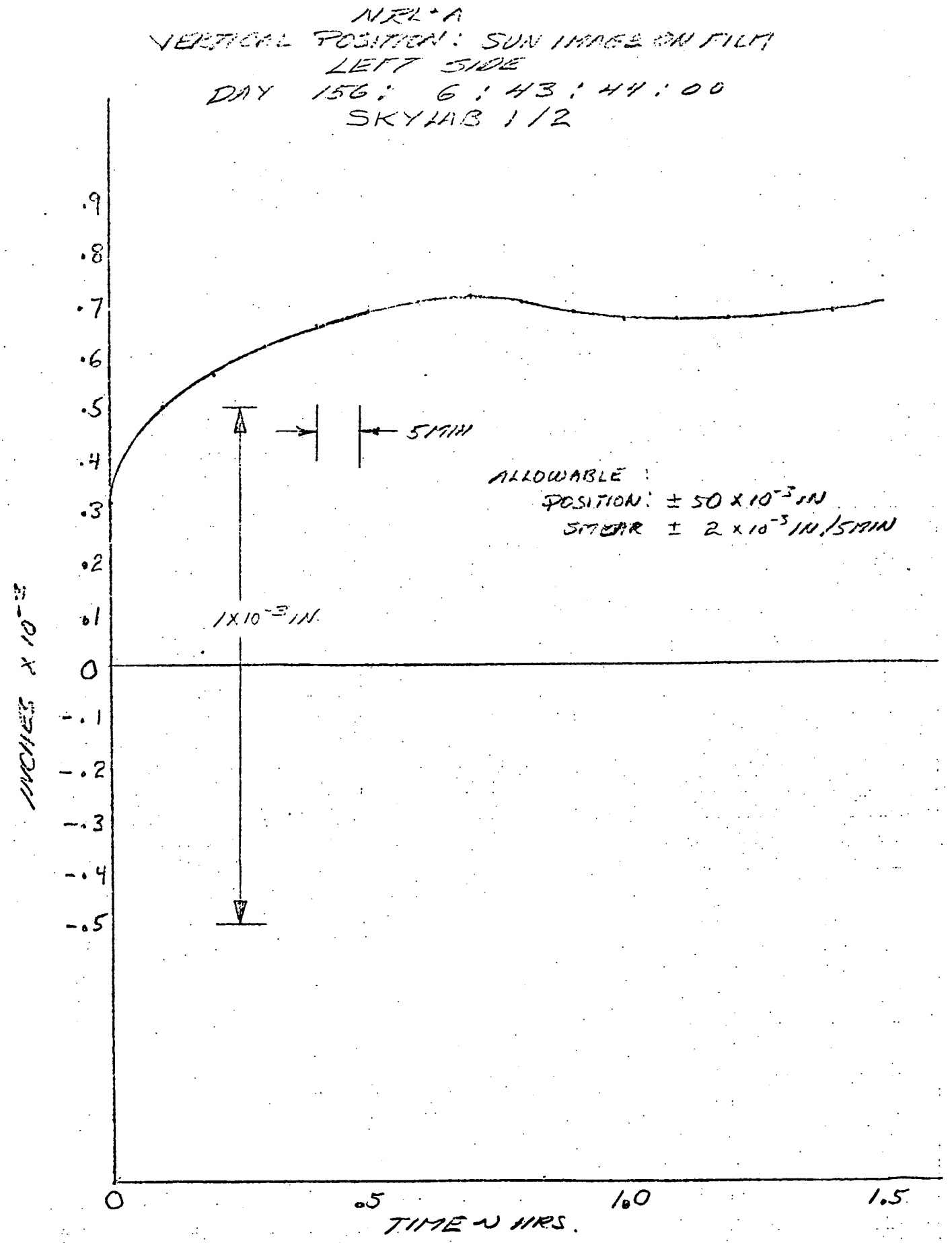
S082B - Skylab 1/2
FIXED POINT THERMAL DISTORTION
(Steady State)

	Orbit Day 150	Orbit Day 154	Allowable
Sun Image on Slit Focus	-0.04×10^{-3}	0.06×10^{-3}	$\pm 5 \times 10^{-3}$
Position, Horizontal	0.47×10^{-3}	0.54×10^{-3}	$\pm 3 \times 10^{-3}$
Position, Vertical	-0.99×10^{-3}	-0.33×10^{-3}	$\pm 1 \times 10^{-3}$
Slit Image on Film			
Focus, Right	-0.65×10^{-3}	-0.37×10^{-3}	$\pm 3 \times 10^{-3}$
Focus, Left	-0.87×10^{-3}	-0.59×10^{-3}	$\pm 3 \times 10^{-3}$
Slit Image on Film Position, Vertical			
Right	-0.45×10^{-3}	-0.47×10^{-3}	$\pm 12 \times 10^{-3}$
Left	-0.27×10^{-3}	-0.32×10^{-3}	$\pm 12 \times 10^{-3}$
Slit Image on Film Position, Horizontal			
Right	-0.98×10^{-3}	-1.09×10^{-3}	$\pm 40 \times 10^{-3}$
Left	-1.33×10^{-3}	-1.46×10^{-3}	$\pm 40 \times 10^{-3}$

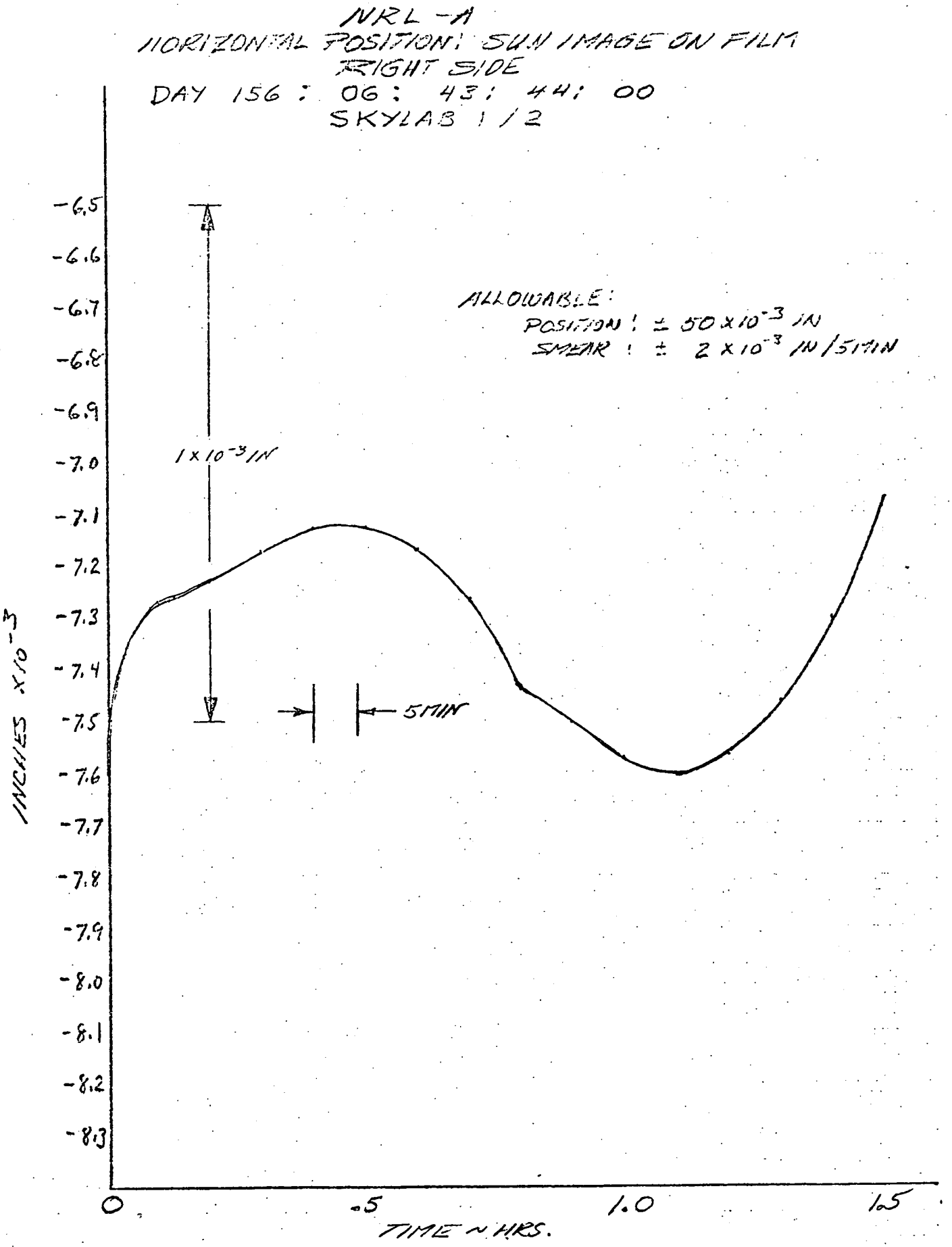
All Dimensions Inches


NRL-A
VERTICAL POSITION: SUN IMAGE ON FILM
RIGHT SIDE
DAY 156 : 6 : 43 : 44 : 00
SKYLAB 1/2
ALLOWABLE
POSITION: ± 50 X 10^-3 IN
SMEAR: ± 2 X 10^-3 IN /5 MIN
5 MIN
1X10^-3 IN
INCHES X 10^-3
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
-.1
-.2
-.3
-.4
-.5
-.6
-.7
-.8
0
.5
1.0
1.5
TIME ~ HRS.

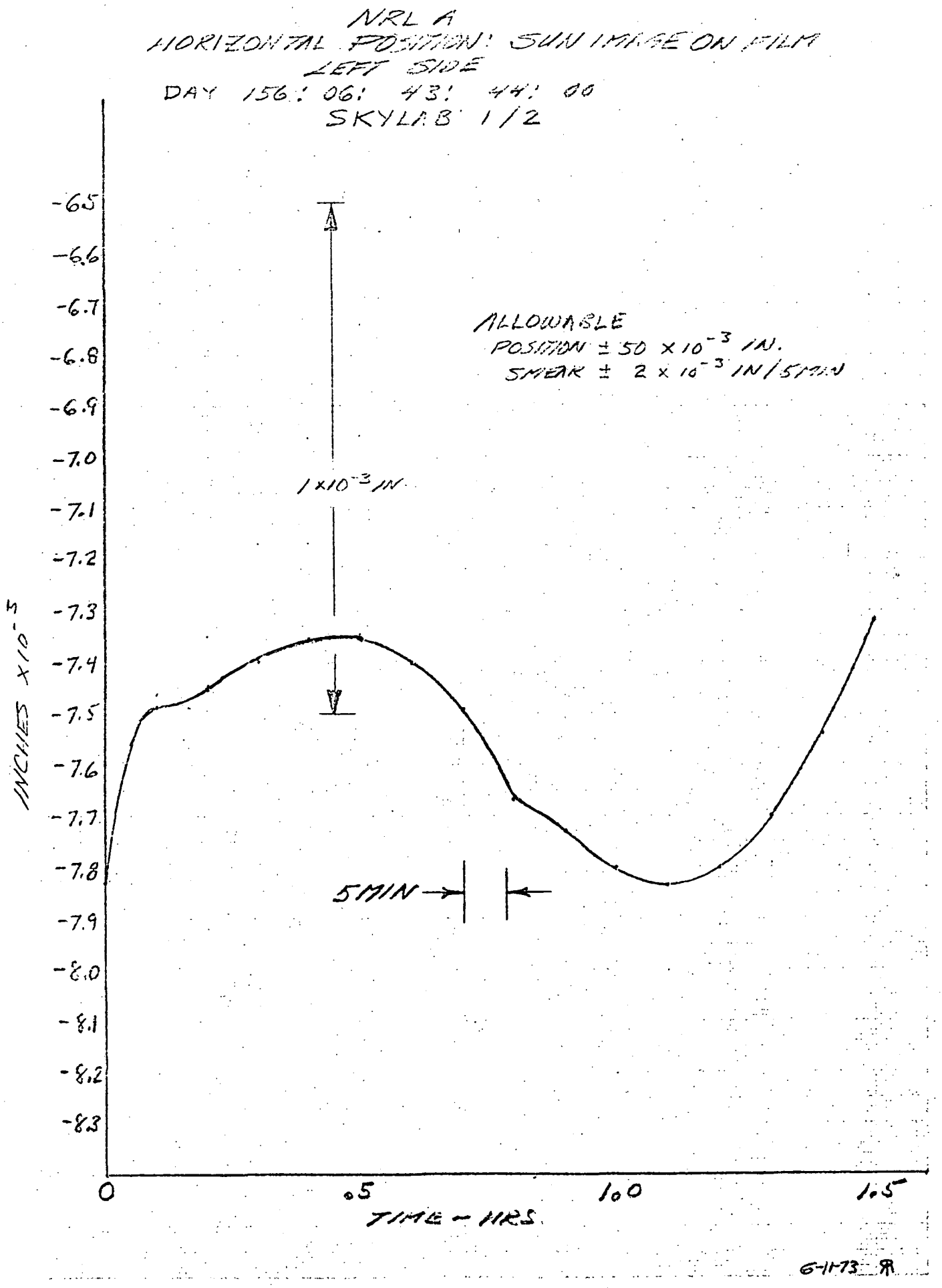
6-11-73

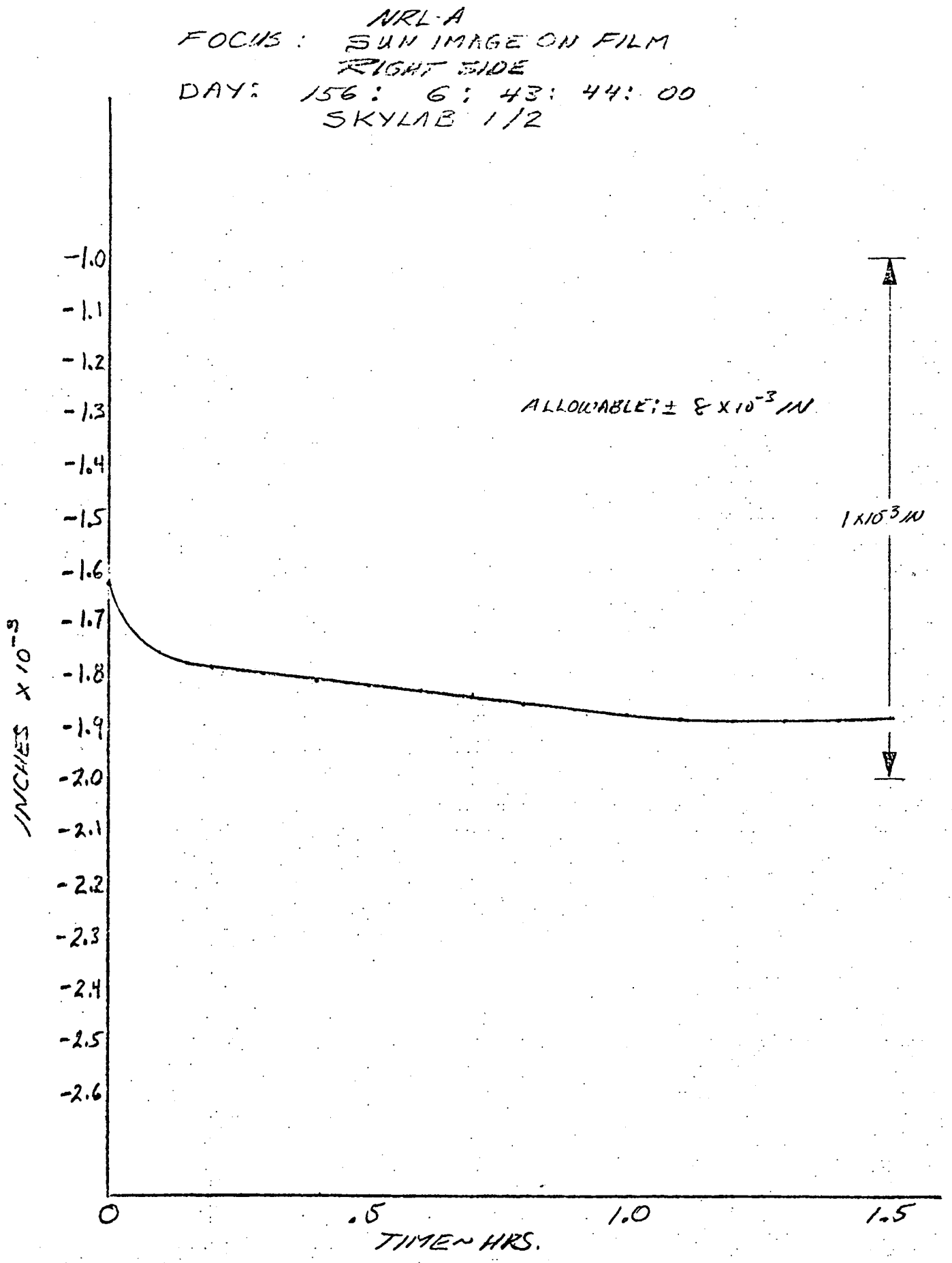

NRL-A
VERTICAL POSITION: SUN IMAGE ON FILM
LEFT SIDE
DAY 156: 6:43:44:00
SKYLAB 1/2
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
-.1
-.2
-.3
-.4
-.5
INCHES X 10^-3
5 MIN
ALLOWABLE:
POSITION: ± 50 X 10^-3 IN
SMEAR ± 2 X 10^-3 IN./5 MIN
1 X 10^-3 IN.
0
.5
1.0
1.5
TIME ~ HRS.

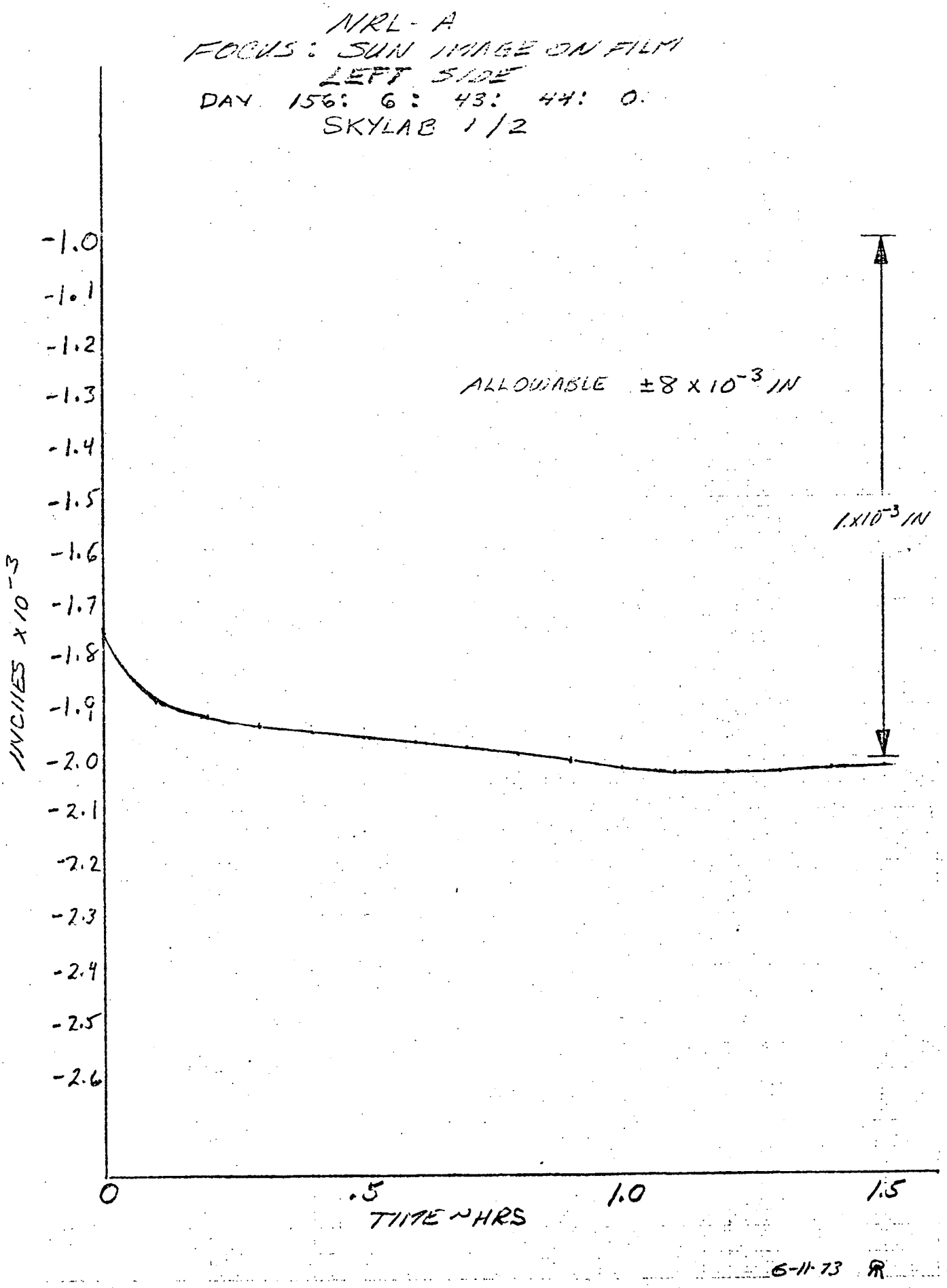
6-1473

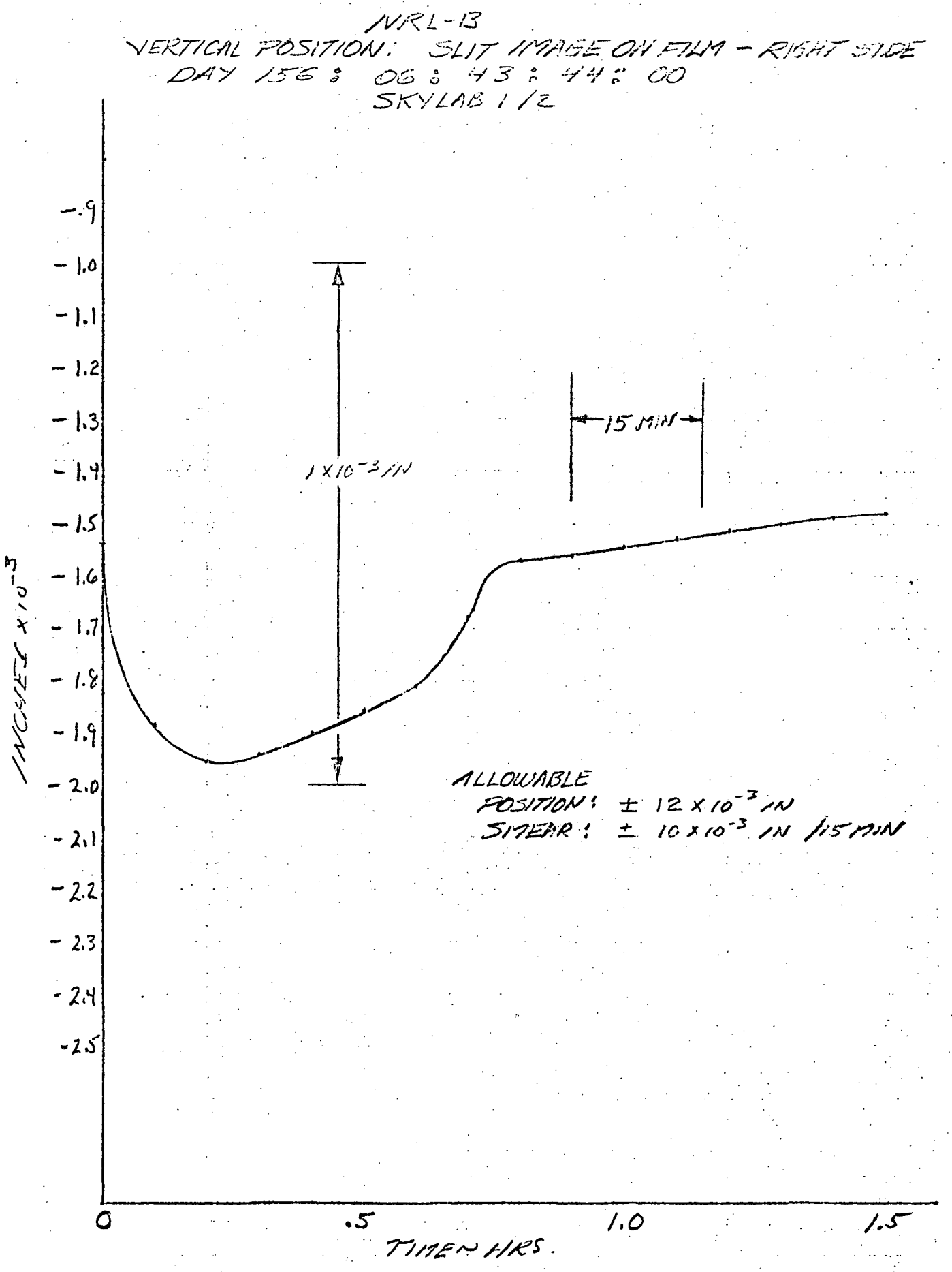

NRL-A
HORIZONTAL POSITION: SUN IMAGE ON FILM
RIGHT SIDE
DAY 156 : 06 : 43 : 44 : 00
SKYLAB 1/2
ALLOWABLE:
POSITION: ± 50 x 10^-3 IN
SMEAR: ± 2 x 10^-3 IN/5MIN
1 x 10^-3 IN
5MIN
INCHES x 10^-3
-6.5
-6.6
-6.7
-6.8
-6.9
-7.0
-7.1
-7.2
-7.3
-7.4
-7.5
-7.6
-7.7
-7.8
-7.9
-8.0
-8.1
-8.2
-8.3
0
.5
1.0
1.5
TIME ~ HRS.

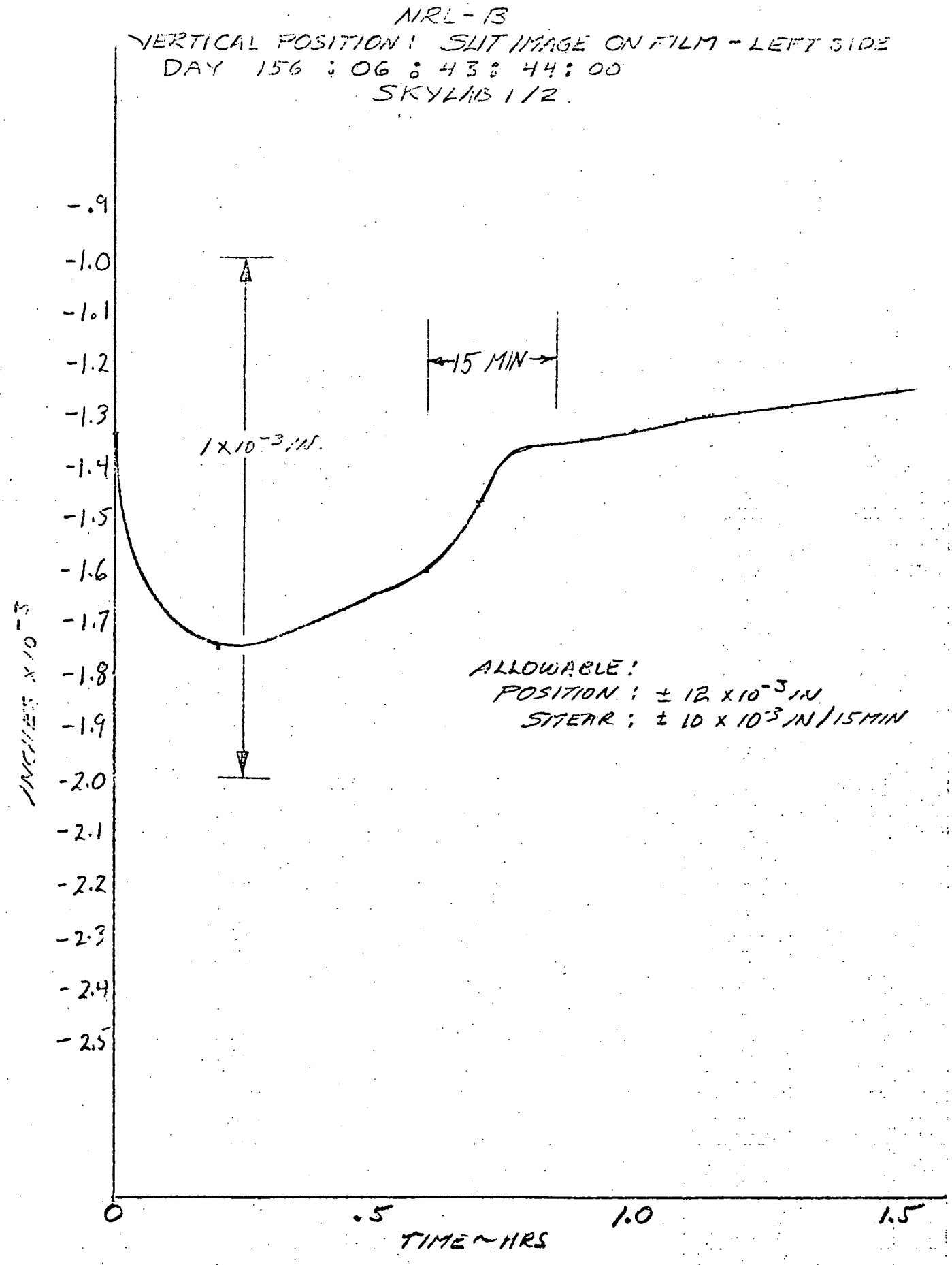
6-11-73 RR


NRL A
HORIZONTAL POSITION: SUN IMAGE ON FILM
LEFT SIDE
DAY 156: 06: 43: 44: 00
SKYLAB 1/2
ALLOWABLE
POSITION ± 50 × 10⁻³ IN.
SMEAR ± 2 × 10⁻³ IN/5MIN
1×10⁻³ IN.
5MIN
INCHES × 10⁻³
-6.5
-6.6
-6.7
-6.8
-6.9
-7.0
-7.1
-7.2
-7.3
-7.4
-7.5
-7.6
-7.7
-7.8
-7.9
-8.0
-8.1
-8.2
-8.3
0
.5
1.0
1.5
TIME – HRS.
6-1-73

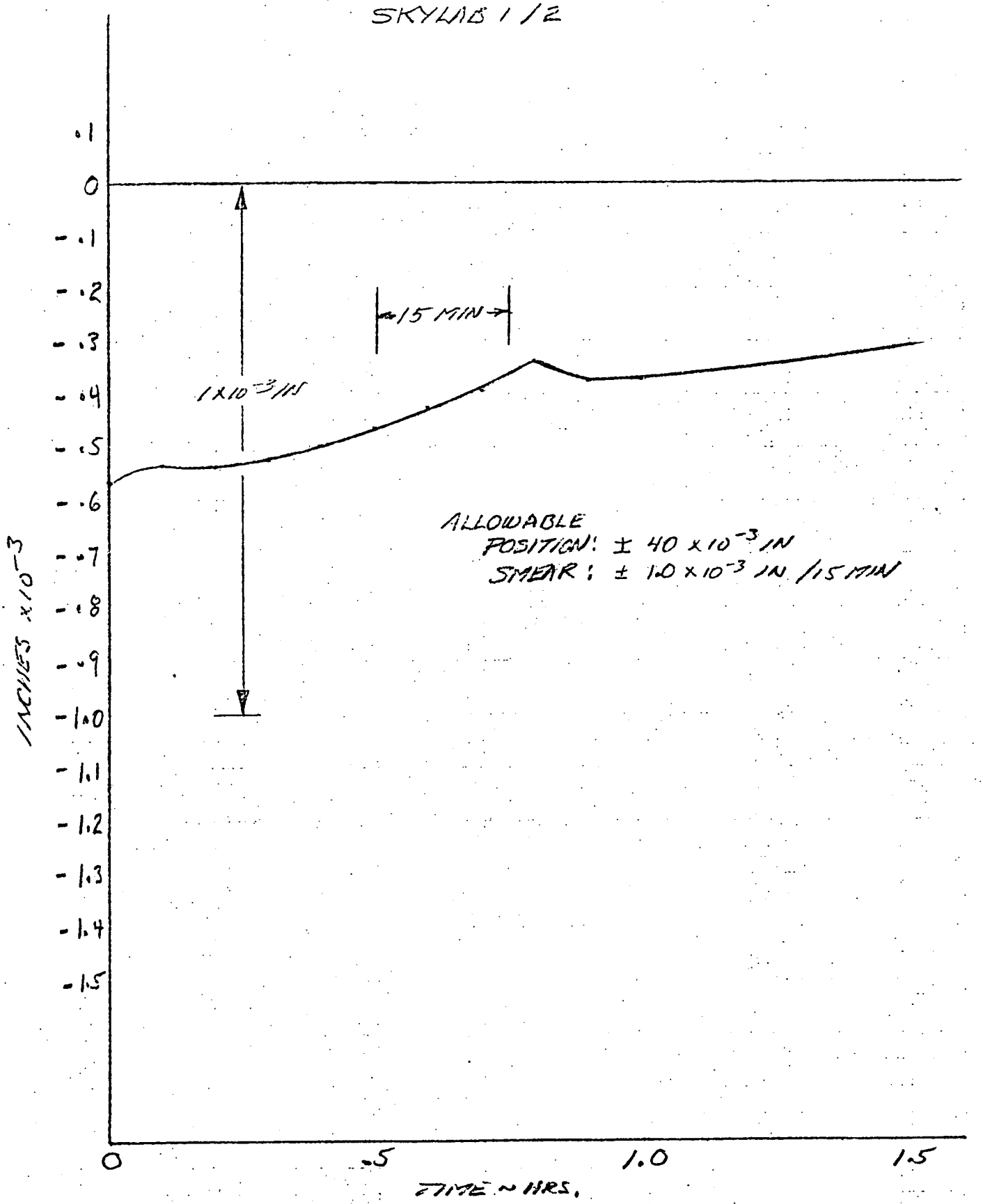

NRL-A
FOCUS: SUN IMAGE ON FILM
RIGHT SIDE
DAY: 156: 6: 43: 44: 00
SKYLAB 1/2
ALLOWABLE: ± 8 X 10^-3 IN
1 X 10^-3 IN
INCHES X 10^-3
-1.0
-1.1
-1.2
-1.3
-1.4
-1.5
-1.6
-1.7
-1.8
-1.9
-2.0
-2.1
-2.2
-2.3
-2.4
-2.5
-2.6
0
.5
1.0
1.5
TIME~HRS.
6-11-73


NRL - A
FOCUS : SUN IMAGE ON FILM
LEFT SIDE
DAY 156: 6 : 43: 44: 0.
SKYLAB 1/2
ALLOWABLE ±8 x 10^-3 IN
1 x 10^-3 IN
INCHES x 10^-3
-1.0
-1.1
-1.2
-1.3
-1.4
-1.5
-1.6
-1.7
-1.8
-1.9
-2.0
-2.1
-2.2
-2.3
-2.4
-2.5
-2.6
0
.5
1.0
1.5
TIME ~ HRS
6-11-73

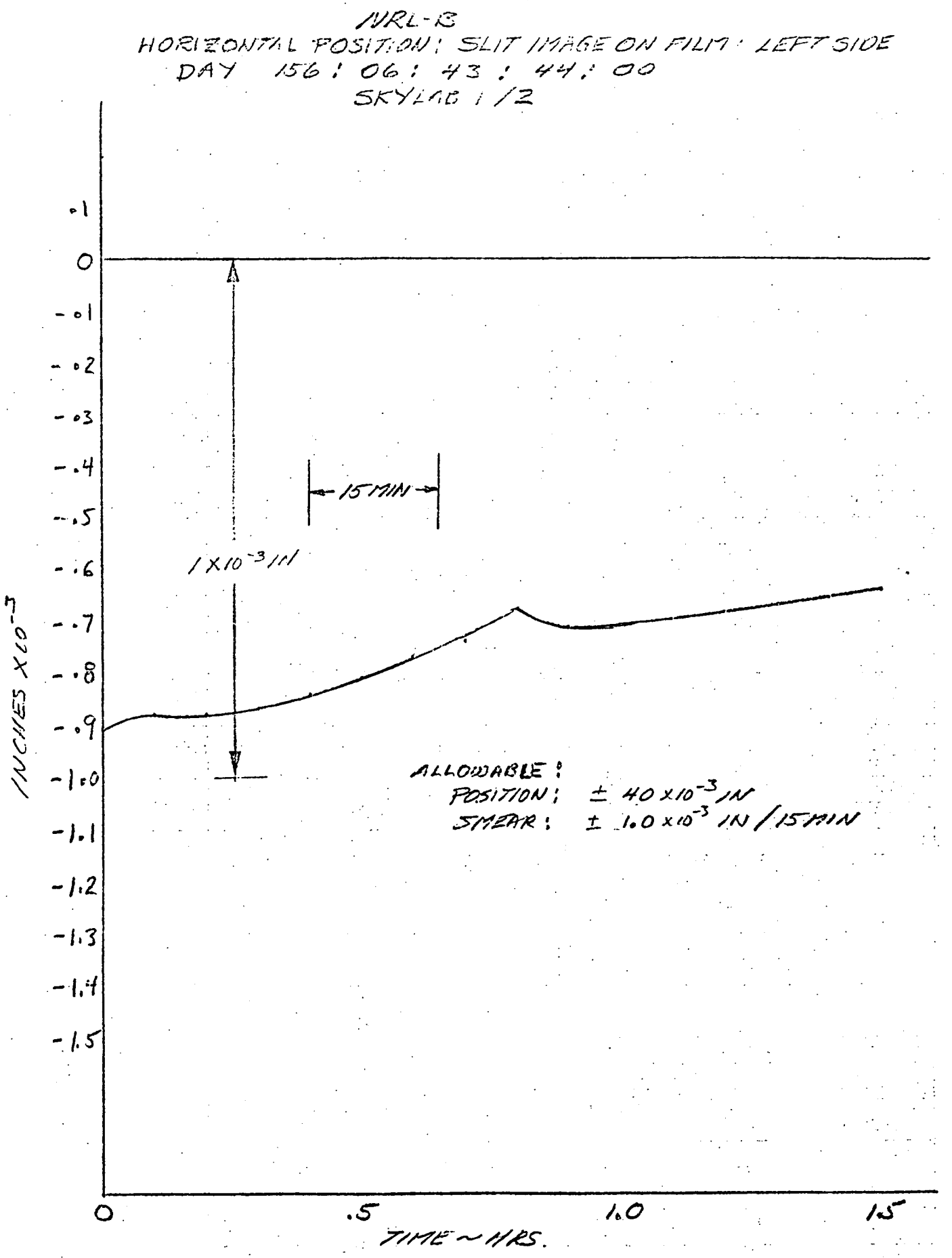

NRL-13
VERTICAL POSITION: SLIT IMAGE ON FILM - RIGHT SIDE
DAY 156 : 06 : 43 : 44 : 00
SKYLAB 1/2
-.9
-1.0
-1.1
-1.2
-1.3
-1.4
-1.5
-1.6
-1.7
-1.8
-1.9
-2.0
-2.1
-2.2
-2.3
-2.4
-2.5
INCHES x 10^-3
1 x 10^-3 IN
15 MIN
ALLOWABLE
POSITION: ± 12 x 10^-3 IN
SMEAR: ± 10 x 10^-3 IN /15 MIN
0
.5
1.0
1.5
TIME ~ HRS.
6-11-73


NRL-13
VERTICAL POSITION: SLIT IMAGE ON FILM - LEFT SIDE
DAY 156 : 06 : 43 : 44 : 00
SKYLAB 1/2
-.9
-1.0
-1.1
-1.2
-1.3
-1.4
-1.5
-1.6
-1.7
-1.8
-1.9
-2.0
-2.1
-2.2
-2.3
-2.4
-2.5
INCHES X 10^-3
1 X 10^-3 IN.
15 MIN
ALLOWABLE:
POSITION: ± 12 X 10^-3 IN
STEAR: ± 10 X 10^-3 IN/15 MIN
0
.5
1.0
1.5
TIME ~ HRS
6-11-73

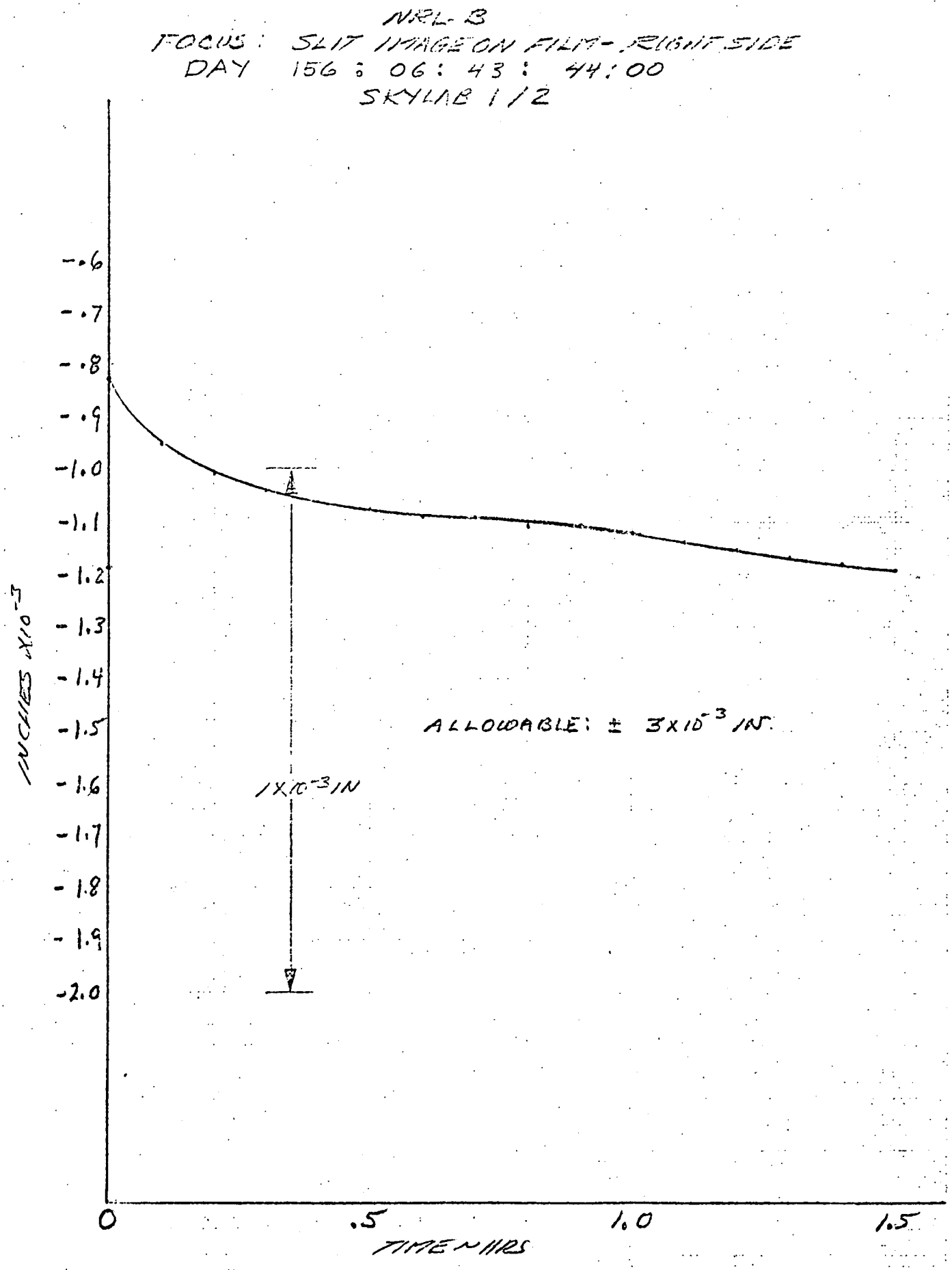
NRL-B
HORIZONTAL POSITION: SLIT IMAGE ON FILM - RIGHT SIDE
DAY 156 : 06 : 43 : 44 : 00
SKYLAB 1/2



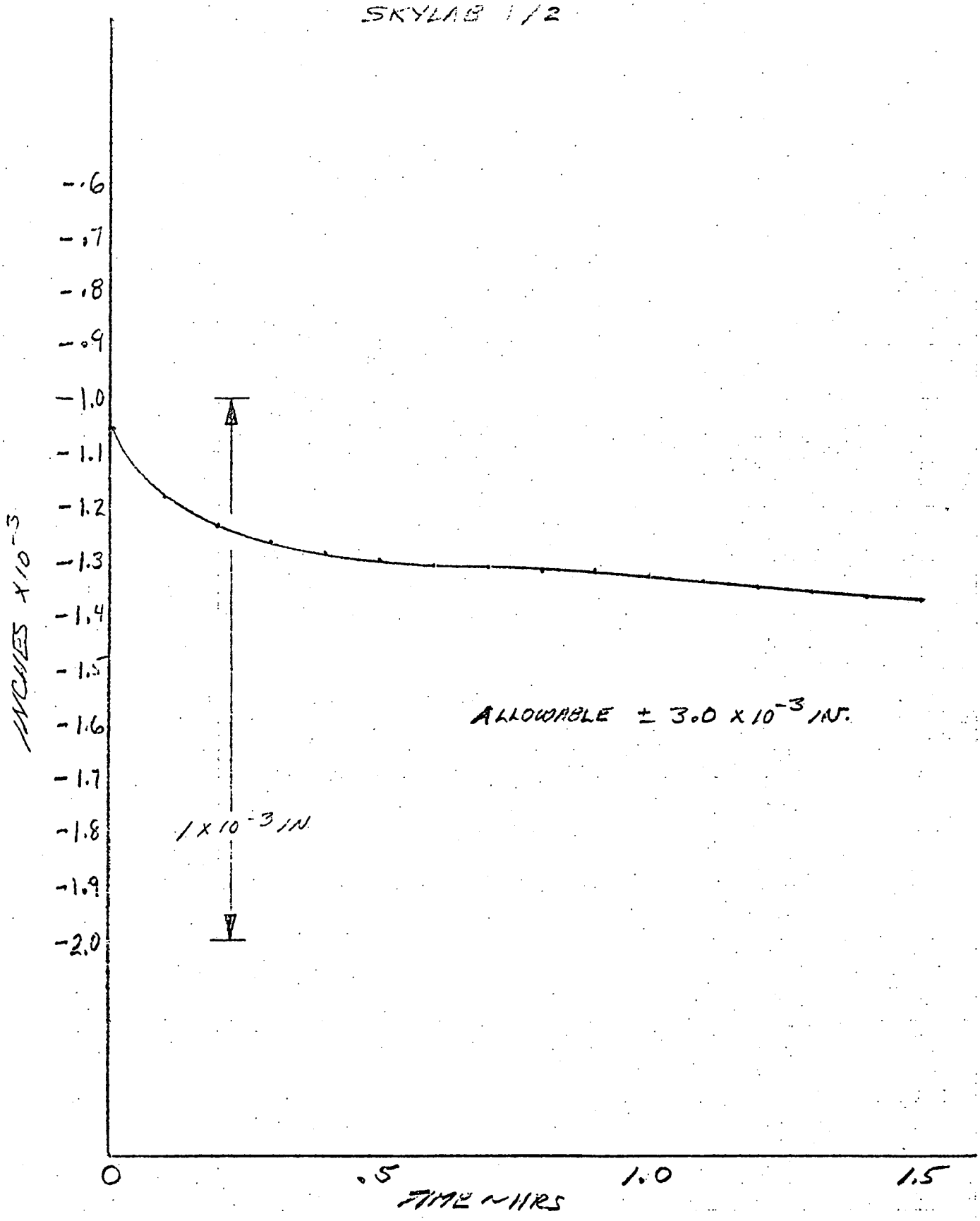
6-11-73 R


NRL-B
HORIZONTAL POSITION: SLIT IMAGE ON FILM: LEFT SIDE
DAY 156: 06: 43: 44: 00
SKYLAB 1/2
.1
0
-.1
-.2
-.3
-.4
-.5
-.6
-.7
-.8
-.9
-1.0
-1.1
-1.2
-1.3
-1.4
-1.5
INCHES X10^-3
15 MIN
1X10^-3 IN
ALLOWABLE:
POSITION: ± 40 X10^-3 IN
SMEAR: ± 1.0 X10^-3 IN/15 MIN
0
.5
1.0
1.5
TIME ~ HRS.

6-11-73 R

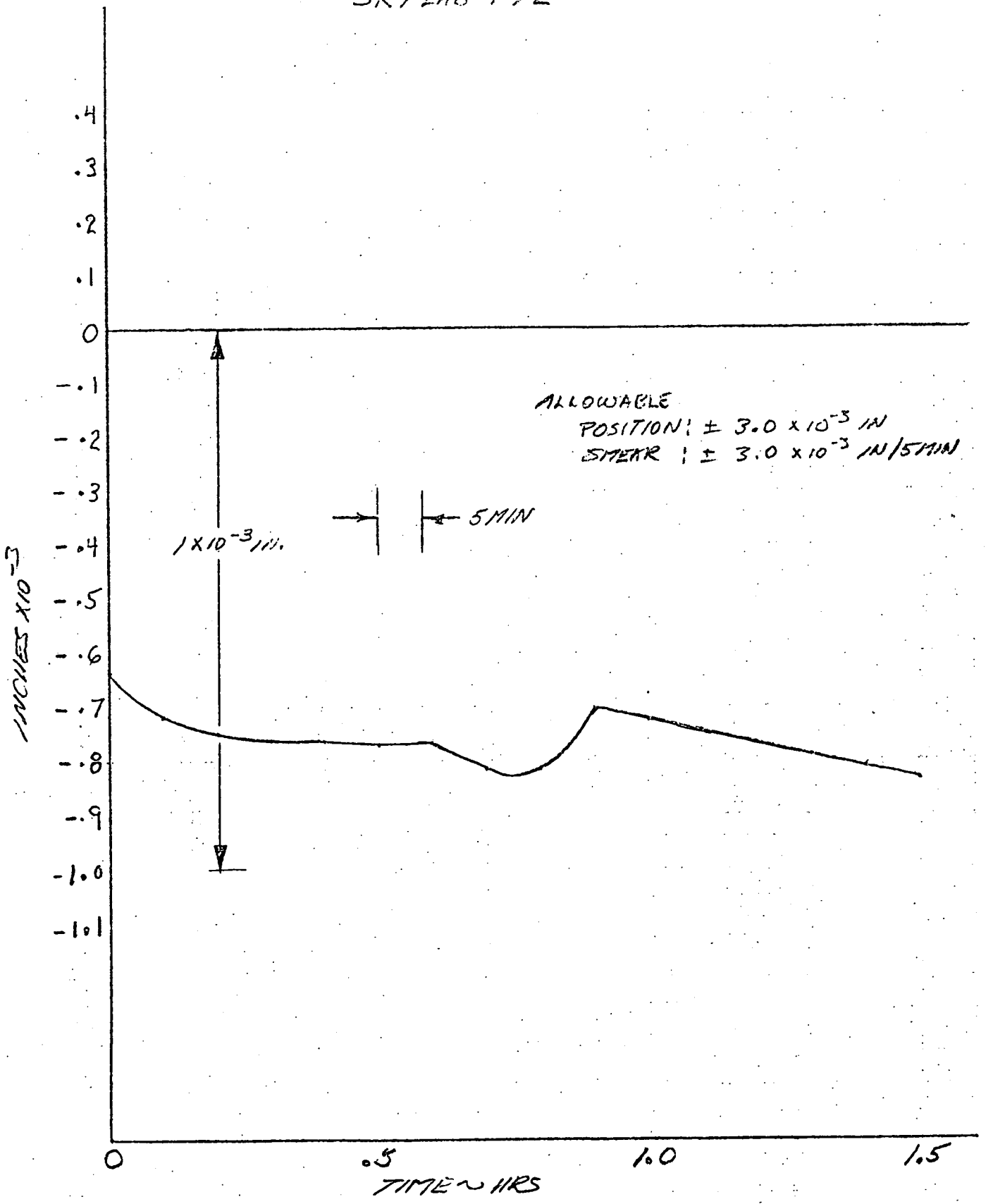

NRL-B
FOCUS: SLIT IMAGE ON FILM - RIGHT SIDE
DAY 156 : 06 : 43 : 44:00
SKYLAB 1/2
-.6
-.7
-.8
-.9
-1.0
-1.1
-1.2
-1.3
-1.4
-1.5
-1.6
-1.7
-1.8
-1.9
-2.0
INCHES X10^-3
ALLOWABLE: ± 3X10^-3 IN.
1X10^-3 IN
0
.5
1.0
1.5
TIME ~ HRS
6-11-73

NRL - B
FOCUS: SLIT IMAGE ON FILM LEFT SIDE
DAY 156 : 06 : 43 : 44 : 00
SKYLAB 1/2



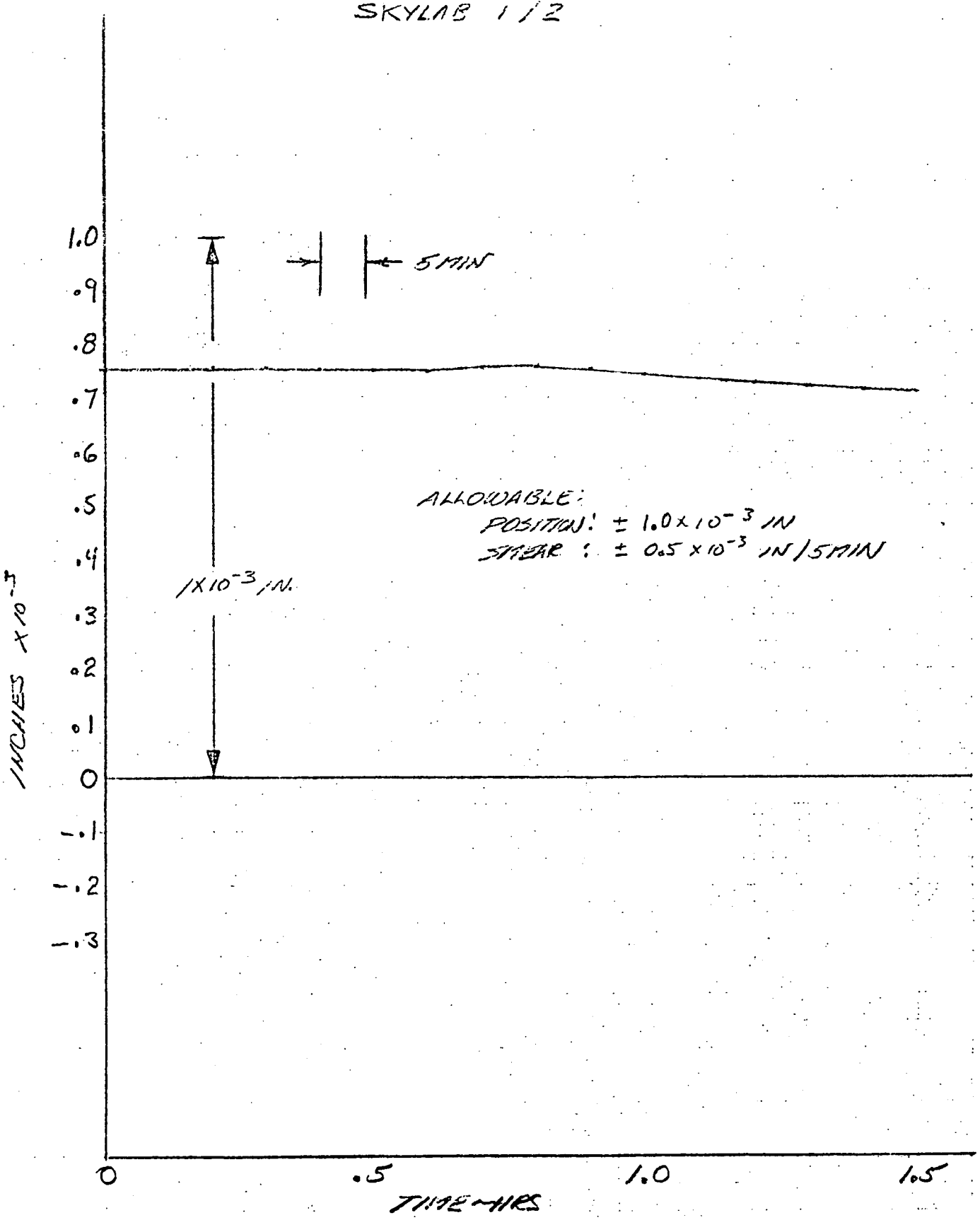
6-11-73 RR

NRL-B
VERTICAL POSITION: SUN IMAGE ON SLIT
DAY 156 : 06 : 43 : 44 : 00
SKYLAB 1/2

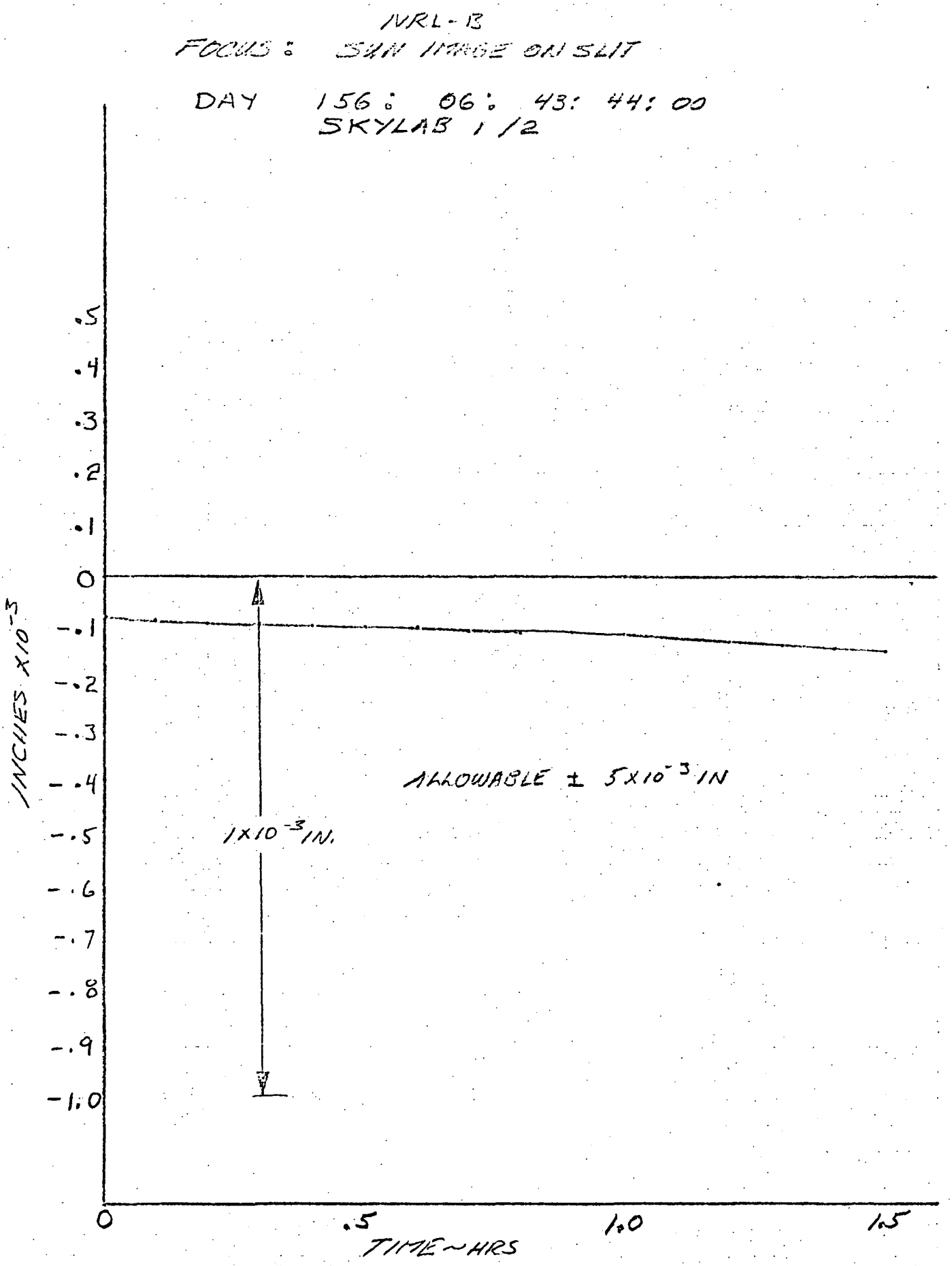


6-11 73

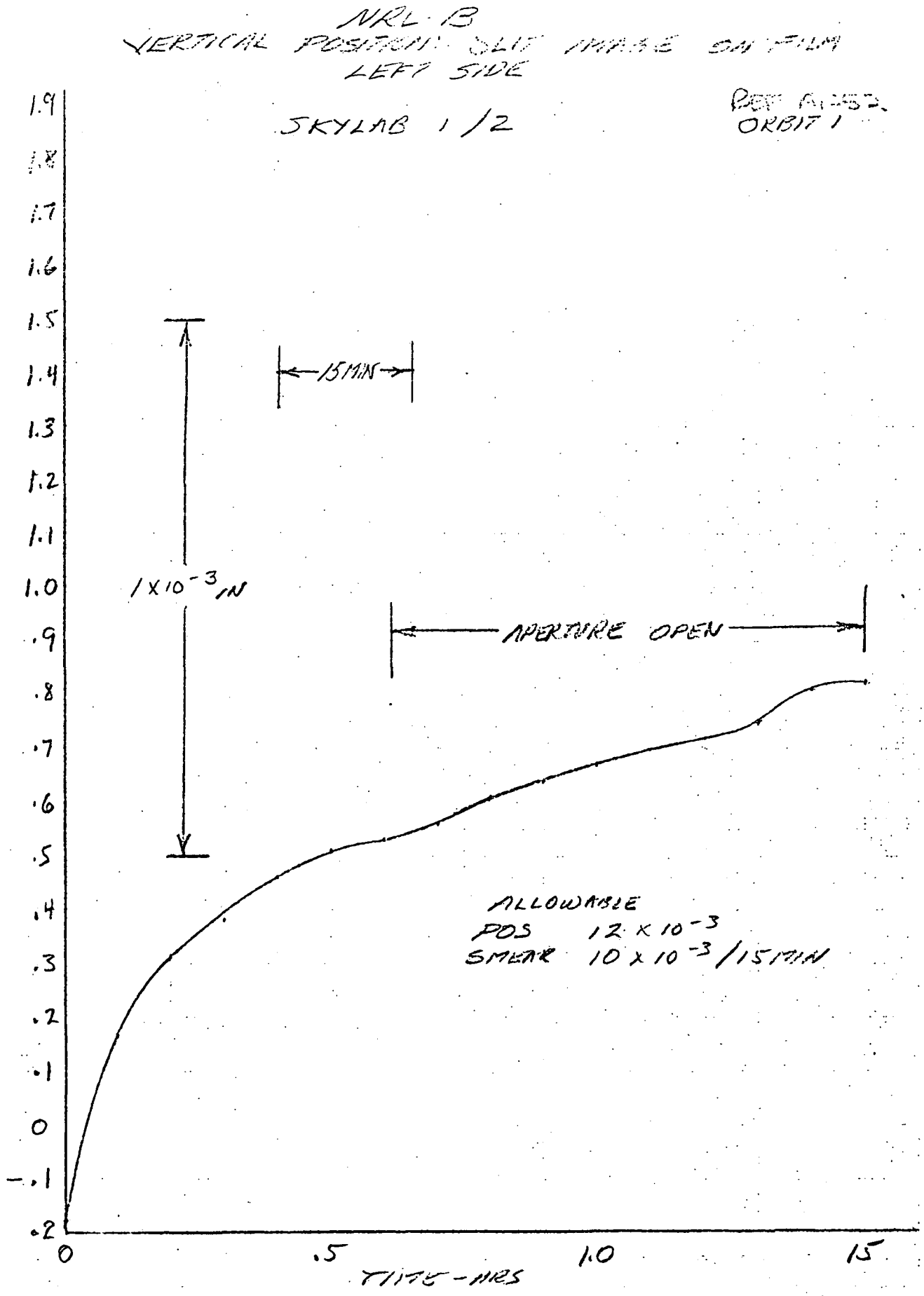
NRL-B
HORIZONTAL POSITION: SUN IMAGE ON SLIT
DAY 156 : 06 : 43 : 44 : 00
SKYLAB 1/2



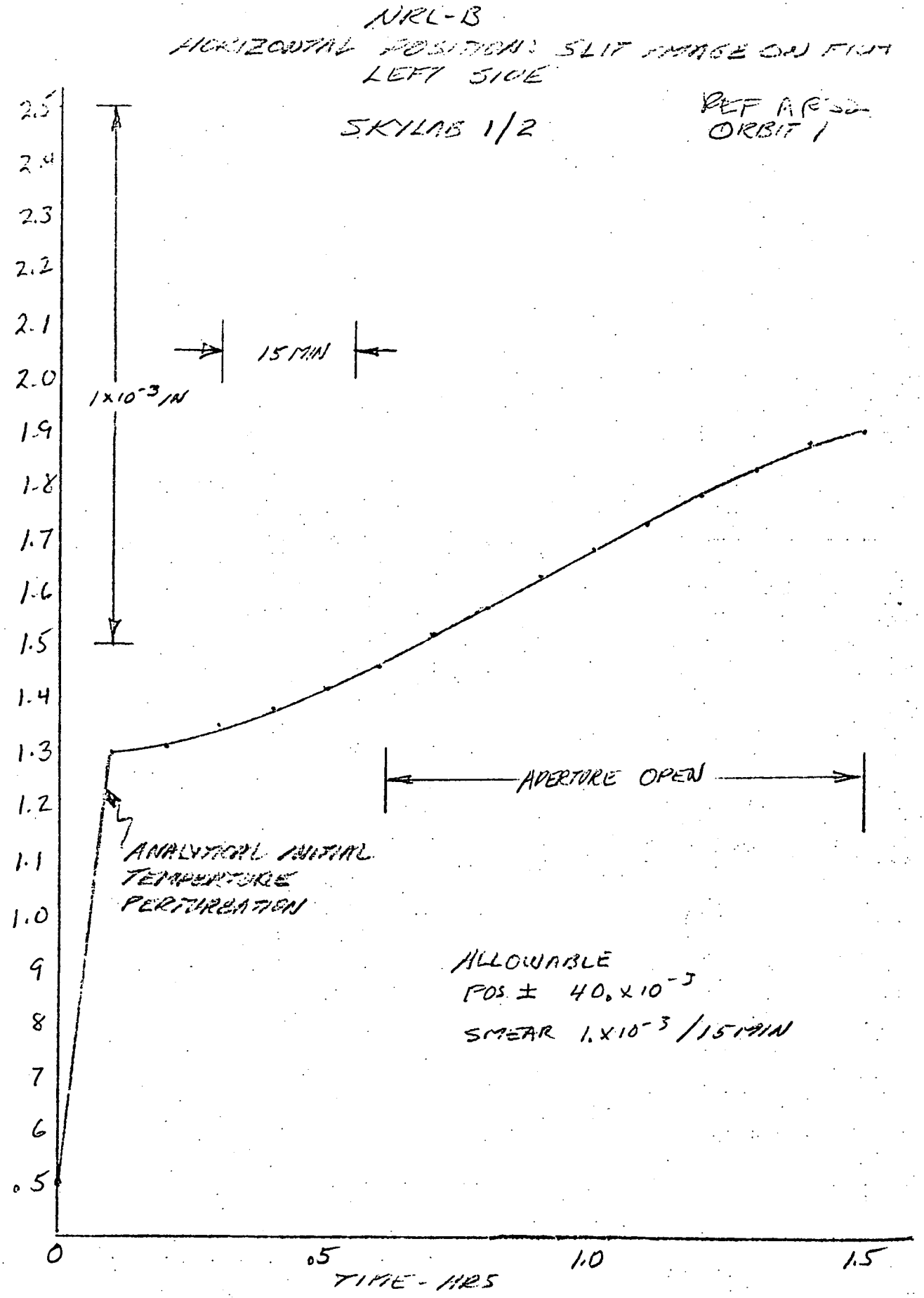
6-11-73 RR


NRL-13
FOCUS: SUN IMAGE ON SLIT
DAY 156: 06: 43: 44: 00
SKYLAB 1/2
.5
.4
.3
.2
.1
0
-.1
-.2
-.3
-.4
-.5
-.6
-.7
-.8
-.9
-1.0
INCHES X10^-3
ALLOWABLE ± 5X10^-3 IN
1X10^-3 IN.
0
.5
1.0
1.5
TIME~HRS

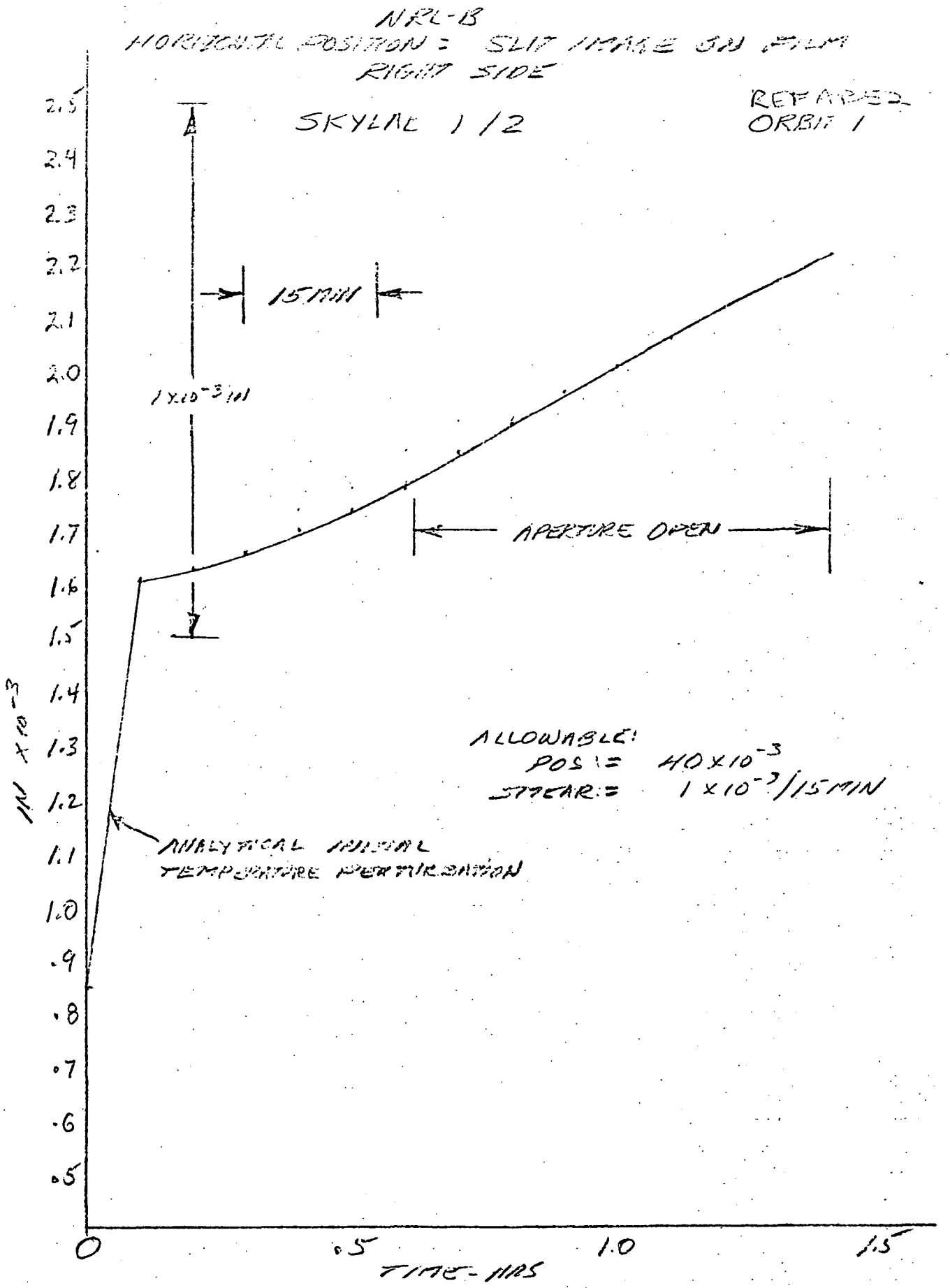
6-11-73 FR

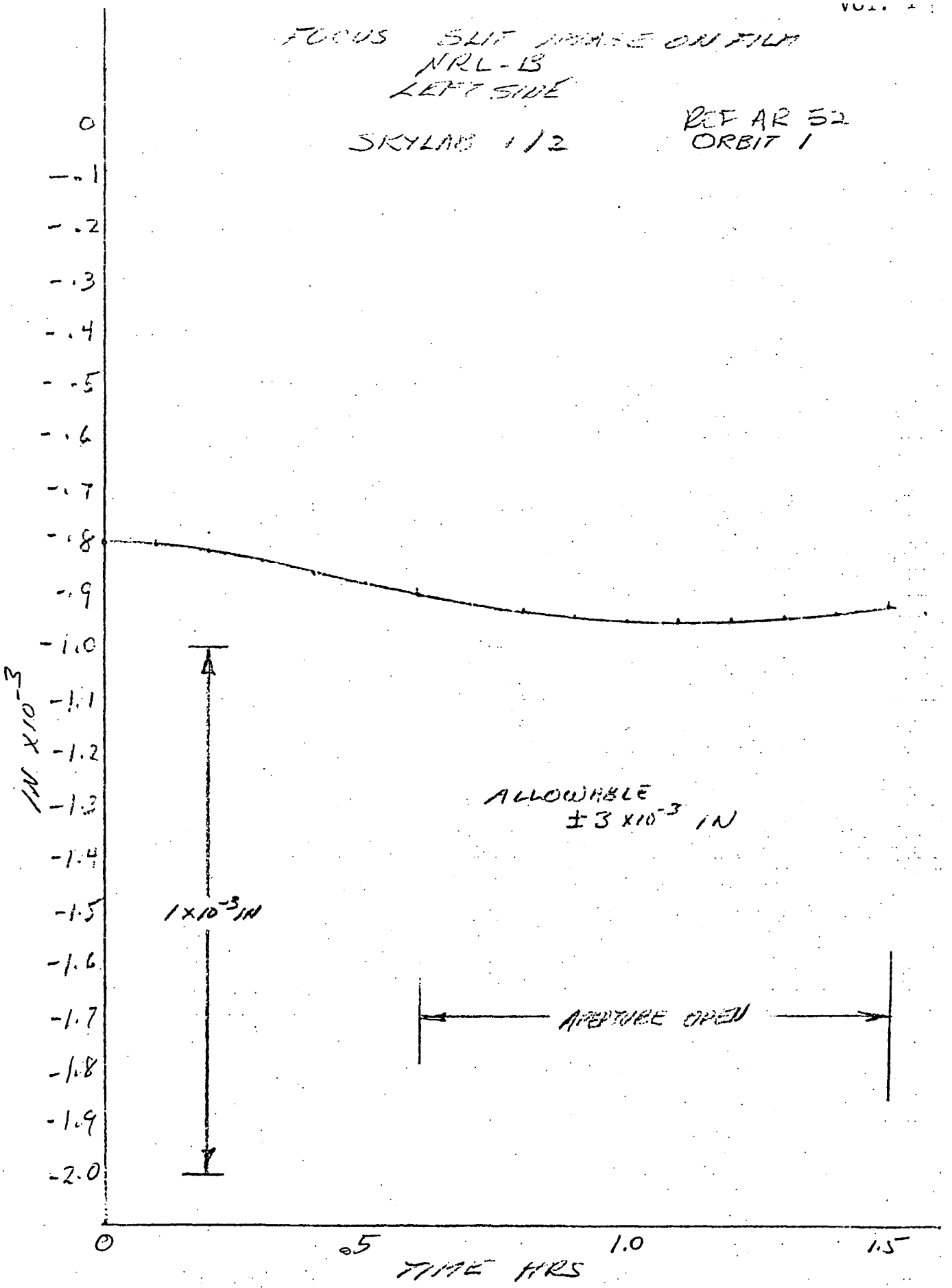

NRL-B
VERTICAL POSITION SLIT IMAGE ON FILM
LEFT SIDE
SKYLAB 1/2
ORBIT 1
15 MIN
1 X 10^-3 IN
APERTURE OPEN
ALLOWABLE
POS 12 X 10^-3
SMEAR 10 X 10^-3 / 15 MIN
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
-.1
-.2
0
.5
1.0
1.5
TIME - HRS

5-27-73

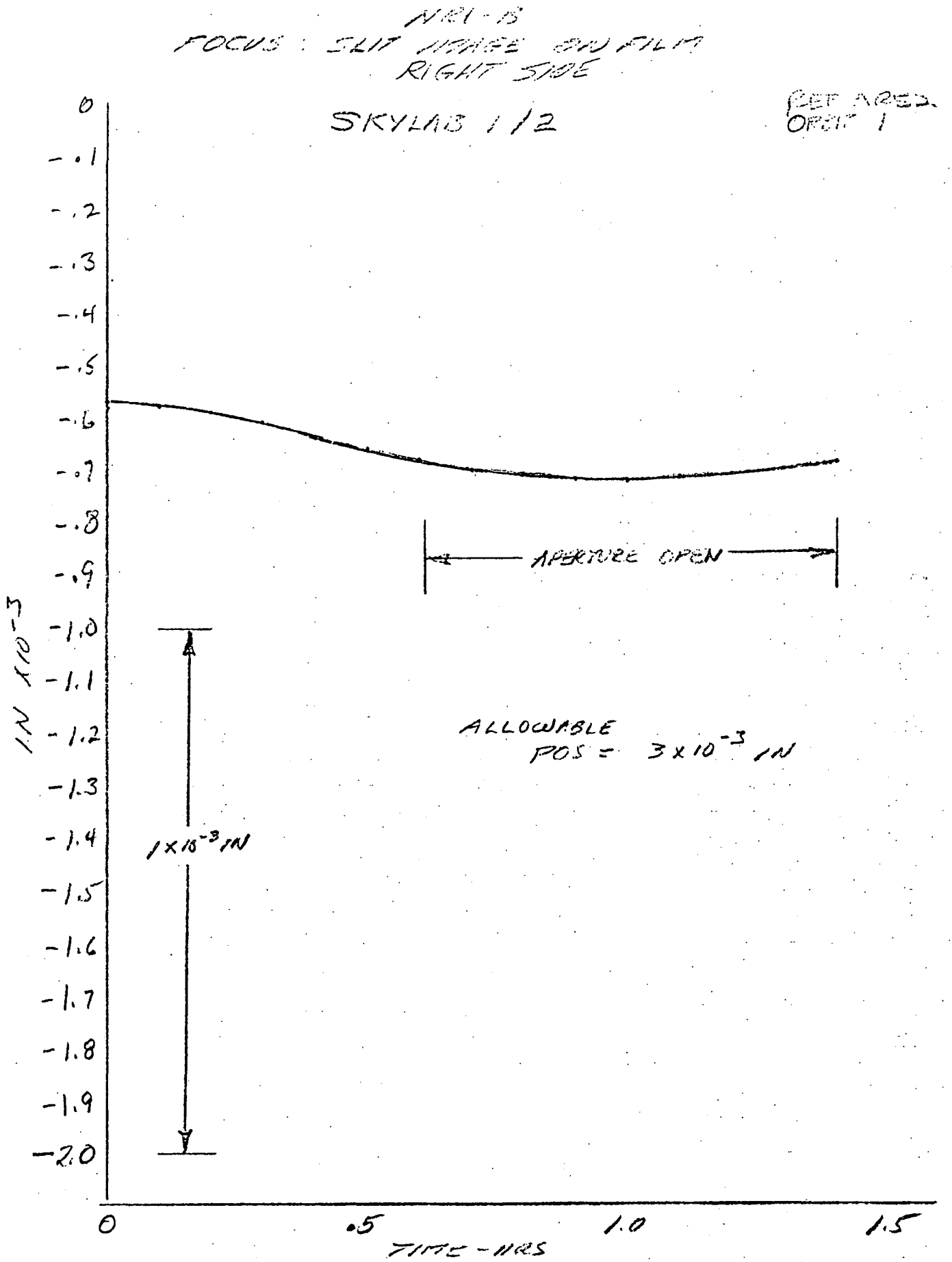

NRL-B
HORIZONTAL POSITION: SLIT IMAGE ON FILM
LEFT SIDE
SKYLAB 1/2
REF AREA
ORBIT 1
15 MIN
1×10⁻³ IN
APERTURE OPEN
ANALYTICAL INITIAL
TEMPERATURE
PERTURBATION
ALLOWABLE
POS. ± 40.×10⁻³
SMEAR 1.×10⁻³ /15 MIN
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
9
8
7
6
.5
0
.5
1.0
1.5
TIME - HRS

527-23

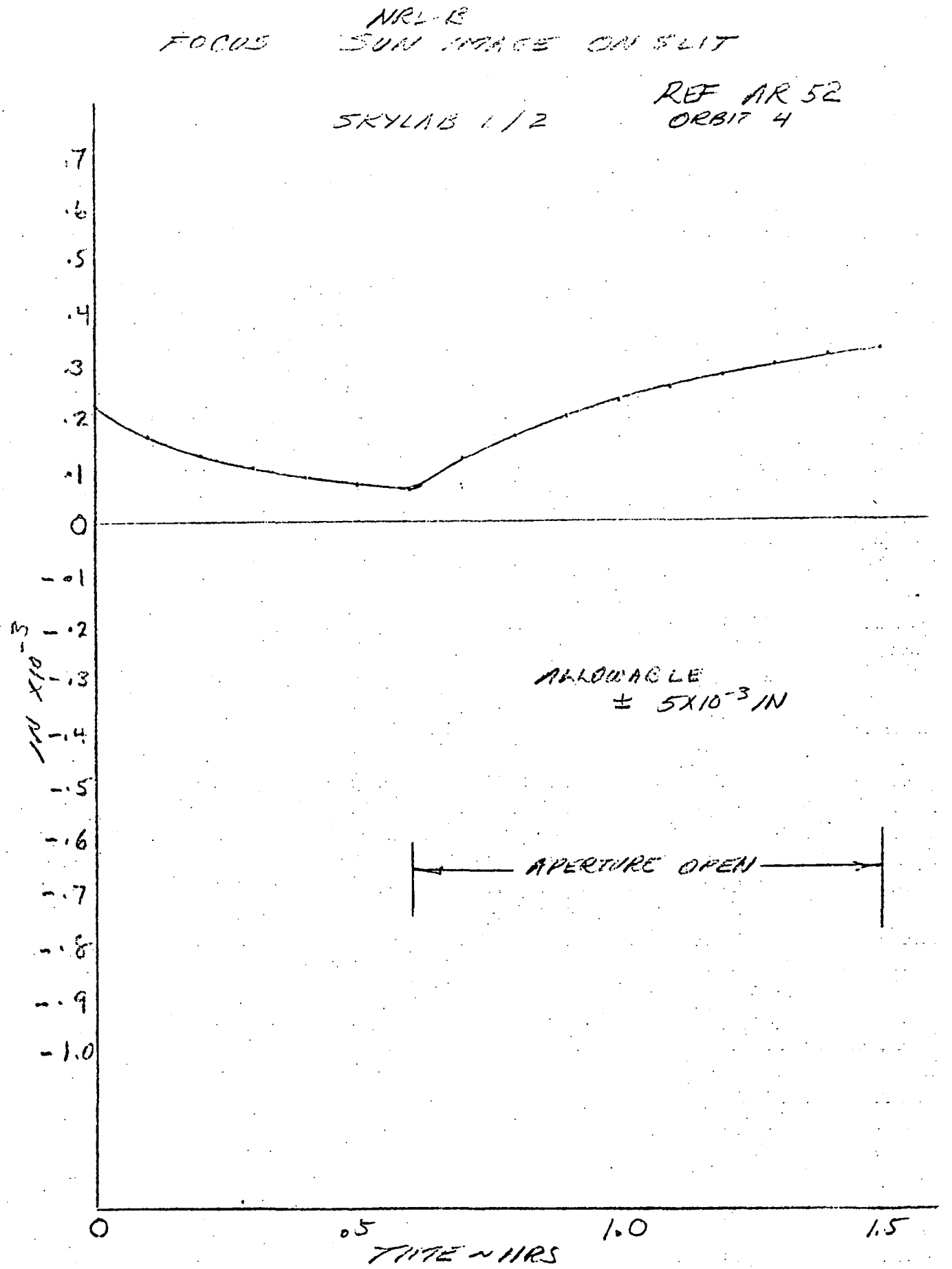

NRL-B
HORIZONTAL POSITION = SLIT IMAGE ON FILM
RIGHT SIDE
SKYLINE 1/2
REFARRED
ORBIT 1
15 MIN
1 X 10^-3 IN
APERTURE OPEN
ALLOWABLE:
POS := 40 X 10^-3
SMEAR := 1 X 10^-3 / 15 MIN
ANALYTICAL INITIAL
TEMPERATURE PERTURBATION
IN X 10^-3
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
0
.5
1.0
1.5
TIME-HRS
5-17-78


FOCUS SLIT IMAGE ON FILM
NRL-B
LEFT SIDE
SKYLAB 1/2
REF AR 52
ORBIT 1
0
-.1
-.2
-.3
-.4
-.5
-.6
-.7
-.8
-.9
-1.0
-1.1
-1.2
-1.3
-1.4
-1.5
-1.6
-1.7
-1.8
-1.9
-2.0
IN X10^-3
ALLOWABLE
±3 X10^-3 IN
1X10^-3 IN
APERTURE OPEN
0
.5
1.0
1.5
TIME HRS

5-27-73


NRI-13
FOCUS : SLIT IMAGE ON FILM
RIGHT SIDE
SKYLAB 1/2
REF AREA.
OPER 1
0
-.1
-.2
-.3
-.4
-.5
-.6
-.7
-.8
-.9
-1.0
-1.1
-1.2
-1.3
-1.4
-1.5
-1.6
-1.7
-1.8
-1.9
-2.0
IN x10^-3
APERTURE OPEN
ALLOWABLE
POS = 3 x 10^-3 IN
1 x 10^-3 IN
0
.5
1.0
1.5
TIME - HRS

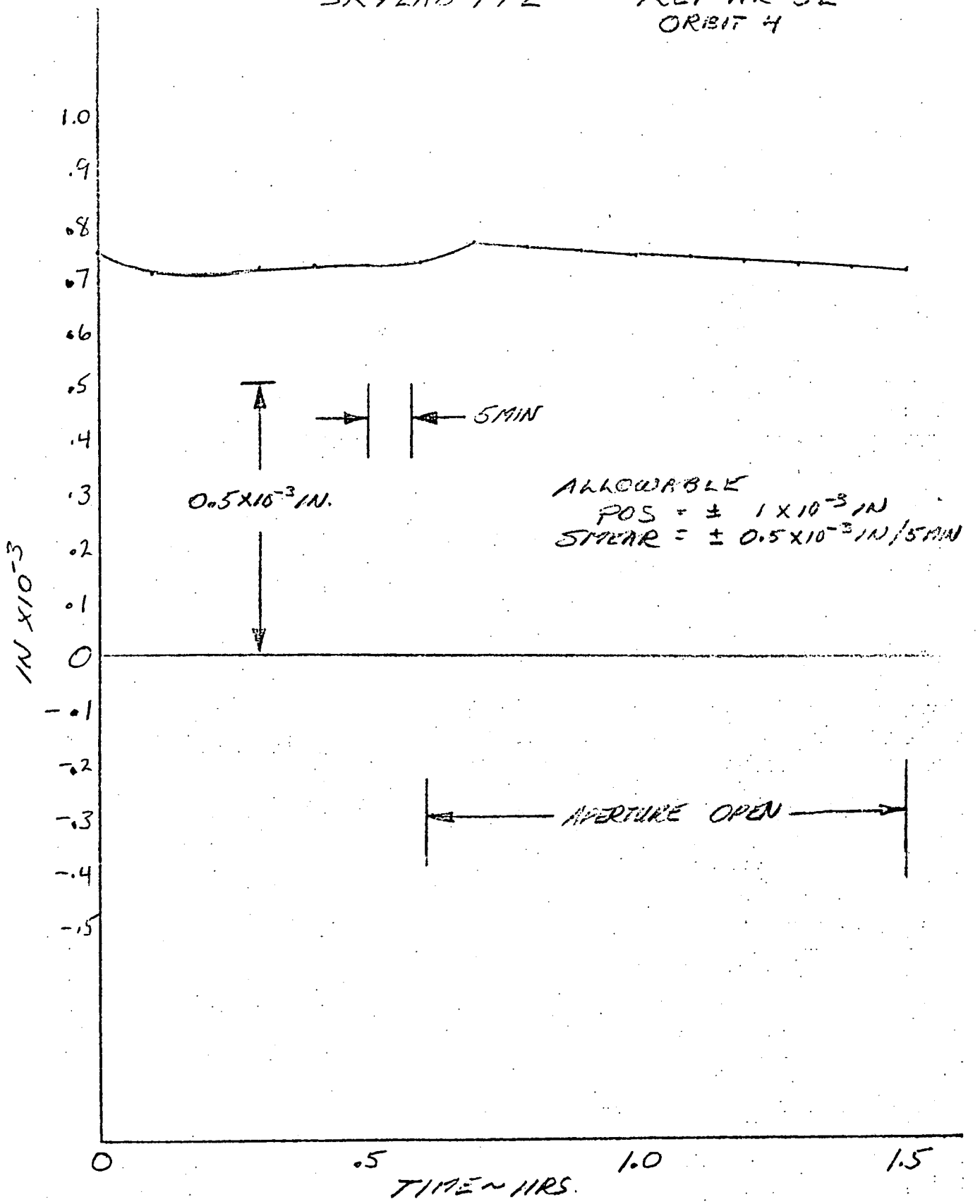
5-27-73


NRL-E
FOCUS SUN IMAGE ON SLIT
REF AR 52
ORBIT 4
SKYLAB 1/2
.7
.6
.5
.4
.3
.2
.1
0
-.1
-.2
-.3
-.4
-.5
-.6
-.7
-.8
-.9
-1.0
IN X10^-3
ALLOWABLE
± 5X10^-3 IN
APERTURE OPEN
0
.5
1.0
1.5
TIME ~ HRS

5-27-73 DRA

NRL B
HORIZONTAL POSITION - SUN IMAGE ON SLIT

SKYLAB 1/2 REF AR 52
ORBIT 4

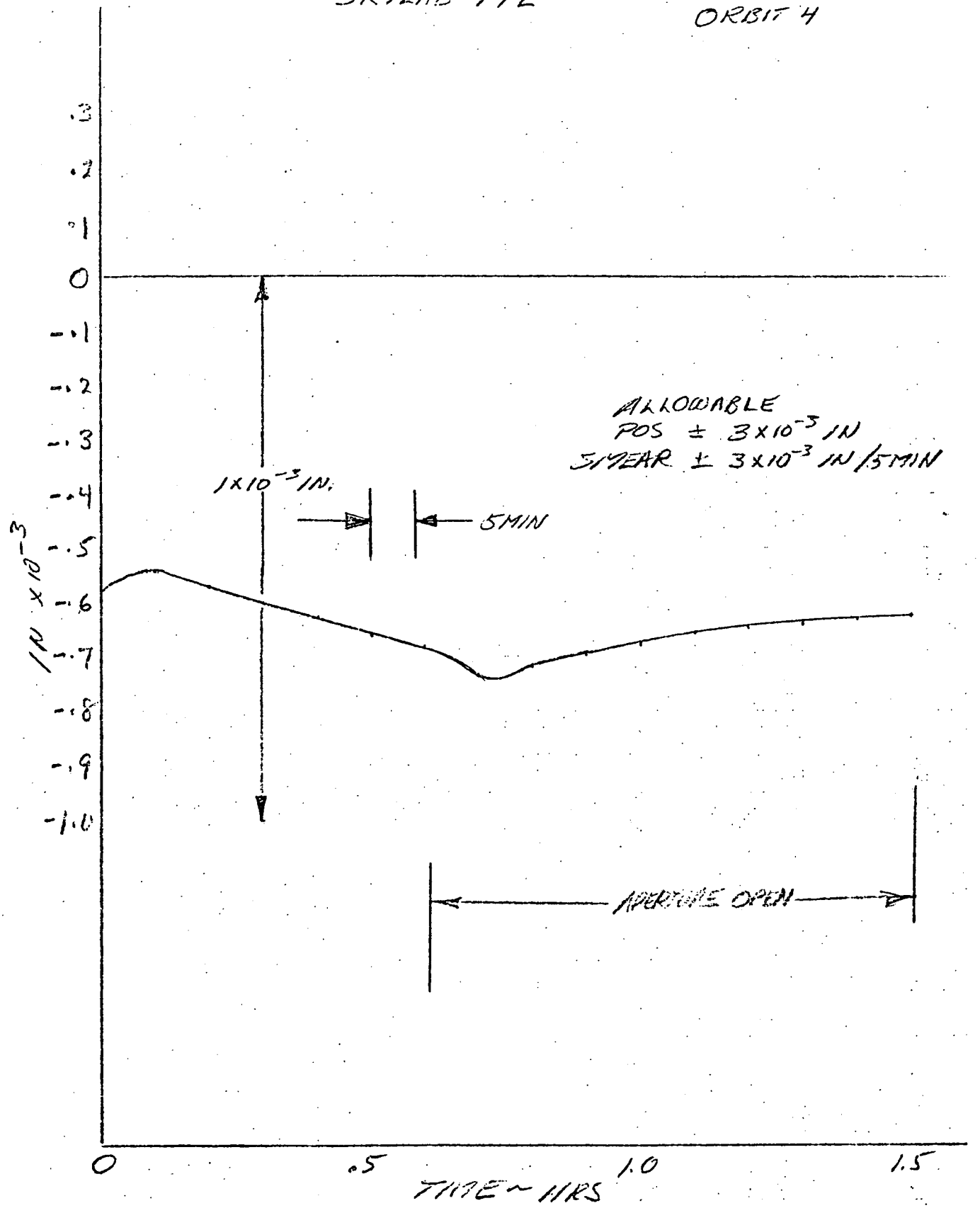


5-27-73 RRA

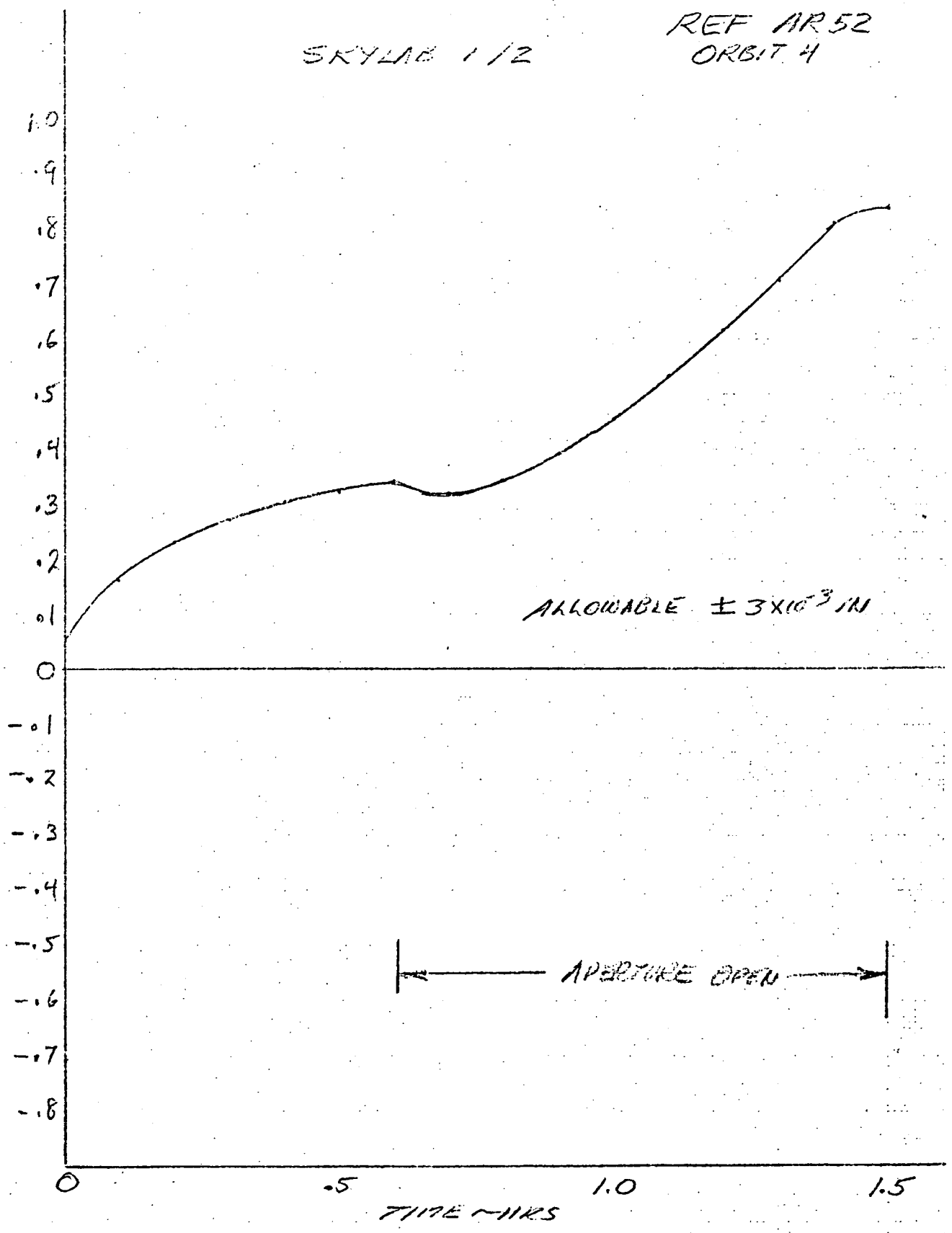
NRL B
VERTICAL POSITION – SUN IMAGE ON SLIT

SKYLAB 1/2

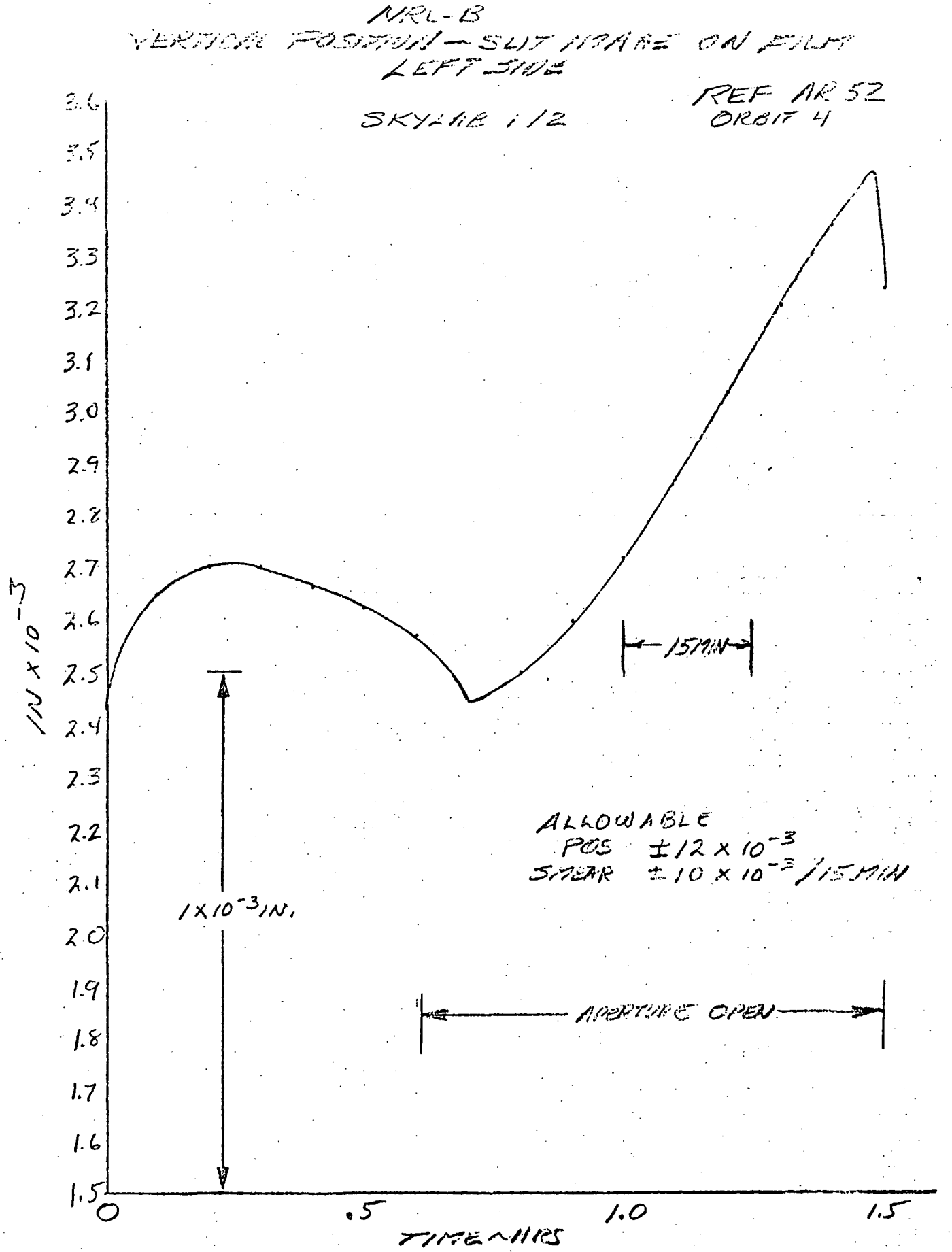
REF AR 52
ORBIT 4

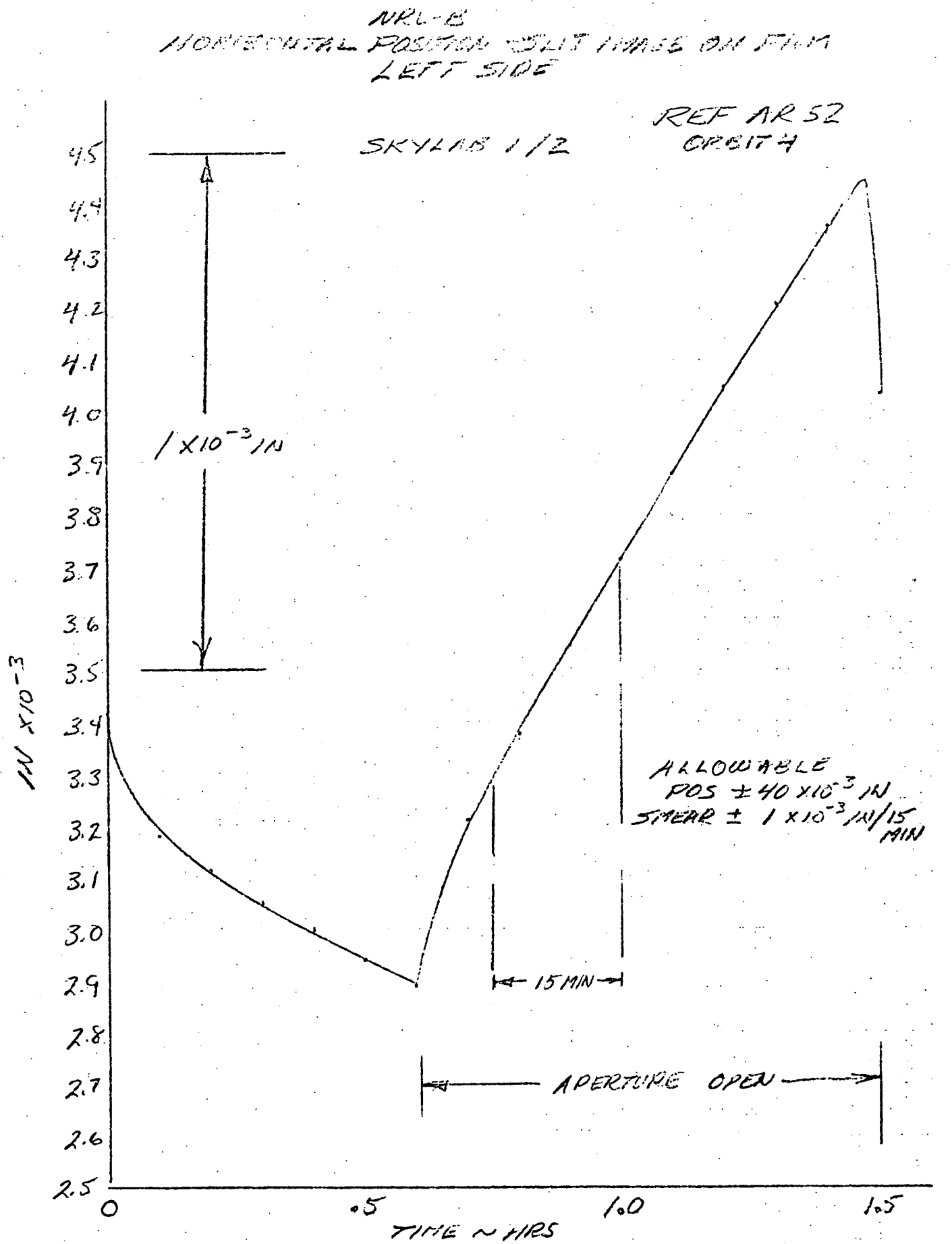


5-27-73 RRA

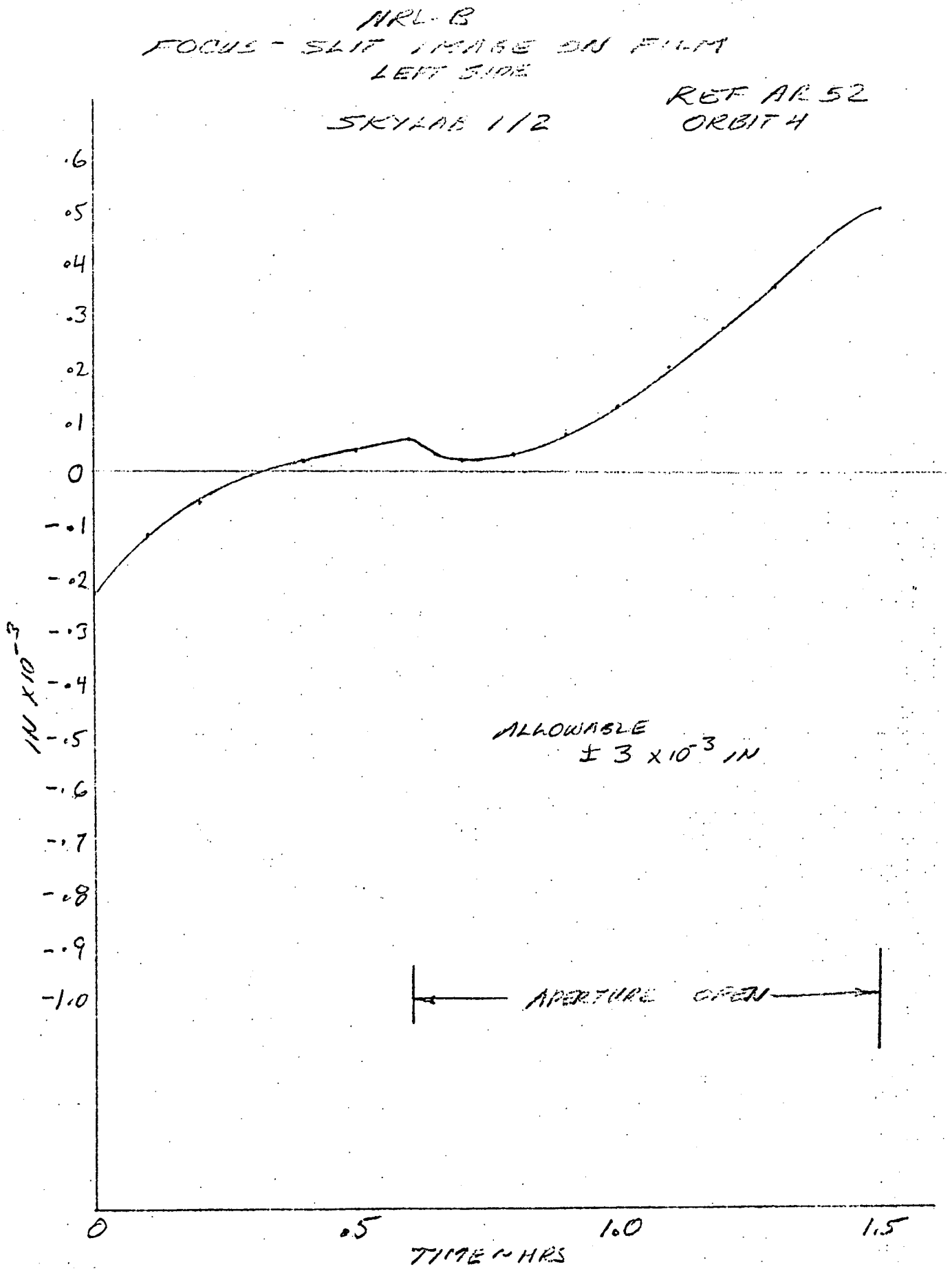

NPL-6
FOCUS SLIT IMAGE ON FILM
RIGHT SIDE
SKYLAB 1/2
REF AR52
ORBIT 4
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
-.1
-.2
-.3
-.4
-.5
-.6
-.7
-.8
ALLOWABLE ±3X10⁻³ IN
APERTURE OPEN
0
.5
1.0
1.5
TIME ~HRS

5-27-73 RBA

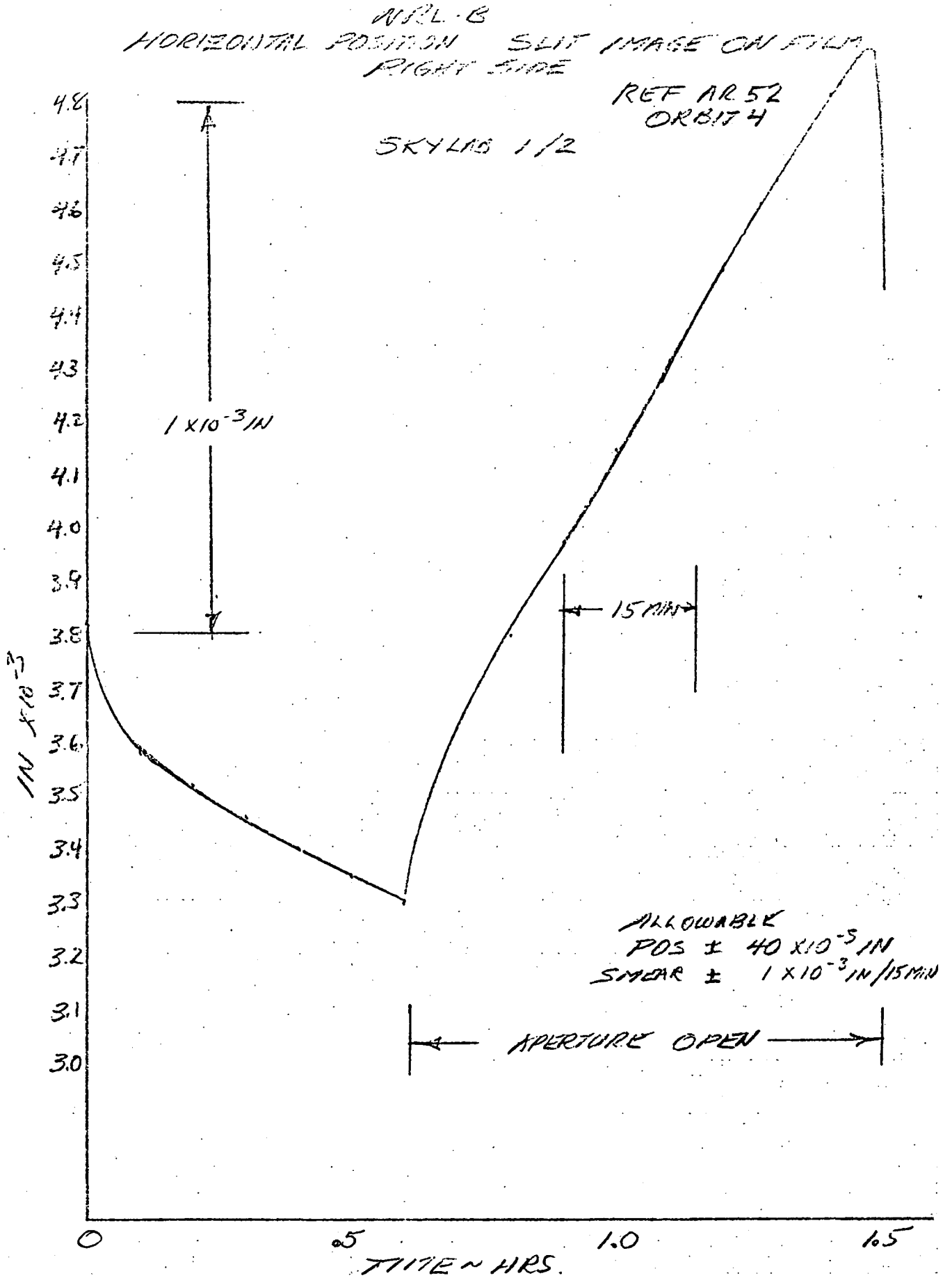

NRL-B
VERTICAL POSITION — SLIT IMAGE ON FILM
LEFT SIDE
SKYLAB 1/2
REF AR 52
ORBIT 4
IN x 10^-3
3.6
3.5
3.4
3.3
3.2
3.1
3.0
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
0
.5
1.0
1.5
TIME ~ HRS
15 MIN
1 X 10^-3 IN.
ALLOWABLE
POS ±12 X 10^-3
SHEAR ±10 X 10^-3 / 15 MIN
APERTURE OPEN
5-27-73 PEA


NRL-B
HORIZONTAL POSITION SLIT IMAGE ON FILM
LEFT SIDE
REF AR 52
ORBIT 4
SKYLAB 1/2
1 X10^-3 IN
ALLOWABLE
POS ± 40 X10^-3 IN
SMEAR ± 1 X10^-3 IN/15 MIN
15 MIN
APERTURE OPEN
IN X10^-3
4.5
4.4
4.3
4.2
4.1
4.0
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3.0
2.9
2.8
2.7
2.6
2.5
0
.5
1.0
1.5
TIME ~ HRS

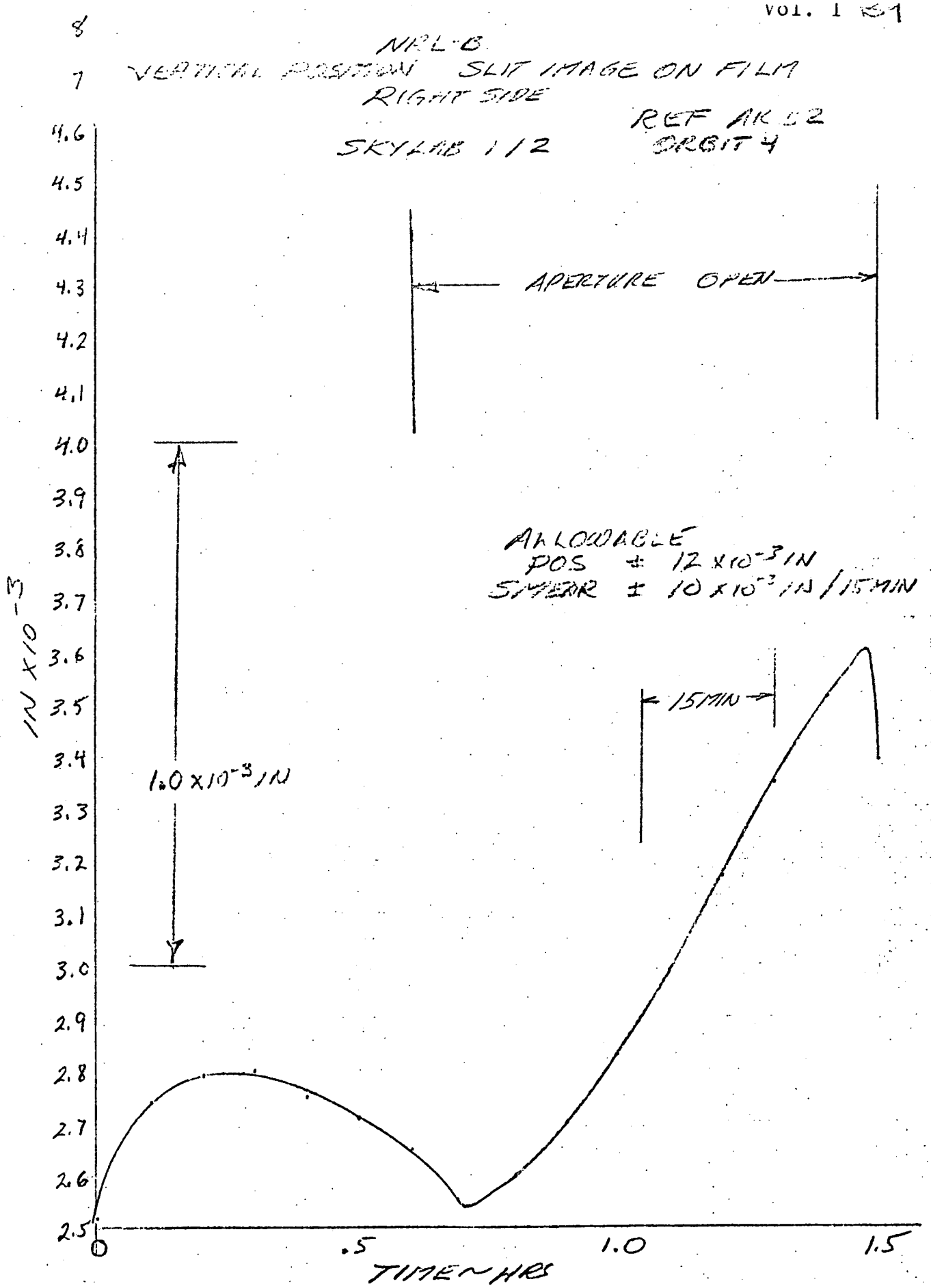
5-27-73 RRA


NRL-B
FOCUS - SLIT IMAGE ON FILM
LEFT SIDE
SKYLAB 1/2
REF AR 52
ORBIT 4
.6
.5
.4
.3
.2
.1
0
-.1
-.2
-.3
-.4
-.5
-.6
-.7
-.8
-.9
-1.0
IN X10^-3
ALLOWABLE
± 3 X10^-3 IN
APERTURE OPEN
0
.5
1.0
1.5
TIME ~ HRS

5-27-73 ARA


NRL-B
HORIZONTAL POSITION SLIT IMAGE ON FILM
RIGHT SIDE
REF AR 52
ORBIT 4
SKYLAB 1/2
1 X10^-3 IN
15 MIN
ALLOWABLE
POS ± 40 X10^-5 IN
SMEAR ± 1 X10^-3 IN/15 MIN
APERTURE OPEN
IN X10^-3
4.8
4.7
4.6
4.5
4.4
4.3
4.2
4.1
4.0
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3.0
0
.5
1.0
1.5
TIME ~ HRS.

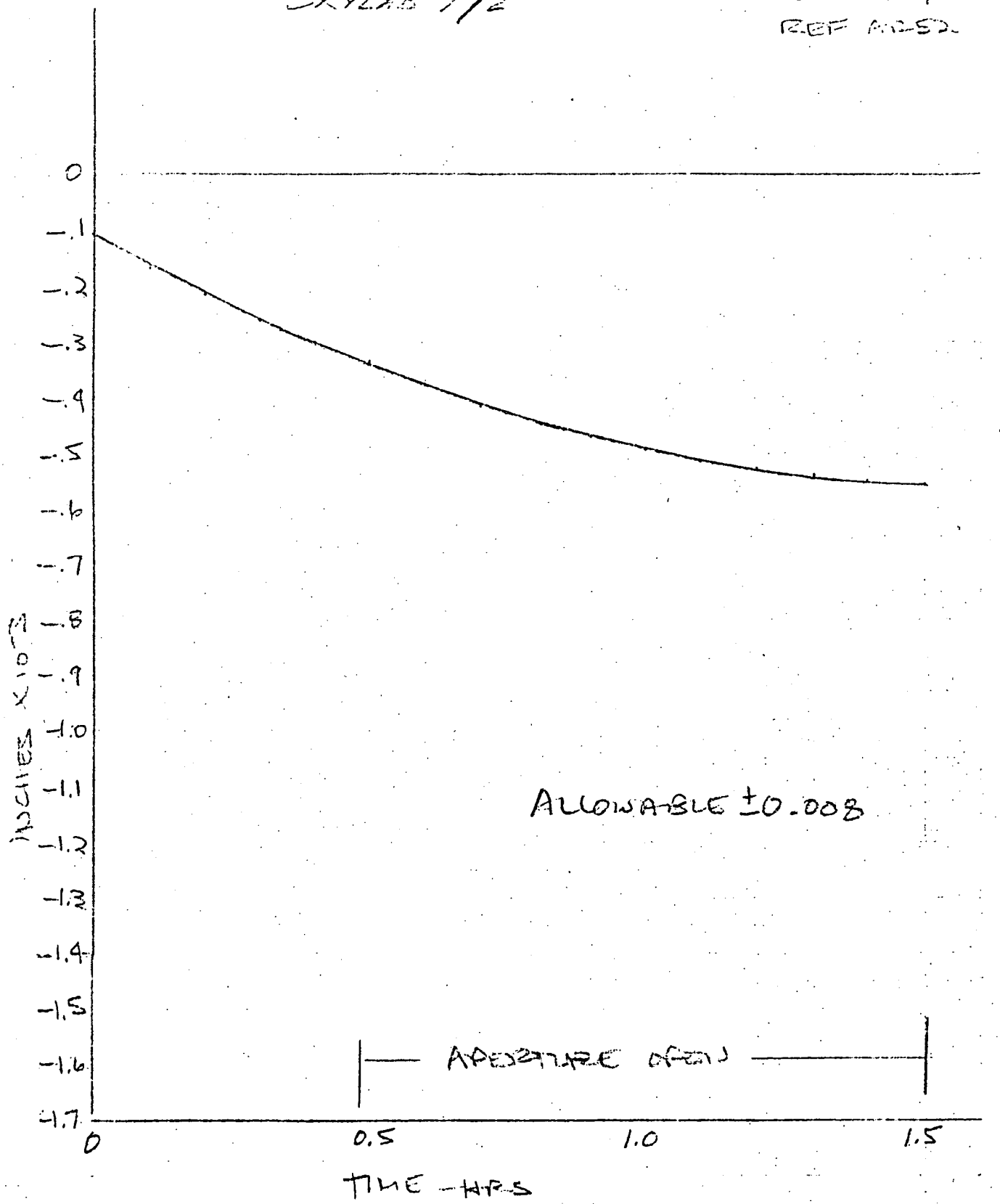
5-27-73 RRA


NRL-B
VERTICAL POSITION SLIT IMAGE ON FILM
RIGHT SIDE
REF AK 52
ORBIT 4
SKYLAB 1/2
APERTURE OPEN
ALLOWABLE
POS ± 12 x10⁻³ IN
SHEAR ± 10 x10⁻³ IN/15MIN
15MIN
1.0 x10⁻³ IN
IN x10⁻³
4.6
4.5
4.4
4.3
4.2
4.1
4.0
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3.0
2.9
2.8
2.7
2.6
2.5
0
.5
1.0
1.5
TIME~HRS

5-27-73 RRA

NRLA
FOCUS IMAGE ON FILM
RIGHT SIDE
SKYLAB 1/2

ORBIT 1
REF MISSI



5/26/73

NRLA

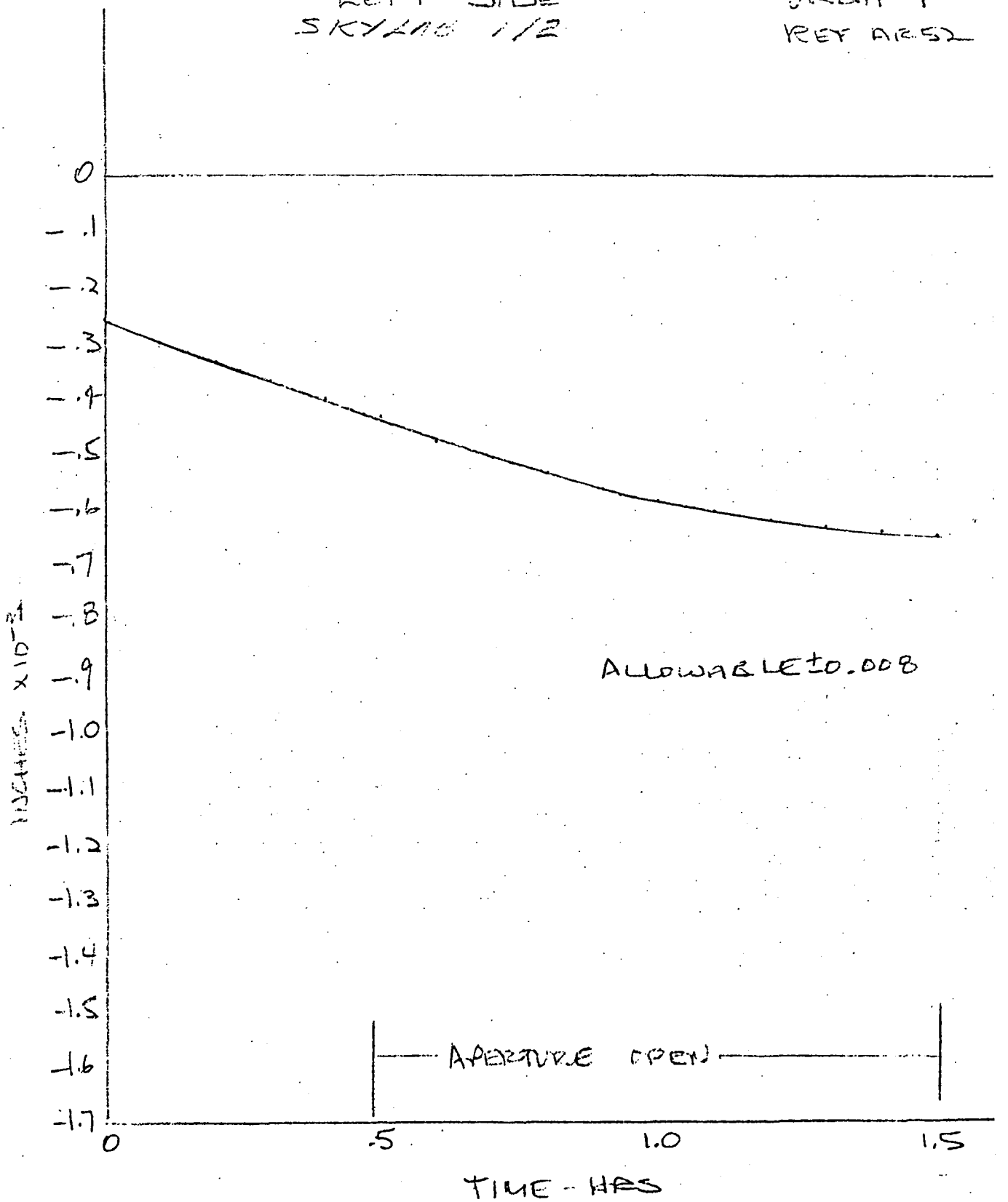
FOCUS SUN IMAGE ON FILM

LEFT SIDE

SKYLAB 1/2

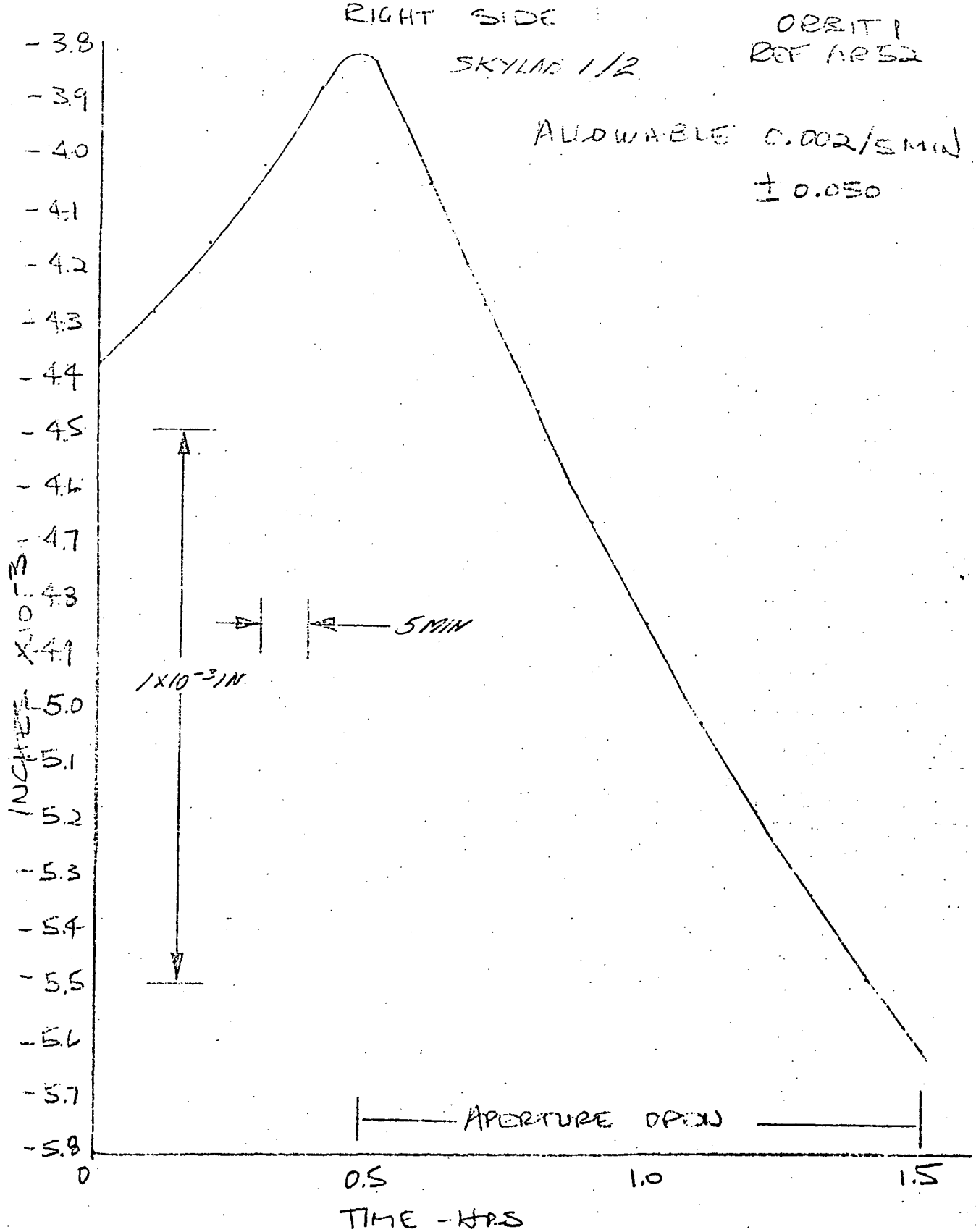
ORBIT 1

REF AR52

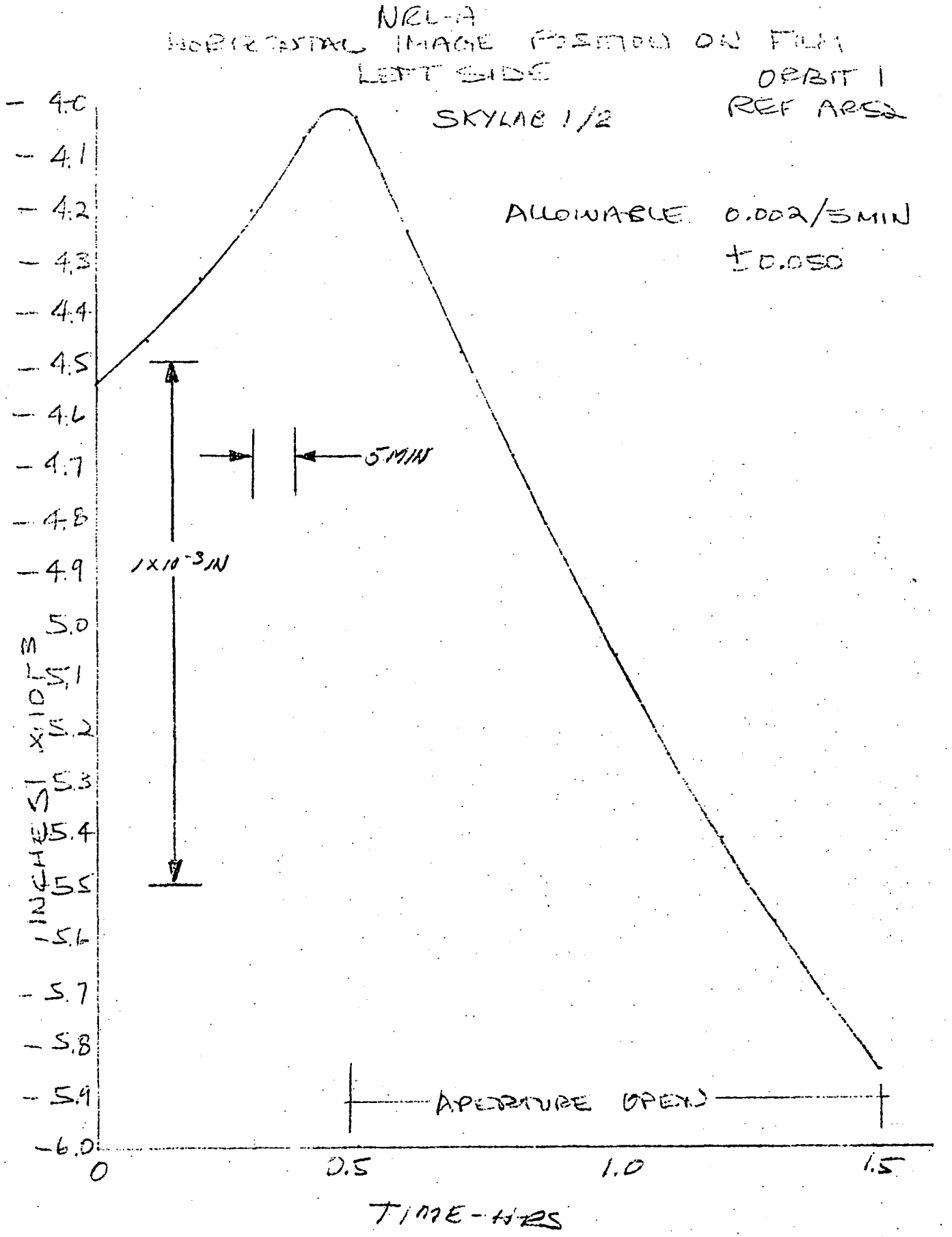


RHS 8/26/73

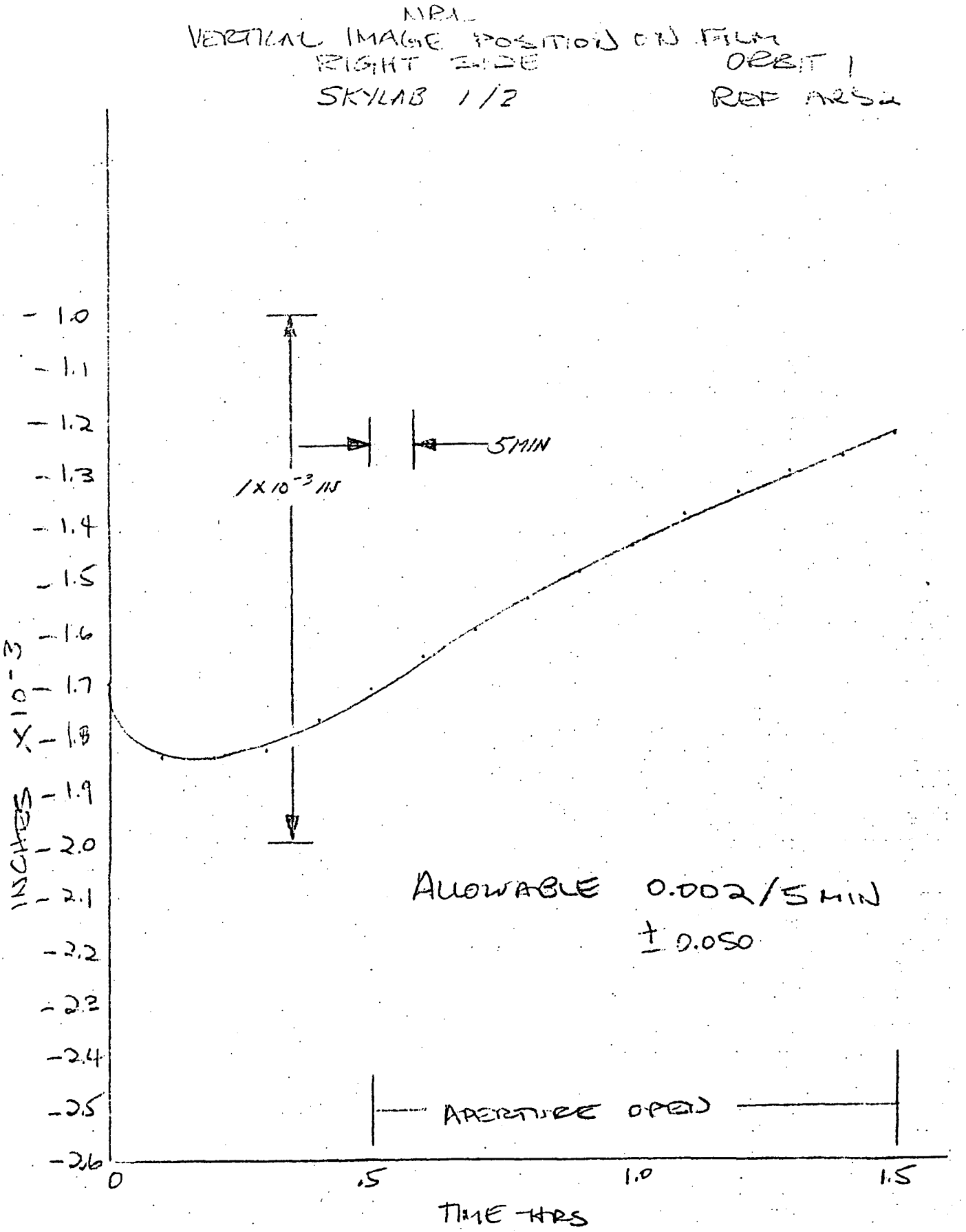
NRLA
HORIZONTAL IMAGE POSITION ON FILM
RIGHT SIDE



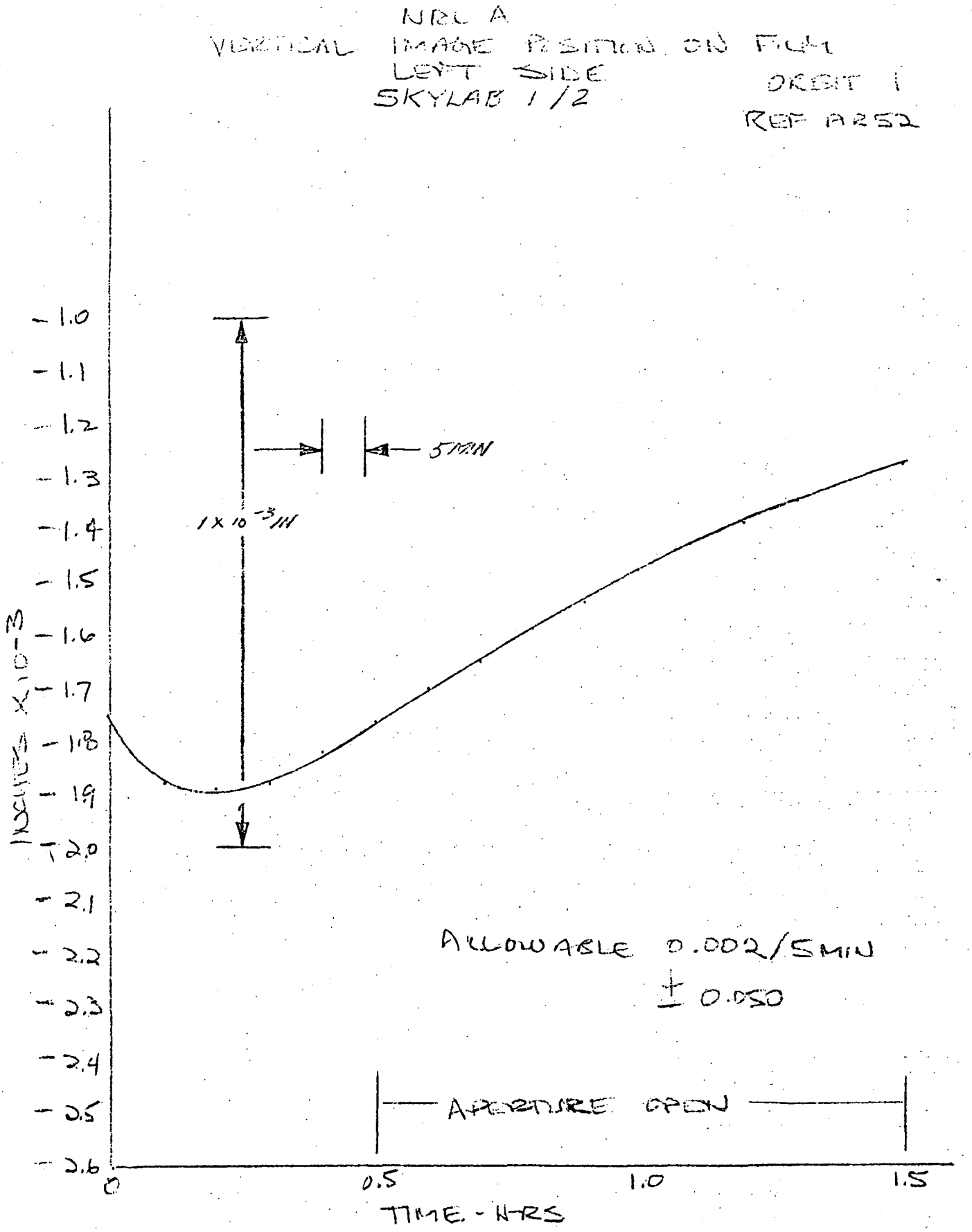
RAB 5/26/73


NRL-A
HORIZONTAL IMAGE POSITION ON FILM
LEFT SIDE
ORBIT 1
REF ARS2
SKYLAB 1/2
ALLOWABLE 0.002/5MIN
±0.050
5MIN
1X10⁻³IN
APERTURE OPEN
INCHES X 10⁻³
4.0
4.1
4.2
4.3
4.4
4.5
4.6
4.7
4.8
4.9
5.0
5.1
5.2
5.3
5.4
5.5
5.6
5.7
5.8
5.9
6.0
0
0.5
1.0
1.5
TIME-HRS

RH & 5/26/73


NRL
VERTICAL IMAGE POSITION ON FILM
RIGHT EDGE
ORBIT 1
SKYLAB 1/2
REF ARSA
-1.0
-1.1
-1.2
-1.3
-1.4
-1.5
-1.6
-1.7
-1.8
-1.9
-2.0
-2.1
-2.2
-2.3
-2.4
-2.5
-2.6
X 10^-3 INCHES
1 X 10^-3 IN
5 MIN
ALLOWABLE 0.002/5 MIN
± 0.050
APERTURE OPEN
0
.5
1.0
1.5
TIME-HRS

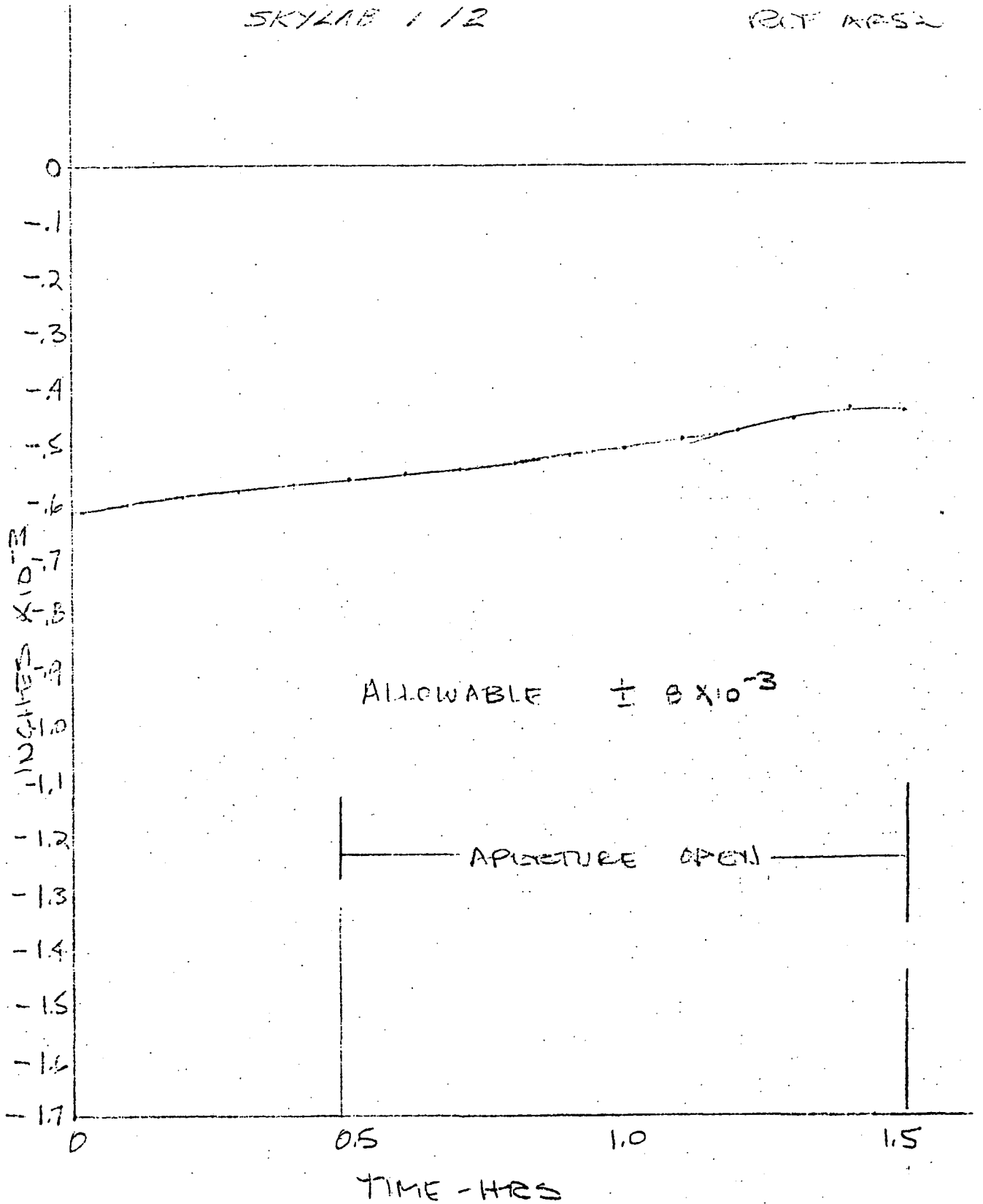
RHL 5/26/73


NRL A
VERTICAL IMAGE POSITION ON FILM
LEFT SIDE
SKYLAB 1/2
ORBIT 1
REF A252
5 MIN
1 X 10^-3 IN
INCHES X 10^-3
-1.0
-1.1
-1.2
-1.3
-1.4
-1.5
-1.6
-1.7
-1.8
-1.9
-2.0
-2.1
-2.2
-2.3
-2.4
-2.5
-2.6
ALLOWABLE 0.002/5MIN
± 0.050
APERTURE OPEN
0
0.5
1.0
1.5
TIME - HRS

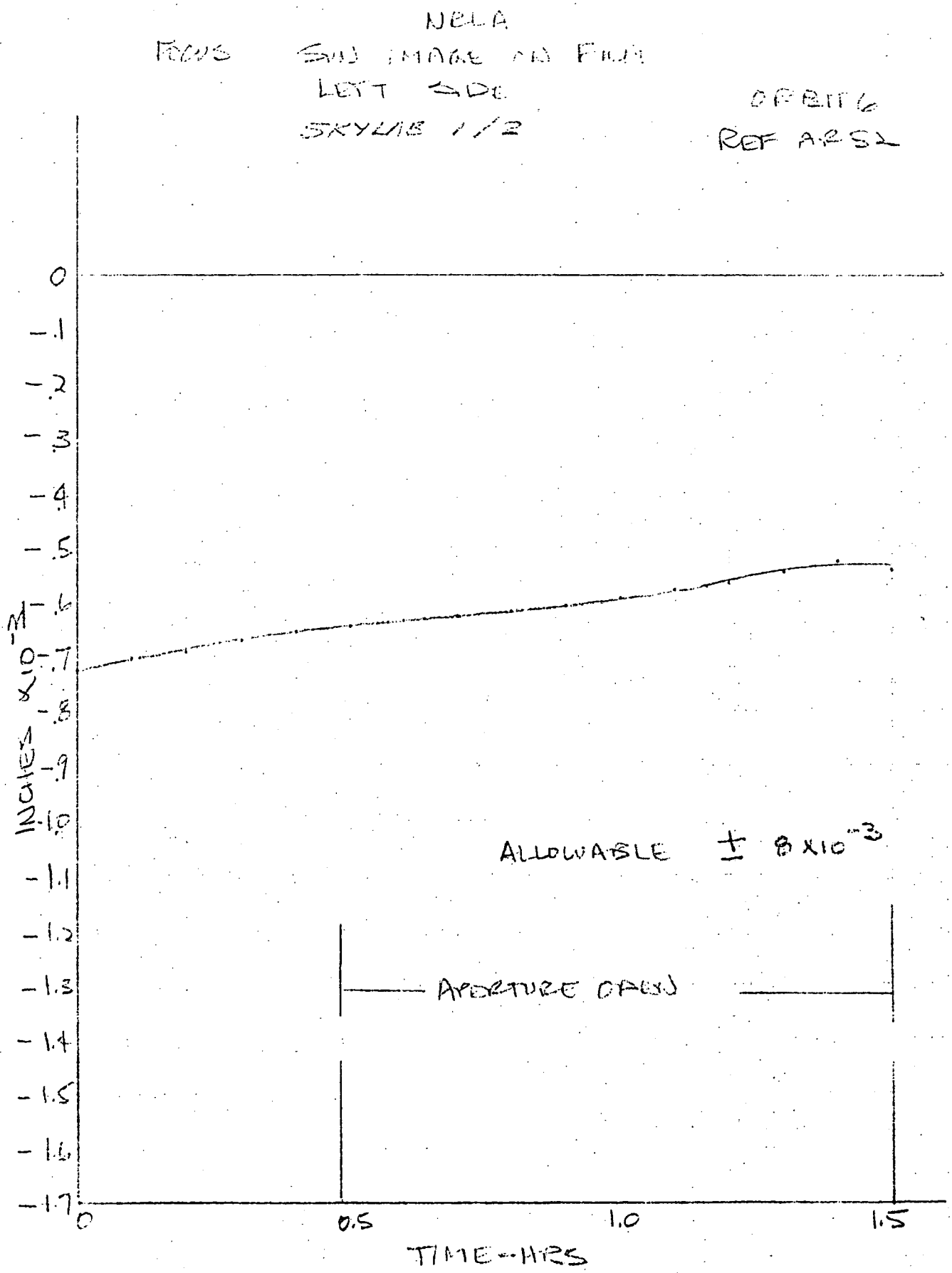
C1165/2213

NRLA
FROUS SUN IMAGE ON FILM
RIGHT SIDE
SKYLAB 1/12

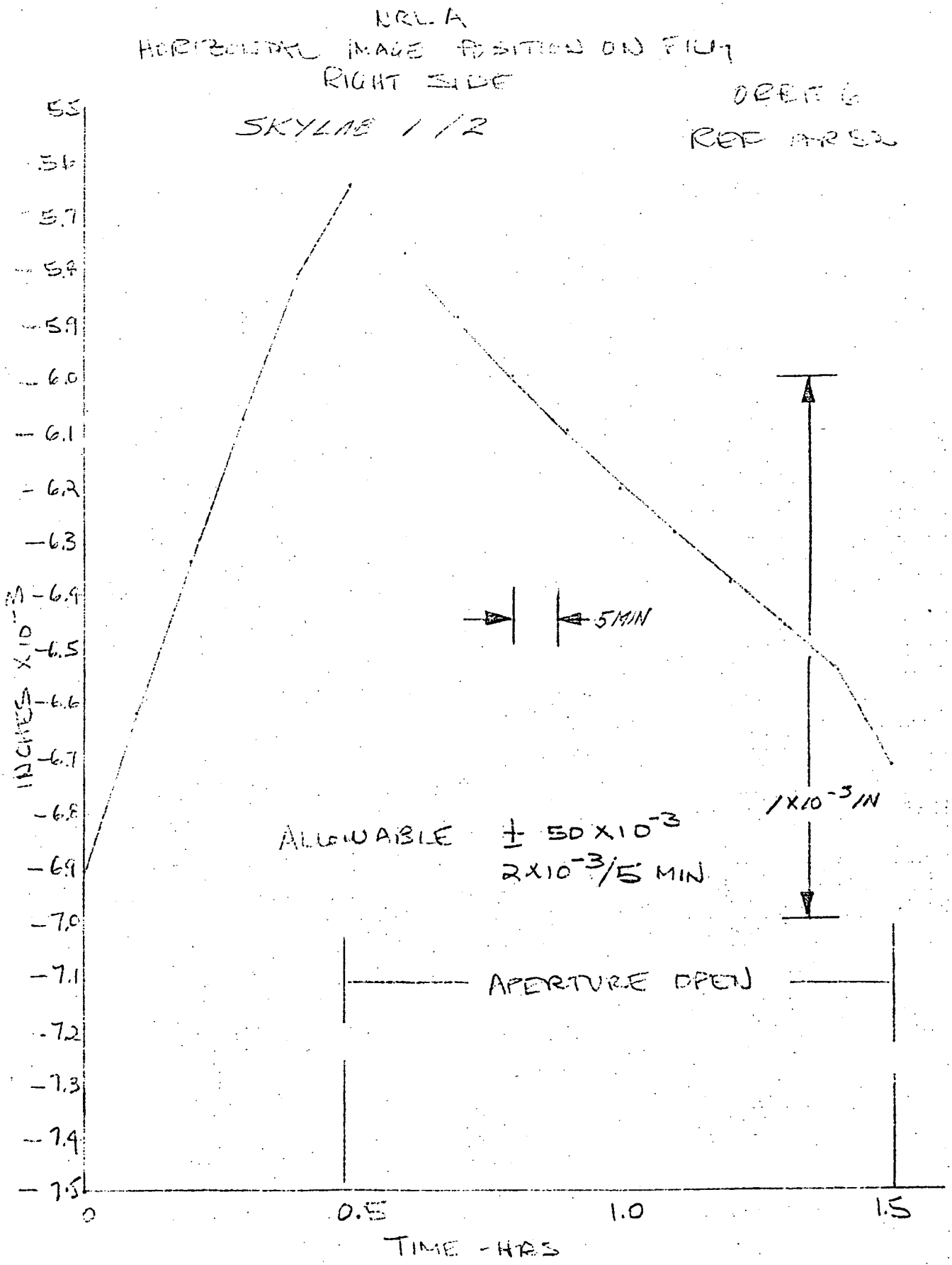
ORBIT 6
RUN AP52



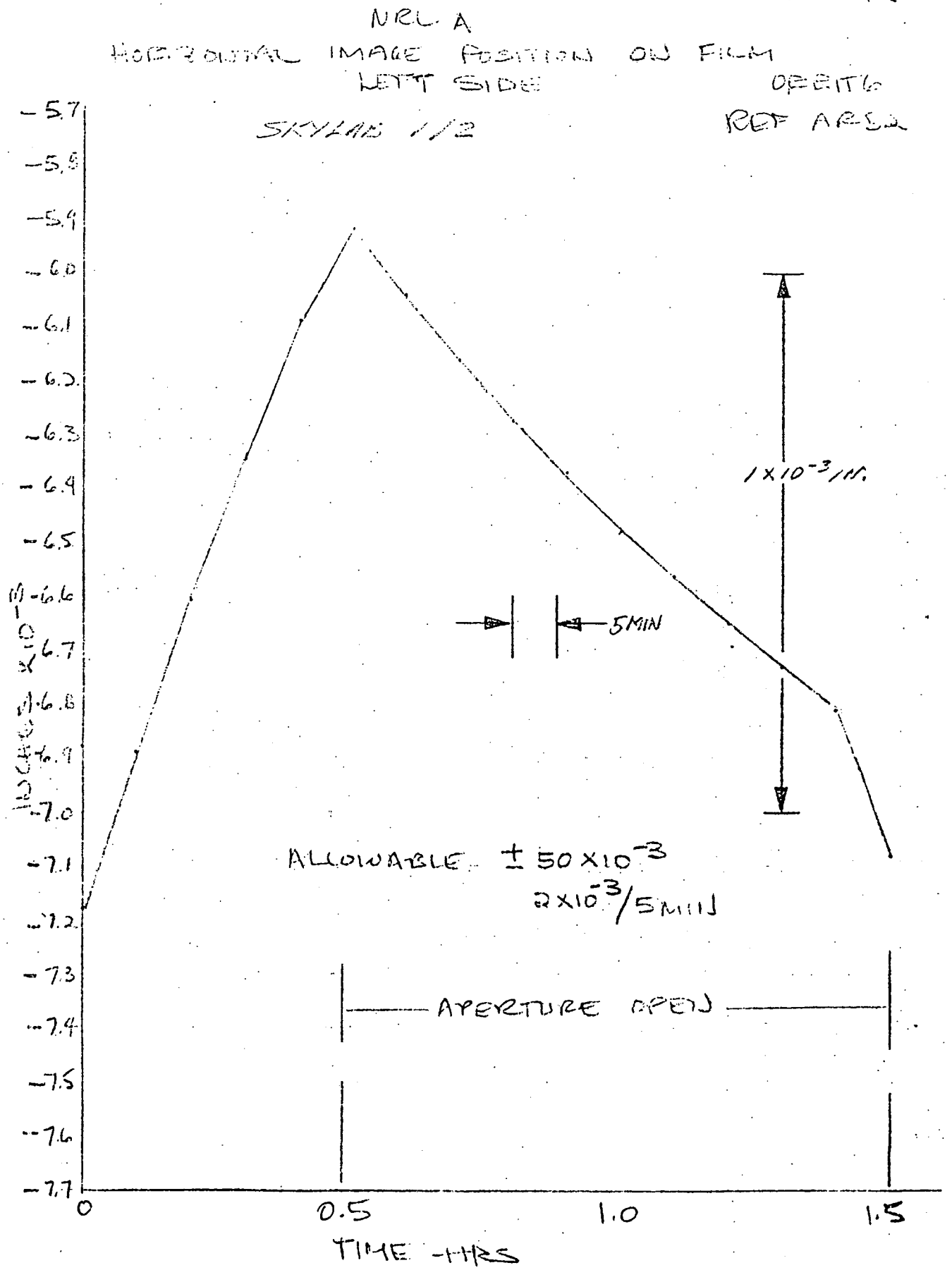
RAB 5/07/73


NELA
FOCUS SUN IMAGE ON FILM
LEFT SIDE
SKYLAB 1/2
ORBIT 6
REF A-2-52
0
-.1
-.2
-.3
-.4
-.5
-.6
-.7
-.8
-.9
-1.0
-1.1
-1.2
-1.3
-1.4
-1.5
-1.6
-1.7
INCHES X10^-3
ALLOWABLE ± 8 X10^-3
APERTURE OPEN
0
0.5
1.0
1.5
TIME-HRS

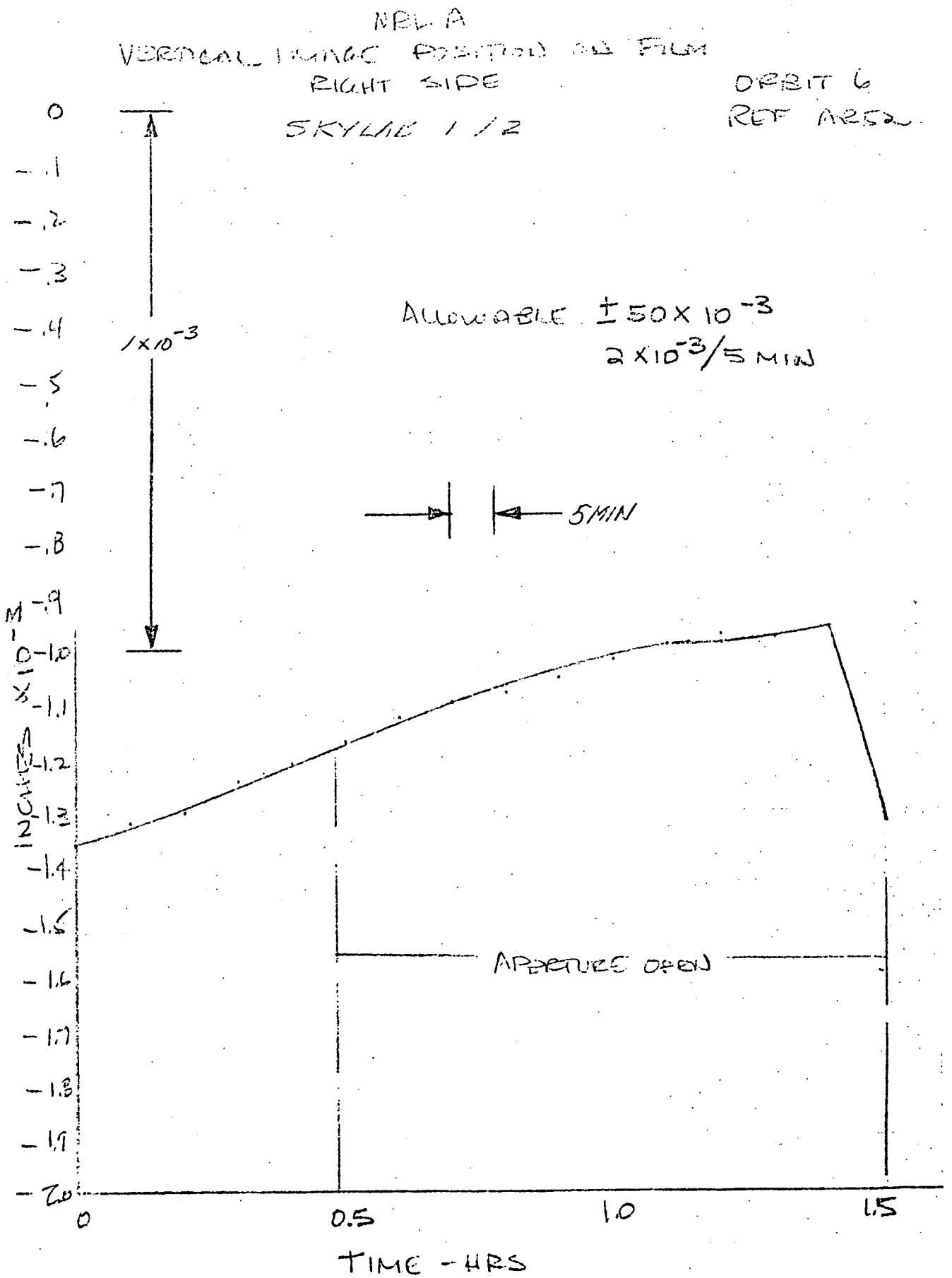
RAG 3/27/73


NRL A
HORIZONTAL IMAGE POSITION ON FILM
RIGHT SIDE
SKYLAB 1/2
ORBIT 6
REF MR 502
5.5
5.6
5.7
5.8
5.9
6.0
6.1
6.2
6.3
6.4
6.5
6.6
6.7
6.8
6.9
7.0
7.1
7.2
7.3
7.4
7.5
INCHES X 10^-0
5 MIN
1 X 10^-3 IN
ALLOWABLE ± 50 X 10^-3
2 X 10^-3/5 MIN
APERTURE OPEN
0
0.5
1.0
1.5
TIME - HRS

DAG 5/27/73


NRL A
HORIZONTAL IMAGE POSITION ON FILM
LEFT SIDE
ORBIT 6
SKYLAB 1/2
REF AREA
-5.7
-5.8
-5.9
-6.0
-6.1
-6.2
-6.3
-6.4
-6.5
-6.6
-6.7
-6.8
-6.9
-7.0
-7.1
-7.2
-7.3
-7.4
-7.5
-7.6
-7.7
1 X 10^-3/M.
5MIN
ALLOWABLE ± 50 X 10^-3
2 X 10^-3/5MIN
APERTURE OPEN
0
0.5
1.0
1.5
TIME -HRS

RHS 2/7/72

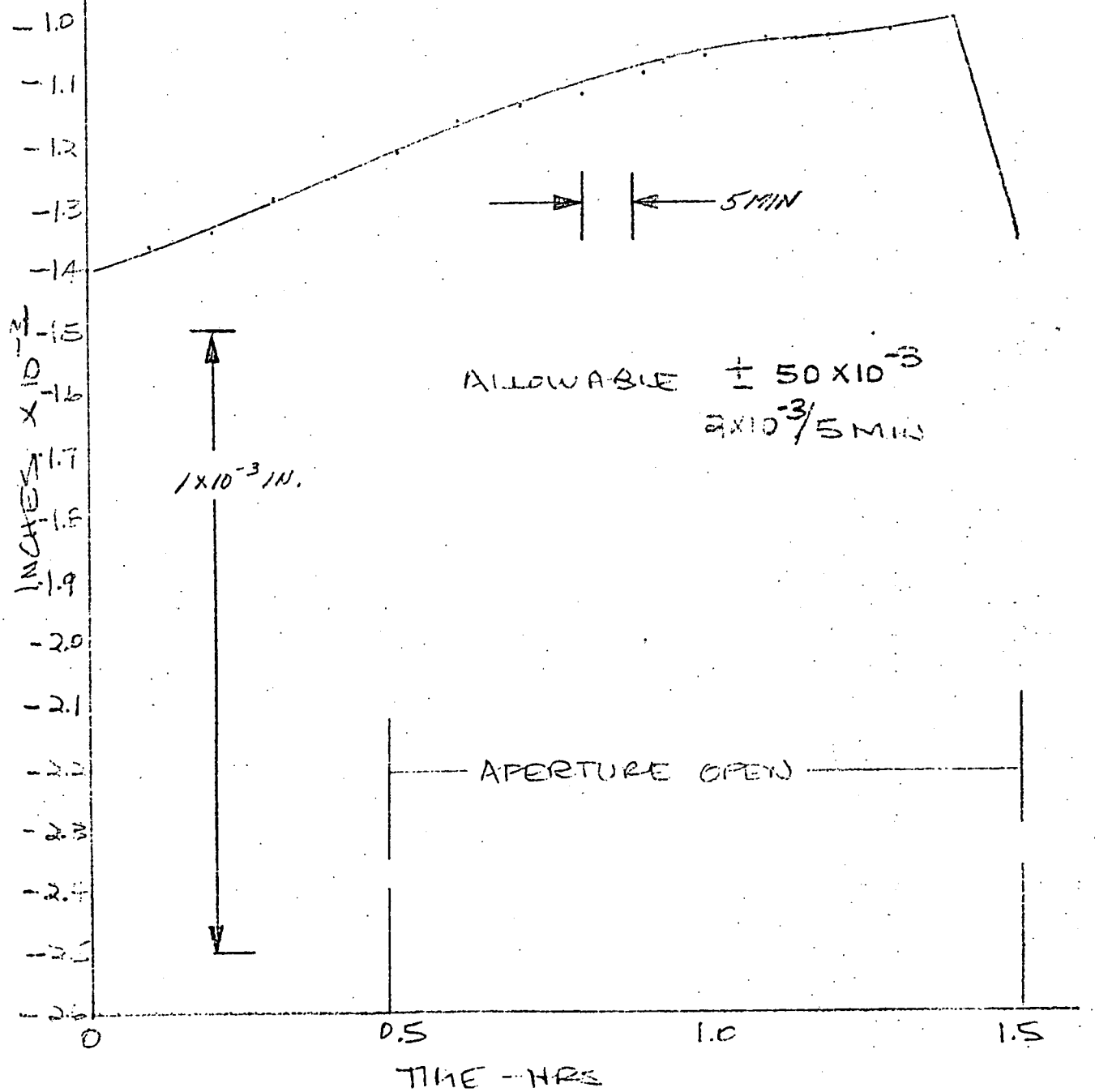

NBL A
VERTICAL IMAGE POSITION ON FILM
RIGHT SIDE
SKYLAB 1/2
ORBIT 6
REF AR52
1 x 10^-3
ALLOWABLE ±50 X 10^-3
2 X 10^-3/5 MIN
5 MIN
APERTURE OPEN
0
-.1
-.2
-.3
-.4
-.5
-.6
-.7
-.8
-.9
-1.0
-1.1
-1.2
-1.3
-1.4
-1.5
-1.6
-1.7
-1.8
-1.9
-2.0
0
0.5
1.0
1.5
TIME - HRS

RH-2 5/27/73

NBLA
VERTICAL IMAGE POSITIONS ON FILM
LEFT SIDE

ORBIT 6
REF AR 52

SKYLAB 1/2



DMS 5/27/73

INTEROFFICE MEMORANDUM

TO:	M.W. Frank	NO:	73.036 B5502
FROM:	R.R. Anderson, ext. 4221	DATE:	1 October 1973
SUBJECT:	S-082A & B Thermal Performance Report -- Skylab 3 Mission	CC:	See Distribution

The attached report presents a summary of the S-082A and B experiment thermal performance during the Skylab 3 mission.

R.R. Anderson

R.R. Anderson
SMTS

jb

Distribution

J.E. Butler
R.H. Grunz
C.E. Noble
W.R. Sidle
H.L. Valentine

THERMAL DISTORTION ANALYSIS
SKYLAB 3

Thermal distortion analyses of the S-082A and S-082B experiments were completed for a total of 26 randomly selected orbits during the Skylab 3 mission -- 13 for each experiment.

The results of these analyses in the form of plotted thermal distortion parameters vs. time were forwarded to BBRC-NRL personnel at Johnson Space Center as they were completed. These analyses show that the performance of the S-082A and S-082B thermal control systems were acceptable throughout the SL-3 mission. No failures were noted in the TCS systems, the associated temperature probes, or the experiment temperature measurements. The average case temperatures, differential temperatures across the case, and the rate of change of differential temperatures were held within the allowable limits throughout the SL-3 mission. The only anomalous behavior noted was that, as during the SL-2 mission, the S-082A experiment temperatures were slightly colder than the temperature seen during the Flight Thermal Vacuum test at JSC and the calibration temperature. However, the S-082A case average temperatures were consistently ~0.5°F warmer than during the SL-2 mission and ranged from 0.5 to 1.3°F colder than the alignment temperature of 70°F. This variation in instrument average case temperature causes an instrument defocus of about 10 percent (maximum) of the total allowable defocus or about 16 percent of the allowable due to thermal distortion. The S-082B instrument case temperature averages were also warmer than those observed during the Skylab 2 mission. The S-082B case average temperature ranged from 0.1°F colder to 0.36°F hotter than the alignment temperature of 69.8°F. This variation in instrument average case temperature causes a maximum defocus of about 30 percent of the allowable defocus due to thermal distortion.

The higher instrument case temperatures during the SL-3 mission can be attributed to higher canister sun end temperatures which ranged from 1.8°F to 5.4°F (1°C to 3°C) hotter than during the SL-2 mission. Canister wall and MDA end temperatures were essentially unchanged from the SL-2 mission. The sun end temperature rise has been attributed to degradation of the white thermal control paint on the canister sun end.

A relatively high horizontal image smear rate was noted for the S-082B instrument for the orbit beginning at day 249, 18th hour, 40th minute. During the first 15 minutes after aperature opening, the rate of change of horizontal position, slit image on film was 43.7% of the allowable 0.001 in/15 min rate. The total change for a 26 minute period was 0.544×10^{-3}in or 54.4% of the allowable. Corresponding smear rate for the horizontal position of the sun image on the slit plate was 0.141×10^{-3}in/5 min or 28 percent of the allowable 0.5×10^{-3}in/5 min. During a 26 minute period the image shift was 0.429×10^{-3}in or 85.8% of the allowable.

Most of the problems which plagued the Skylab 1/2 mission thermal distortion analyses were solved during the unmanned phase between missions or during the first four weeks of the Skylab 3 mission. The problems encountered during the Skylab 3 mission included the following:

1. Program errors which caused the distortion parameter plots to be mis-identified.
   Comment: All computer plot routines have been corrected and checked against tabular output data.

2. Computing account number was changed without notice at the end of the fiscal year and all runs were rejected by the computer causing a one and one-half day delay.
   Comment: A new account number was assigned which should be good until the end of the fiscal year.

3. Thermal distortion program tape developed a parity error causing submitted runs to fail resulting in a one day delay.
   Comment: Programs were run from a back up tape and new tapes have been generated.

4. Failure of the program to read aperture data from HOSC-EUC tape or card input revealed a program fluke which caused the program to fail if the orbit start time was not within the first 1.5 hours of data on the HOSC tape -- all check runs had met this criteria.
   Comment: Re-programing and generation of the program tape delayed production runs 11 days.

5. Aperture data on tape is noisy and program logic cannot distinguish between noise and real aperture open or close signals.
   Comment: The decision was made not to attempt to develop the complex logic required to distinguish between noise and aperture data. Aperture open and close times can be determined using the auto scan data, the daily logs and Data Book 6 temperature plots, and input on cards.

6. Hα data for temperature sensors C-0373-701 and C-0386-701 used as the source for 17 Hα thermal model nodes are not on the PI (S-082B) compressed format user tape.
   Comment: When NRL-B thermal distortion analyses are run from the PI user tape, these 17 nodes must be deleted as program generated specified temperature nodes and re-designated as computed temperature nodes or specified temperature nodes from card input tables.

7. Thermal distortion analysis for S-082A was successfully run from the PI user tape but attempts to run S-082B failed. The computing time required to complete one

orbit using the PI user tape is about 17 minutes. The identical run using the HOSC-ATM fixed format EUC tape requires less than 5 minutes.

Comment: The failure of the S-082B thermal distortion analysis to run from the S-082 user tape remains unsolved. The computer error flag output is insufficient to identify the problem area. We have asked Huntsville BBRC personnel to attempt another run during the week ending October 6, 1973. If this attempt also fails, it will be necessary to insert diagnostic print statements throughout the program to isolate the problem area. However, unless otherwise authorized by the NRL project office, no further attempts to run S-082B thermal distortion from the PI user tape will be made until the SL-4 mission.

Many minor frustrating computer problems occured during the SL-3 mission — such as computer power failure, lost distortion plots lost card output and runs delayed for unknown reasons — but all in all cooperation of the HOSC computer personnel has been good and the turn-around time for a run was in general over night.

The attachments to this report include:

1. A list of thermal distortion analyses run for the S-082A and S-082B instruments.
2. Sample S-082A and S-082B thermal distortion parameter plots for the orbit beginning Day 249, 18th hour, 40th min.
3. Sample S-082A and S-082B instrument case average temperatures for 4 times during the orbit beginning Day 249, 18th hour, 40th min.

Items 2 and 3 plots and tabulations are available for all runs listed in item 1.

R.R. Anderson

R.R. Anderson

THERMAL DISTORTION ANALYSIS - SKYLAB 3

S-082A*

DAY	HR	MIN	SEC	MSEC
219	19	1	0	0
230	14	33	0	0
231	12	18	42	0
233	12	40	0	0
235	12	46	0	0**
237	19	13	0	0
238	12	19	0	0
238	18	36	0	0
241	16	25	0	0
243	21	19	0	0
249	18	40	0	0
250	18	6	30	0
251	12	32	30	0

* Thermal distortion analyses and plots were completed for orbits with beginning times listed in this table using fixed format HOSC-ATM Engineering Unit Conversion Tape.

** Day 235 was run both from HOSC EUC tape and the S-082 PI compressed format user tape.

THERMAL DISTORTION ANALYSES - SKYLAB 3

S-082B*

DAY	HR	MIN	SEC	MSEC
219	19	1	0	0
230	14	33	0	0
231	12	18	42	0
233	12	40	0	0
235	12	46	0	0
237	19	13	0	0
238	12	19	0	0
238	18	36	0	0
241	14	56	0	0
243	21	19	0	0
249	18	40	0	0
250	18	6	30	0
251	12	32	30	0

* Thermal distortion analyses were completed for orbits with beginning times listed in this table using fixed format HOSC-ATM Engineering Unit Conversion Tape.

NRL-B (S-082B) | TIME | DAY 249: 15:40

NODE NUMBER	EQUATION IN TERMS OF MEASUREMENT NUMBER		APERTURE OPEN (APOPEN)	APOPEN + ~15 MIN	APOPEN + ~30 MIN	APERTURE CLOSED	REMARKS
			θ=0.568	θ=0.80	θ=1.036	θ=1.50	CALIBRATION TEMP
413	C-217		71.659	71.781	71.984	71.997	CASE AVG = 69.8°F
414	C-219		70.465	70.465	70.482	70.465	
415	C-220		69.513	69.556	69.541	69.527	ANODIZED AVERAGE
429	C-225 - C-223		68.450	68.493	68.446	68.496	TEMPERATURE [illegible]
437	C-210 + C-093		70.263	70.242	70.284	70.315	TO INLET FOCUS
438	C-212 + C-094		70.189	70.170	70.197	70.201	REQUIREMENT 69.8 ± 1.2°F
439	C-212 + C-094		70.189	70.170	70.197	70.201	
440	C-213 + C-207		69.497	69.410	69.478	69.546	MAXIMUM [illegible]
442	C-213		68.619	68.588	68.627	68.682	~ 0.214 °F
443	C-212		69.944	69.948	69.965	69.948	%
444	C-212		69.944	69.948	69.965	69.948	θ ΔT(CALC = [illegible]) $\left(\frac{\Delta T}{T_2}\right)$ 10[illegible]
445	C-210		70.434	70.371	70.434	70.558	0.568 ± 0.145 [illegible]
452	C-209 + C-089		69.735	69.662	69.746	69.869	0.800 ± [illegible] 11.8%
454	C-413		69.969	69.985	69.989	70.010	1.036 ± 0.170 14.2%
456	C-407		69.893	69.886	69.892	69.901	1.500 ± 0.214 [illegible]
457	C-405		69.526	69.527	69.527	69.527	
464	C-209		69.595	69.564	69.612	69.750	
471	C-214 - C-208		70.024	70.082	70.076	70.144	
473	C-417		69.915	69.913	69.915	69.941	
474	C-214		69.818	69.870	69.870	69.932	
476	C-215 (Backup CO 415)		70.188	70.147	70.161	70.271	
477	C-224		70.198	70.198	70.184	70.262	
479	C-225		68.779	68.760	68.791	68.822	
485	C-215 - C-216		71.295	71.321	71.386	71.548	
486	C-224 - C-222		70.525	70.555	70.510	70.578	
APERTURES OPEN 0.5500 → 1.500		Σ	1748.626	1748.524	1749.257	1750.349	
		AVG	69.945	69.941	69.970	70.014	

NRL-A (S082A)

NODE NUMBER	EQUATION IN TERMS OF MEASUREMENT NUMBER	TIME: APERTURE OPEN (APOPEN)	AP OPEN + ~ 15MIN	AP OPEN + ~ 30MIN	APERTURE CLOSED	DAY: 249: 18:40 REMARKS
310	C-095	68.621	68.774	68.731	68.837	[illegible]
311	C-096 — C205	69.441	69.469	69.484	69.376	CALIBRATION TEMPERATURE
312	C 197	69.382	69.360	69.436	69.392	CAL T 70°F
323	C 090	68.590	68.590	68.590	68.621	
324	C 091	69.114	69.114	69.114	69.114	ALLOWABLE VARIATION
325	C 092	69.207	69.207	69.229	69.268	TO MEET FORMS
328	C092 + C201	69.860	69.853	69.878	69.914	REQUIREMENT
329	C091 + C202	69.402	69.398	69.366	69.399	$T_{avg} = 70°F \pm 8°F$
330	C090 + C203	68.691	68.904	68.900	68.905	
356	C095 - C206	68.750	68.785	68.860	68.956	% Θ ΔT (BIAS-TRUE) $(\frac{\Delta T}{\Theta})$
357	C096	69.411	69.453	69.453	69.461	0.777 = .778
358	C197 + C204	69.029	69.015	69.097	69.095	0.771 = .829
		$\Sigma \rightarrow$	829.708	830.04	830.138	830.188
		AVERAGE	69.142	69.170	69.178	69.182
APERTURE GAIN 0.5500 - 1.500		Θ	0.567	0.801	1.068	1.500

NRL-B DAY 249:18:40

NAME- BBRCNB

DIST. CODE- BIN232

RUN ID- NRLBTD

JOB NO- 140006

SEQ NO- 70075

DATE- 09-16-73

TIME- 06-27-58

S082B THERMAL DISTORTION
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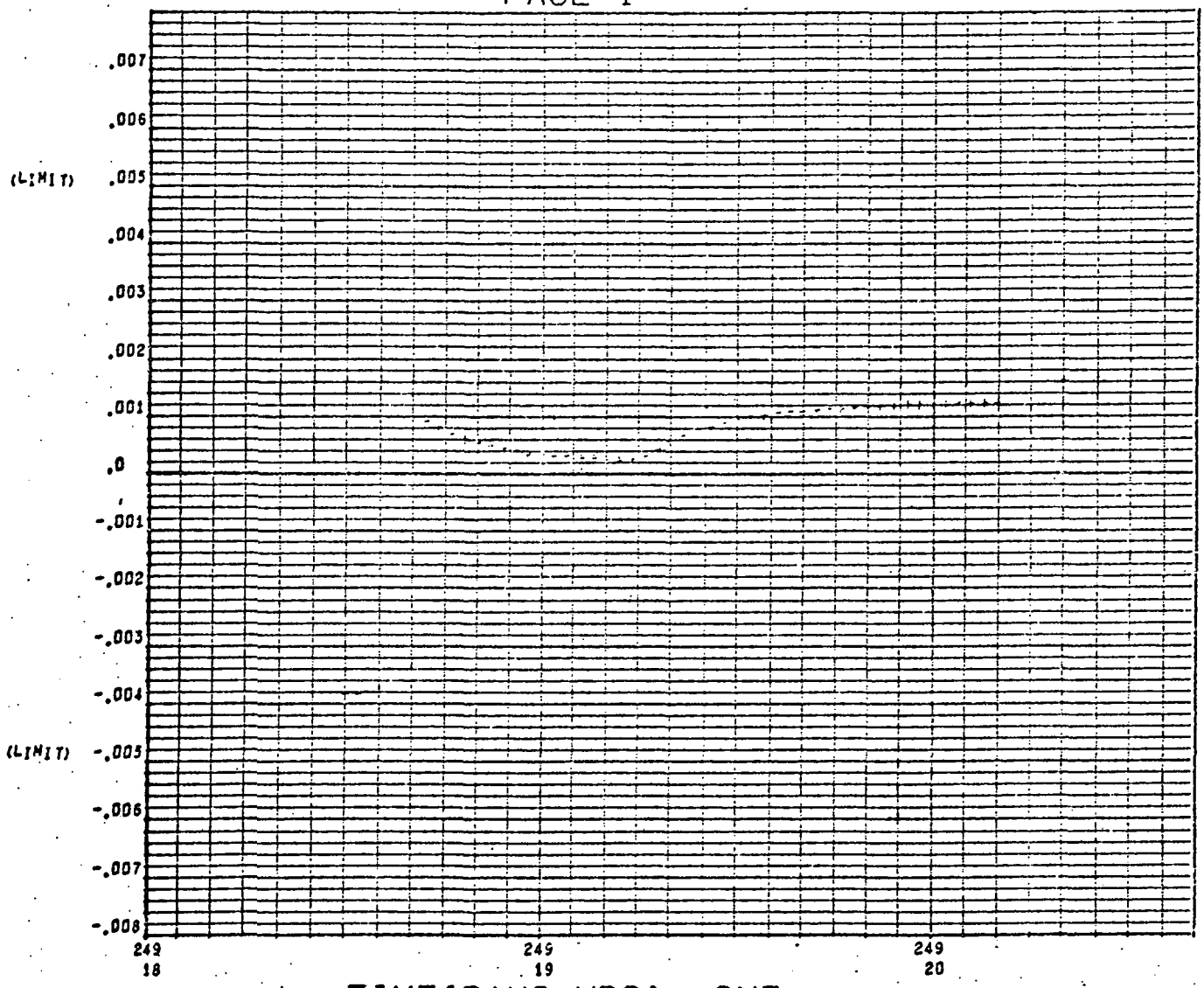
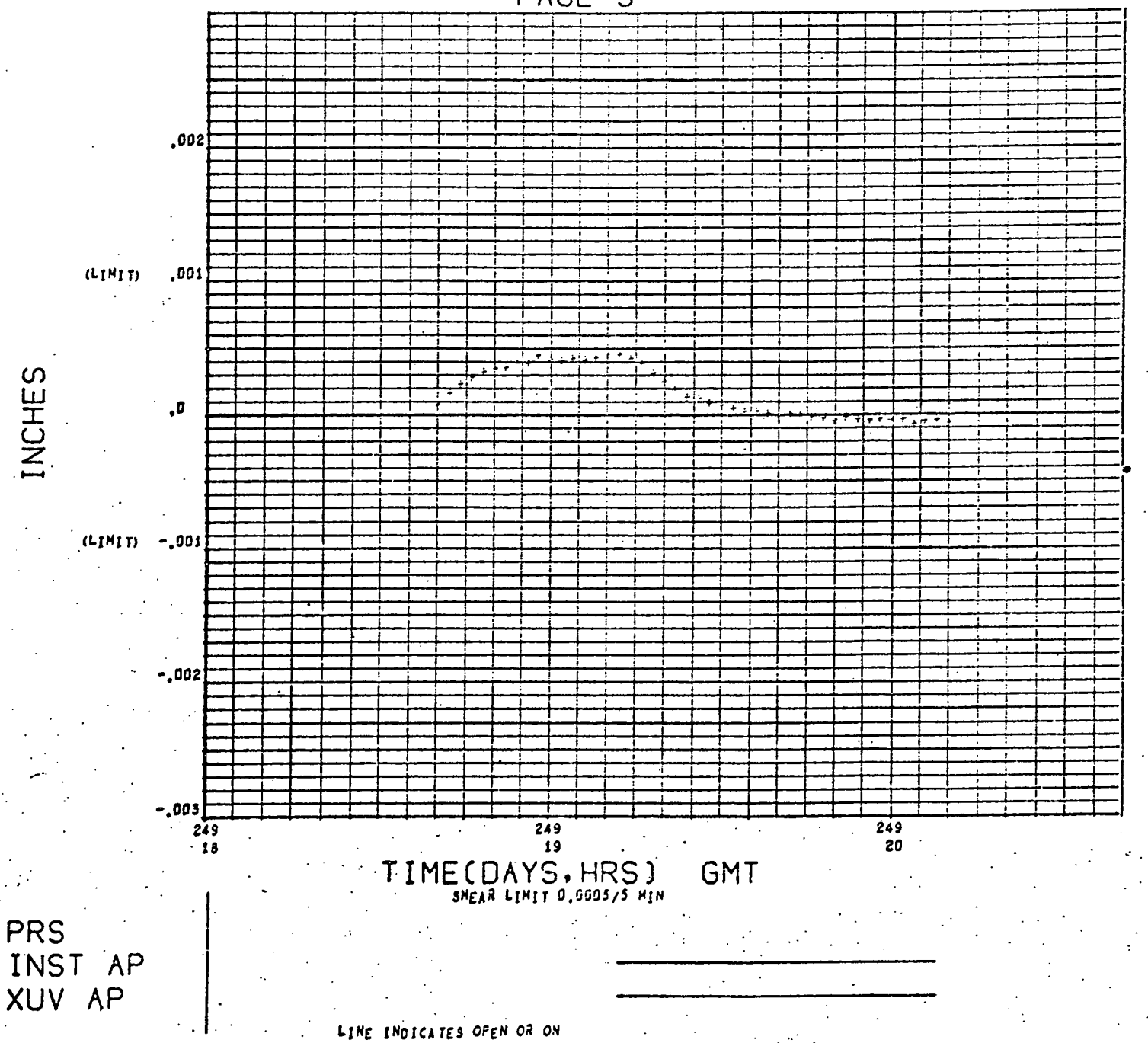
PAGE 1



PRS
INST AP
XUV AP

LINE INDICATES OPEN OR ON

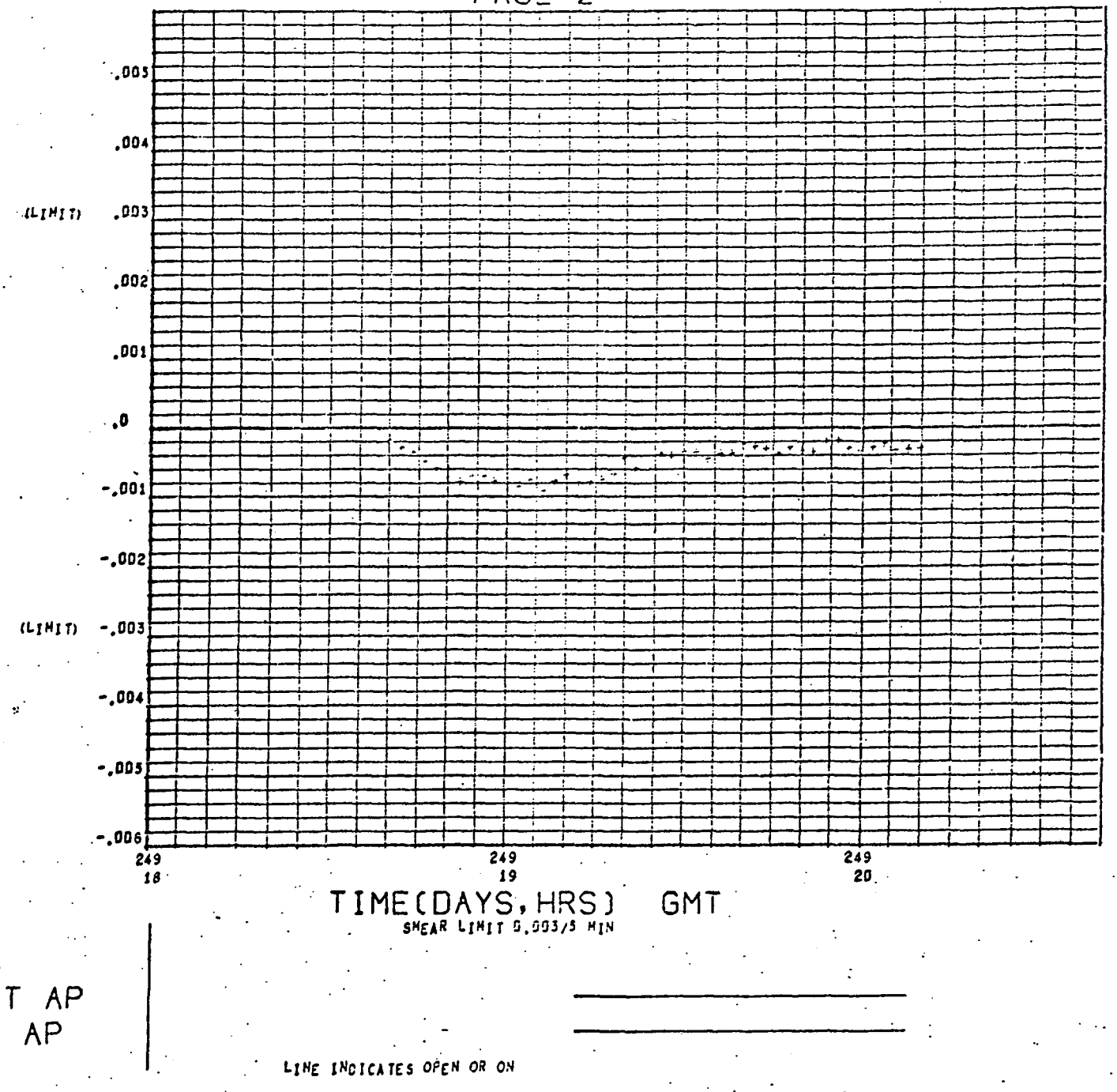
S082B THERMAL DISTORTION
SUN IMAGE ON SLIT PLATE, HORIZONTAL POSITION
PAGE 3



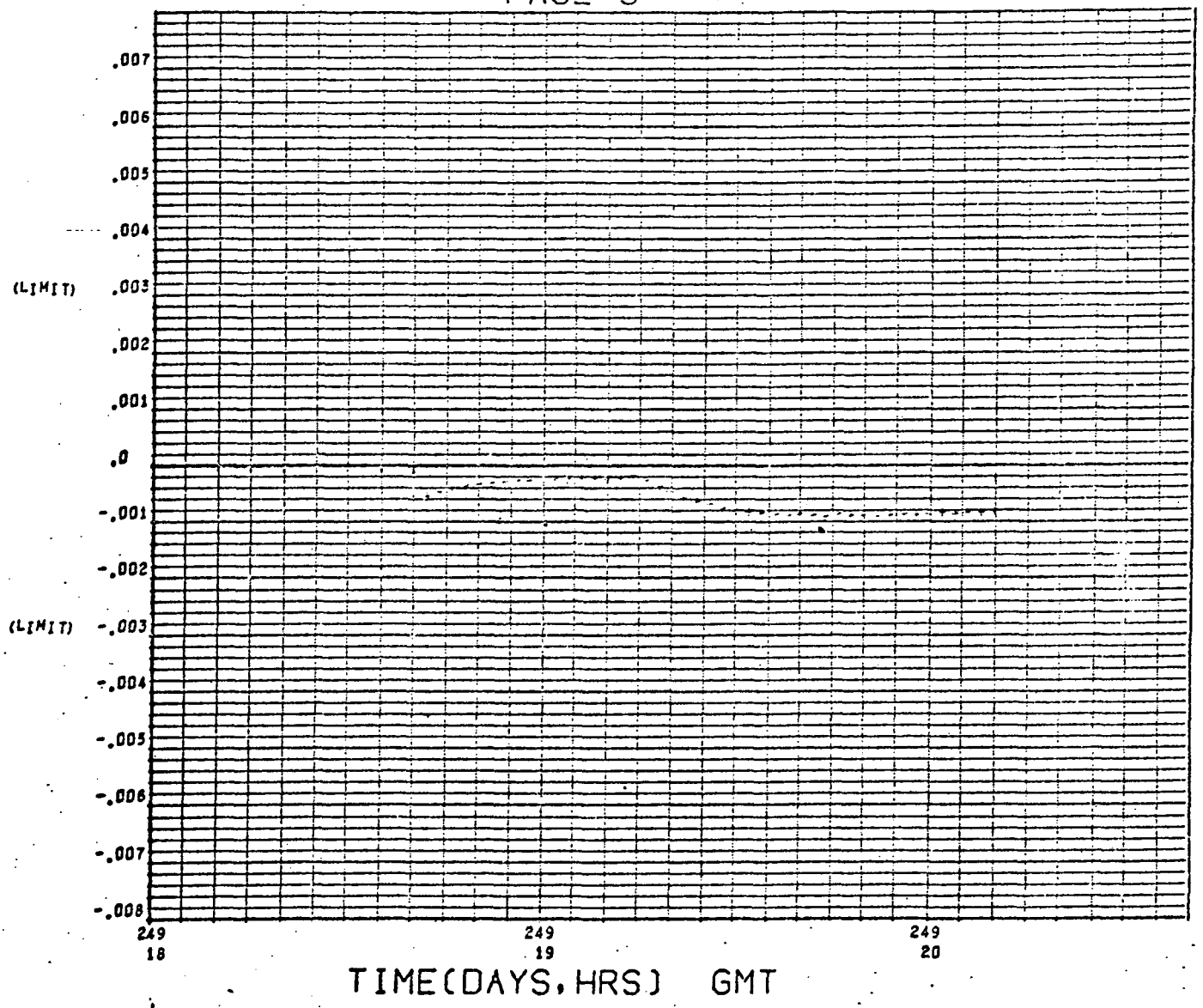
PRS
INST AP
XUV AP

LINE INDICATES OPEN OR ON

S082B THERMAL DISTORTION
SUN IMAGE ON SLIT PLATE, VERTICAL POSITION
PAGE 2



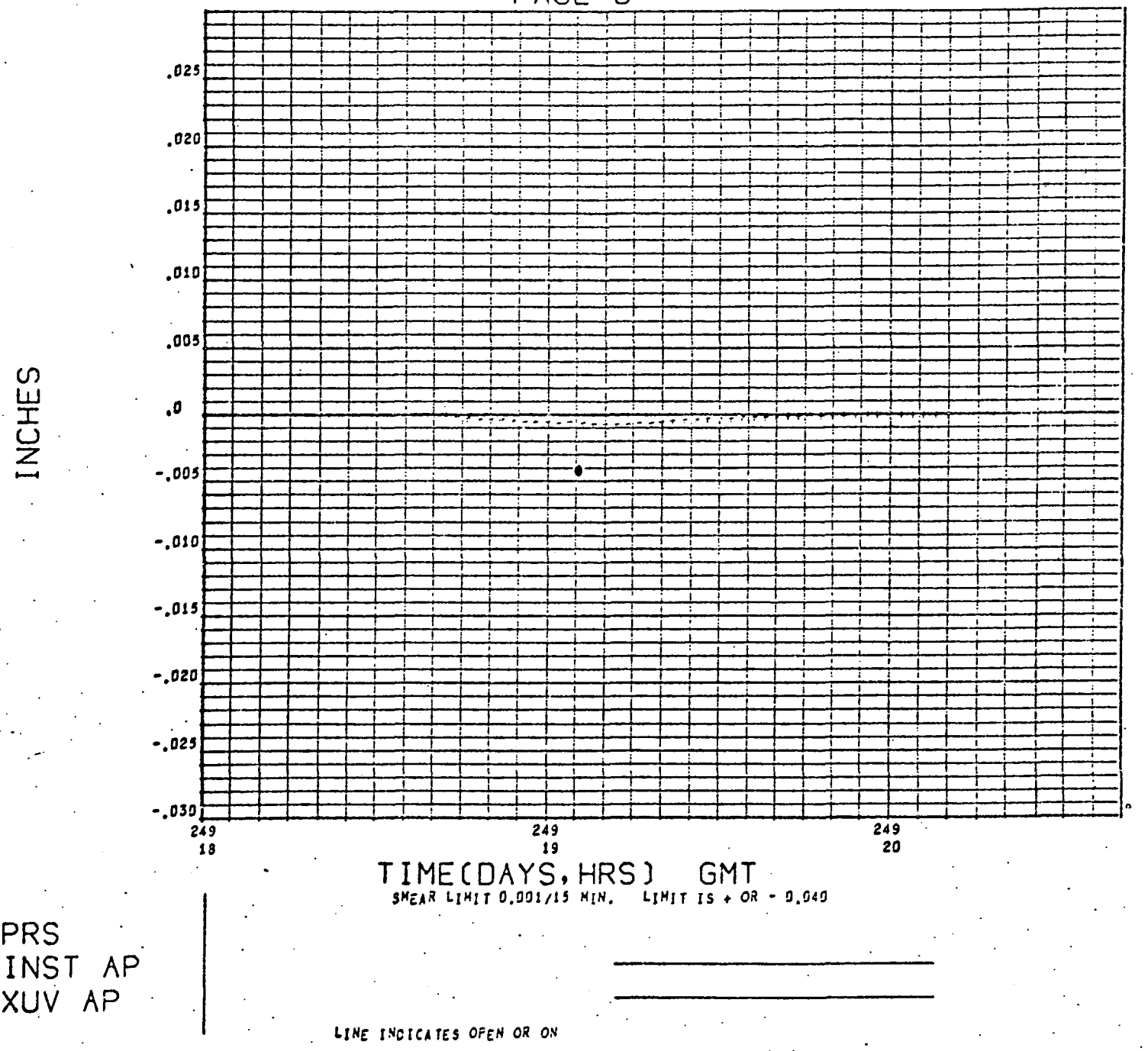
S082B THERMAL DISTORTION
SLIT IMAGE ON FILM, FOCUS, LEFT SIDE
PAGE 5



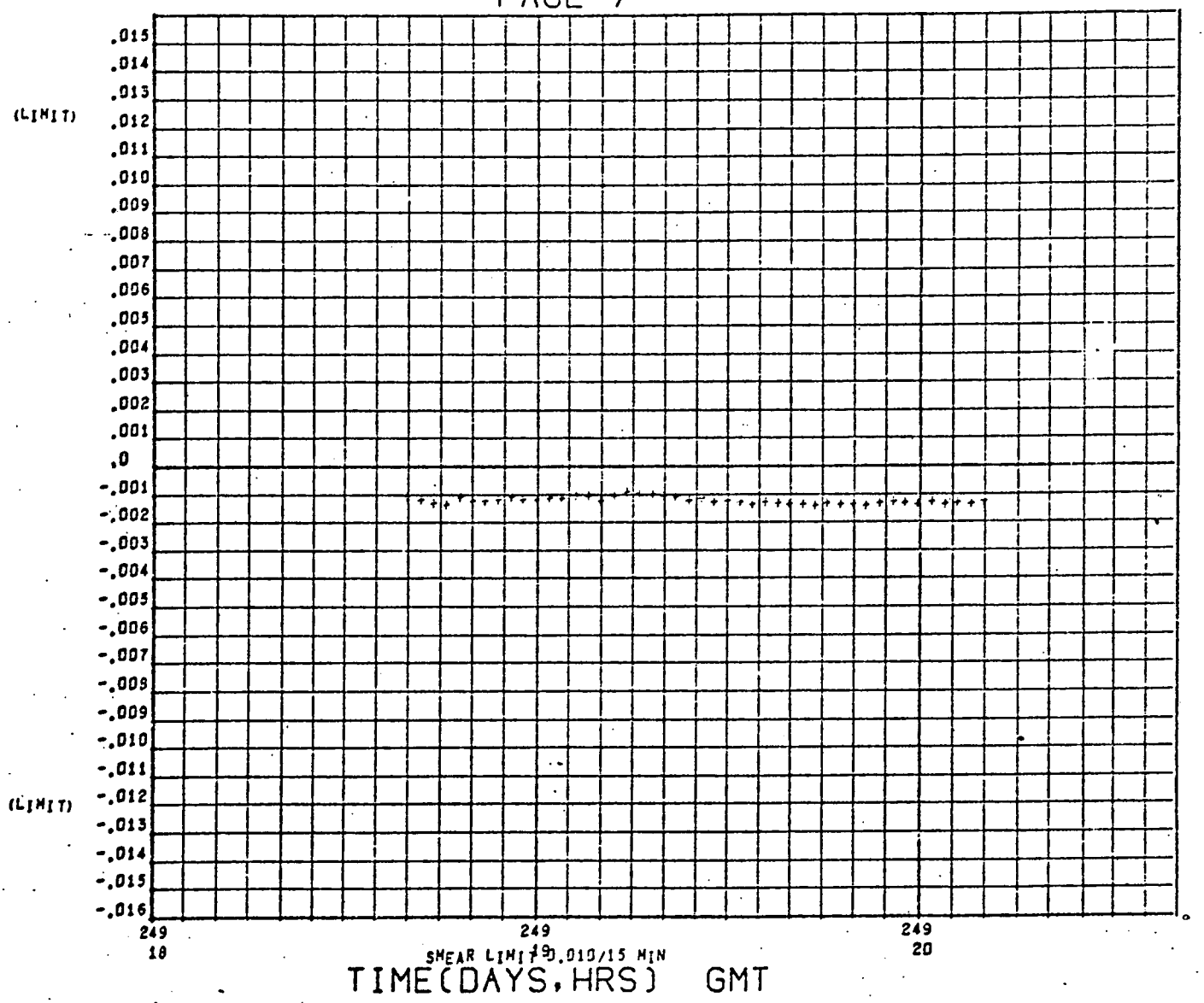
PRS
INST AP
XUV AP

LINE INDICATES OPEN OR ON

S082B THERMAL DISTORTION
SLIT IMAGE ON FILM, HORIZONTAL POSITION, LEFT SIDE
PAGE 9



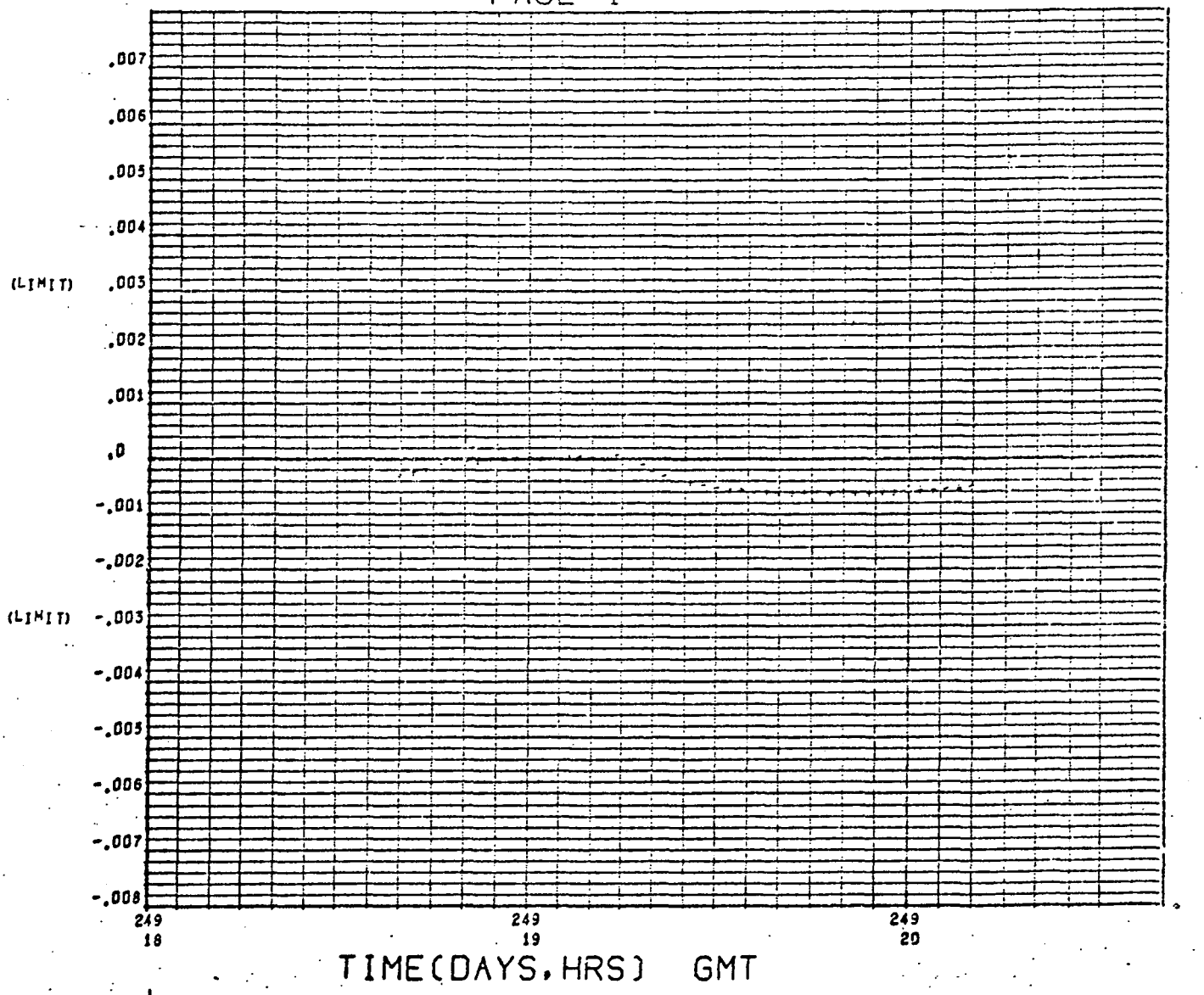
S082B THERMAL DISTORTION
SLIT IMAGE ON FILM, VERTICAL POSITION, LEFT SIDE
PAGE 7

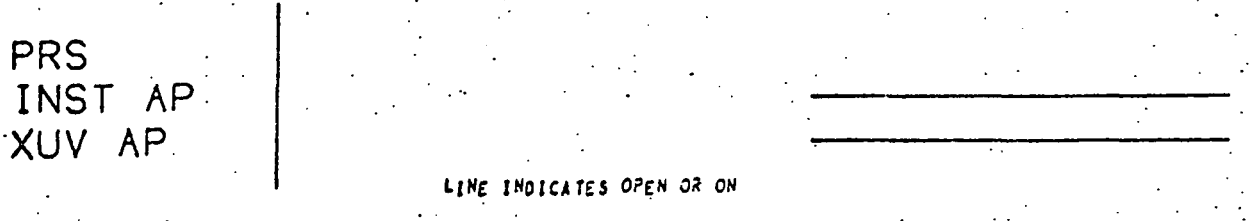


PRS
INST AP
XUV AP

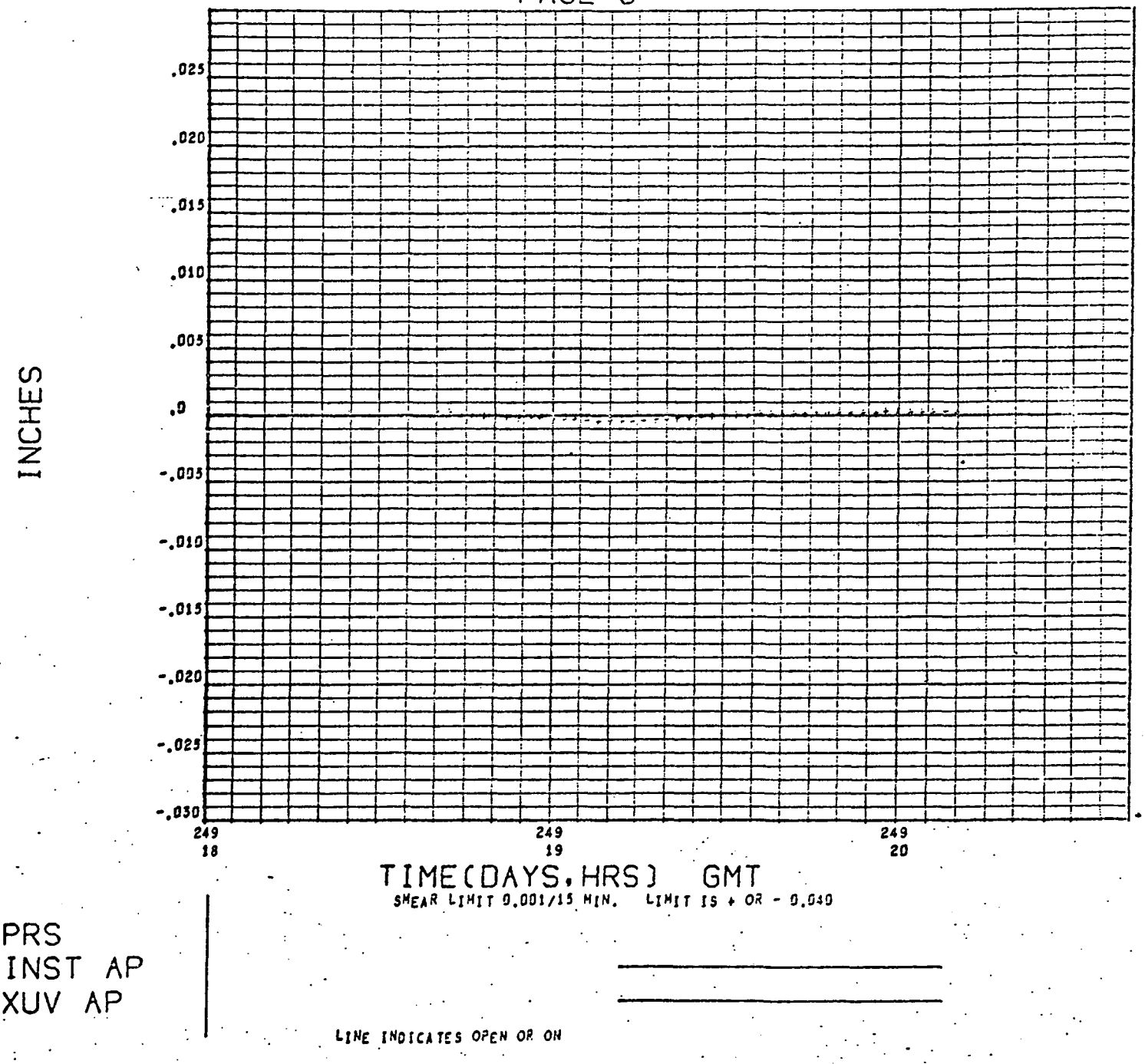
LINE INDICATES OPEN OR ON

S082B THERMAL DISTORTION
SLIT IMAGE ON FILM, FOCUS, RIGHT SIDE
PAGE 4

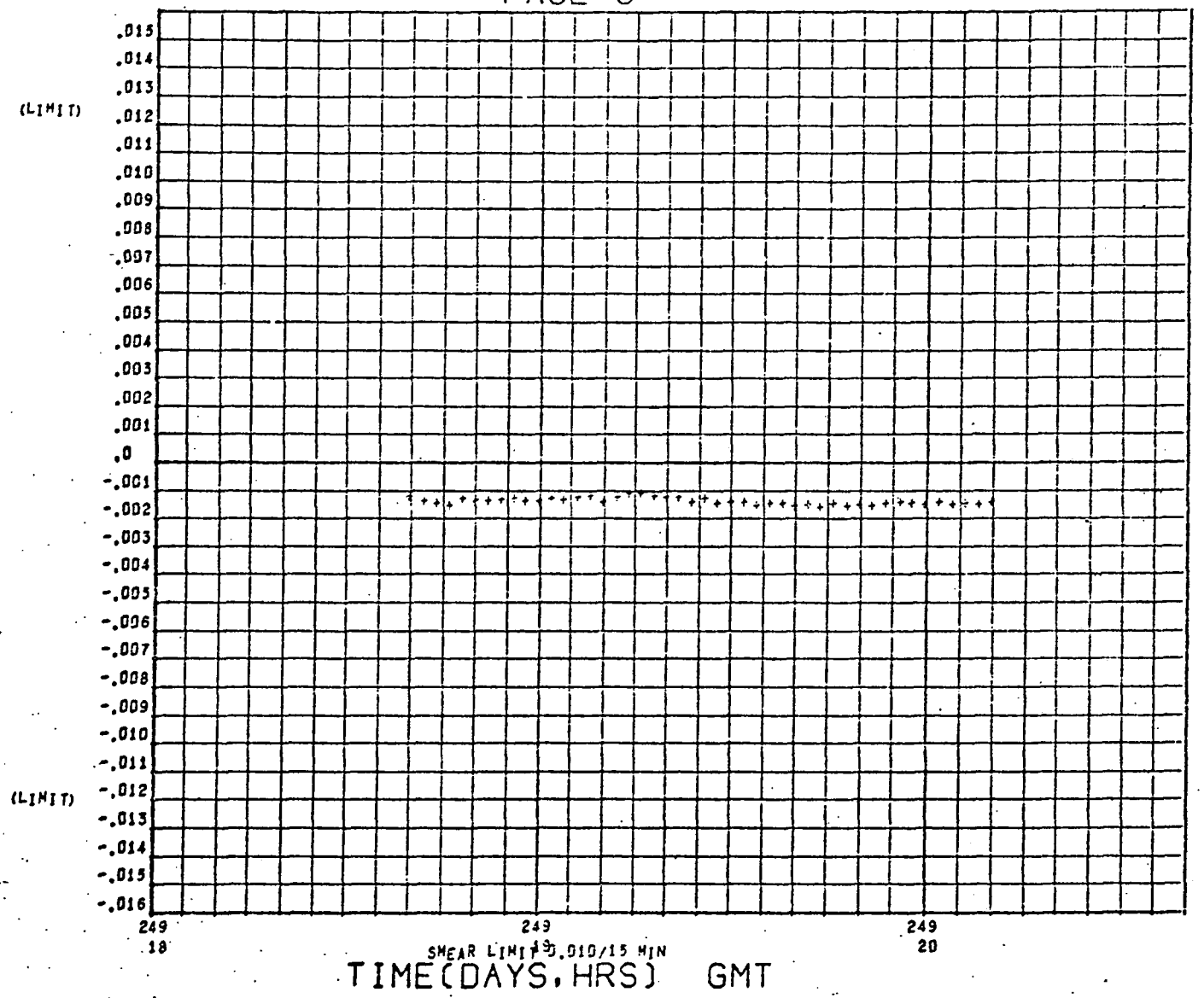




S082B THERMAL DISTORTION
SLIT IMAGE ON FILM, HORIZONTAL POSITION, RIGHT SIDE
PAGE 8



S082B THERMAL DISTORTION
SLIT IMAGE ON FILM, VERTICAL POSITION, RIGHT SIDE
PAGE 6



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LINE INDICATES OPEN OR ON

NRL-A DAY 249:18:40

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DIST. CODE-BIN232

RUN ID-NRLATD

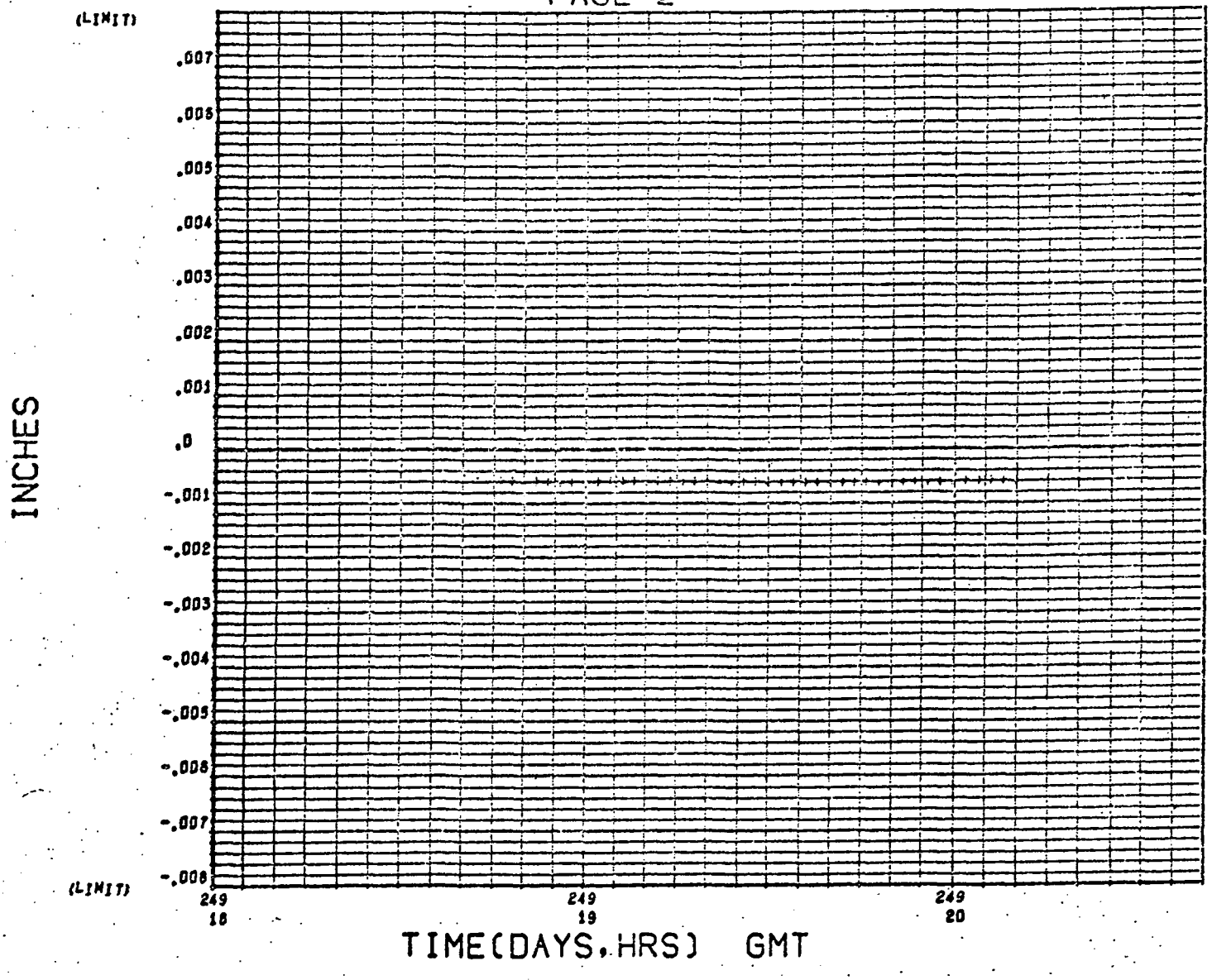
JOB NO- 140006

SEQ NO- 70046

DATE- 09-16-73

TIME- 04-20-05

S082A THERMAL DISTORTION
SUN IMAGE ON FILM, FOCUS, LEFT SIDE
PAGE 2

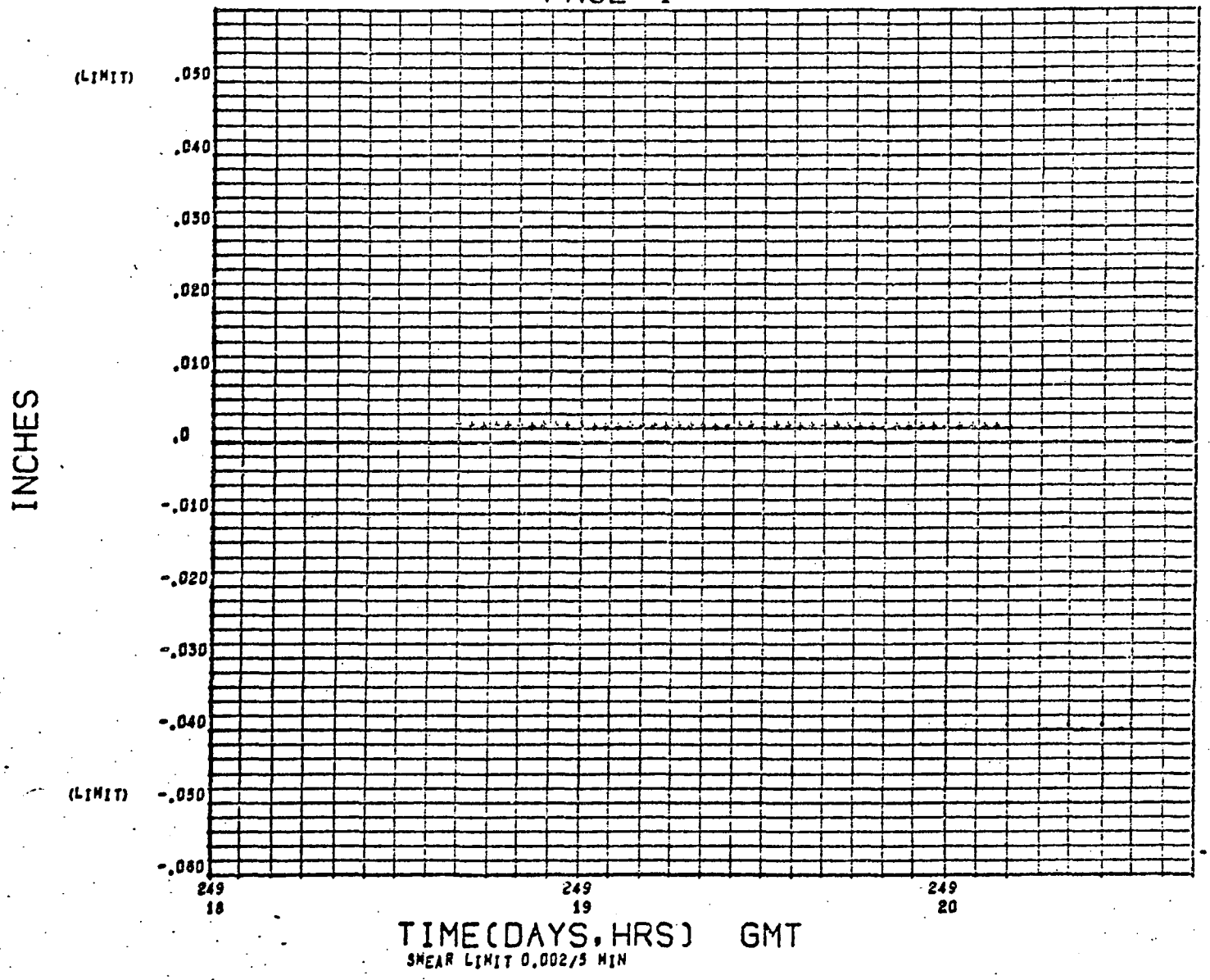


SHRT WL

INST AP

LINE INDICATES OPEN OR IN POSITION

S082A THERMAL DISTORTION
SUN IMAGE ON FILM, VERTICAL POSITION, LEFT SIDE
PAGE 4



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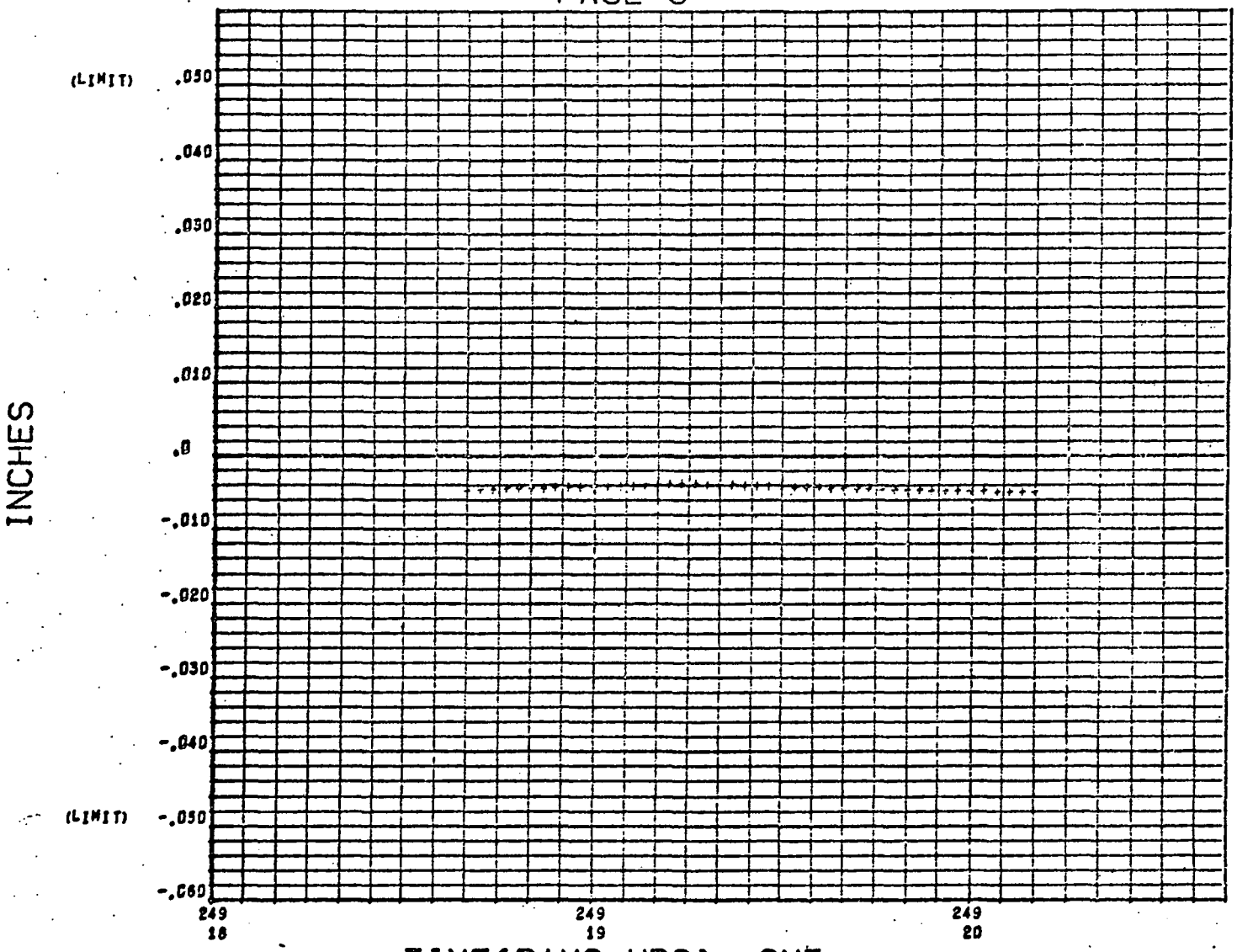
LINE INDICATES OPEN OR IN POSITION

S082A THERMAL DISTORTION
SUN IMAGE ON FILM, HORIZONTAL POSITION, LEFT SIDE
PAGE 6



SHEAR LIMIT 0.002/5 MIN

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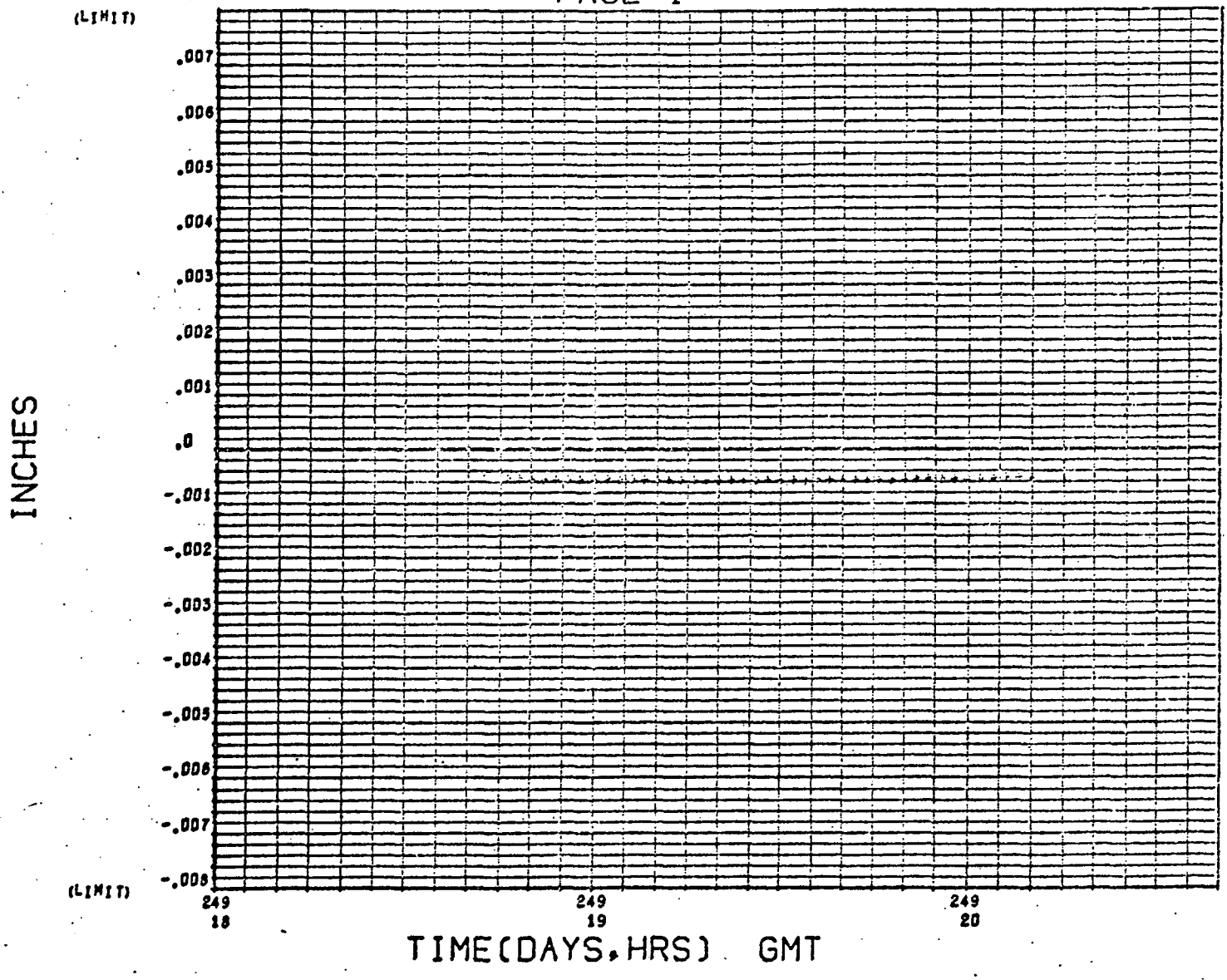
INST AP

LINE INDICATES OPEN OR IN POSITION

S082A THERMAL DISTORTION
SUN IMAGE ON FILM, FOCUS, RIGHT SIDE
PAGE 1



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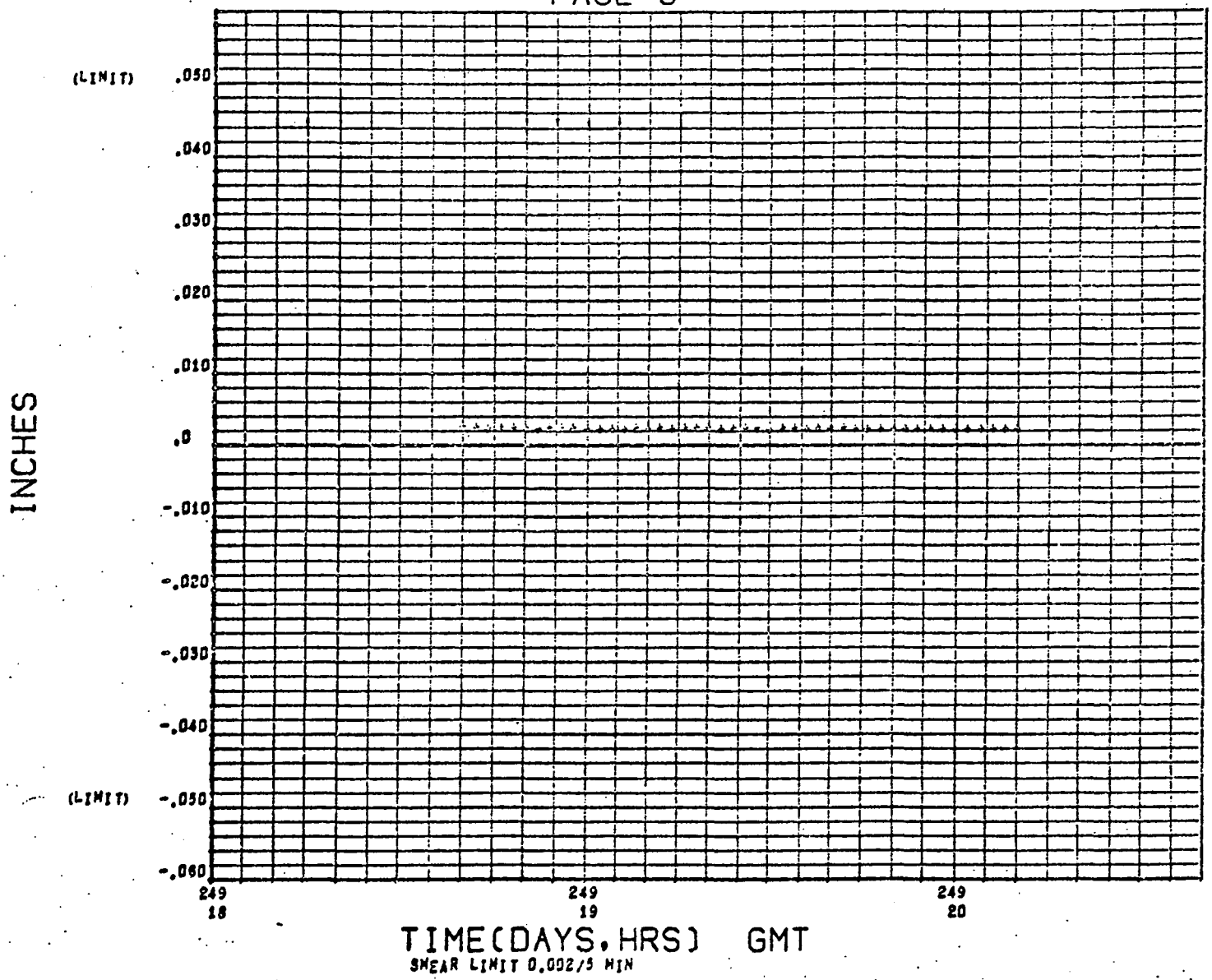
LINE INDICATES OPEN OR IN POSITION

S082A THERMAL DISTORTION
SUN IMAGE ON FILM, VERTICAL POSITION, RIGHT SIDE
PAGE 3



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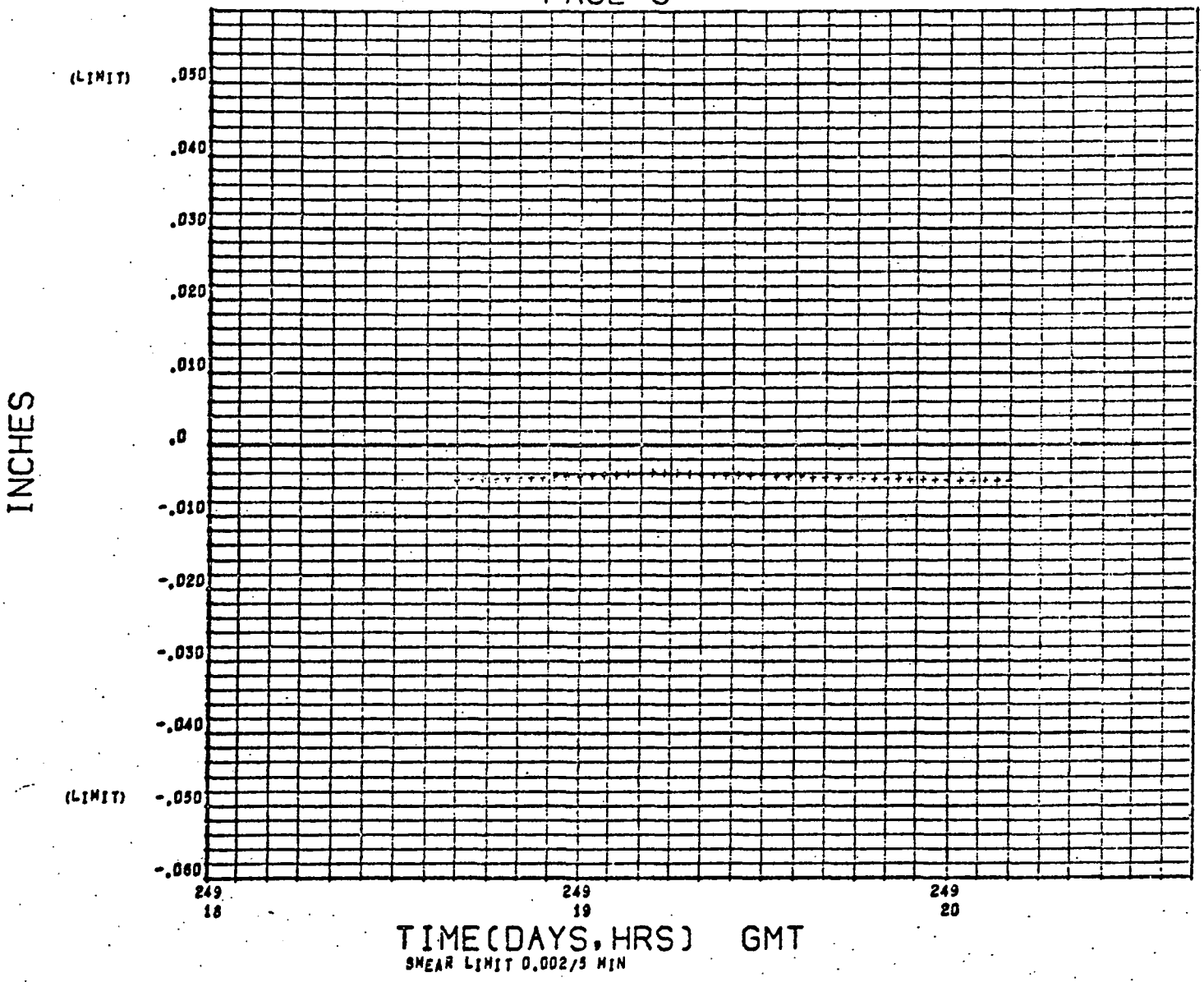
LINE INDICATES OPEN OR IN POSITION

S082A THERMAL DISTORTION
SUN IMAGE ON FILM, HORIZONTAL POSITION, RIGHT SIDE
PAGE 5



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INST AP

LINE INDICATES OPEN OR IN POSITION

INTEROFFICE MEMORANDUM

TO: M. W. Frank

FROM: R. R. Anderson X4221

SUBJECT: S-082A AND S-082B THERMAL PERFORMANCE REPORTS-- SKYLAB 4 MISSION

NO: B5502 74.002

DATE: 5 April 1974

cc: J. E. Butler
C. E. Noble
R. H. Grunz
W. R. Sidle

The attached reports summarize the thermal performance of the S-082A and B instruments during the Skylab 4 mission.

The computer program used to run the thermal distortion analyses at HOSC for the four BBRC/ATM instruments was punched out on cards and listed. The cards and listing are presently in the custody of Leo Frobom at Huntsville. In addition, the program tapes (4 copies) were withdrawn from the HOSC tape library to prevent their destruction by HOSC's automatic purge of outdated tapes. Two copies are stored at MSFC in the custody of D. Klein and two copies are in the custody of R. R. Anderson at BBRC.

The S-082A and B thermal model card decks are also in the custody of Leo Frobom and will be shipped, with the program deck, to BBRC with his household goods. Computer tape copies (1 each) of these decks are in R. R. Anderson's possession at BBRC.

The above program tapes or card decks can be used to run the thermal distortion programs at HOSC on the 1108 computer or at the NASA/Slidell computer facility.

The program would have to be re-coded before it could be run at any other computer facility or if software changes are made at HOSC or Slidell.

R. R. Anderson

R. R. Anderson
Senior Member Technical Staff

pcb

Attachments

SKYLAB SL-4 MISSION
NRL S-082A SPECTROHELIOGRAPH THERMAL PERFORMANCE

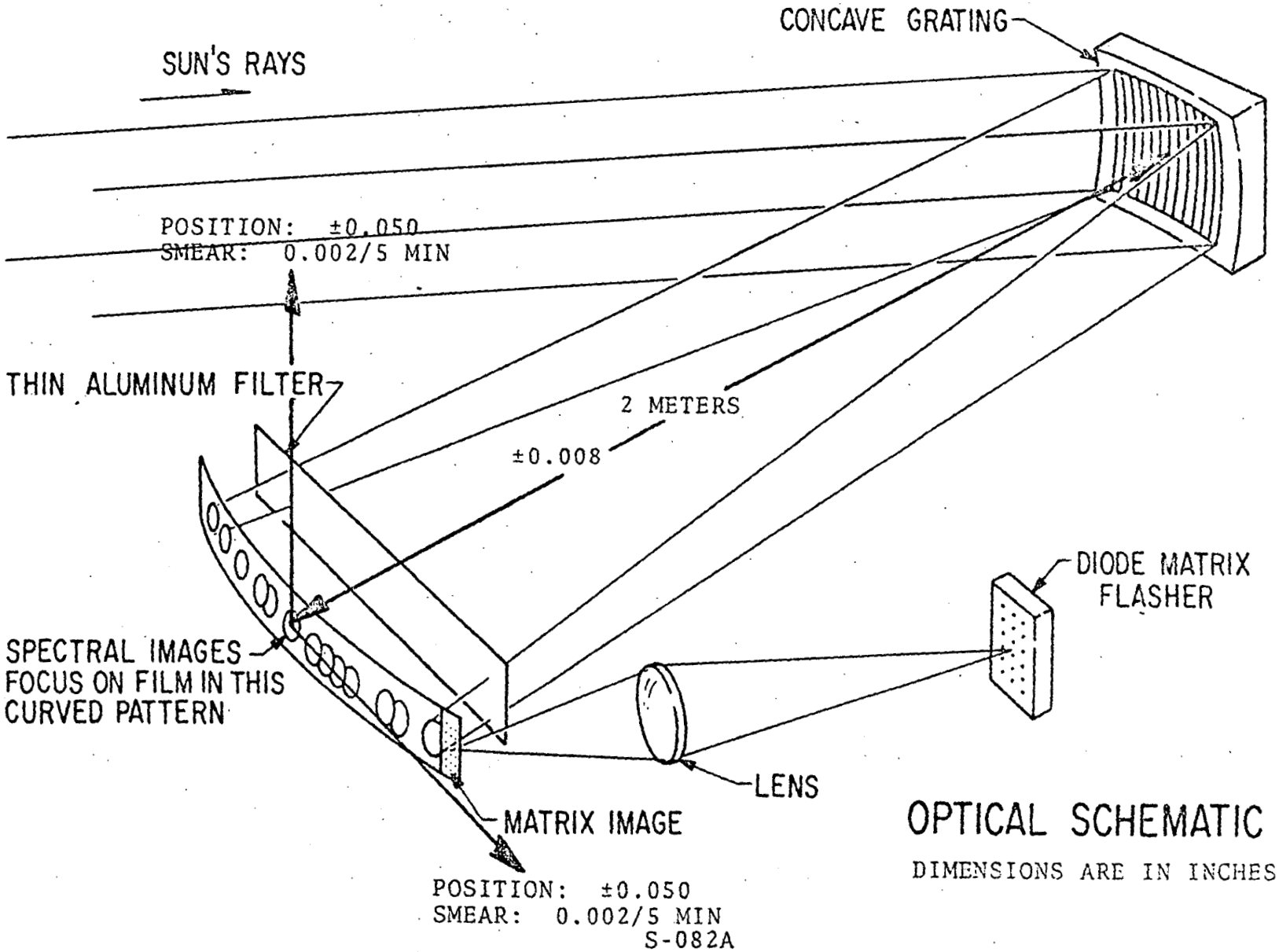
The S-082A thermal control system performance was acceptable throughout the SL-4 mission. The average case temperatures (affecting image focus), differential temperatures across the case (affecting image position), and the rate of change of differential temperatures (affecting image smear) were held within the allowable limits throughout the mission. No failures were noted in the thermal control system, the associated temperature sensors or the instrument temperature probes.

Alignment and focus requirements for the S-082A Spectroheliograph required an active thermal control system to maintain the absolute temperature level within the limits of 294.27K ± 4.4K (70 F ± 8.8 F) and dynamic temperature gradients across the instrument less than ±0.12K (±0.22F) in five minutes. The maximum allowable thermal distortions and related temperature--temperature gradients are shown in Figure 1 and Table 1.

The thermal control system includes both active and passive elements. The active elements consist of low thermal capacity stand-off heater panels. The panels (8) are thermally coupled to the instrument by radiation and conductively isolated by the low conductance stand-off mounts. The passive elements consist of multi-layer aluminized Mylar insulation panels and skirts which cover most areas of the instrument not covered by heater panels.

The thermal control system was designed to operate in the controlled environment of the Skylab/ATM Canister. The canister design temperature limits were 281.5K (47F) to 287.6K (58F). However, the ATM liquid thermal conditioning system maintained the canister (controlled wall) temperature within the limits of 282.86K (49.5F),

MAXIMUM ALLOWABLE THERMAL DISTORTIONS



OPTICAL SCHEMATIC

DIMENSIONS ARE IN INCHES

Table 1

S082A SPECTROHELIOGRAPH

OPTICAL IMAGE TOLERANCES FOR THERMAL DISTORTION

Solar Image on Film

Focus		$(X-X_o)$ Image on Film		$T-T_o$*	Basis
Tolerance		±0.20 mm	±0.008 inch	±8.0°F	D&PS
Accuracy		±0.05	±0.002	±2.0°F	
Horiz. Position		$(Z-Z_o)$ Image on Film		ΔT Hor.	
Tolerance	2 $\widehat{\text{min}}$ Solar Image	±1.25 mm	±0.050 inch	±13.0°F	Estimate
Accuracy					
Vert. Position		$(Y-Y_o)$ Image on Film		ΔT Vert.	
Tolerance	2 $\widehat{\text{min}}$ Solar Image	±1.25 mm	±0.050 inch	±5.5°F	Estimate
Accuracy					
Horiz. Smear		$\Delta(Z-Z_o)$ in 5 Minutes		ΔΔT/5 Min.	
Tolerance	5 $\widehat{\text{sec}}$/5 Minutes	0.05 mm	0.002 inch	0.5°F	D&PS
Accuracy		±0.012	±0.0005	±0.12°F	
Vert. Smear		$\Delta(Y-Y_o)$ in 5 Minutes		ΔΔT/5 Min.	
Tolerance	5 $\widehat{\text{sec}}$/5 Minutes	0.05 mm	0.002 inch	0.22°F	D&PS
Accuracy		±0.012	±0.0005	±0.05°F	

* T_o = Calibration Temperature = 70°F

minimum inlet temperature, and 285.7K (54.5F) maximum outlet temperature. Tables 2 and 3 present the canister temperatures for the three missions. Higher temperatures were observed on the Canister Sun End Plate, spar and MDA End Plate throughout the flight and particularly during the high β angle orbits when successive full sunlit orbits occurred. These areas of the ATM canister were passively controlled whereas the canister wall temperature was controlled actively by the ATM Liquid Thermal Conditioning System. Fluid inlet temperatures also increased by about 1.3K (2.3F) during the high β angle orbits.

Ten thermal distortion computer program runs were made during the SL-4 mission to analyze the S-082A instrument thermal performance. Run times are shown in Table 4. The data summarized below is derived from these runs.

The instrument case temperatures were in general slightly colder, 0.69K (1.24 F), than the alignment temperature, 294.27K (70 F), throughout the Skylab 4 mission. The average case temperatures for the ten thermal distortion runs are shown in Tables 5 through 15. The average case temperature varied from this general condition during the high β angle periods when successive full sunlit orbits occurred (Tables 16 through 19). The case average temperature during the full sunlit orbit reached 294.7K (70.7 F)--about 0.39K (0.7F) hotter than the instrument calibration temperature. The observed instrument case average temperature range was 293.5K (68.6 F) to 294.7K (70.7 F). This temperature deviation from the alignment temperature results in an instrument defocus of -15.5 percent to 8.9 percent of the allowable defocus due to thermal distortion. The percent defocus values quoted here are based on case average temperature alone--unrestrained thermal expansion--and are somewhat higher than computed by the thermal structural model where more detailed computations are made.

Table 2

SKYLAB-ATM CANISTER TEMPERATURE
SL-2 AND SL-3 MISSIONS

	SL-2 Quadrant 3 DOY 157 to 163	SL-2 Quadrant 4 DOY 157 to 163
Sun End	288.16K ± 0.5K (59°F ± 0.9F)	290.66K ± 0.5K (63.5F ± 0.9F)
MDA End	282.66K (49.1F)	282.66K (49.1F)
	SL-3 Quadrant 3	SL-3 Quadrant 4
Sun End	289.66K ± 0.5K (61.7F ± 0.9F)	290.66K ± 0.5K (63.5F ± 0.9F)
MDA End	285.41K ± 0.25K (54.05F ± 0.45F)	284.41K ± 0.25K (52.25F ± 0.45F)

1. Ref. telecon Howard Trucks, MSFC
   R. R. Anderson, BBRC 9/24/73

2. Canister liquid thermal control system temperatures were nominal

   M/W Inlet ~ 282.9K (49.5°F)
   Sun End ΔT ~ 1.5K (2.7F)
   MDA End ΔT ~ 0.7K (1.26F)

Table 3

SKYLAB-ATM CANISTER TEMPERATURE
SL-4 MISSION

Location	Temperature °K(°F) Min	Max	
Canister Liquid Thermal Control System			Fluid system min values are more correctly nominal values
M/W Inlet Temp.	282.86(49.5)	284.2(51.8)	
ΔT(Rise)MDA End	1.5 (2.70)	1.5(2.7)	
ΔT(Rise)Sun End	0.7 (1.26)		
		285.7(54.5)	All max values occurred during high orbit β angle operation when successive 100% sunlit orbits occurred
MDA End Plate			
Quadrant 1	288.7 (60.0)	292.6(67.0)	
2	283.4 (50.4)	287.8(58.4)	
3	283.2 (50.1)	286.3(55.7)	
4	280.5 (45.2)	284.0(51.5)	
Sun End Plate			
Quadrant 1	291.3 (64.7)	299.8(80.0)	Ref. telecon Uwe Hueter, MSFC & R. R. Anderson, BBRC - Feb. 1974
2	291.8 (65.6)	294.6(70.6)	
3	287.9 (58.5)	299.7(79.8)	
4	288.3 (59.3)	297.2(75.3)	
SPAR			
MDA End	290.4 (63.0)	293.6 (68.8)	
Center	288.6 (59.8)	291.7 (65.4)	
Sun End	289.8 (61.91)	294.4 (70.2)	

Table 4

RUN LIST - NRL-A THERMAL DISTORTION

No.	Day	Hr.	Min.	Comments
1	331	21	00*	
2	332	14	6	Lost Plot
3	333	21	15	
4	335	21	21	
5	336	14	25	
6	337	12	12	
7	338	19	16	
8	339	20	07	Lost Plot
9	340	13	13	
10	350	01	40	Lost Tab

* Times shown are run initial times.
Runs are one-orbit normally starting at sunset.

Table 5

NRL-A (S-082A)		TIME				DAY: 331:21:00		
NODE NUMBER	EQUATION IN TERMS OF MEASUREMENT NUMBER	APERTURE OPEN (APOPEN)	AP OPEN + ~15MIN	AP OPEN + ~30MIN	APERTURE CLOSED	REMARKS		
310	C-095	68.654	68.647	68.713	68.837	CASE AVERAGE		
311	C-096 — C205	69.495	69.475	69.502	69.530	CALIBRATION TEMPERA		
312	C 197	69.577	69.493	69.577	69.638	T(CAL) = 70°F		
323	C 090	68.579	68.590	68.590	68.590			
324	C 091	69.114	69.140	69.114	69.268	ALLOWABLE VARIATION		
325	C 092	69.392	69.409	69.416	69.484	TO MEET FOCUS		
328	C092 + C201	70.039	70.031	70.050	70.089	REQUIREMENT		
329	C091 + C202	69.388	69.405	69.401	69.522	T(AVG) = 70 ± 8°F		
330	C090 + C203	68.894	68.905	68.916	68.885	TIME	ΔT °F	PERCE
356	C095 - C206	68.749	68.752	68.812	68.935	θ	ΔT(T_AVG − T_CAL)	ΔT/θ (1
357	C096	69.453	69.453	69.466	69.515	0.534	−0.791	−9.88
358	C197 + C204	69.184	69.094	69.214	69.220	0.768	−0.801	−10.01
	APERTURE OPEN					1.035	−0.769	−9.61
	Σ →	830.513	830.394	830.771	831.513	1.500	−0.707	−8.84
	0.5333 → 1.5000. AVERAGE	69.209	69.200	69.231	69.293			
	TIME HRS	0.534	0.768	1.035	1.5			

Table 6

NRL-A (S-082A)

NODE NUMBER	EQUATION IN TERMS OF MEASUREMENT NUMBER	TIME: APERTURE OPEN (APOPEN)	AP OPEN + ~ 15MIN	AP OPEN + ~ 30MIN	APERTURE CLOSED	DAY: 332:14:06 REMARKS		
310	C-095	68.089	68.097	68.097	68.097	CASE AVERAGE		
311	C-096 — C205	69.099	69.109	69.081	69.109	CALIBRATION TEMPERATU		
312	C 197	69.238	69.238	69.279	69.330	T(CAL) = 70°F		
323	C 090	67.850	67.870	67.811	67.912			
324	C 091	68.892	68.816	68.837	68.837	ALLOWABLE VARIATION		
325	C 092	69.083	69.020	69.123	69.114	TO MEET FOCUS		
328	C092 + C201	69.772	69.693	69.799	69.771	REQUIREMENTS		
329	C091 + C202	69.243	69.172	69.193	69.162	T(AVG) = 70 ± 8 °F		
330	C090 + C203	68.321	68.344	68.254	68.372	TIME	ΔT °F	PERCE
356	C095 - C206	68.103	68.112	68.112	68.185	θ	ΔT(TAVG - TCAL)	ΔT/8(10
357	C096	69.114	69.114	69.114	69.114	0.633	−1.190	−14.8
358	C197 + C204	68.917	68.915	68.948	68.984	0.867	−1.208	−15.1
						1.134	−1.196	−14.9
	APERTURE OPEN Σ →	825.721	825.500	825.648	825.987	1.500	−1.168	−14.6
	0.6333 → 1.5000 AVERAGE	68.810	68.792	68.804	68.832			
		0.6330	0.867	1.134	1.500			

Table 7

NRL-A (S082A)			TIME				DAY: 333 : 21 : 15		
NODE NUMBER	EQUATION IN TERMS OF MEASUREMENT NUMBER		APERTURE OPEN (APOPEN)	AP OPEN + ~ 15MIN	AP OPEN + ~ 30MIN	APERTURE CLOSED	REMARKS		
310	C-095		68.722	68.744	68.755	68.795	CASE AVERAGE		
311	C-096—C205		69.514	69.531	69.536	69.641	CALIBRATION TEMPERATURE		
312	C 197		69.577	69.589	69.596	69.712	T(CAL) = 70°F		
323	C 090		63.568	68.590	68.590	68.600			
324	C 091		69.263	69.293	69.114	69.310	ALLOWABLE VARIATION		
325	C 092		59.436	69.429	69.453	69.515	TO MEET FOCUS		
328	C092 + C201		70.047	70.054	70.066	70.120	REQUIREMENTS		
329	C091 + C202		69.537	69.575	69.377	69.556	TAVG = 70 ± 8 °F		
330	C090 + C203		68.896	68.922	68.905	68.915	TIME	ΔT °F	PERCEN
356	C095 - C206		68.810	68.838	68.853	68.873	θ	ΔT(TAVG-TCAL)	ΔT/8(10
357	C096		69.506	69.496	69.493	69.577	0.468	− 0.744	− 9.3
358	C197 + C204		69.167	69.230	69.224	69.300	0.735	− 0.726	− 9.0
							0.966	− 0.753	− 9.4
	APERTURE OPEN 0.4667 → 1.450	Σ →	831.073	831.291	830.962	831.934	1.467	− 0.672	− 8.4
		AVERAGE	69.256	69.274	69.247	69.328			
			0.468	0.735	0.966	1.467			

Table 8

NRL-A (S-082A)		TIME				DAY: 335 : 21 : 21		
NODE NUMBER	EQUATION IN TERMS OF MEASUREMENT NUMBER	APERTURE OPEN (APOPEN)	AP OPEN + ~ 15 MIN	AP OPEN + ~ 30 MIN	APERTURE CLOSED	REMARKS		
310	C-095	68.118	68.097	68.097	68.128	CASE AVERAGE		
311	C-096 — C205	69.078	69.117	69.033	69.033	CALIBRATION TEMPERATURE		
312	C 197	69.055	69.086	69.096	69.207	T(CAL) = 70 °F		
323	C 090	67.954	67.973	67.912	67.973			
324	C 091	68.714	68.837	68.800	68.775	ALLOWABLE VARIATION		
325	C 092	68.920	68.897	68.948	68.991	TO MEET FOCUS		
328	C092 + C201	69.689	69.626	69.664	69.720	REQUIREMENTS		
329	C091 + C202	69.104	69.193	69.156	69.142	T(AVG) = 70 ± 8 °F		
330	C090 + C203	68.403	68.384	68.372	68.382	TIME	ΔT °F	PERCENT
356	C095 - C206	68.164	68.112	68.112	68.143	θ	ΔT (TAVG-TCAL)	ΔT/8 (100)
357	C096	69.104	69.143	69.114	69.114	0.567	−1.233	−15.41
358	C197 + C204	68.806	68.802	68.799	68.902	0.801	−1.228	−15.35
						1.035	−1.237	−15.46
	APERTURE OPEN	Σ →	825,207	825.267	825.158	825.565	1.500	−1.203	−15.04
	0.5500 → 1.500	AVERAGE	68.767	68.772	68.763	68.797			
			0.567	0.801	1.035	1.500			

Table 9

NODE NUMBER	EQUATION IN TERMS OF MEASUREMENT NUMBER		TIME: APERTURE OPEN (APOPEN)	AP OPEN + ~ 15MIN	AP OPEN + ~ 30MIN	APERTURE CLOSED	DAY: 336 : 14 : 25 REMARKS		
	NRL-A (S-082A)								
310	C-095		68.097	68.097	68.060	68.097	CASE AVERAGE		
311	C-096 − C205		69.095	69.079	69.084	69.058	CALIBRATION TEMPERATURE		
312	C 197		69.114	69.114	69.231	69.330	T(CAL) = 70°F		
323	C 090		67.850	67.850	67.850	69.973			
324	C 091		68.775	68.744	68.775	68.837	ALLOWABLE VARIATION		
325	C 092		68.991	69.022	69.022	69.083	TO MEET FOCUS		
328	C092 + C201		69.682	69.710	69.715	69.781	REQUIREMENTS		
329	C091 + C202		69.135	69.101	69.140	69.193	T(AVG) = 70 ± 8 °F		
330	C090 + C203		68.324	68.331	68.318	68.413	TIME	ΔT °F	PERCENT
356	C095 − C206		68.112	68.112	68.075	68.143	θ	ΔT(TAVG−TCAL)	ΔT/8 (DEG)
357	C096		69.114	69.085	69.102	69.083	0.567	−1.240	−15.49
358	C197 + C204		68.837	68.849	68.947	68.994	0.801	−1.242	−15.53
							1.035	−1.223	−15.35
	APERTURE OPEN	Σ →	825.126	825.094	825.319	827.985	1.500	−1.001	−12.52
	0.5500 → 1.500	AVERAGE	68.761	68.758	68.777	68.999			
			0.567	0.801	1.035	1.500			

Table 10

NODE NUMBER	EQUATION IN TERMS OF MEASUREMENT NUMBER		TIME: APERTURE OPEN (APOPEN)	AP OPEN + ~ 15 MIN	AP OPEN + ~ 30 MIN	APERTURE CLOSED	DAY: 337 : 12 : 12 REMARKS		
310	C-095		68.097	68.097	68.097	68.097	CASE AVERAGE		
311	C-096 − C205		69.071	69.059	69.100	69.109	CALIBRATION TEMPERATURE		
312	C 197		69.114	69.114	69.207	69.268	T(CAL) = 70 °F		
323	C 090		67.892	67.851	67.912	67.912			
324	C 091		68.817	68.837	68.801	68.837	ALLOWABLE VARIATION		
325	C 092		69.001	69.022	69.057	69.033	TO MEET FOCUS		
328	C092 + C201		69.702	69.730	69.731	69.771	REQUIREMENTS		
329	C091 + C202		69.174	69.194	69.158	69.162	T(AVG) = 70 ± 8 °F		
330	C090 + C203		68.380	68.312	68.372	68.372	TIME	ΔT °F	PERCEN
356	C095 − C206		68.112	68.112	68.133	68.133	θ	ΔT(TAVG − TCAL)	ΔT/θ (100
357	C096		69.104	69.085	69.114	69.114	0.567	−1.226	−15.33
358	C197 + C204		68.823	68.828	68.835	68.901	0.801	−1.230	−15.37
							1.068	−1.207	−15.09
	APERTURE OPEN	Σ →	825.287	825.241	825.517	825.759	1.500	−1.187	−14.83
	0.5667 → 1.500	AVERAGE	68.774	68.770	68.793	68.813			
			0.5670	0.8010	1.0680	1.500			

Table 11

NRL-A (S-082A)

NODE NUMBER	EQUATION IN TERMS OF MEASUREMENT NUMBER	TIME: APERTURE OPEN (APOPEN)	AP OPEN + ~ 15 MIN	AP OPEN + ~ 30 MIN	APERTURE CLOSED	DAY: 338:19:16 REMARKS
310	C-095	68.432	68.448	68.467	68.528	CASE AVERAGE
311	C-096 − C205	69.323	69.313	69.345	69.345	CALIBRATION TEMPERATURE
312	C 197	69.267	69.207	69.268	69.330	T(CAL) = 70°F
323	C 090	68.250	68.238	68.319	68.343	
324	C 091	68.960	68.942	69.003	69.022	ALLOWABLE VARIATION
325	C 092	69.115	69.085	69.108	69.114	TO MEET FOCUS
328	C092 + C201	69.797	69.771	69.795	69.771	REQUIREMENTS
329	C091 + C202	69.285	69.257	69.323	69.337	T(AVG) = 70 ± 8°F
330	C090 + C203	68.617	68.655	68.675	68.700	
356	C095 − C206	68.520	68.542	68.561	68.627	
357	C096	69.328	69.305	69.330	69.330	
358	C197 + C204	68.931	68.885	68.939	68.984	
	APERTURE OPEN 0.5500 → 1.500 — Σ →	827.825	827.696	828.133	828.431	
	AVERAGE	68.985	68.975	69.011	69.036	
		0.501	0.735	1.035	1.500	

TIME θ	ΔT °F ΔT(TAVG − TCAL)	PERCENT ΔT/T(CAL)
0.501	−1.015	−12.68
0.735	−1.025	−12.82
1.035	−0.989	−12.36
1.500	−0.964	−12.05

Table 12

NRL-A (S-082A)

NODE NUMBER	EQUATION IN TERMS OF MEASUREMENT NUMBER		TIME: APERTURE OPEN (APOPEN)	AP OPEN + ~15 MIN	AP OPEN + ~30 MIN	APERTURE CLOSED	DAY: 339 : 20 : 07 REMARKS
310	C-095		68.457	68.468	68.494	68.467	CASE AVERAGE
311	C-096 − C205		69.319	69.263	69.263	69.345	CALIBRATION TEMPERATURE
312	C 197		69.114	69.114	69.131	69.268	T(CAL) = 70 °F
323	C 090		68.282	68.136	68.251	68.343	
324	C 091		68.960	68.960	68.932	68.960	ALLOWABLE VARIATION
325	C 092		69.002	69.022	69.022	69.053	TO MEET FOCUS
328	C092 + C201		69.689	69.680	69.701	69.791	REQUIREMENTS
329	C091 + C202		69.265	69.295	69.297	69.275	T(AVG) = 70 ± 8 °F
330	C090 + C203		68.652	68.504	68.615	68.710	
356	C095 − C206		68.528	68.526	68.582	68.555	
357	C096		69.310	69.268	69.260	69.330	
358	C197 + C204		68.802	68.779	68.848	68.932	
	APERTURE OPEN 0.5667 → 1.500	Σ →	827.320	827.015	827.496	828.059	
		AVERAGE	68.948	68.918	68.958	69.005	
			0.567	0.801	1.068	1.500	

TIME	ΔT (°F)	PERCENT
−θ	ΔT(TAVG − TCAL)	ΔT/θ (%)
0.567	−1.052	−13.15
0.801	−1.082	−13.53
1.068	−1.042	−13.03
1.500	−0.995	−12.44

Table 13

NRL-A (S-082A)

NODE NUMBER	EQUATION IN TERMS OF MEASUREMENT NUMBER		TIME: APERTURE OPEN (APOPEN)	APOPEN + ~ 15MIN	AP OPEN + ~ 30MIN	APERTURE CLOSED	DAY: 340 : 13 : 13 REMARKS
310	C-095		68.097	68.097	68.030	68.097	CASE AVERAGE
311	C-096 — C205		69.035	69.059	69.038	69.099	CALIBRATION TEMPERATURE
312	C 197		69.114	69.082	69.140	69.237	T(CAL) = 70 °F
323	C 090		67.870	67.912	67.912	67.912	
324	C 091		68.837	68.834	68.819	68.837	ALLOWABLE VARIATION
325	C 092		68.999	68.961	69.013	68.991	TO MEET FOCUS
328	C092 + C201		69.694	69.688	69.715	69.678	REQUIREMENTS
329	C091 + C202		69.193	69.171	69.170	69.193	T(AVG) = 70 ± 8 °F
330	C090 + C203		68.320	68.352	68.359	68.320	
356	C095 - C206		68.123	68.142	68.069	68.143	
357	C096		69.093	69.083	69.106	69.114	
358	C197 + C204		68.810	68.737	68.829	68.901	
	APERTURE OPEN	Σ →	825.778	825.118	825.253	825.522	
	0.5667 → 1.5000	AVERAGE	68.769	68.760	68.771	68.794	
			0.5667	0.8010	1.0667	1.5000	

TIME	ΔT (°F)	PERCENT
-θ	ΔT (TAVG-TCAL)	ΔT/θ (NOC
0.5667	-1.231	-15.39
0.8010	-1.240	-15.50
1.0667	-1.229	-15.36
1.5000	-1.206	-15.08

Table 14

NRL-A (S082A)							DAY: 381 22 21	
NODE NUMBER	EQUATION IN TERMS OF MEASUREMENT NUMBER		TEMPERATURE (°F)				REMARKS 100% SHUTDOWN	
310	C-095		69.854				69.854	
311	C-096 − C205		70.502	-.1809			70.6829	
312	C 197		71.796				71.796	@ TIME θ
323	C 090		69.731				69.731	θ = 22:31
324	C 091		70.409				70.409	ΔT = 0.636
325	C 092		71.581				71.581	% = +7.95 %
328	C092 + C201		71.581	.1913			71.7723	deferens
329	C091 + C202		70.409	.0362			70.4452	
330	C090 + C203		69.731	.1292			69.8602	$\Delta T = T_{AVG} - T_{CAL}$
356	C095 − C206		69.854	−.0982			69.9522	= 70.636 − 70.0
357	C096		70.502				70.502	= 0.636
358	C197 + C204		71.796	−.7495			71.0465	
		Σ →					847.6323	
		AVERAGE					70.636	

Table 15

NRL-A (S-082A)

DAY: 381:22:51

NODE NUMBER	EQUATION IN TERMS OF MEASUREMENT NUMBER	TEMPERATURE °F				REMARKS °F	100% SUNLIT ORB
310	C-095	69.947				69.947	
311	C-096 — C205	70.502	-0.1809			70.6829	
312	C 197	71.735				71.735	
323	C 090	69.823				69.823	$\Delta T = +0.7$
324	C 091	70.563				70.563	$\gamma_0 = 8.75°$
325	C 092	71.581				71.581	defocus
328	C092 + C201	71.781	0.1913			71.9723	
329	C091 + C202	70.563	0.0465			70.6095	$\Delta T = T_{AW} - T_{OW}$
330	C090 + C203	69.823	0.0982			69.9212	$= 70.90 - 70.0$
356	C095 - C206	69.947	-0.0982			70.0452	$= 0.7\ °F$
357	C096	70.502				70.502	
358	C197 + C204	71.735	-0.7185			71.0165	
	$\Sigma \rightarrow$					848.3986	
	AVERAGE					70.6999	

Table 16

16 NRL-A (S082A)

DAY: 381:23:21

NODE NUMBER	EQUATION IN TERMS OF MEASUREMENT NUMBER	TEMPERATURE °F				REMARKS °F	100% SUNLIT 0.837
310	C-095	70.008				70.008	
311	C-096 − C205	70.563	−0.1809			70.7439	
312	C 197	71.673				71.673	ΔT = 0.698
323	C 090	69.854				69.854	+ 8.7370
324	C 091	70.502				70.502	defocus
325	C 092	71.611				71.611	
328	C092 + C201	71.611	0.1913			71.8023	ΔT = T_{AVG} − T_{OAL}
329	C091 + C202	70.502	0.0362			70.5382	= 70.698 − 70.0
330	C090 + C203	69.854	0.0775			69.9315	= 0.698 °F
356	C095 − C206	70.008	−0.1292			70.1372	
357	C096	70.563				70.563	
358	C197 + C204	71.673	−0.6565			71.0165	
	Σ →					848.3806	
	AVERAGE					70.698	

Table 17

NRL-A (S082A)

DAY: 381:23:52

NODE NUMBER	EQUATION IN TERMS OF MEASUREMENT NUMBER	TEMPERATURE °F				REMARKS °F	100% SIGNIFICANT DIGIT
310	C-095	70.070	-0			70.070	
311	C-096 — C205	70.563	-0.1809			70.7439	
312	C 197	71.581				71.581	ΔT = 0.711
323	C 090	69.947				69.947	± 8.89 %
324	C 091	70.563				70.563	of [illegible]
325	C 092	71.581				71.581	
328	C092 + C201	71.581	0.1913			71.7723	$\Delta T = T_{AVE} - T_{CRL}$
329	C091 + C202	70.563	0.0052			70.5682	= 70.711 - 70.0
330	C090 + C203	69.947	0.0775			70.0245	= 0.711 °F
356	C095 - C206	70.070	-0.1396			70.2096	
357	C096	70.563				70.563	
358	C197 + C204	71.581	-0.6772			70.9038	
	Σ →					848.5273	
	AVERAGE					70.711	

Table 18

NRL-A (S-082A)						DAY: 382:18:11	
NODE NUMBER	EQUATION IN TERMS OF MEASUREMENT NUMBER	TEMPERATURE °F				°F	REMARKS 100% SUNLIT ORBIT
310	C-095	69.854				69.854	
311	C-096 — C205	70.502	-0.1602			70.6622	
312	C 197	71.704				71.704	$\Delta T = 0.642$
323	C 090	69.823				69.823	% defocus
324	C 091	70.471				70.471	$= \Delta T/8(100)$
325	C 092	71.581				71.581	= 8.03%
328	C092 + C201	71.581	0.1809			71.7619	
329	C091 + C202	70.471	0.0465			70.5175	$\Delta T = T_{AVG} - T_{OIL}$
330	C090 + C203	69.823	0.1086			69.9316	= 70.642 - 70.0
356	C095 - C206	69.854	-0.0982			69.9522	= 0.642 °F
357	C096	70.502				70.502	
358	C197 + C204	71.704	-0.7599			70.9441	
	$\Sigma \rightarrow$					847.7045	
	AVERAGE					70.642	

Table 19

NRL-A (S-082A)						DAY: 382:18:39	
NODE NUMBER	EQUATION IN TERMS OF MEASUREMENT NUMBER	TEMPERATURE °F				REMARKS °F	100% SUNLIT OR
310	C-095	69.947				69.947	
311	C-096 − C205	70.563	−0.1809			70.7439	
312	C 197	71.796				71.796	ΔT = 0.699
323	C 090	69.823				69.823	% of focus
324	C 091	70.563				70.563	= + 8.74
325	C 092	71.581				71.581	
328	C092 + C201	71.581	0.1913			71.7723	ΔT = TAM − TCAL
329	C091 + C202	70.563	0.0362			70.5992	= 70.699 − 70.0
330	C090 + C203	69.823	0.0775			69.9005	= 0.699 °F
356	C095 − C206	69.947	−0.1189			70.0659	
357	C096	70.563				70.563	
358	C197 + C204	71.796	−0.7599			71.0361	
	Σ →					848.3909	
	AVERAGE					70.699	

Thermal distortion parameter plots for DOY 331:21:00 (Nov. 27, 1973) are included as examples of the S-082A thermal performance data (Figures 2 through 7). The defocus data of Table 3, DOY 331 21:00, may be compared with the instrument defocus plots of Figures 2 and 5.

All S-082A thermal distortion computer program runs for SL-3 and SL-4 have been reviewed with the following results: The maximum image defocus computed was 12 percent of the allowable defocus. Horizontal image smear due to dynamic side to side temperature gradients across the instrument case was always less than 1 percent of the allowable smear. Vertical image smear was about one-half of the horizontal image smear. Total horizontal image smear over a 55 minute period, following aperture door opening, was less than 10 percent of the allowable smear--based on a 5 minute exposure. The total image smear was 0.0002 inch in 55 minutes whereas the allowable is 0.002 inch in 5 minutes.

Therefore it is concluded that thermal distortion of the S-082A instrument caused only negligible degradation of the solar images on film.

Figure 8 provides a block diagram and flow chart of the thermal distortion analysis program. The basic building blocks of the program are the thermal model, Figures 9, 10 and 11, used in the thermal design analysis and the structural model, Figure 12 used for the stress dynamics analysis. The thermal and structural models were updated to the flight configuration and the thermal analytical predictions compared with data from the flight unit tests at Johnson Space Center. The total program was then coded for use on the HOSC 1108 computer at the Marshall Space Flight Center.

NRL-A DAY 331:21:00

NAME- BBRCNA

DIST. CODE- BIN232

RUN ID- NRLATD

JOB NO- 140006

SEQ NO- 20403

DATE- 12-04-73

TIME- 23-33-20

Figure 2

S082A THERMAL DISTORTION
SUN IMAGE ON FILM, FOCUS, LEFT SIDE
PAGE 2

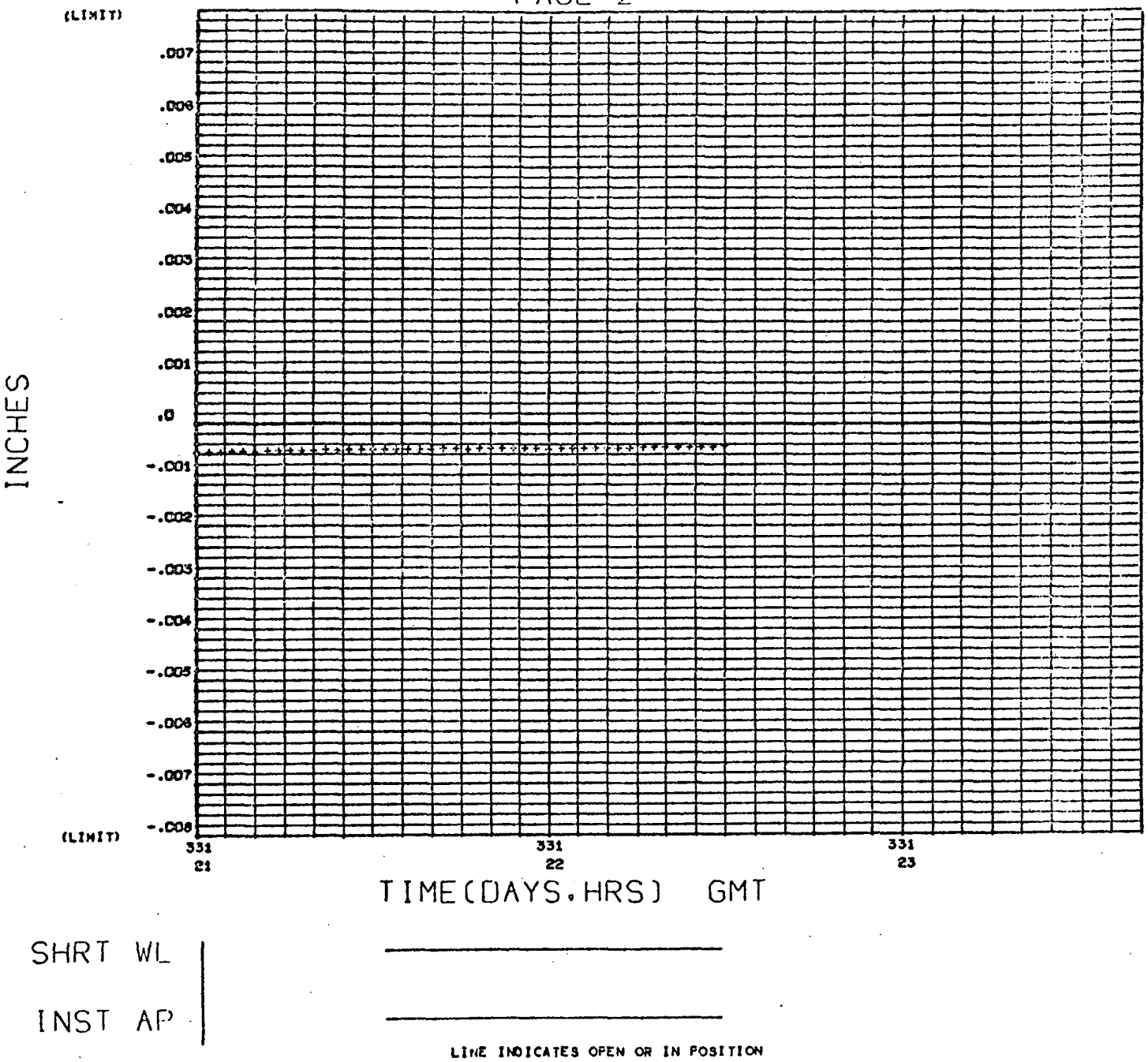
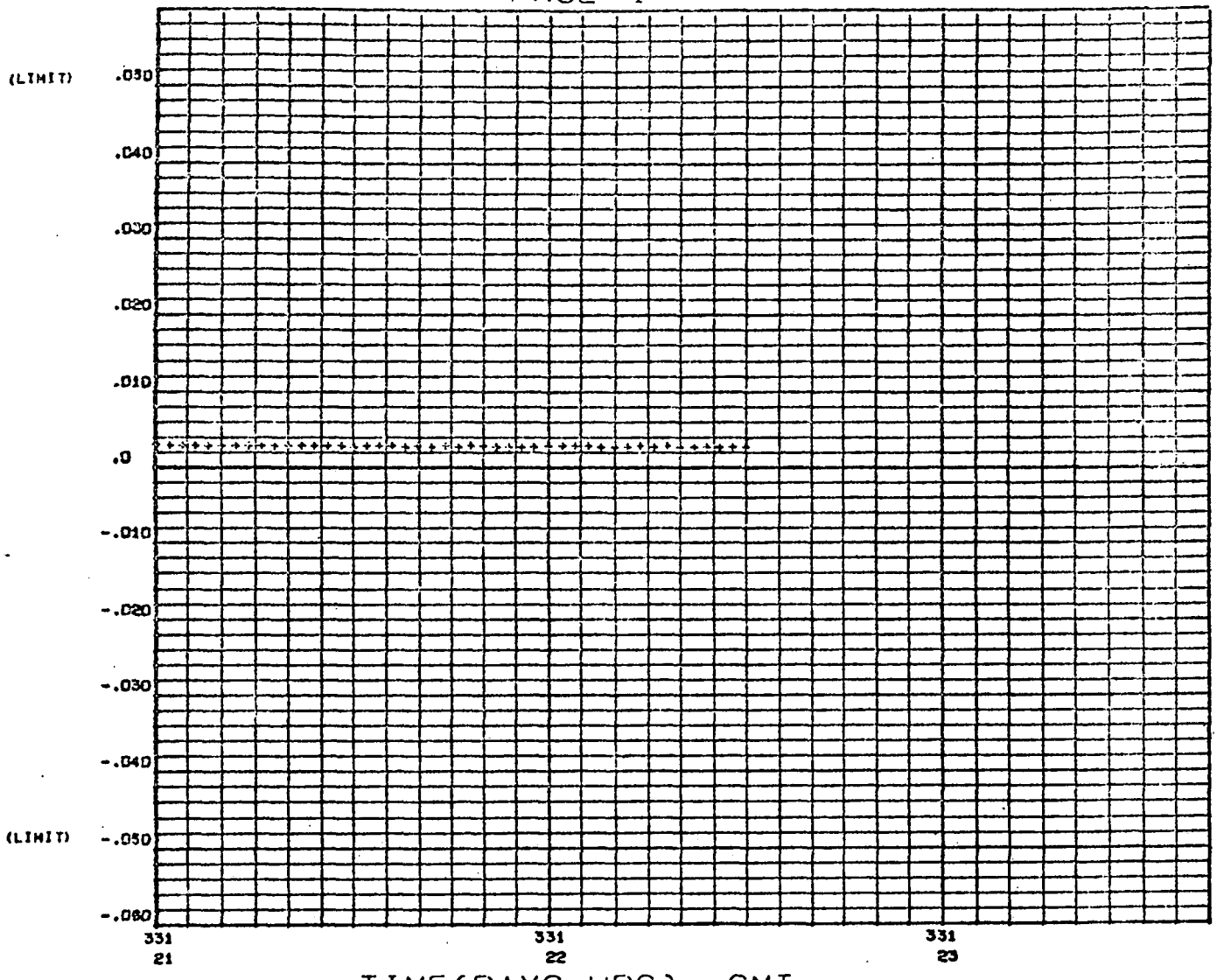


Figure 3

S082A THERMAL DISTORTION
SUN IMAGE ON FILM, VERTICAL POSITION, LEFT SIDE
PAGE 4



SHRT WL

INST AP

LINE INDICATES OPEN OR IN POSITION

Figure 4

S082A THERMAL DISTORTION
SUN IMAGE ON FILM, HORIZONTAL POSITION, LEFT SIDE
PAGE 6

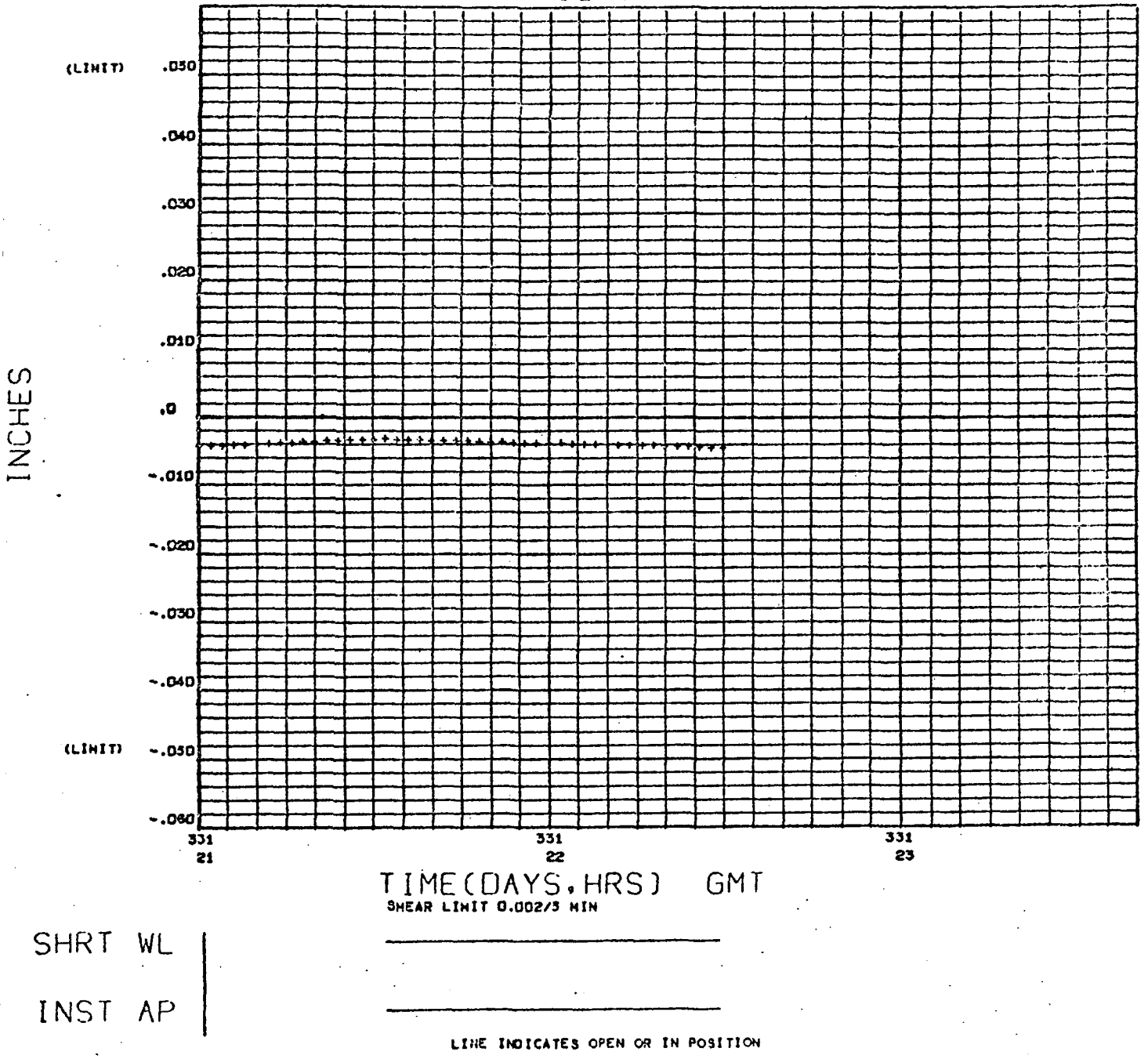


Figure 5

S082A THERMAL DISTORTION
SUN IMAGE ON FILM, FOCUS, RIGHT SIDE
PAGE 1

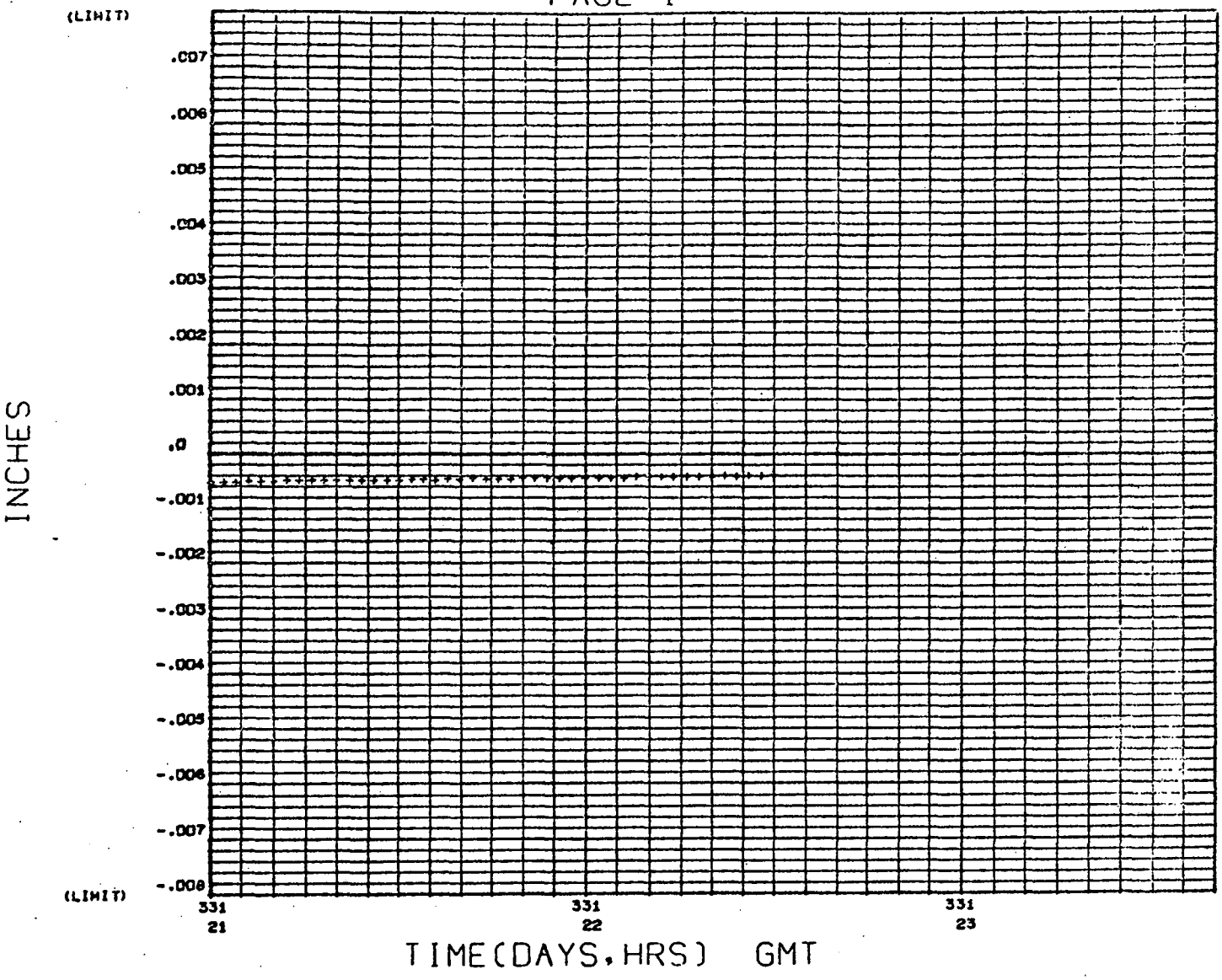
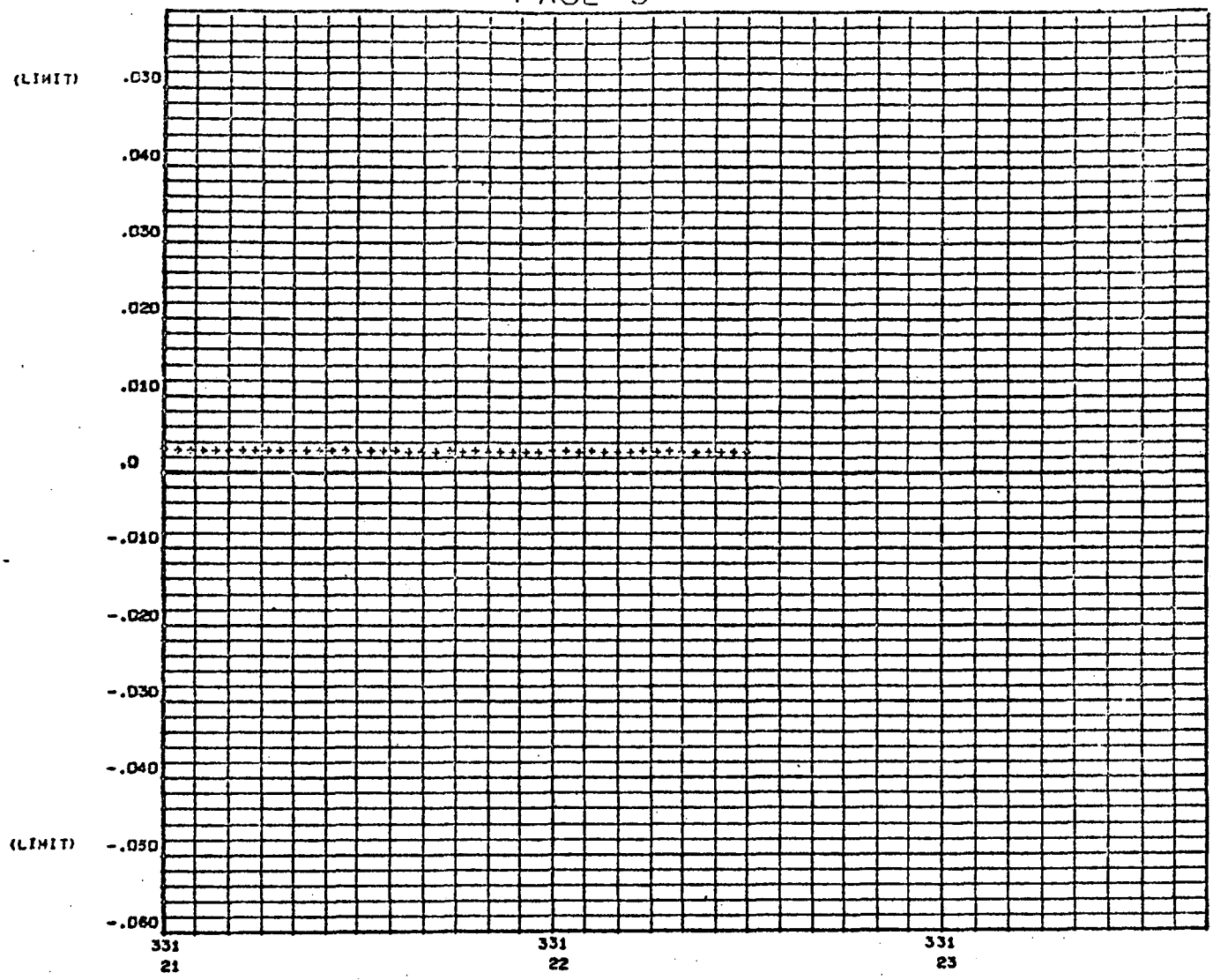


Figure 6

S082A THERMAL DISTORTION
SUN IMAGE ON FILM, VERTICAL POSITION, RIGHT SIDE
PAGE 3



SHEAR LIMIT 0.002/5 MIN

SHRT WL

INST AP

LINE INDICATES OPEN OR IN POSITION

Figure 7

S082A THERMAL DISTORTION
SUN IMAGE ON FILM, HORIZONTAL POSITION, RIGHT SIDE
PAGE 5

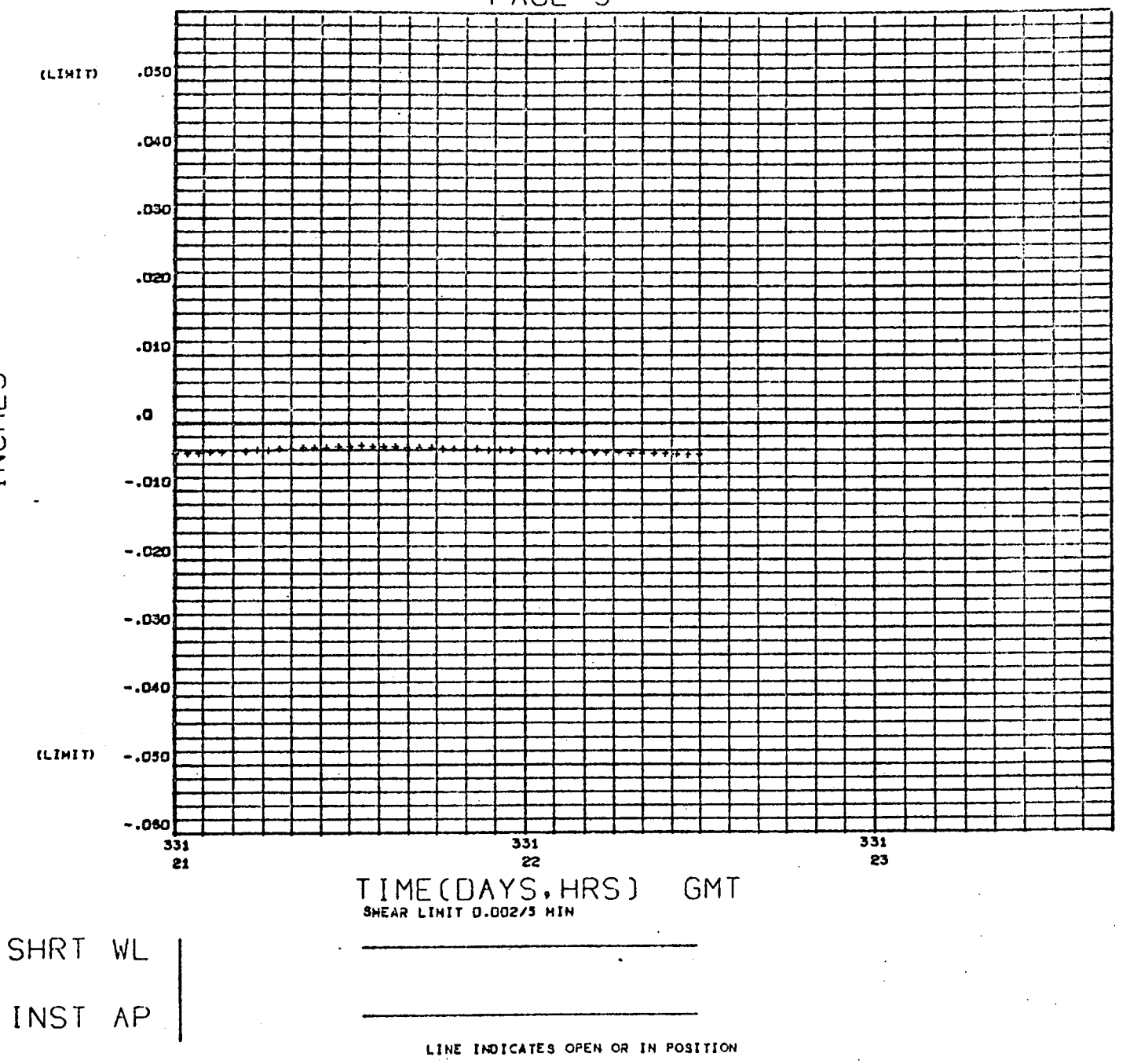
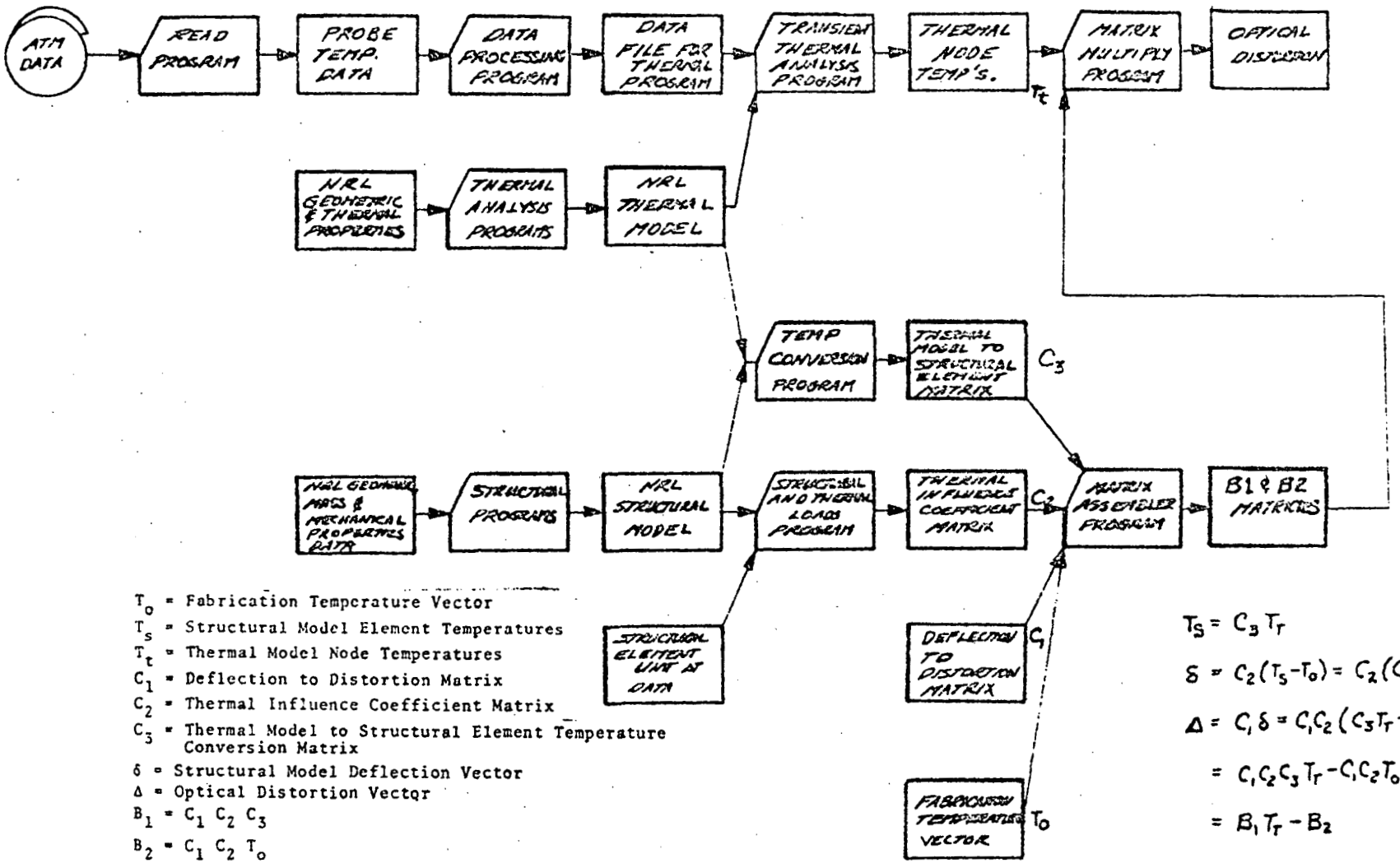


Figure 8

NRL THERMAL DISTORTION ANALYSIS



T_0 = Fabrication Temperature Vector

T_s = Structural Model Element Temperatures

T_t = Thermal Model Node Temperatures

C_1 = Deflection to Distortion Matrix

C_2 = Thermal Influence Coefficient Matrix

C_3 = Thermal Model to Structural Element Temperature Conversion Matrix

δ = Structural Model Deflection Vector

Δ = Optical Distortion Vector

$B_1 = C_1 C_2 C_3$

$B_2 = C_1 C_2 T_0$

$$T_S = C_3 T_T$$

$$\delta = C_2(T_S - T_0) = C_2(C_3 T_T - T_0)$$

$$\Delta = C_1 \delta = C_1 C_2 (C_3 T_T - T_0)$$

$$= C_1 C_2 C_3 T_T - C_1 C_2 T_0$$

$$= B_1 T_T - B_2$$

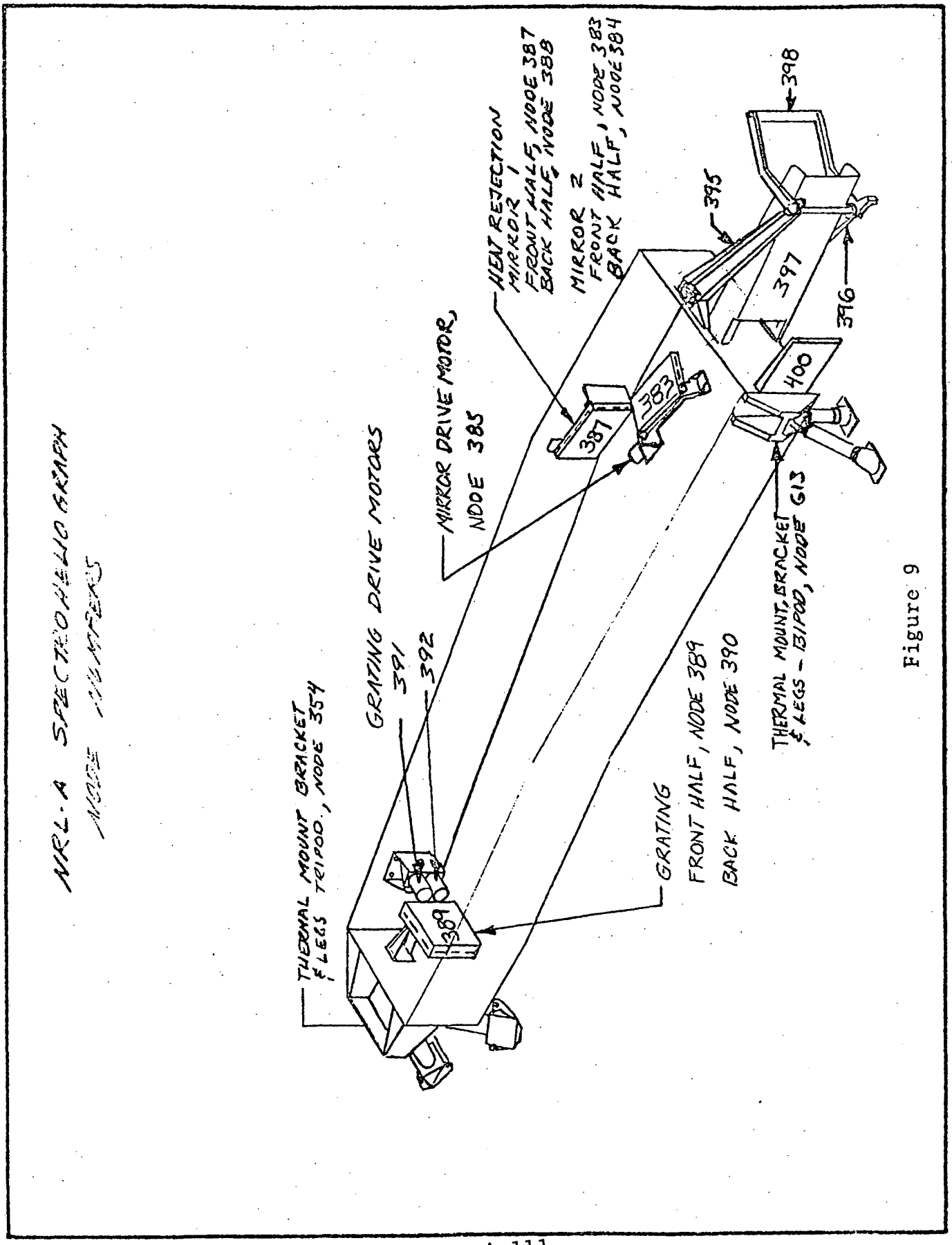
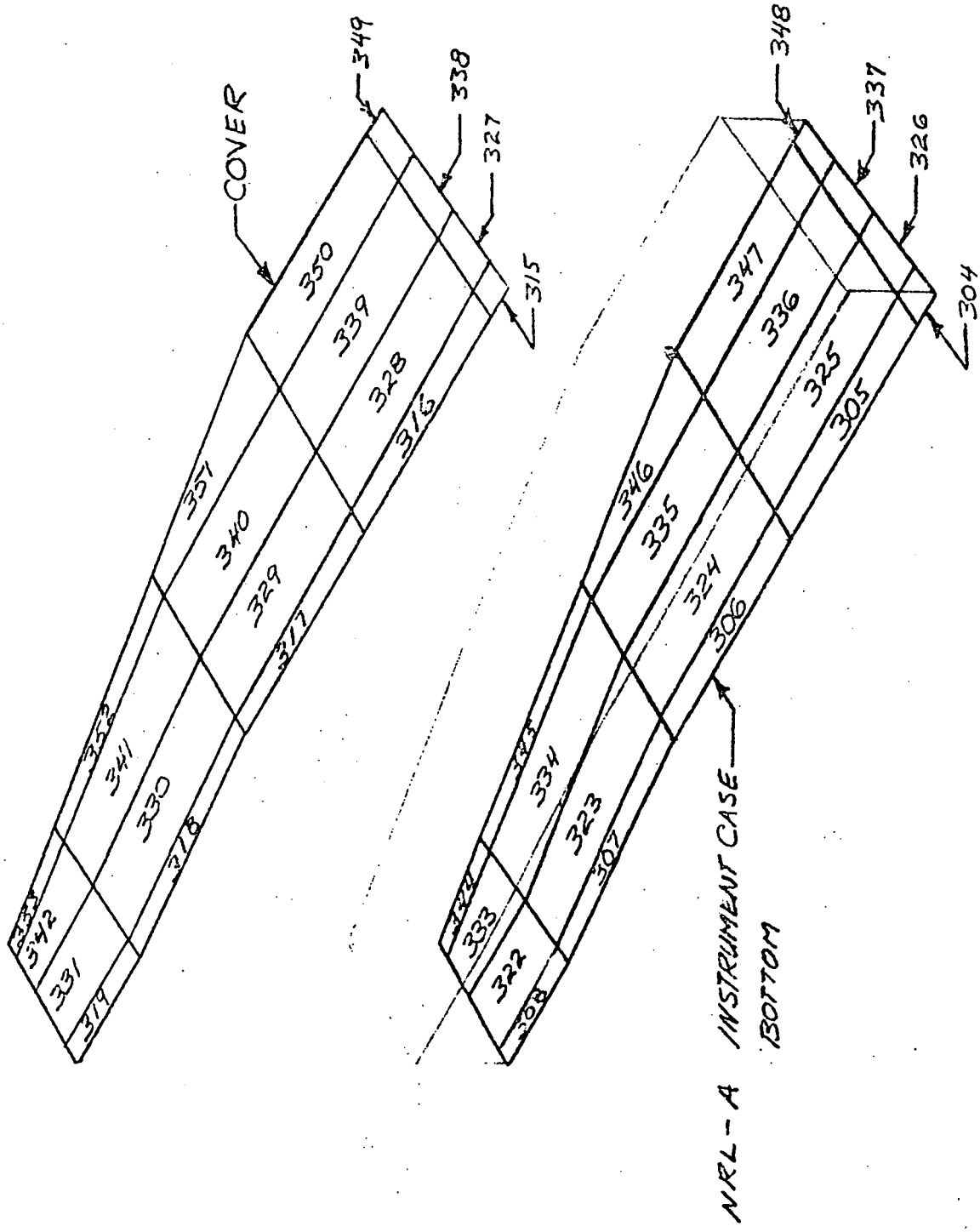

NRL-A SPECTROHELIOGRAPH
MODE ASSEMBLIES
THERMAL MOUNT BRACKET & LEGS TRIPOD, NODE 354
GRATING DRIVE MOTORS
391
392
389
GRATING
FRONT HALF, NODE 389
BACK HALF, NODE 390
MIRROR DRIVE MOTOR, NODE 385
387
383
HEAT REJECTION MIRROR 1
FRONT HALF, NODE 387
BACK HALF, NODE 388
MIRROR 2
FRONT HALF, NODE 383
BACK HALF, NODE 384
395
397
398
396
400
THERMAL MOUNT BRACKET & LEGS - BIPOD, NODE 613

Figure 9


COVER
349
338
327
315
350
339
328
316
351
340
329
317
352
341
330
318
353
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331
319
348
337
326
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347
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323
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333
322
308
NRL-A INSTRUMENT CASE
BOTTOM

Figure 10

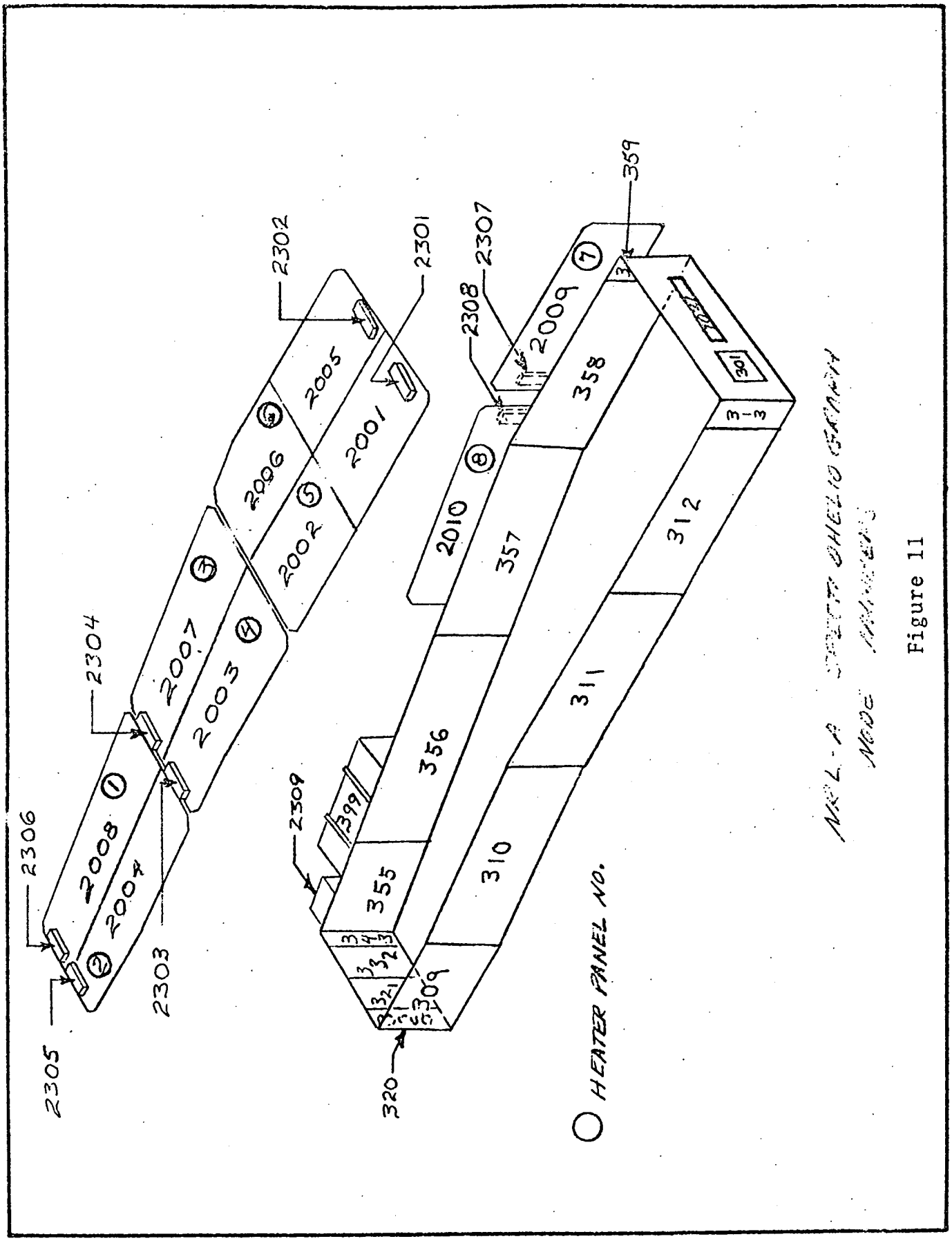
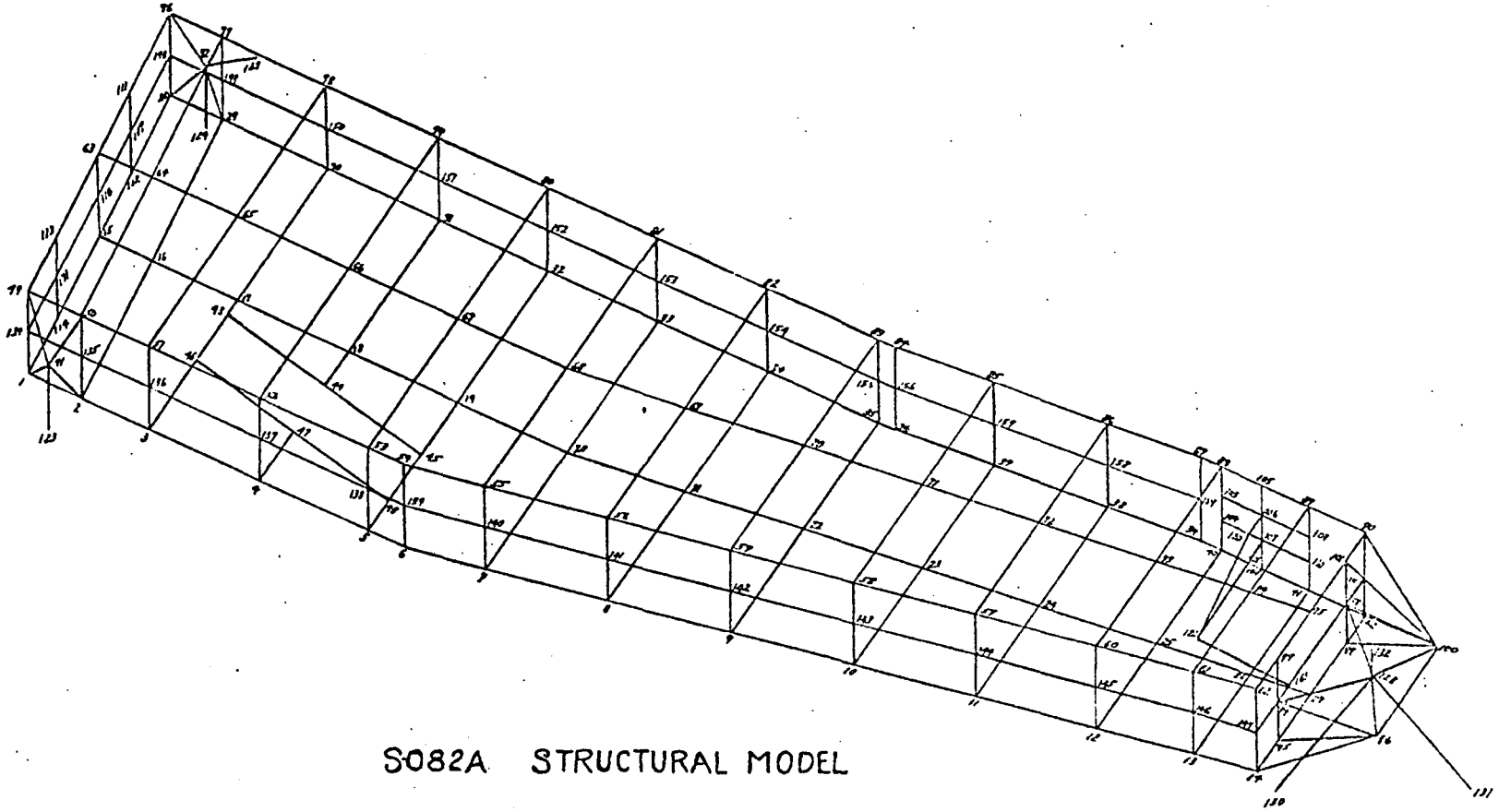

2302
2301
2307
359
2308
2009
2005
2006
2001
358
2010
357
2002
2007
2003
312
2304
356
2008
2004
311
2306
2309
399
355
310
2303
2305
320
309
301
HEATER PANEL NO.

Figure 11



S082A STRUCTURAL MODEL

Figure 12

The scope of this report does not permit a more detailed description of the thermal distortion analysis program, however, a final report is in preparation wherein the thermal model and the thermal distortion program will be described. A "cook-book" for use of the program also will be provided.

SKYLAB SL-4 MISSION
NRL S-082B SPECTROGRAPH THERMAL PERFORMANCE

The S-082B thermal control system performance was acceptable throughout all Skylab missions with the exception that some out-of-tolerance conditions were observed during the Comet Kohoutek observations and during the full sunlit orbit periods of the SL-4 mission.

No failures were noted in the thermal control system, the associated temperature sensors, or the instrument temperature probes.

Alignment and focus requirements for the S-082B Spectrograph required that an active thermal control system be provided to maintain the absolute temperature level within the limits of 294.16°K ± 0.67°K (69.8°F ± 1.2°F) and dynamic temperature gradients across the instrument less than ±0.18°K (±0.33°F) in 15 minutes. The maximum allowable thermal distortions and related temperature/temperature gradients are presented in Figures 1, 2, and 3.

The thermal control system includes both active and passive elements. The active elements consist of low thermal capacity stand-off heater panels. The panels are thermally coupled to the instrument by radiation and conductively isolated by the low conductance stand-off mounts. The passive elements consist of multi-layer aluminized Mylar insulation panels and skirts which cover most areas not covered by heater panels.

The thermal control system was designed to operate in the controlled environment of the Skylab/ATM Canister. The canister design temperature limits were 281.5°K (47°F) to 287.6°K (58°F). However, the canister liquid thermal control system maintained the canister (controlled wall) temperature within the limits of 282.86°K (49.5°F),

Figure 1

MAXIMUM ALLOWABLE THERMAL DISTORTIONS

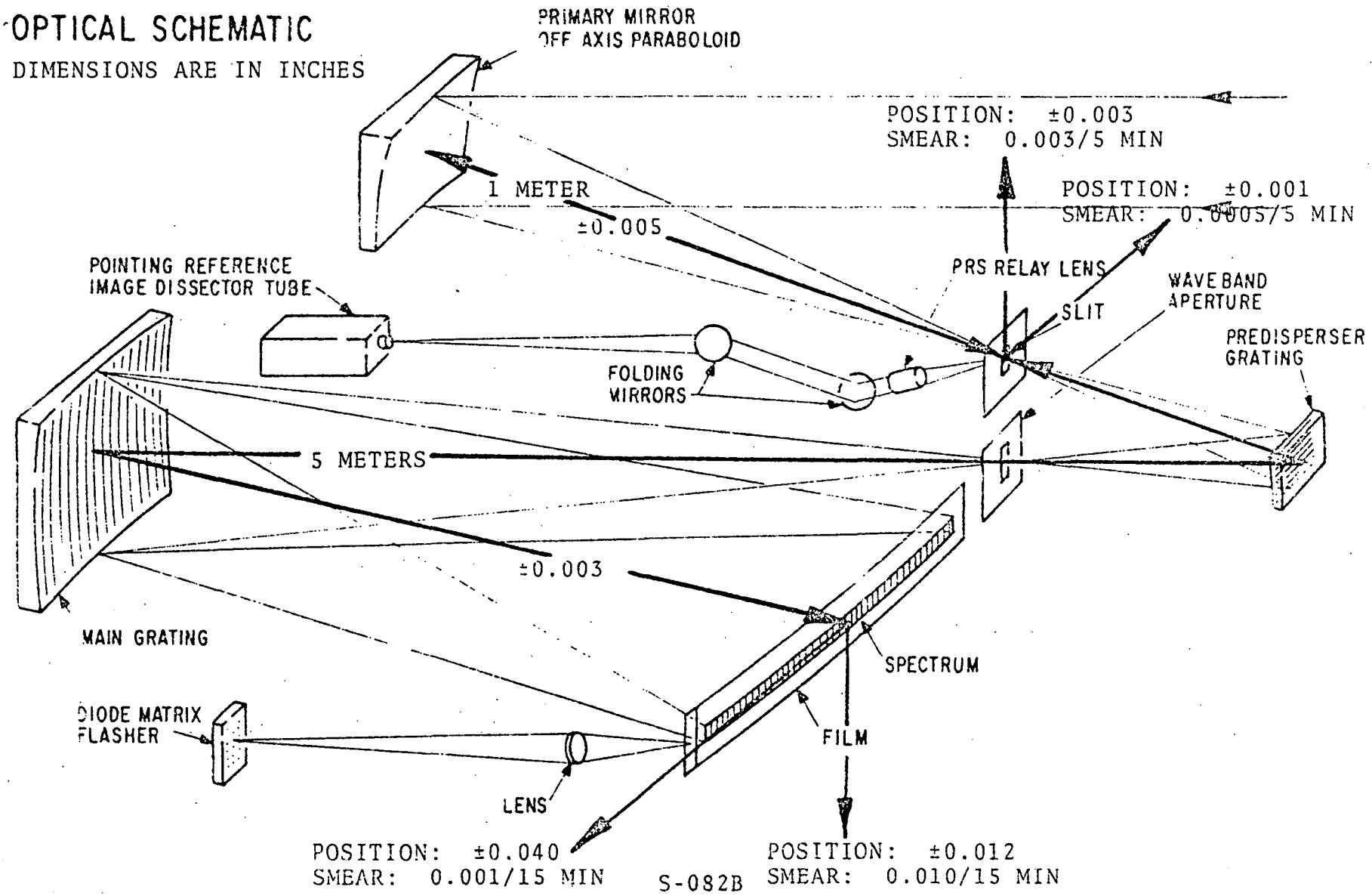


Figure 2
S082B SPECTROGRAPH AND XUV MONITOR
OPTICAL IMAGE TOLERANCES FOR THERMAL DISTORTION

Sun Image on Slit Plate

Focus		$(X-X_o)$ Sun Image			$T-T_o$*	Basis
Tolerance	2.5 sec Image Blur	±0.126 mm	±0.005	inch	±9.6°F	D&PS
Accuracy		±0.025	±0.001		±2.0°F	
Horiz. Position		$(Y-Y_o)$ Sun Image			ΔT Hor.	
Tolerance	±5 sec on Solar Image	±0.025 mm	±0.001	inch	±2.5°F	Co-Align
Accuracy		±0.010	±0.0004		± 1°F	HCO
Vert. Position		$(Z-Z_o)$ Sun Image			ΔT Vert.	
Tolerance	±15 sec on Solar Image	±0.075 mm	±0.003	inch	±2.5°F	Co-Align
Accuracy		±0.030	±0.0012		± 1°F	HCO
Horiz. Smear		$\Delta(Y-Y_o)$ in 5 Minutes			ΔΔT/5 Min.	
Tolerance	2.5 sec/5 Minutes	0.0125 mm	0.0005	inch	±1.25°F	D&PS
Accuracy		±0.005	±0.0002		±0.5°F	
Vert. Smear		$\Delta(Z-Z_o)$ in 5 Minutes			ΔΔT/5 Min.	
Tolerance	15 sec/5 Minutes	0.075 mm	0.003	inch	2.5°F	Est.
Accuracy		±0.025	±0.001		±0.8°F	

* T_o = Calibration temperature = 69.8°F

Figure 3

NRL-B OPTICAL IMAGE TOLERANCES FOR THERMAL DISTORTION

Slit Image on Film

Focus		$(X-X_o)$ Image on Film		$T-T_o$*	Basis
Tolerance	6 μ Image Blur	±0.076 mm	±0.003 inch	±1.2°F	D&PS
Accuracy		±0.025	±0.001	±0.4°F	
Horiz. Position		$(Y-Y_o)$ Image on Film		ΔT Hor.	
Tolerance		±1.0 mm	±0.04 inch	± 13°F	Estimate
Accuracy		±0.25	±0.01	± 3°F	(Conservative
Vert. Position		$(Z-Z_o)$ Image on Film		ΔT Vert.	
Tolerance		±0.3 mm	±0.012 inch	±1.3°F	Estimate
Accuracy		±0.1	±0.004	±0.4°F	
Horiz. Smear		$\Delta(Y-Y_o)$ Image on Film/15 Min		ΔΔT/15 Min.	
Tolerance	25 μ/15 Minutes	0.025 mm	0.001 inch	0.33°F	D&PS
Accuracy		±0.005	±0.0002	±0.07°F	
Vert. Smear		$\Delta(Z-Z_o)$ Image on Film/15 Min		ΔΔT/15 Min.	
Tolerance	250 μ/15 Minutes	0.25 mm	0.010 inch	1.1°F	D&PS
Accuracy		±0.05	±0.002	±0.2°F	

* T = Calibration temperature = 69.8°F

minimum inlet temperature, and 285.7°K (54.5°F) maximum outlet temperature. (Tables 1 and 2 present the canister temperatures for the three missions.) Higher temperatures were observed on the Canister Sun End Plate, spar and MDA End Plate throughout the flight and particularly during the high β angle orbits when successive full sunlit orbits occurred. These areas of the ATM canister were passively controlled whereas the canister wall temperature was controlled actively by the canister liquid thermal control system. Fluid temperatures increased by ~1.3°K (2.3°F) during the high β angle orbits.

Forty-nine thermal distortion runs were made during the SL-4 mission including 27 orbits during the Comet Kohoutek observation period and 7 during the high β angle orbit period. A summary of the thermal distortion runs is shown in Table 3, sheets 1 and 2.

The out-of-tolerance conditions observed during some Comet Kohoutek observations consist of smear rates that could result in excessive horizontal smear of the slit image on the film. The performance summary Table 3, for the below listed days shows horizontal image smear rates from 1.5 to 2 times the maximum allowable value during the first 15 to 20 minutes after aperture opening.

DOY	Hr	Min
357	18	49
358	18	01
358	19	31
365	22	29

However, the total image smear may be within the allowable for short exposures since the allowable smear is based upon a 15 minute exposure. An exposure of 7.5 minutes duration would result in the maximum allowable image smear. Shorter exposures would

Table 1

SKYLAB-ATM CANISTER TEMPERATURE
SL-2 AND SL-3 MISSIONS

	SL-2 Quadrant 3 DOY 157 to 163	SL-2 Quadrant 4 DOY 157 to 163
Sun End	288.16K ± 0.5K (59°F ± 0.9F)	290.66K ± 0.5K (63.5F ± 0.9F)
MDA End	282.66K (49.1F)	282.66K (49.1F)
	SL-3 Quadrant 3	**SL-3 Quadrant 4**
Sun End	289.66K ± 0.5K (61.7F ± 0.9F)	290.66K ± 0.5K (63.5F ± 0.9F)
MDA End	285.41K ± 0.25K (54.05F ± 0.45F)	284.41K ± 0.25K (52.25F ± 0.45F)

1. Ref. telecon Howard Trucks, MSFC
   R. R. Anderson, BBRC 9/24/73

2. Canister liquid thermal control system temperatures were nominal

   M/W Inlet ~ 282.9K (49.5°F)
   Sun End ΔT ~ 1.5K (2.7F)
   MDA End ΔT ~ 0.7K (1.26F)

Table 2

SKYLAB-ATM CANISTER TEMPERATURE
SL-4 MISSION

Location	Temperature °K(°F) Min	Max	
Canister Liquid Thermal Control System			Fluid system min values are more correctly nominal values
M/W Inlet Temp.	282.86(49.5)	284.2(51.8)	
ΔT(Rise)MDA End	1.5 (2.70)	1.5(2.7)	
ΔT(Rise)Sun End	0.7 (1.26)		
		285.7(54.5)	All max values occurred during high orbit β angle operation when successive 100% sunlit orbits occurred
MDA End Plate			
Quadrant 1	288.7 (60.0)	292.6(67.0)	
2	283.4 (50.4)	287.8(58.4)	
3	283.2 (50.1)	286.3(55.7)	
4	280.5 (45.2)	284.0(51.5)	
Sun End Plate			
Quadrant 1	291.3 (64.7)	299.8(80.0)	Ref. telecon Uwe Hueter, MSFC & R. R. Anderson, BBRC - Feb. 1974
2	291.8 (65.6)	294.6(70.6)	
3	287.9 (58.5)	299.7(79.8)	
4	288.3 (59.3)	297.2(75.3)	
SPAR			
MDA End	290.4 (63.0)	293.6 (68.8)	
Center	288.6 (59.8)	291.7 (65.4)	
Sun End	289.8 (61.91)	294.4 (70.2)	

Table 3

S-082B THERMAL DISTORTION ANALYSIS RUN SUMMARY

SKYLAB 4 MISSION

(1) DOY	RUN TIME		RUN TYPE (2)	EXPOSURE TIME (3)		ETR ARMATURE	THERMAL DISTORTION PARAMETERS IN PERCENT OF MAXIMUM ALLOWABLE: SUN IMAGE ON SLIT (4)					SLIT IMAGE ON FILM-RT					SLIT IMAGE ON FILM-L				
DAY	HR	MIN		HR	MIN	(SEC)	FOCUS	HOR. POS.	HOR. STRUC.	VERT. POS.	VERT. STRUC.	FOCUS	HOR. POS.	HOR. STRUC.	VERT. POS.	VERT. STRUC.	FOCUS	HOR. POS.	HOR. STRUC.	VERT. POS.	VERT. STRUC.
332	14	06	NORMAL SOLAR	—	—	—	22	75	36	20	2.8	53.3	1.0	48	16.7	19.1	43.3	1.8	50	15	17.5
333	21	15	NS				27	47.5	36.7	28	6.1	13.3	1.0	57	10.0	8.2	21.6	1.0	0	8.3	12
335	21	21	NS				10	70.	73.3	26.7	9.1	26.7	0.8	100	12.5	0	36.7	1.5	90	12.5	0
336	14	25	NS				26	78	30.	25	7.9	33.3	1.8	75	16.7	0	43.3	1.0	84	15	0
337	12	12	NS				19	75	30	30	5.8	36.7	1.3	60	16.7	10	46.7	1.3	60	15	7.5
337	22	25	NS	23	42	960	16	30	10	30	6.7	10	0.3	20	1.0	1.0	3.0	1.0	20	0.8	0
338	19	16	NS				24	50	35	28.3	6.2	33.3	1.3	50	10	8	40	1.8	36	8.3	6.7
338	20	46	NS				19	35	30	36.7	3.7	36.7	4.8	60	0	0	40	5	57	0	0
338	22	16	NS				28.3	20	0	21.7	0	20	0.6	18	8.3	22.5	30	1.5	20	8	11.3
339	20	07	NS	20	47	360	16	45	20	25	2.8	20	0.5	48	8.3	4.3	26.7	1.0	48	6.7	2.5
				20	54	720															
340	13	13	NS				24	80	40	26.7	8.7	40	0.8	70.9	16.7	6.7	42.3	1.1	48	15.	7.5
340	16	19	NS	17	00	640	14	25	9	26.7	2.5	6.7	0.5	20	2	2	6.7	1.3	10	2	2
341	21	49	NS				20	40	20	33	4.3	10	1.0	75	5.8	3.8	18.3	1.8	82.5	5	2.7
343	16	36	NS	18	02	360	16	30	25	18.3	4.8	10	0.5	40	6.8	0	20	1.0	36	4.2	0
350	01	40	NS				24	65	35	26.7	8	33.3	0.5	40	15.	5	40	1.3	45	14.2	0
355	15	24	KOHOUTEK	16	15		5	47	1.7	26.7	0	18.3	1.8	0	0	0	10	2.5	0	0	0
355	16	29	K	17	29		4	42	5.5	28.3	0	15	0.8	100	5	8.2	6.7	0.5	100	4.2	0.5
357	18	49	K	19	07		2	60	6.0	26.7	0	6.7	3.0	200	10	10	13.3	3.5	200	8.3	10
				19	11																
357	20	09	K	20	49		4	55	50	23.3	0	16.7	3.0	80	4.2	20	23.3	3.5	100	1.7	15
				20	51																
358	18	01	K	18	32		4	45	0	26.7	0	6.7	2.3	180	4.2	7.5	0	2.8	180	4.2	7.5
358	19	31	K	20	08		6	45	0	21.7	0	16.7	0.8	200	5	13.3	6.7	1.3	200	2.5	12
361	14	23	K	15	15		16	20	1.	13.3	1	13.3	1.0	7.9	1.2	0.8	23.3	0.5	7.9	1.0	1
361	15	53	K	16	46		16	20	12	16.7	1	6.7	1.0	20.	6.4	0	13.3	0.5	15.	8.3	1
362	22	29	K	23	40		4	55	5	26.7	1.1	0	1.5	7.5	4.2	3	10.0	2.3	20	5.8	3.6
360	00	00	K	00	14		5	55	10	26.7	1.1	16.7	1.	2	4.2	2	10	1.5	0	2.5	2
				01	23		5	48	0	23.3	3.3	16.7	1.	2	4.2	2	10	1.5	0	2.5	2

NOTES: 1. Where DOY is greater than 365, year 1974 is indicated. DOY (1974) = DOY − 365.

2. Type run abbreviations are: NS = normal solar observations; K = Comet Kohoutek observations; 100% sun = normal solar observations during high orbit β angle periods when successive full sunlit orbits occurred.

3. Exposure time = initial time of exposure.

4. All thermal distortion parameters are given in percent of maximum allowable values. Figures 1, 2 and 3.

5. Thermal distortion results are related to exposure time for runs where exposure times are shown and to orbit sunrise for all other runs. Orbit sunrise (or aperture opening) generally results in the maximum transient thermal distortion.

6. Thermal shield door problem occurred at this time.

Table 3 (Continued)

S-082B THERMAL DISTORTION ANALYSIS RUN SUMMARY
SKYLAB 4 MISSION

DOY RUN TIME			RUN TYPE	EXPOSURE TIME		EXP LENGTH	THERMAL DISTORTION PARAMETERS IN PERCENT OF MAXIMUM ALLOWABLE: SUN IMAGE ON SLIT					SLIT IMAGE ON FILM-RT					SLIT IMAGE ON FILM-L					
DAY	HR	MIN		HR	MIN	(SEC)	FOCUS	HOR POS	HOR SMEAR	VERT POS	VERT SMEAR	FOCUS	HOR POS	HOR SMEAR	VERT POS	VERT SMEAR	FOCUS	HOR POS	HOR SMEAR	VERT POS	VERT SMEAR	
364	12	16	K	—	—		0	72	32	26.7	2.9	20.	0.5	60	12.5	6	26.7	1.0	72	11.7	7.5	
364	13	47	K	14	35		4	50	0	33.3	0	6.7	0.3	0	8.3	0	13.3	0.3	0	7.5	0	
				15	09		4	50	0	33.3	0	6.7	2.0	80	1.6	4.3	3.3	3.0	84	1.7	5	
364	15	22	K	16	07		4	46	0	33.3	0	16.7	3.0	50	2.5	3.8	6.7	3.8	50	4.2	10	
364	16	52	K	17	38		7	30	0	33.3	0	26.7	4.3	50	2.5	15	16.7	2.3	5	4.2	12	
364	20	03		—	—		4	40	53.3	23.3	1.3	0	1.5	60	4.2	2.7	0	0.5	60	1.7	3	
364	21	40	K	22	26		6	45	2.4	25	0	13.3	1.0	7.5	4.2	1.0	6.7	1.5	25	2.5	0.9	
364	22	29	K	00	00		4	45	2	26.3	2	10	0.8	1	1.7	4.3	0	1.3	2	0	5.	
365	14	42	KOHOUTEK	15	25		5	55	0	23.3	1	10	2.3	60	4.2	5	0	2.8	60	1.7	1	
365	16	15	K	16	58		4	50	0	26.7	0	11.7	1.5	25.7	5.8	2.5	3.3	2.3	22.5	4.2	3	
365	18	01	K	18	29		4	47.5	0	26.7	2.3	13.3	2.5	10	3.3	2.4	6.7	3.0	10.0	1.7	2	
365	22	29	K	23	17		5	50	0	23.3	2.2	13.3	2.5	150	0	11.3	0	3.3	150	0	12	
366	21	47	K	22	30		5	50	0	26.7	0	13.3	2.3	10	2.5	4.3	6.7	2.8	10	4.2	2.5	
366	22	29	K	24	00		5	35	100	26.7	0	16.7	0.5	90	2.5	5.0	10.	1.0	100	1.7	5.0	
368	20	24	K	20	41		4	50	0	26.7	0	6.7	1.0	84	4.2	2.0	1.7	0.5	80	3.3	2.0	
368	21	54	K	22	45		4	48	0	26.7	3.3	13.3	0.8	5	3.3	1.7	6.7	1.3	5	2.1	1.0	
370	14	23	K	14	44		6	40	0	28.3	2.2	6.7	0.3	20	8.3	10.	0	0.8	30	6.7	10	
				14	47		6	40	0	28.3	2.2	6.7	0.3	20	8.3	10	0	0.8	30	6.7	10	
371	22	29	K	23	44		5	45	3.3	30	1.7	3.3	0.3	10	4.2	2	1	0.8	10	4.2	2	
380	18	24	100% SUN	19	37	683	16	35	3.3	20	1.1	70.	4.5	10	5.0	2	56.7	3.3	10	5.8	2	EXPOSURE # 1372
381	19	21	100% SUN	20	35	900	36	40	1.7	23.3	10	93.3	4.3	10	4.2	2	80	3.8	10	4.2	0	EXPOSURE # 1425
381	20	51	100% SUN	22	14	180	36	45	3.3	33.3	10	106.7	4.4	5	4.2	2	93.3	3.9	0	4.2	1	EXPOSURE # 1426
381	22	21	100% SUN	22	29	160	34.5	55	3.3	23.3	1.7	106.7	4.5	20	4.2	2	90.	4.0	20	4.2	2	EXPOSURE # 1427
382	17	09	100% SUN	18	13	480	40	63	1.7	26.7	2.2	113.3	4.0	10.	8.3	2	100	3.8	10	6.7	2	EXPOSURE # 1437
				18	22	480																EXPOSURE # 1438
				18	32	380																EXPOSURE # 1439
383	15	00	100% SUN	16	10	847	24	5	0	16.7	2.	60	4.0	10	4.2	2	56.7	3.8	10	4.2	2	EXPOSURE # 1440
383	16	30	100% SUN	17	32	1560	24	10	3.3	20.	1.1	73.3	1.8	10	2.5	2	60.	4.3	10	1.7	2	EXPOSURE # 1441

NOTES: 1. Where (DOY) is greater than 365, year 1974 is indicated DOY (1974) = DOY -365.

2. Some run abbreviations are: NS = normal solar observations; K = Comet Kohoutek observations; 100% sun = normal solar observations during high orbit β angle periods when successive full sunlit orbits occurred.

3. Exposure time = initial time of exposure.

4. Thermal distortion parameters are given in percent of maximum allowable values. Figures 1, 2 and 3.

5. Thermal distortion results are related to exposure time for runs where exposure times are shown and to orbit sunrise for comet runs. (Orbit sunrise (or aperture opening) generally results in the maximum transient thermal distortion.

6. Solar door problem occurred at this time.

result in less than maximum smear.

NOTE: Since this report was prepared Bill Sidle has received exposure data for all Skylab missions and will compute the image thermal distortion parameters for all exposures for which plotted thermal distortion data exists.

During high orbit β angle periods when successive full sunlit orbits occurred, the focus requirements for the slit image on film were exceeded. On DOY 382:17:09 Table 3, sheet 1, the computed image defocus was 13.3% greater than the maximum allowable. All other thermal distortion parameters were held within the allowable limits during these periods.

The thermal distortion values presented in Table 3 are related to exposure time for runs where exposure times are shown and to orbit sunrise for all other runs. Orbit sunrise, or aperture opening when it occurs after sunrise, generally results in the maximum transient thermal distortion. The resulting maximum smear rates generally persist for 15 to 20 minutes after aperture opening. During normal solar observations, these smear rates and focus changes are related to the temperature rise of the slit plate mounting and are also a function of case absolute temperatures. The maximum temperature rise rate of the slit plate mount persists for about 15 to 20 minutes, i.e., the thermal time constant is about 20 minutes.

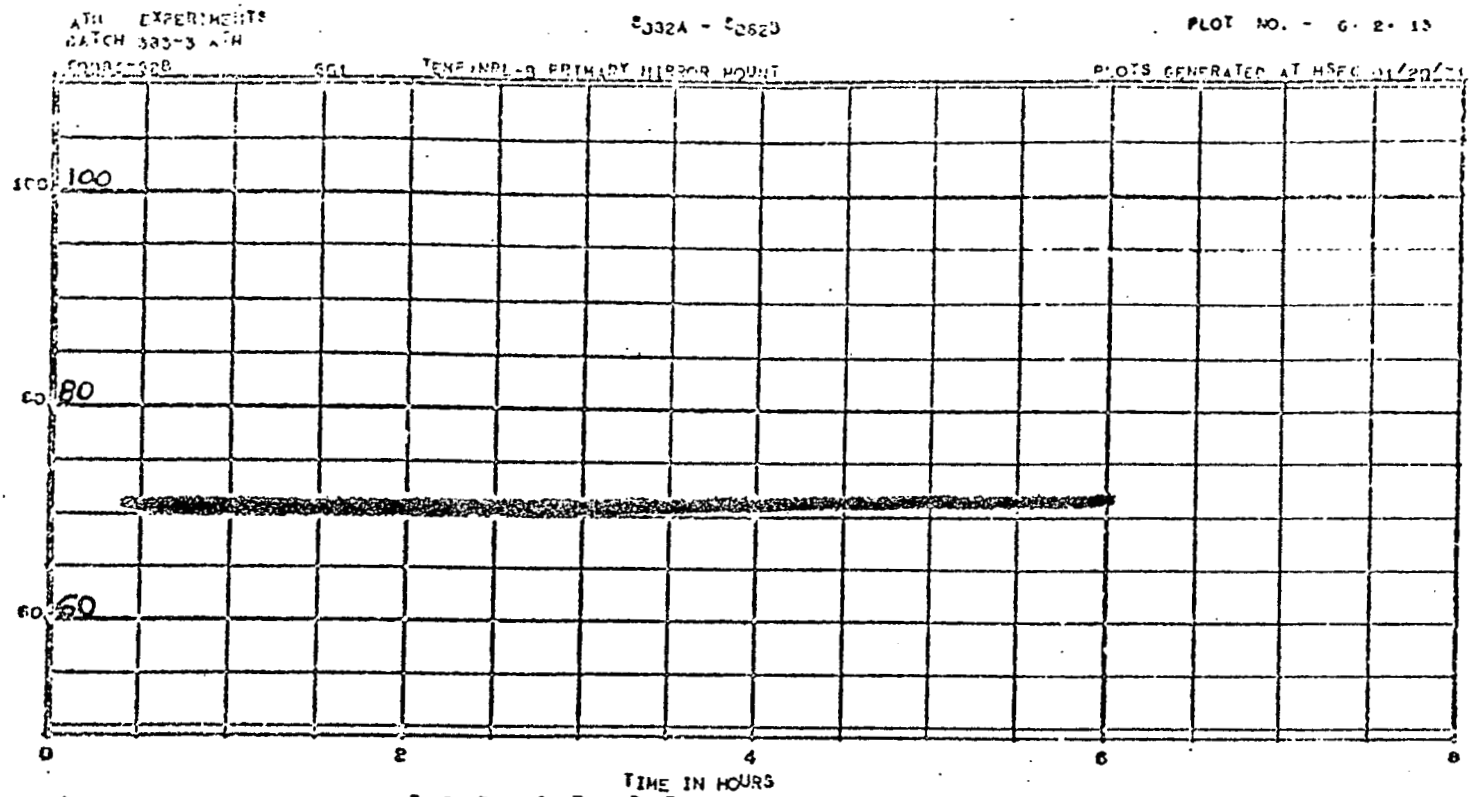
The high smear rates observed during the Comet Kohoutek observations were caused by absorption of solar energy on interior surfaces of the instrument case causing large differential temperature changes. No solar energy impinged on the slit plate and it is noted that the image defocus--both sun image on the slit plate and the slit image on film, was much less during the Kohoutek

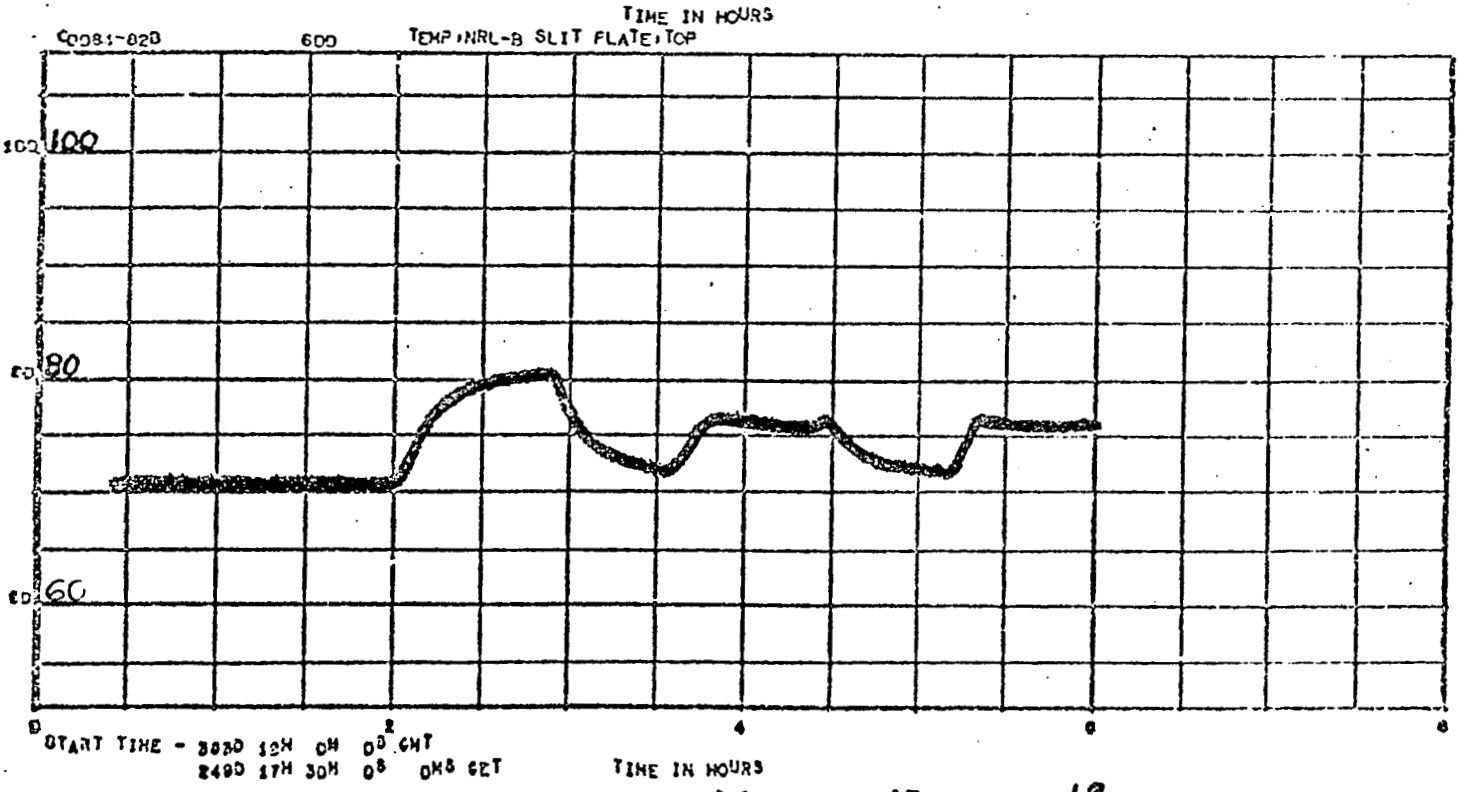
runs than during normal solar observations. The thermal control system was able to compensate for the case differential temperature rise during these runs but the response time was about 15 minutes. Thus peak image smear rates occurred at aperture opening and persisted for about 15 minutes.

Temperature plots from Data Book 6 Figures 4 through 15, and the corresponding thermal distortion parameter plots, Figures 16 through 24, for DOY 383:16:30 (Jan. 18, 1974), are included as examples of the S-082B thermal performance data. Although this data is for a near 100% sunlit orbit, all thermal distortion parameters were within the performance requirements during the noted exposure (Table 3 Sheet 2). Note, that had the exposure been made earlier in the orbit; for example 20 minutes earlier at 383:17:12, the thermal distortion would have been significantly greater (Figures 16 through 24).

Figure 25 provides a block diagram and flow chart of the thermal distortion analysis program. The basic building blocks of the program are the thermal model, Figures 26 and 27, used in the thermal design analysis and the structural model, Figure 28 used for the stress and dynamics analysis. The thermal and structural models were updated to the flight configuration and the thermal analytical predictions compared with data from the flight unit tests at Johnson Space Center. The total program was then coded for use on the NOSC 1108 computer at the Marshall Space Flight Center.

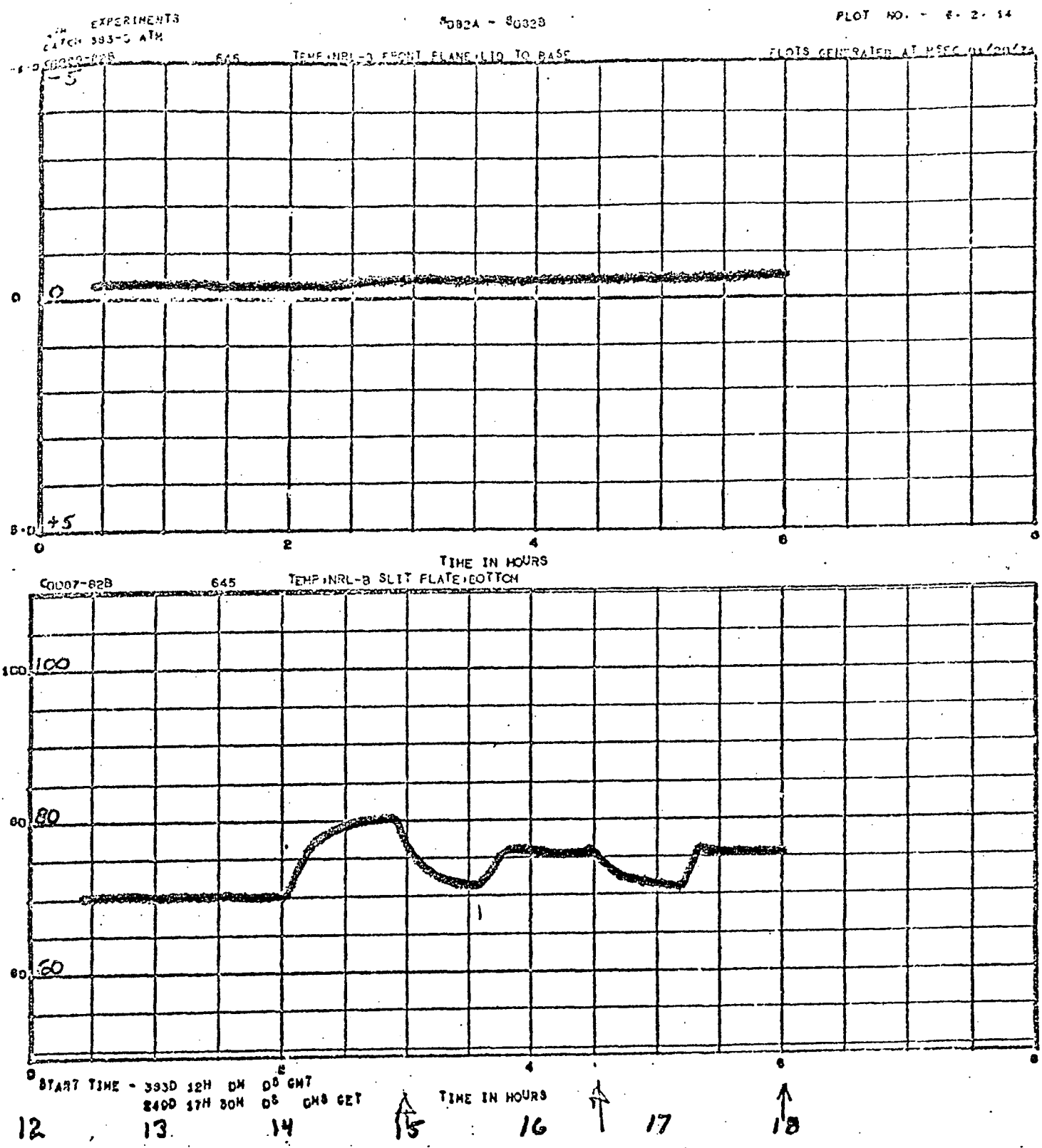
The scope of this report does not permit a more detailed description of the thermal distortion analysis program, however, a final report is in preparation wherein the thermal model and the thermal distortion program will be described. A "cook-book" for use of the program also will be provided.





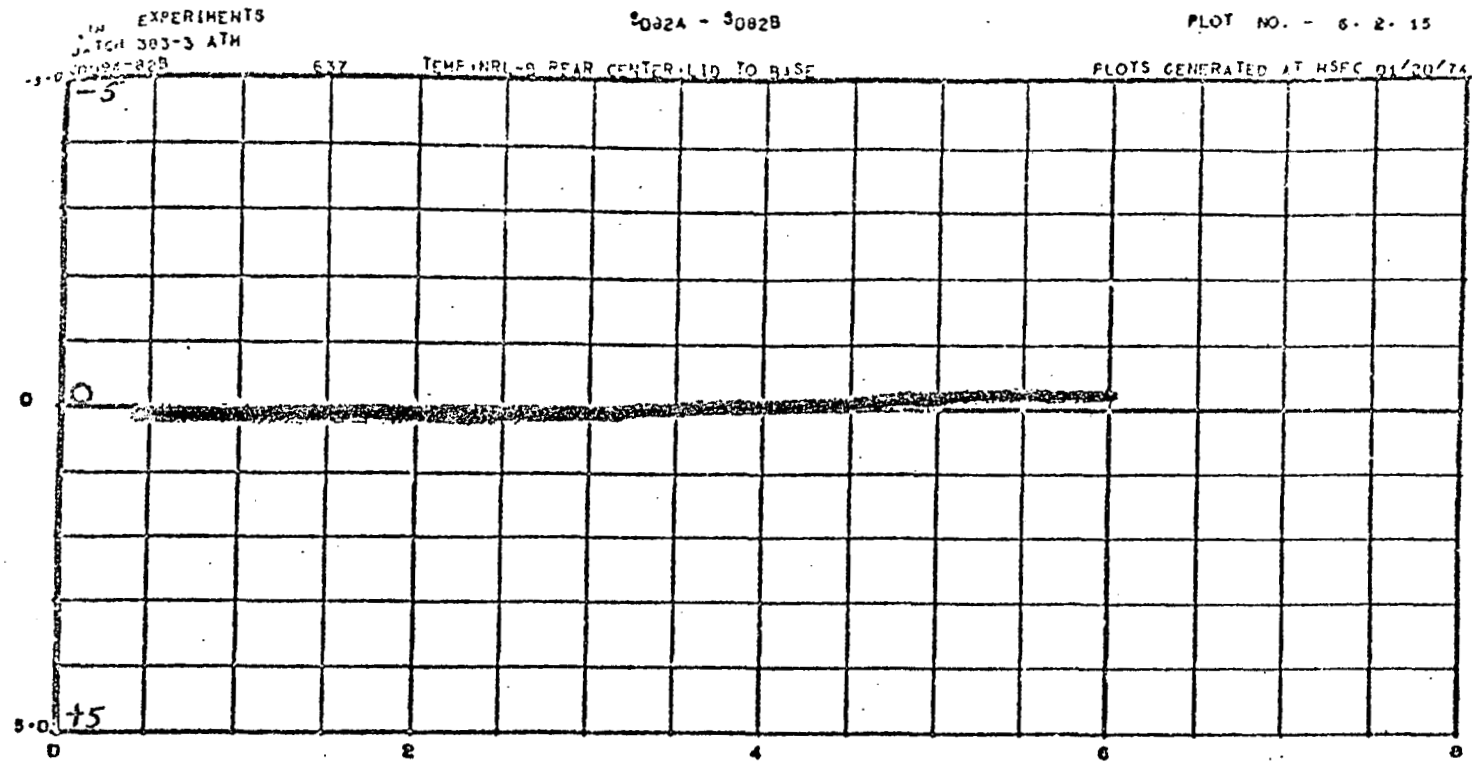
DOY 383: 12:00 → 18:00
DOY(94) 18

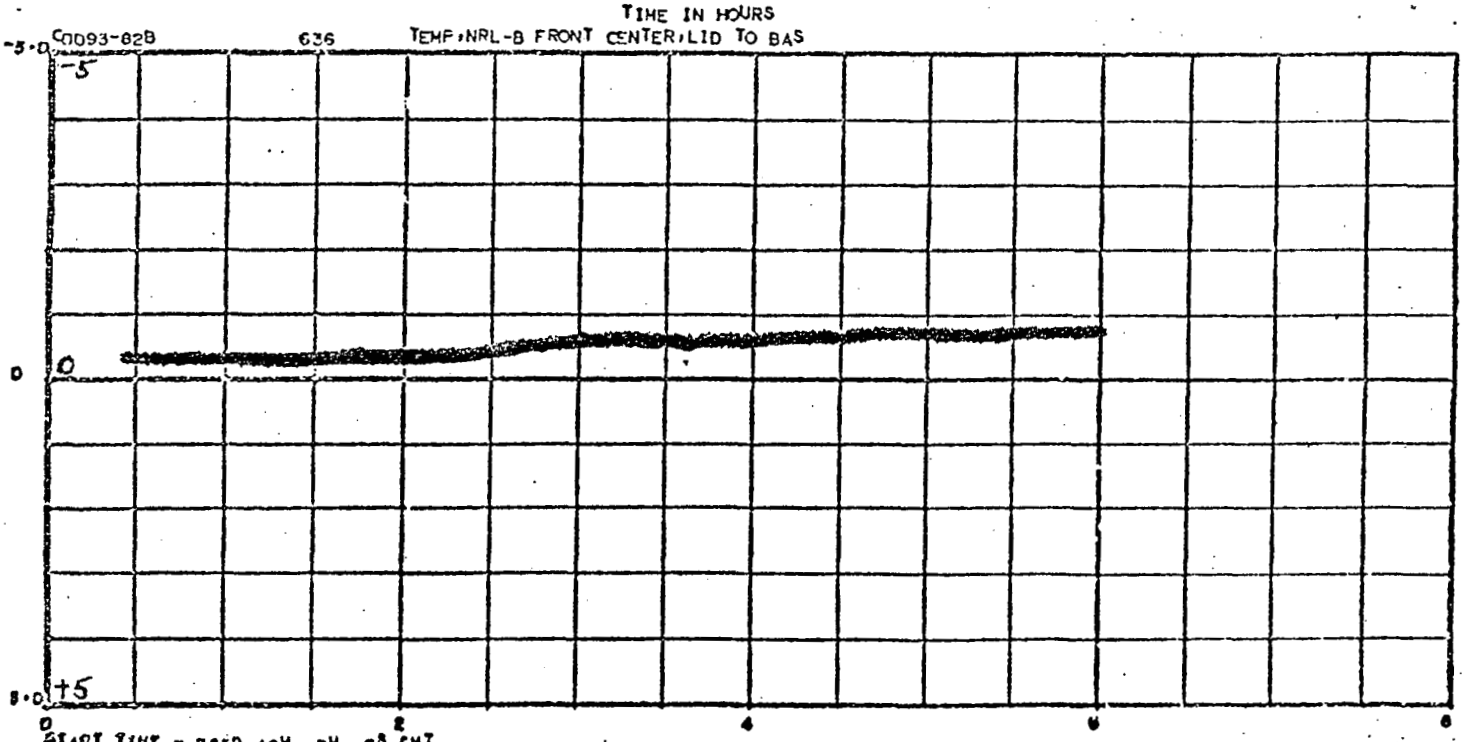
FIGURE 4



DOY 383 12:00 → 18:00 Start
DOY('74) 18

FIGURE 5

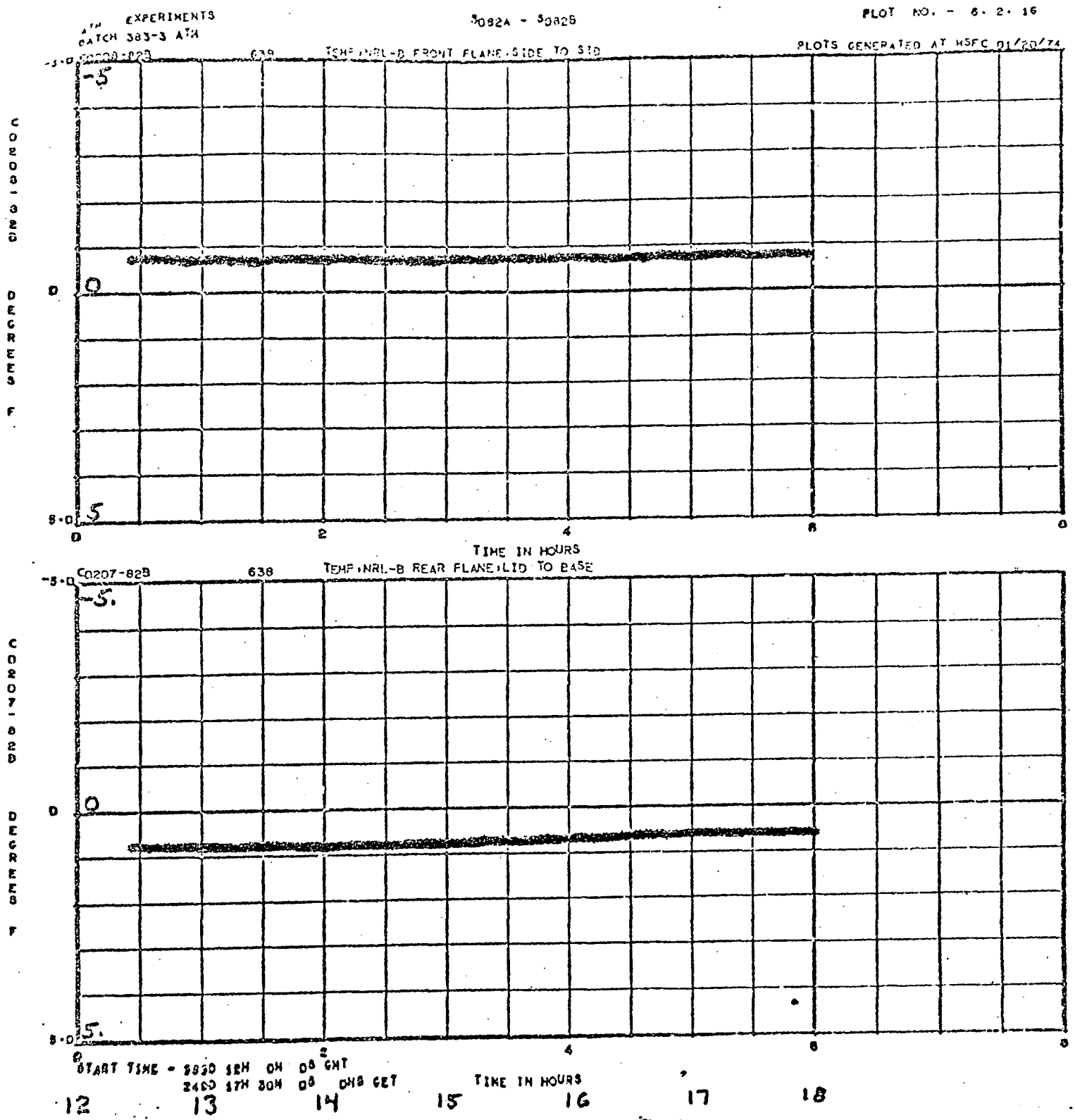




12 13 14 15 16 17 18

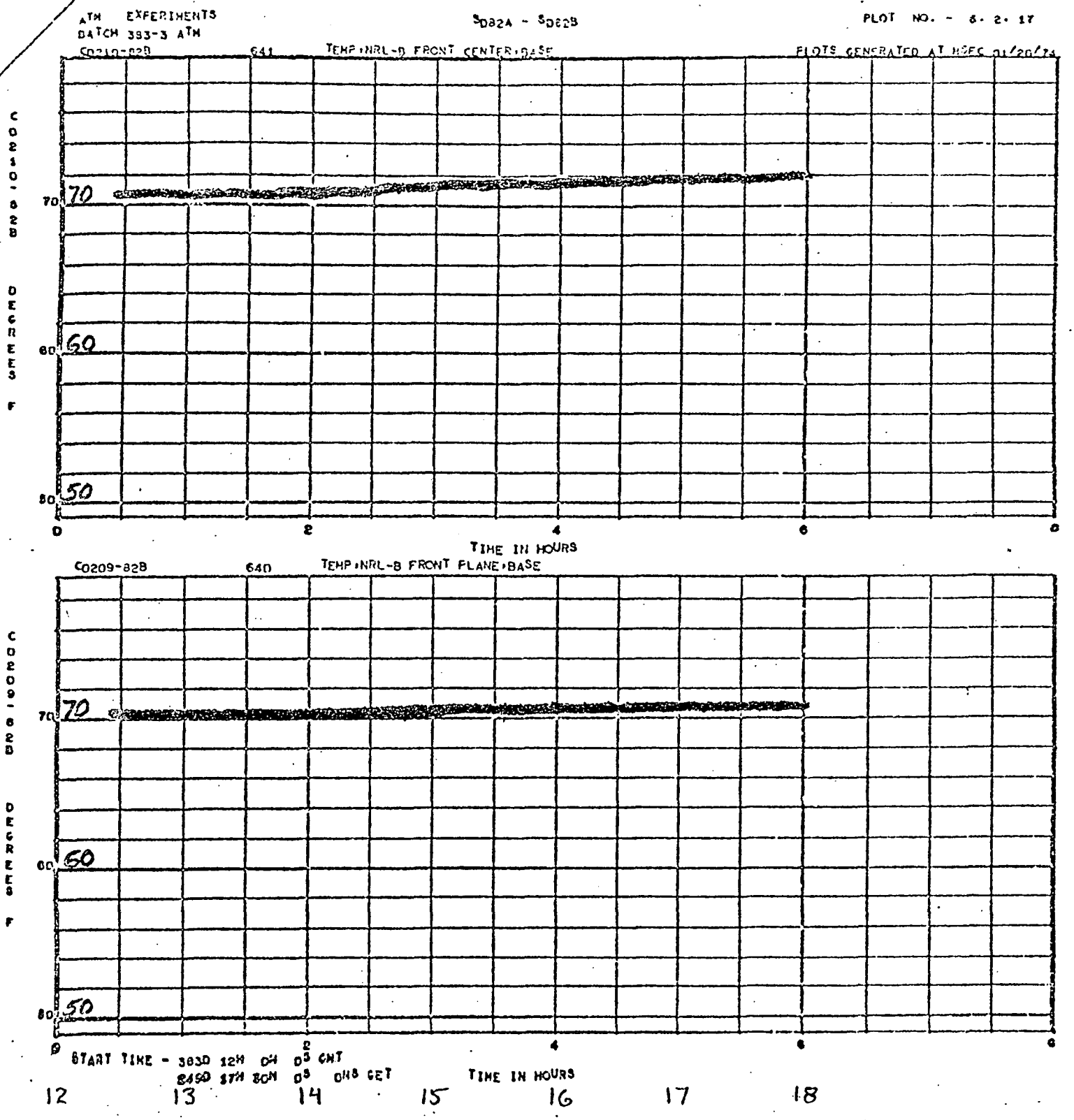
DOY 383 12:00 → 18:00

FIGURE 6



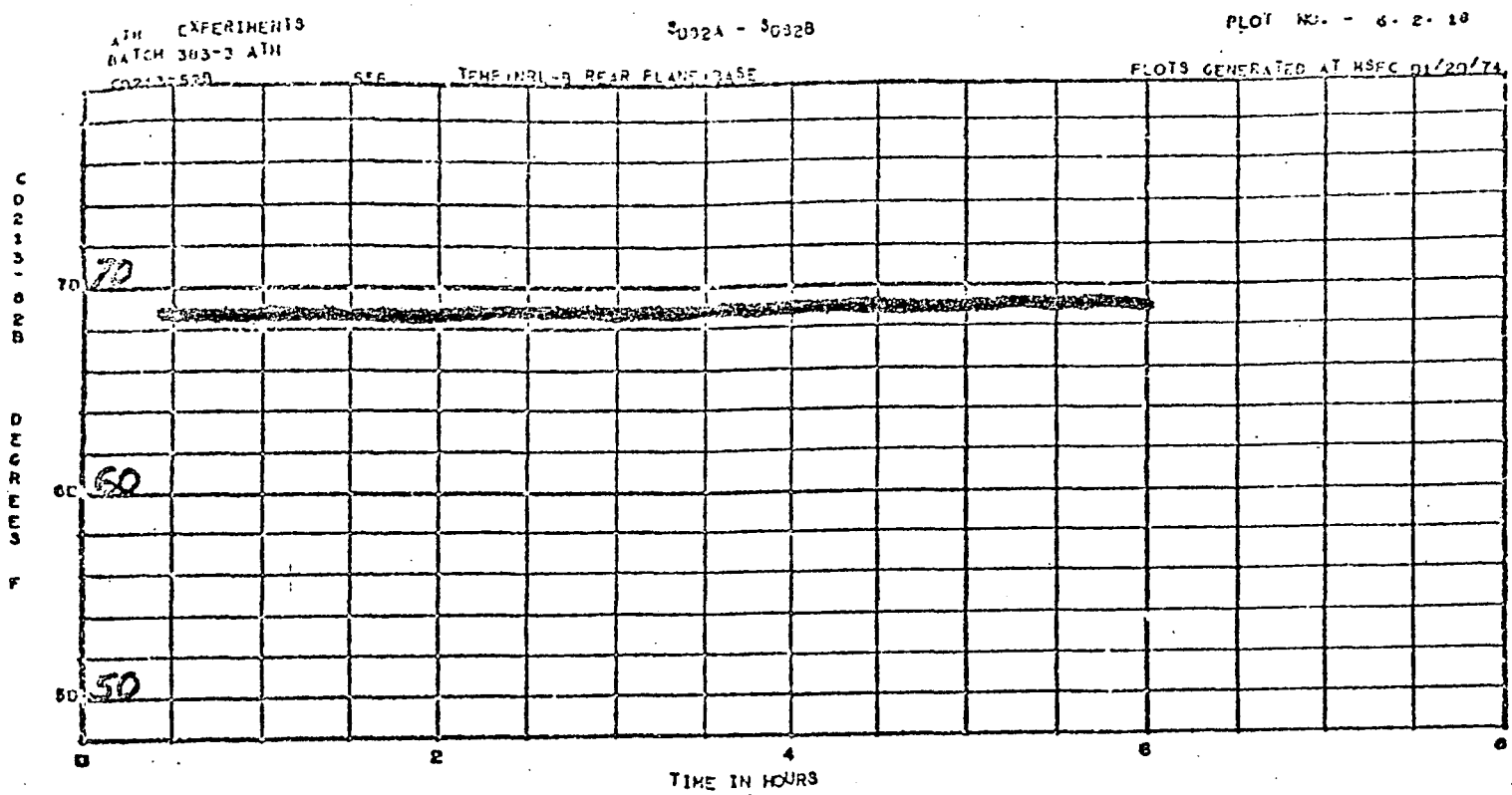
DOY 383 12:00 → 18:00
DOY ('74) 18

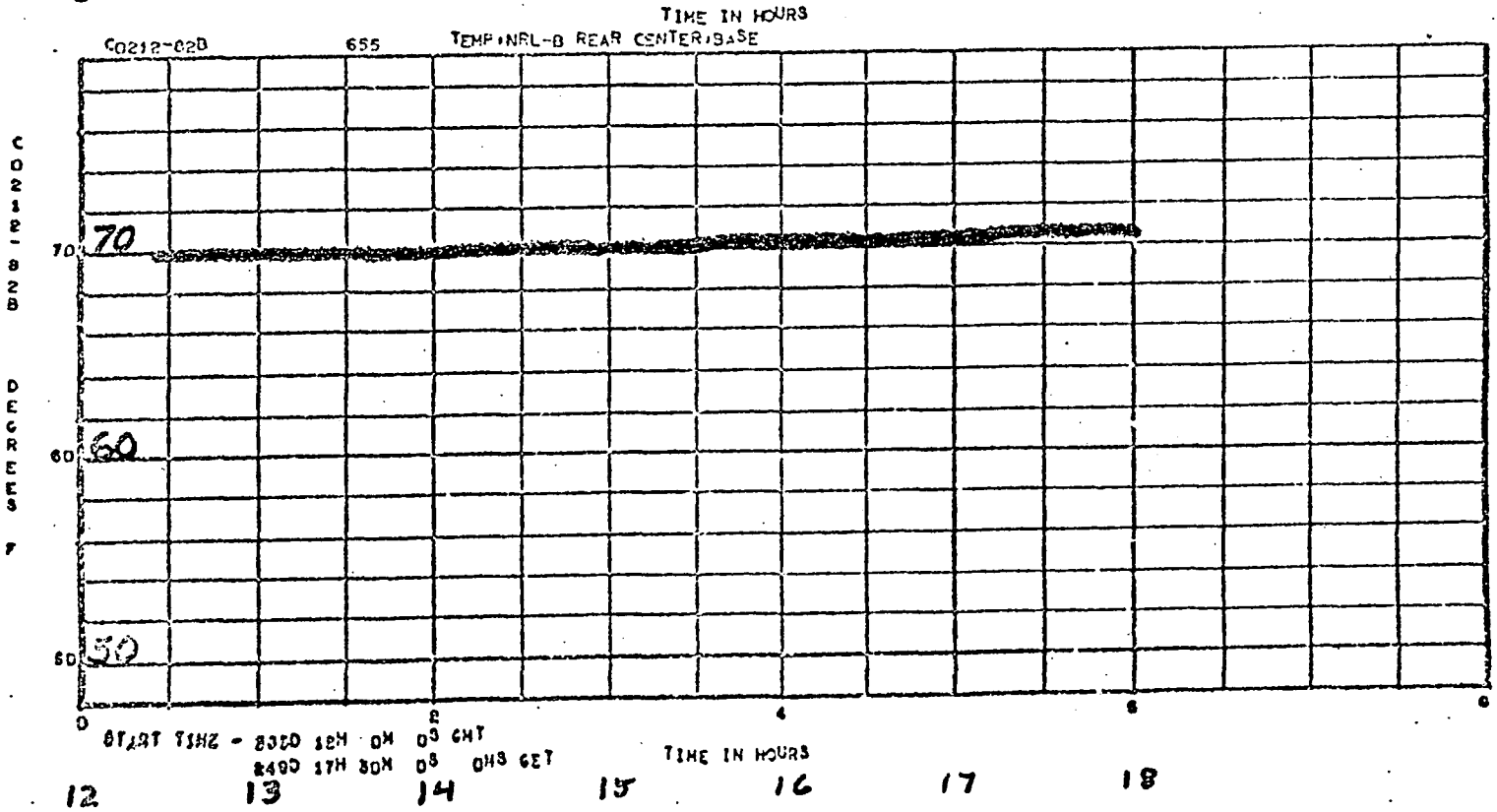
FIGURE 7



DOY 383 12:00 → 18:00
DOY ('74) 18

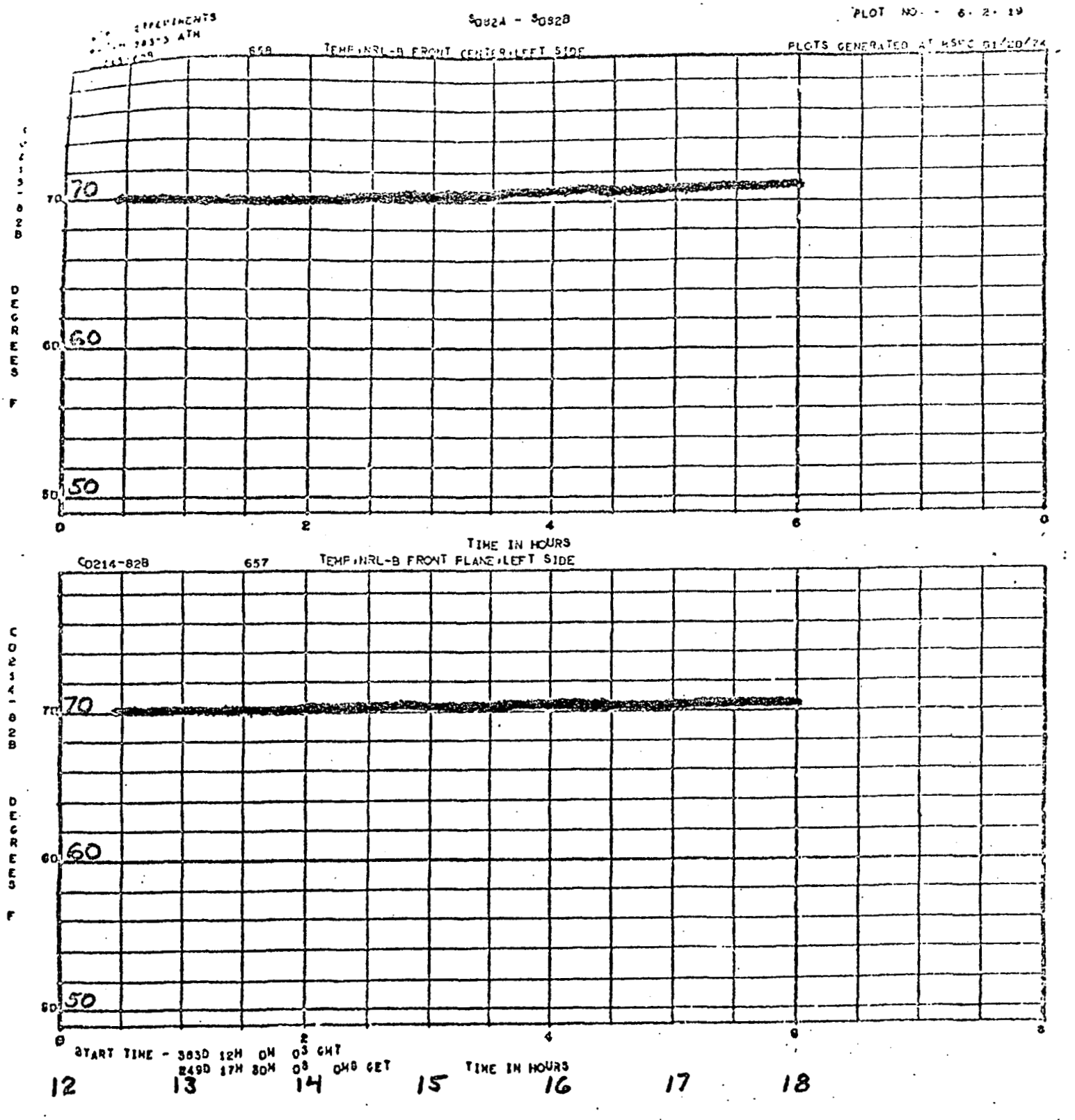
FIGURE 8





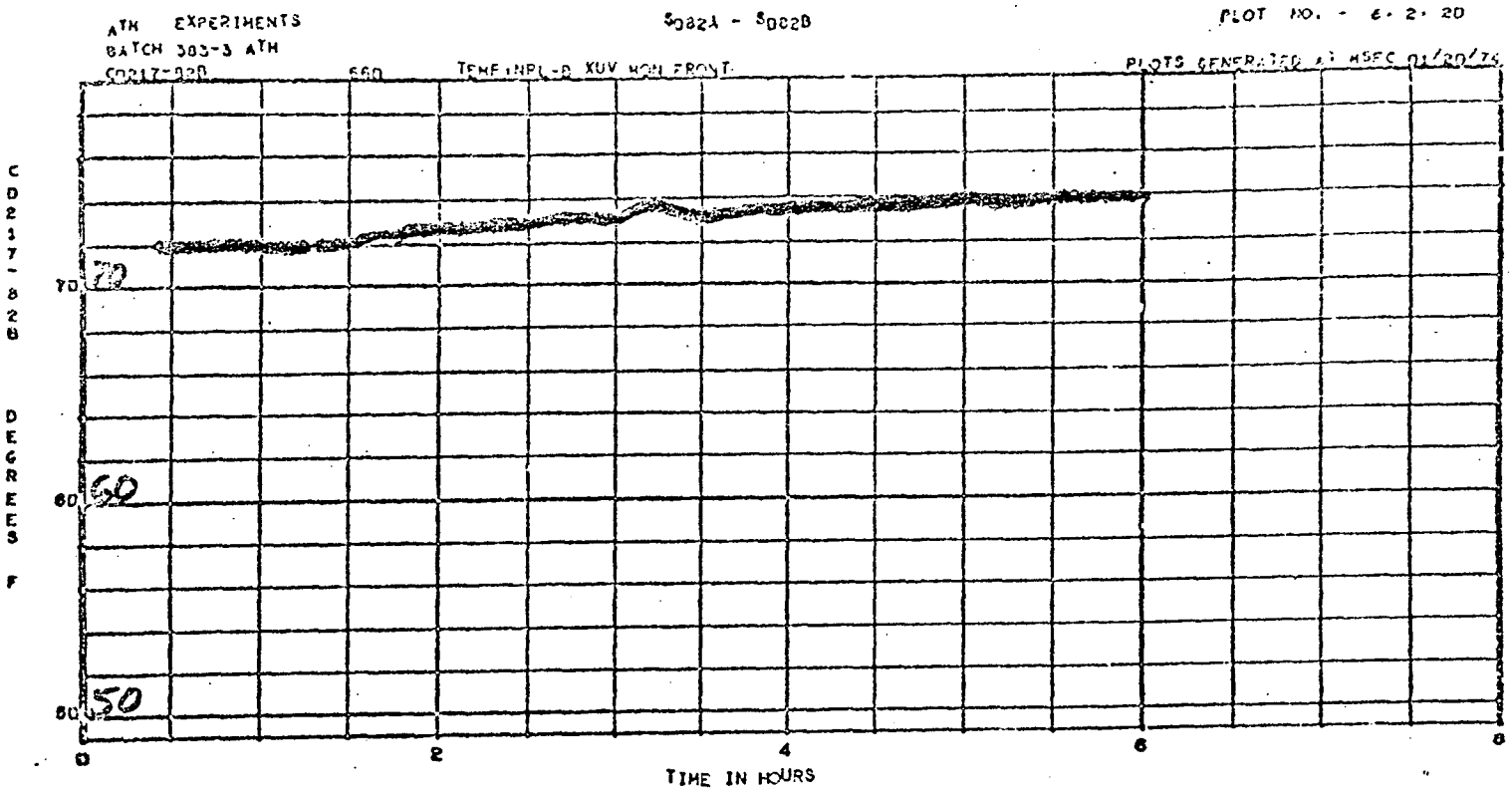
DOY 383 12:00 → 18:00
DOY ('74) 18

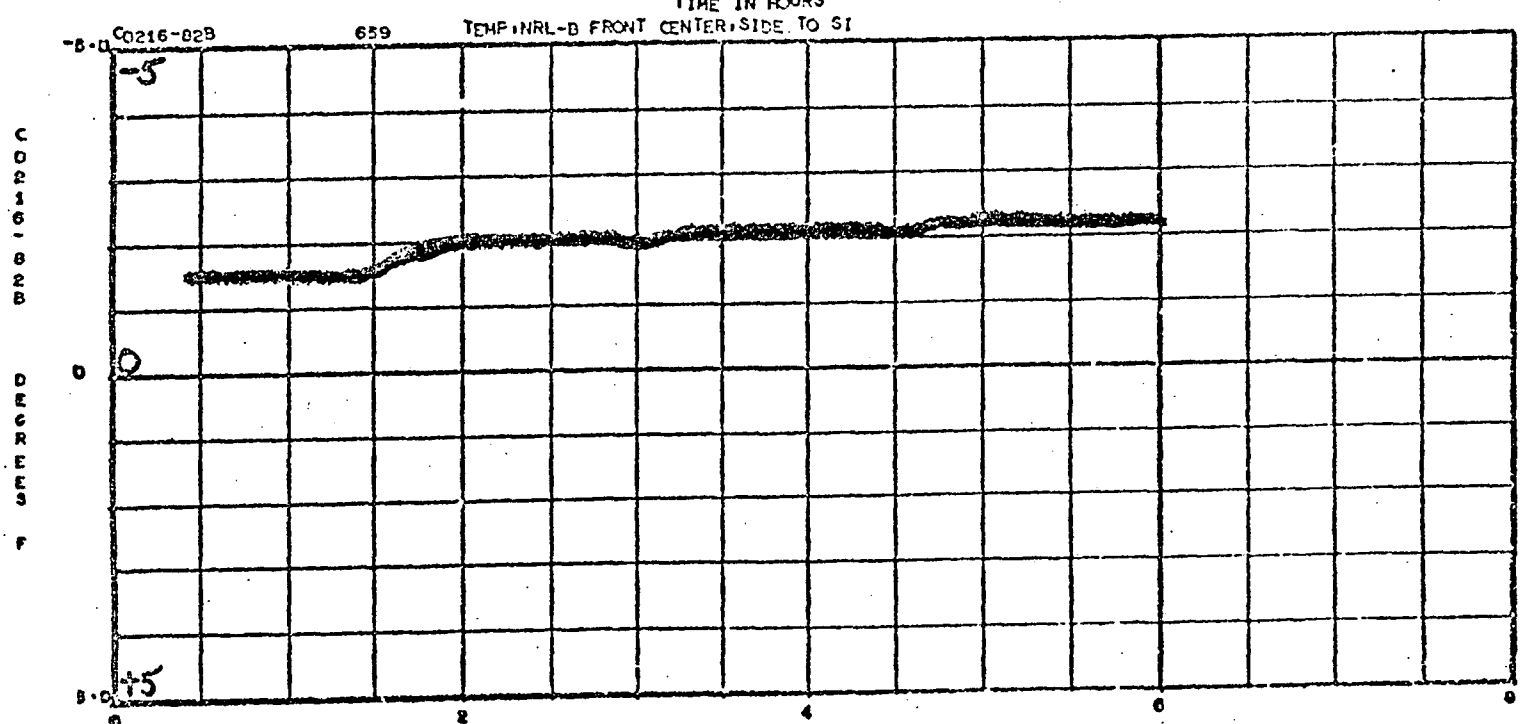
FIGURE 9



DOY 383 12:00 → 18:00
DOY ('74) 18

FIGURE 10

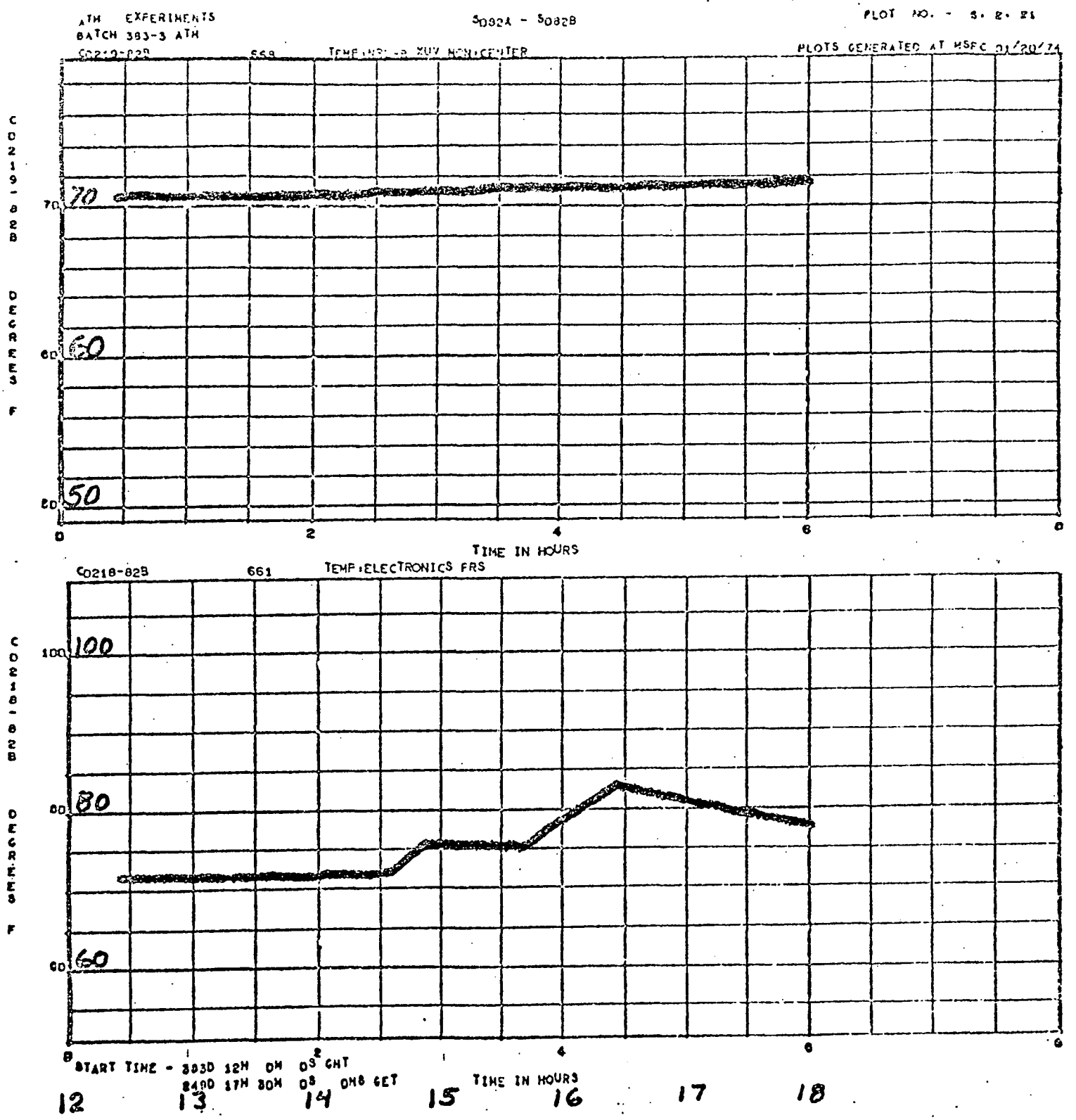




12 13 14 15 16 17 18

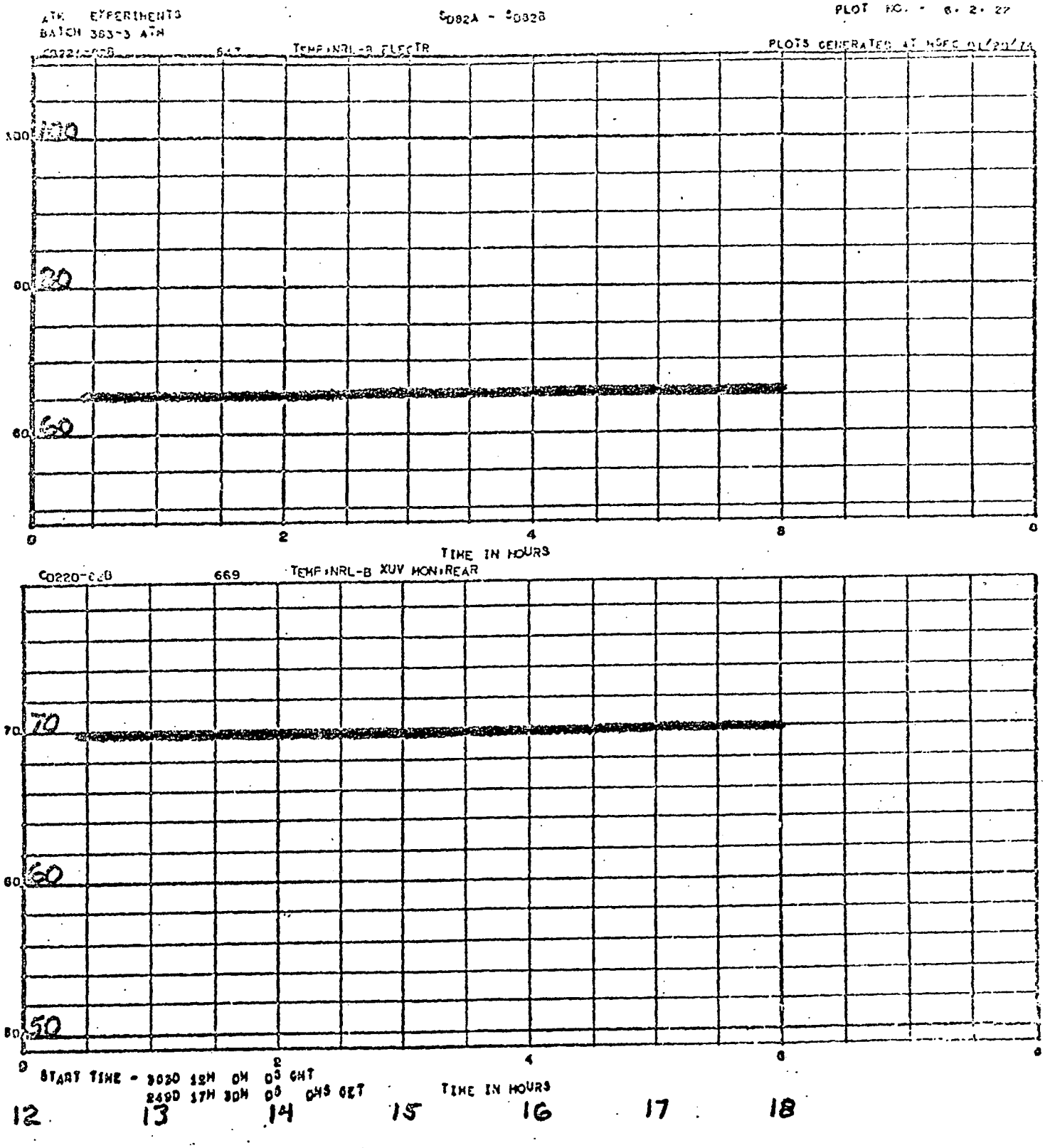
DOY 383 12:00 → 18:00
DOY('74) 18

FIGURE 11



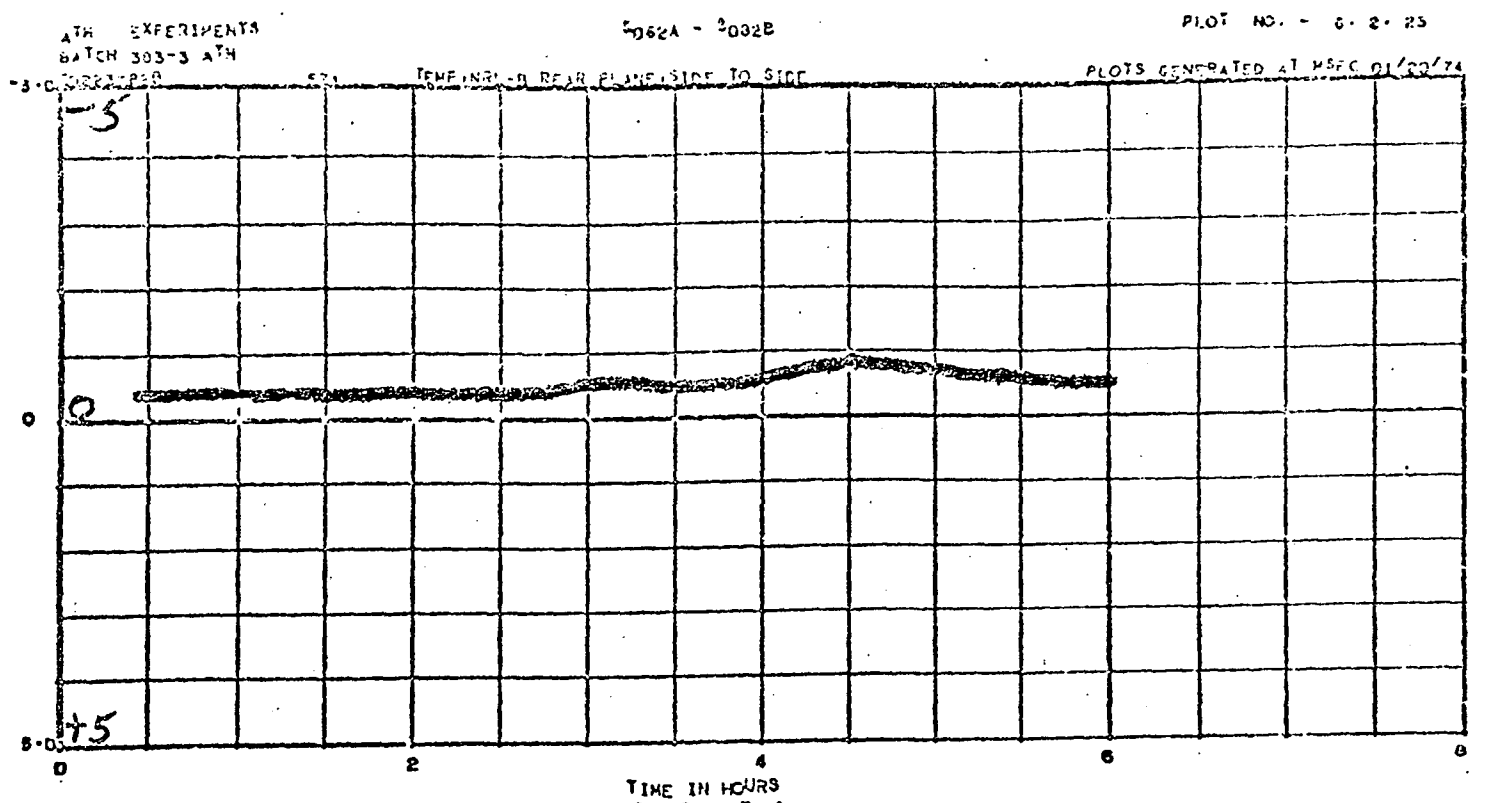
DOY 383 12:00 → 18:00
DOY('74) 18

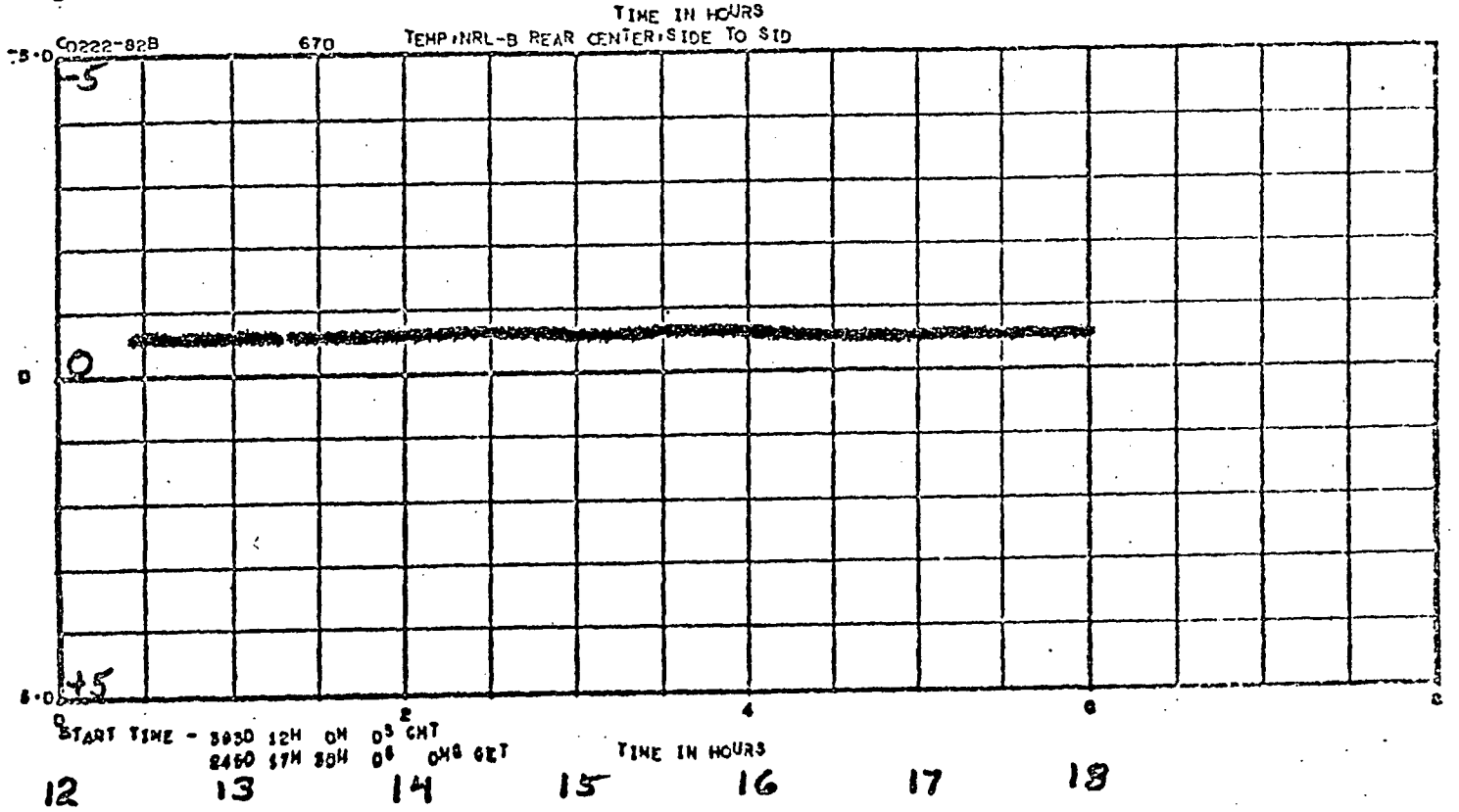
FIGURE 12



DOY 383 12:00—18:00
DOY ('74) 18

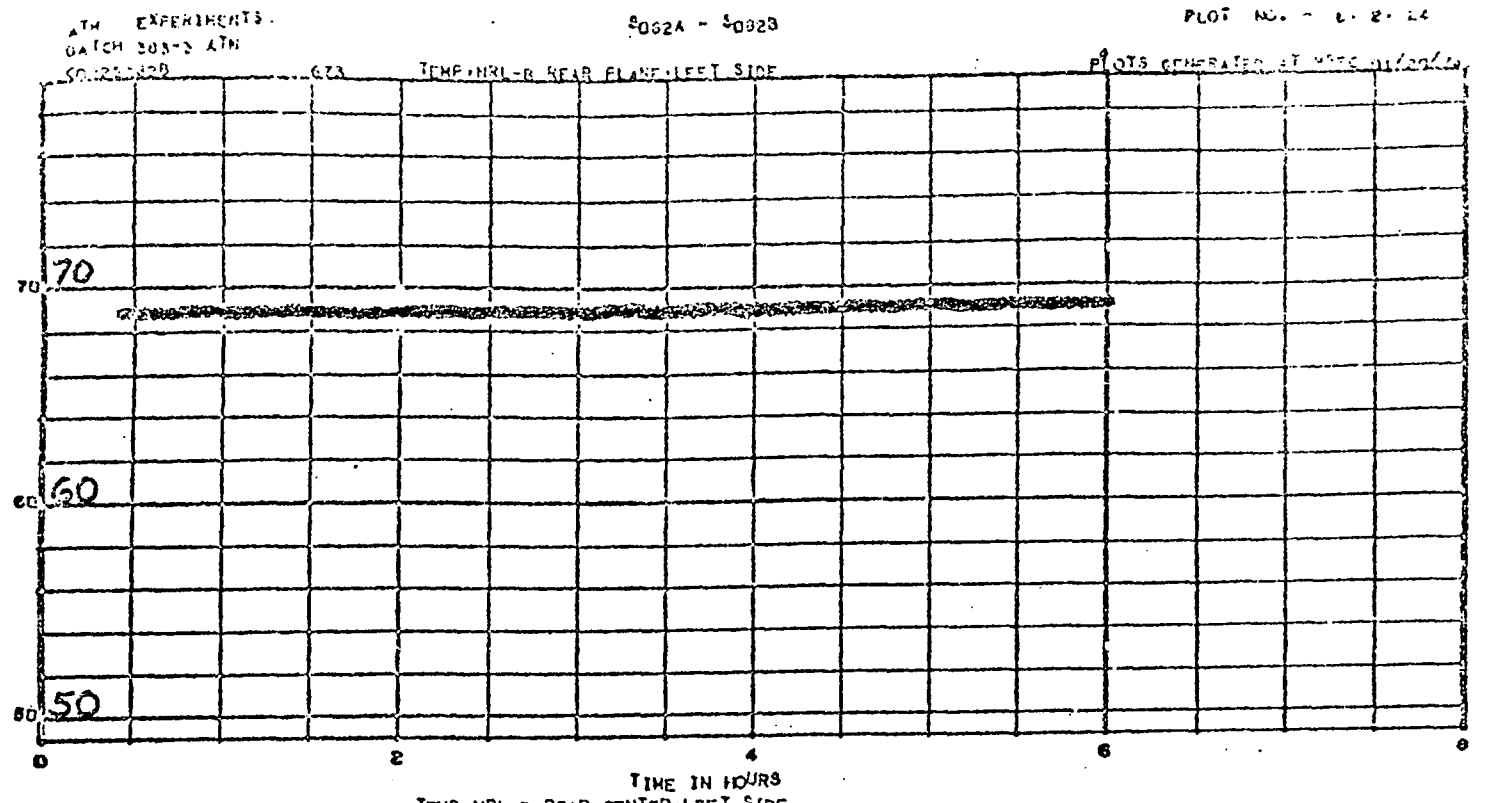
FIGURE 13

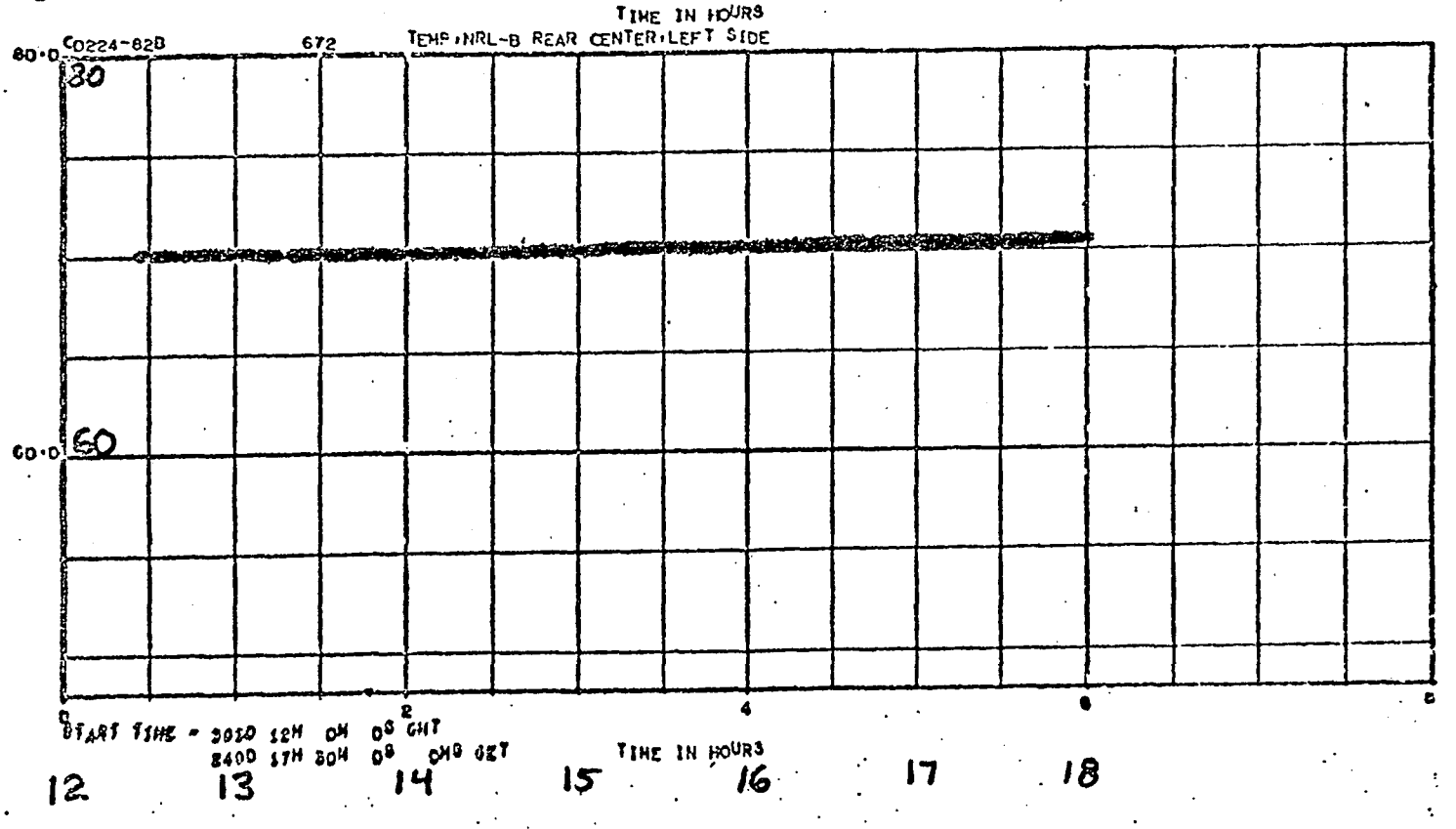




DOY 383 12:00 — 18:00
DOY('74) 18

FIGURE 14





DOY 383 12:00 — 18:00
DOY (74) 18

FIGURE 15

NRL: B DAY 383 : 16 : 30 ('74 DAY 18)
D/N 976
≈ 100 % SUN
1560 SEC EXPOSURE # 1441
@~383 : 17 : 32 → 383 : 17 : 58
SUNRISE 383 : 16 : 50
SUNSET 383 16 41 & 383 : 18 : 14

NAME- BBRCNB

DIST. CODE- BIN232

RUN ID- NRLBTD

JOB NO- 140006

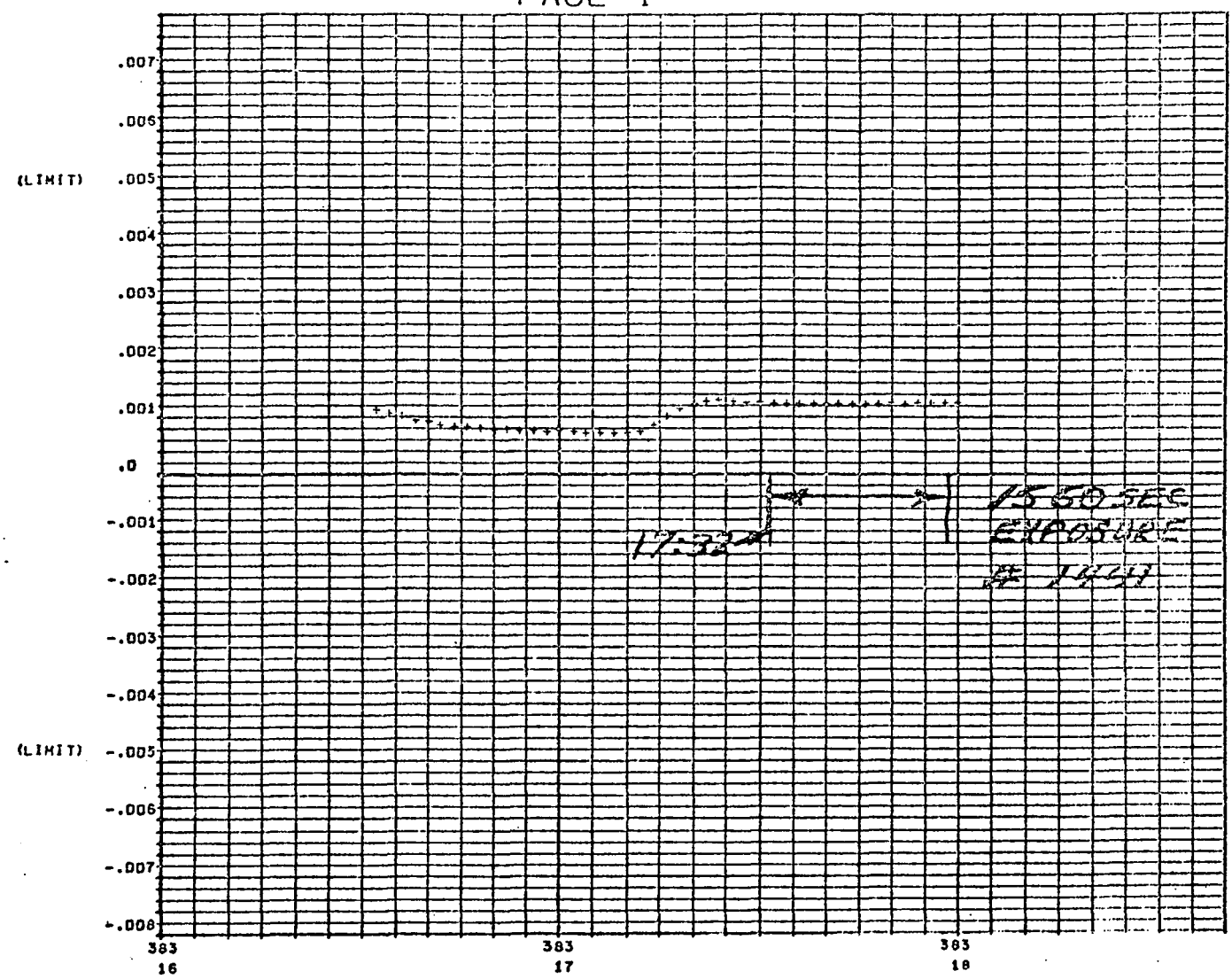
SEQ NO- 4143

DATE- 02-21-74

TIME- 13-27-19

S082 B DAY 383 16 30 ([illegible])
D/N 976 ~ < 100 % SUN
1560 SEC EXPOSURE # 1441
@ ~ 383:17:32 → 383:17:58
SUNRISE ———] 383: 16:50]
SUNSET 383:16:41] & 383: 18:14

S082B THERMAL DISTORTION
SUN IMAGE ON SLIT PLATE, FOCUS
PAGE 1



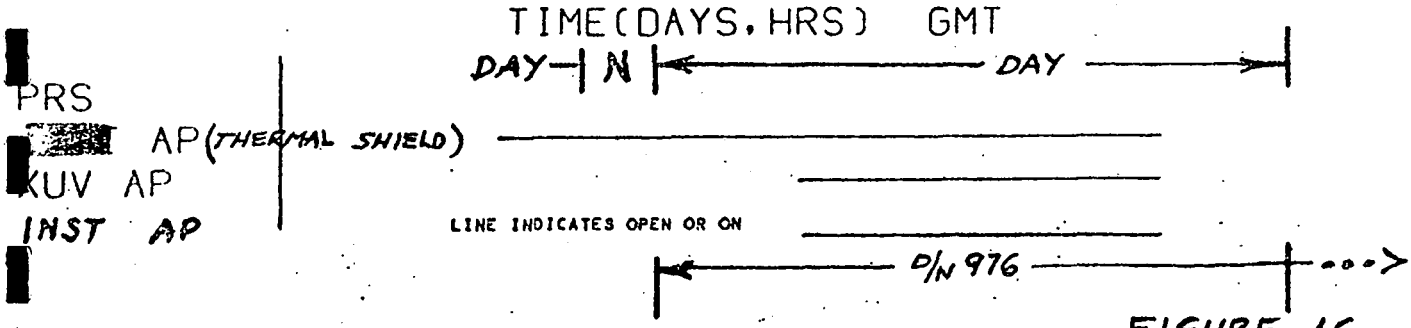


FIGURE 16

S082B THERMAL DISTORTION
SUN IMAGE ON SLIT PLATE, HORIZONTAL POSITION
PAGE 3

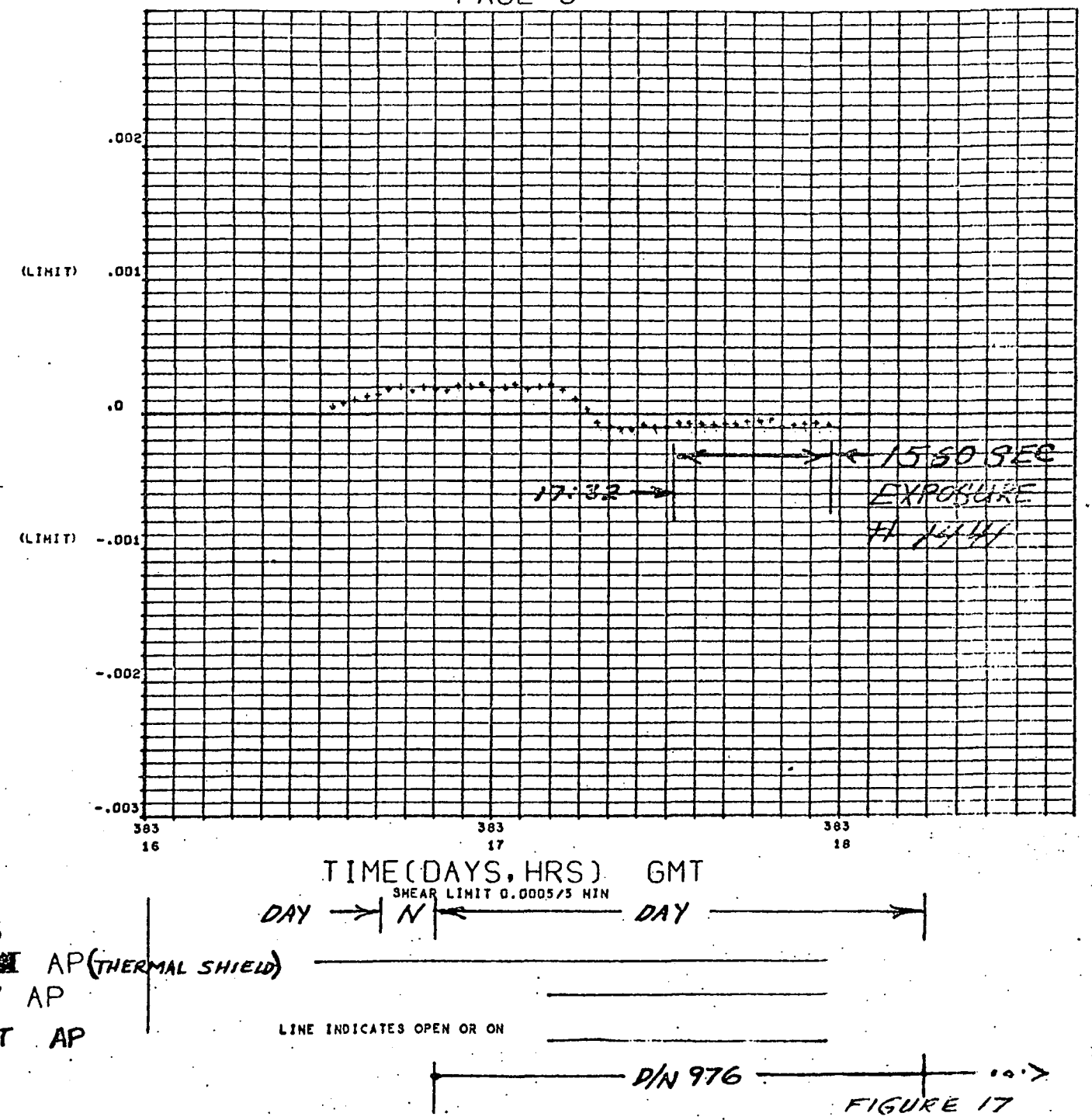


FIGURE 17

S082B THERMAL DISTORTION
SUN IMAGE ON SLIT PLATE, VERTICAL POSITION
PAGE 2

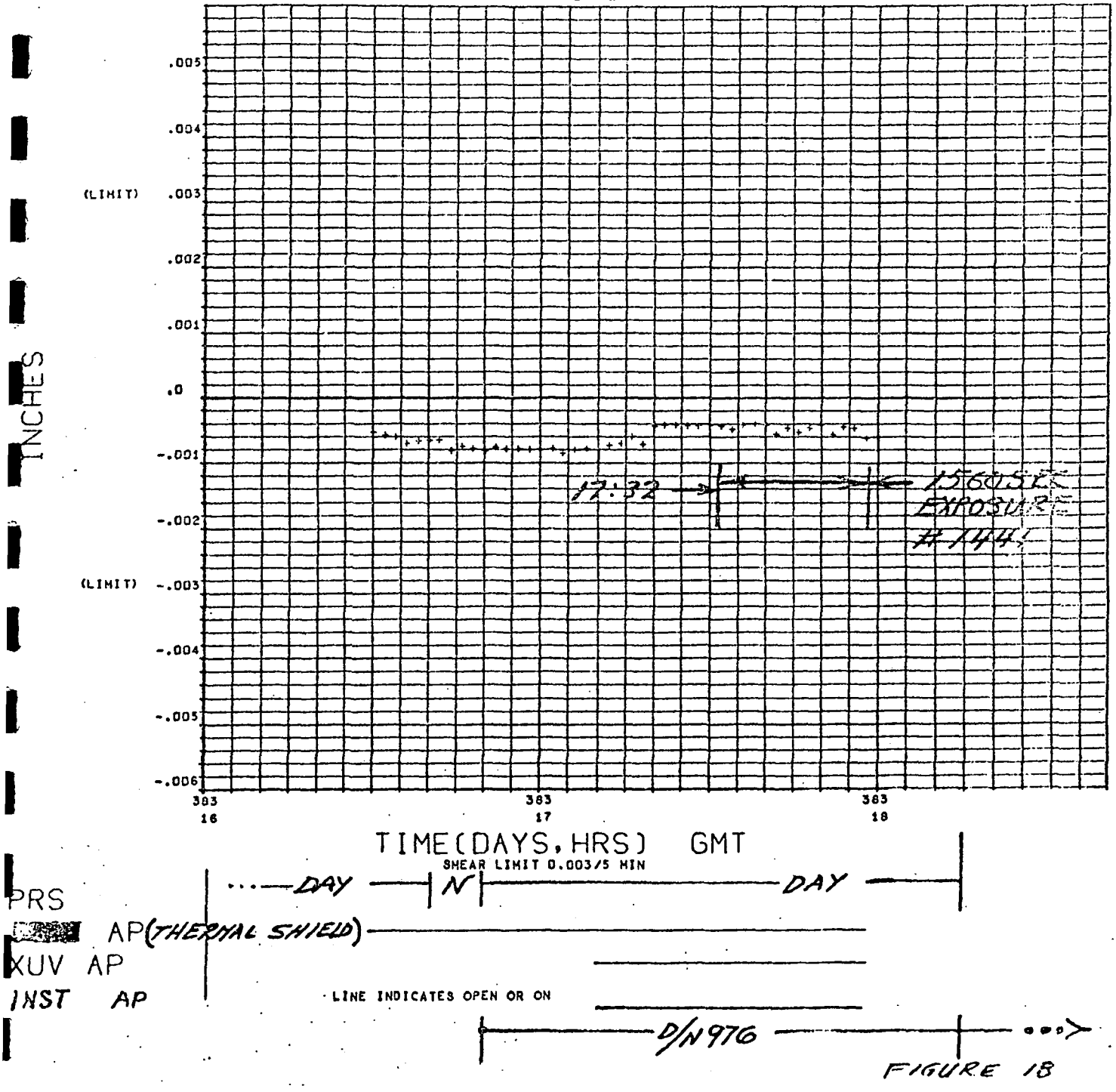


FIGURE 18

S082B THERMAL DISTORTION
SLIT IMAGE ON FILM, FOCUS, LEFT SIDE
PAGE 5

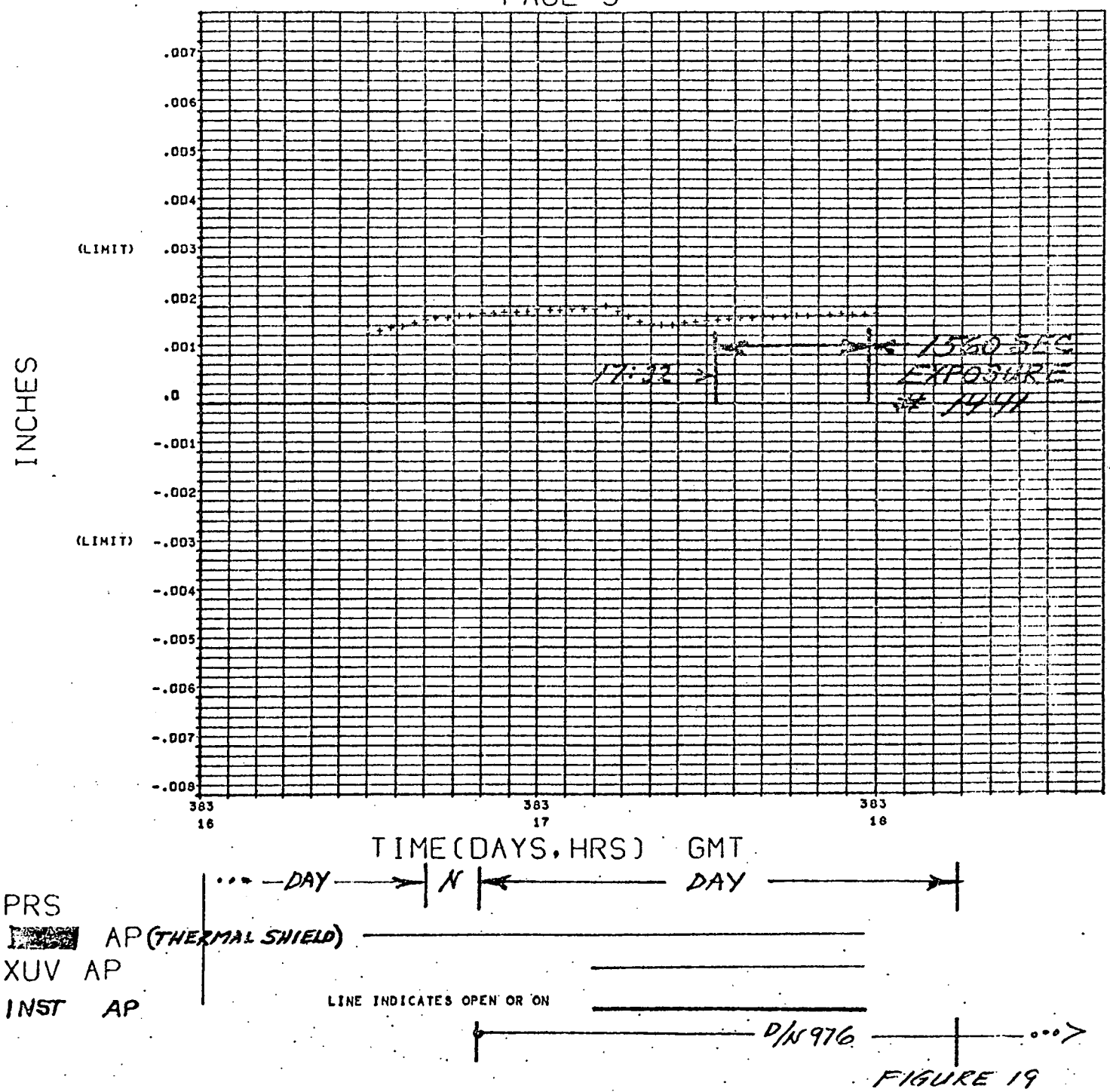


FIGURE 19

S082B THERMAL DISTORTION
SLIT IMAGE ON FILM, HORIZONTAL POSITION, LEFT SIDE
PAGE 9

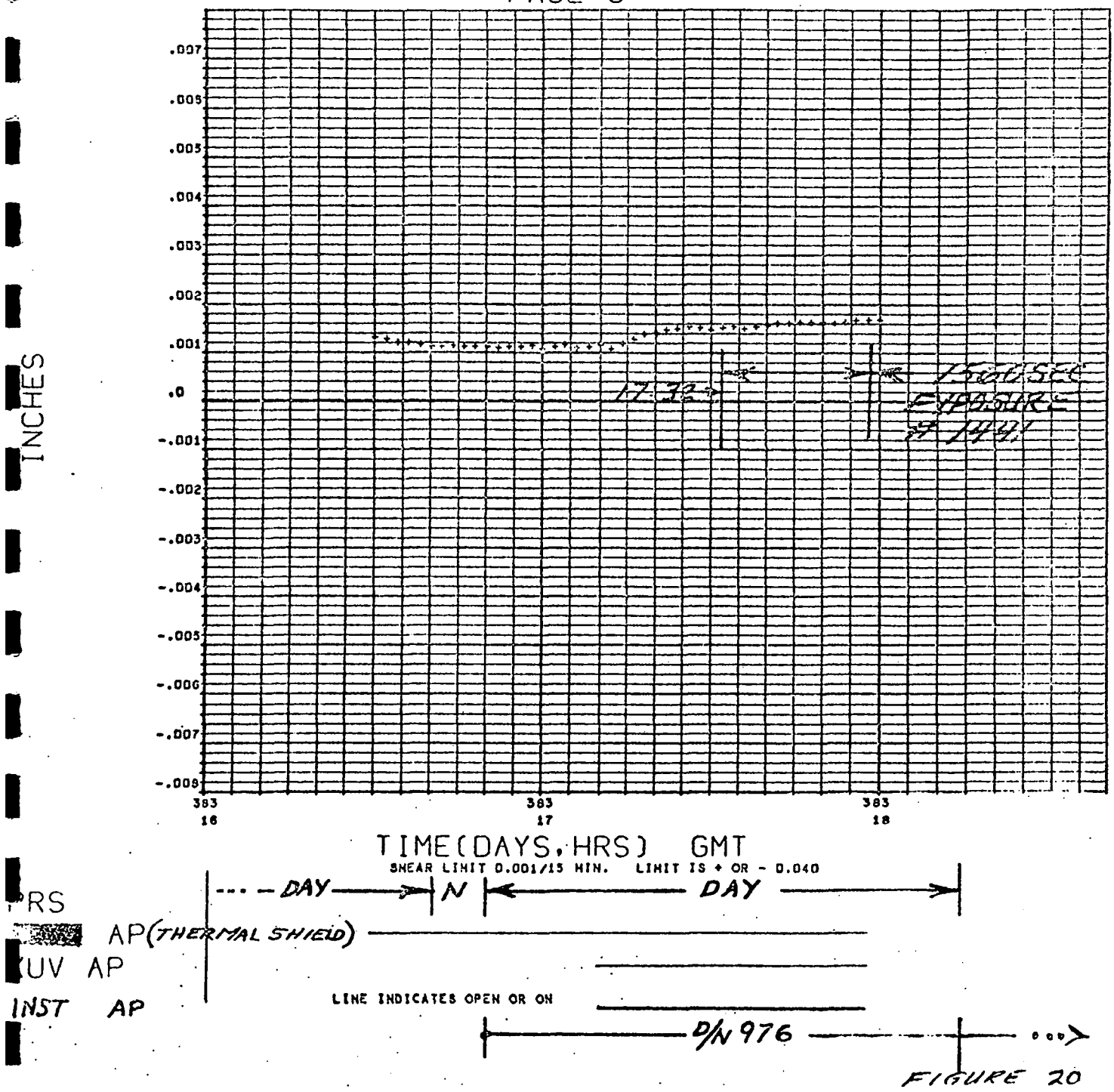


FIGURE 20

S082B THERMAL DISTORTION
SLIT IMAGE ON FILM, VERTICAL POSITION, LEFT SIDE
PAGE 7

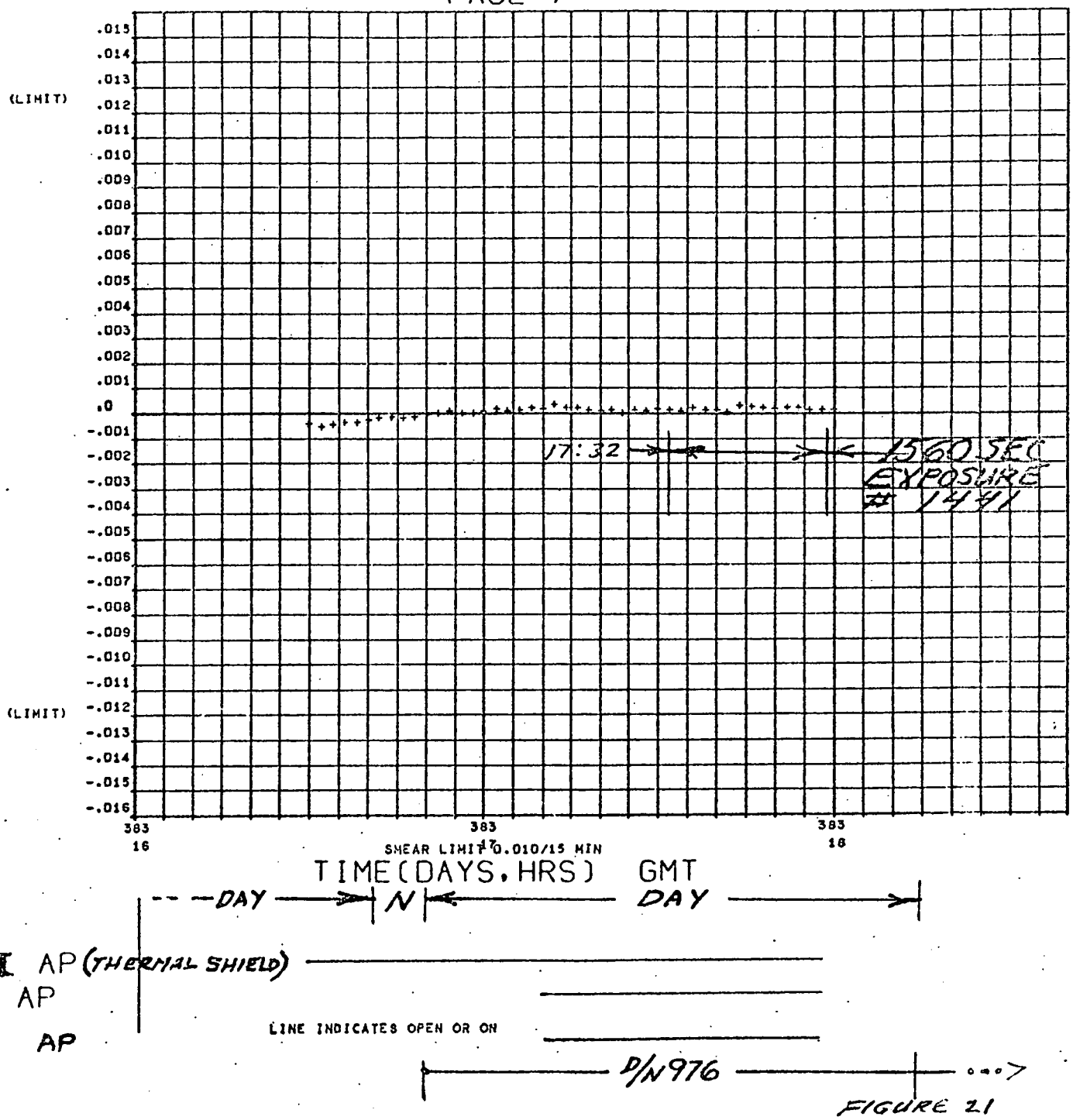


FIGURE 21

S082B THERMAL DISTORTION
SLIT IMAGE ON FILM, FOCUS, RIGHT SIDE
PAGE 4

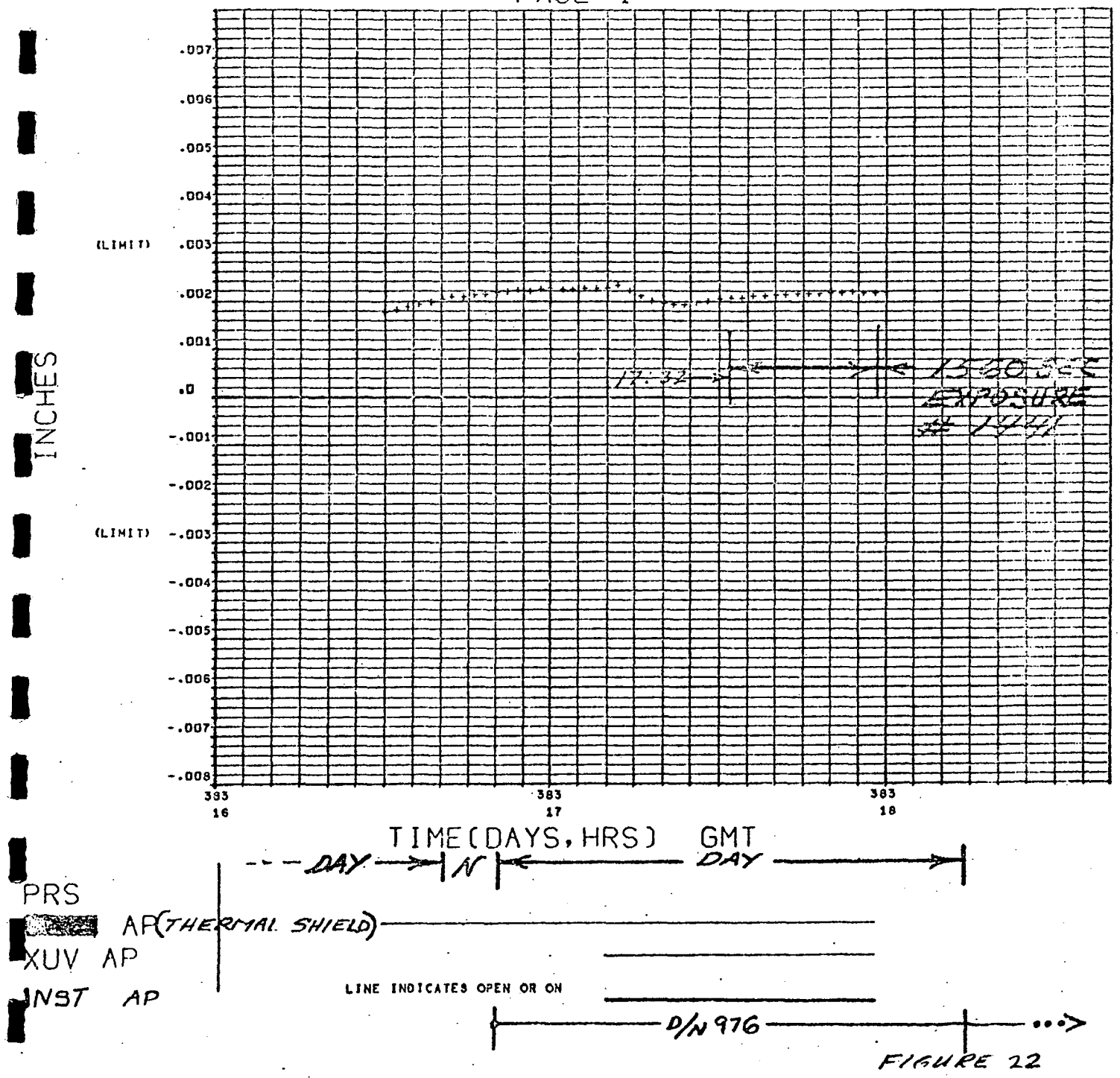


FIGURE 22

S082B THERMAL DISTORTION
SLIT IMAGE ON FILM, HORIZONTAL POSITION, RIGHT SIDE
PAGE 8

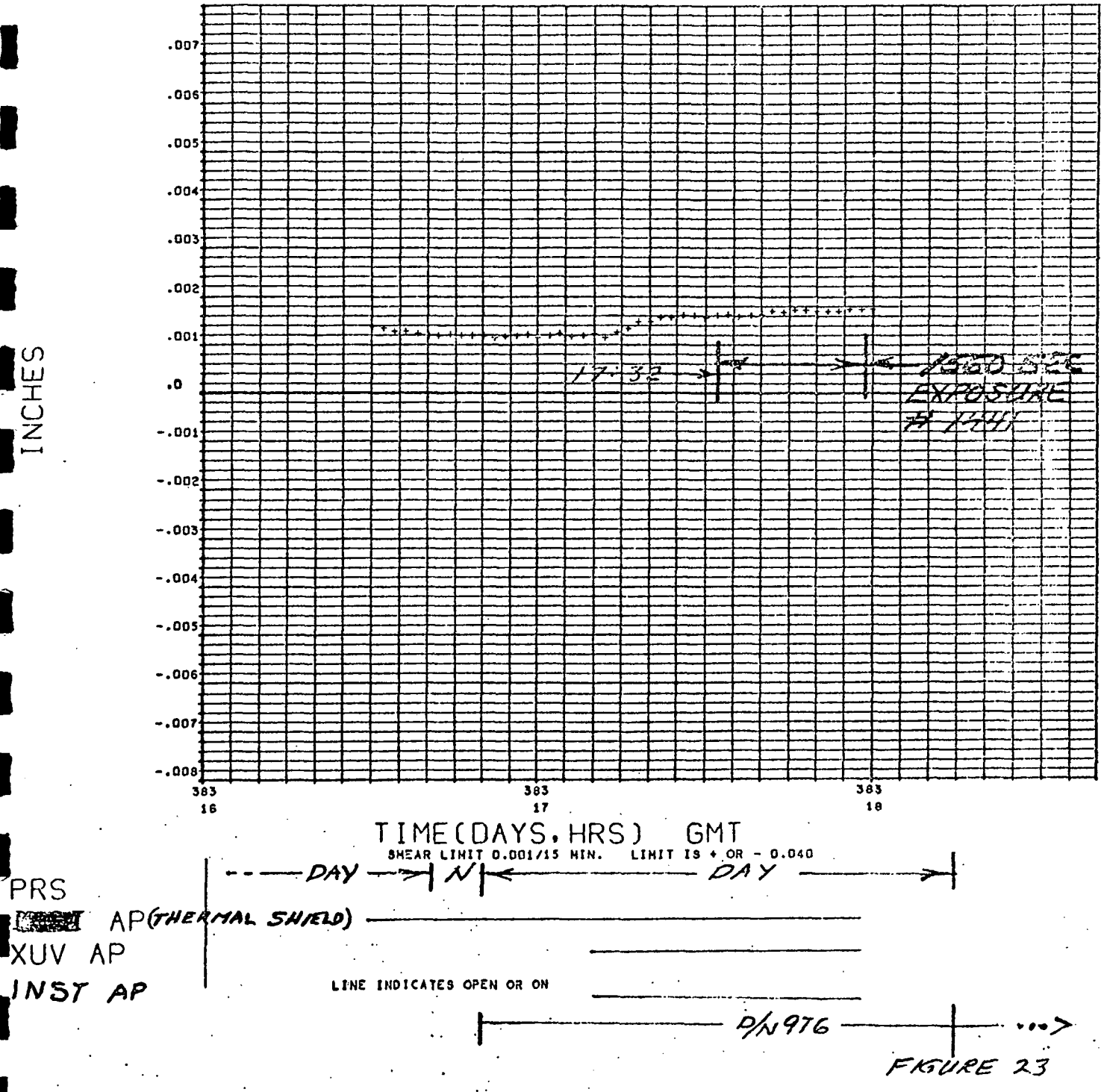


FIGURE 23

S082B THERMAL DISTORTION
SLIT IMAGE ON FILM, VERTICAL POSITION, RIGHT SIDE
PAGE 6

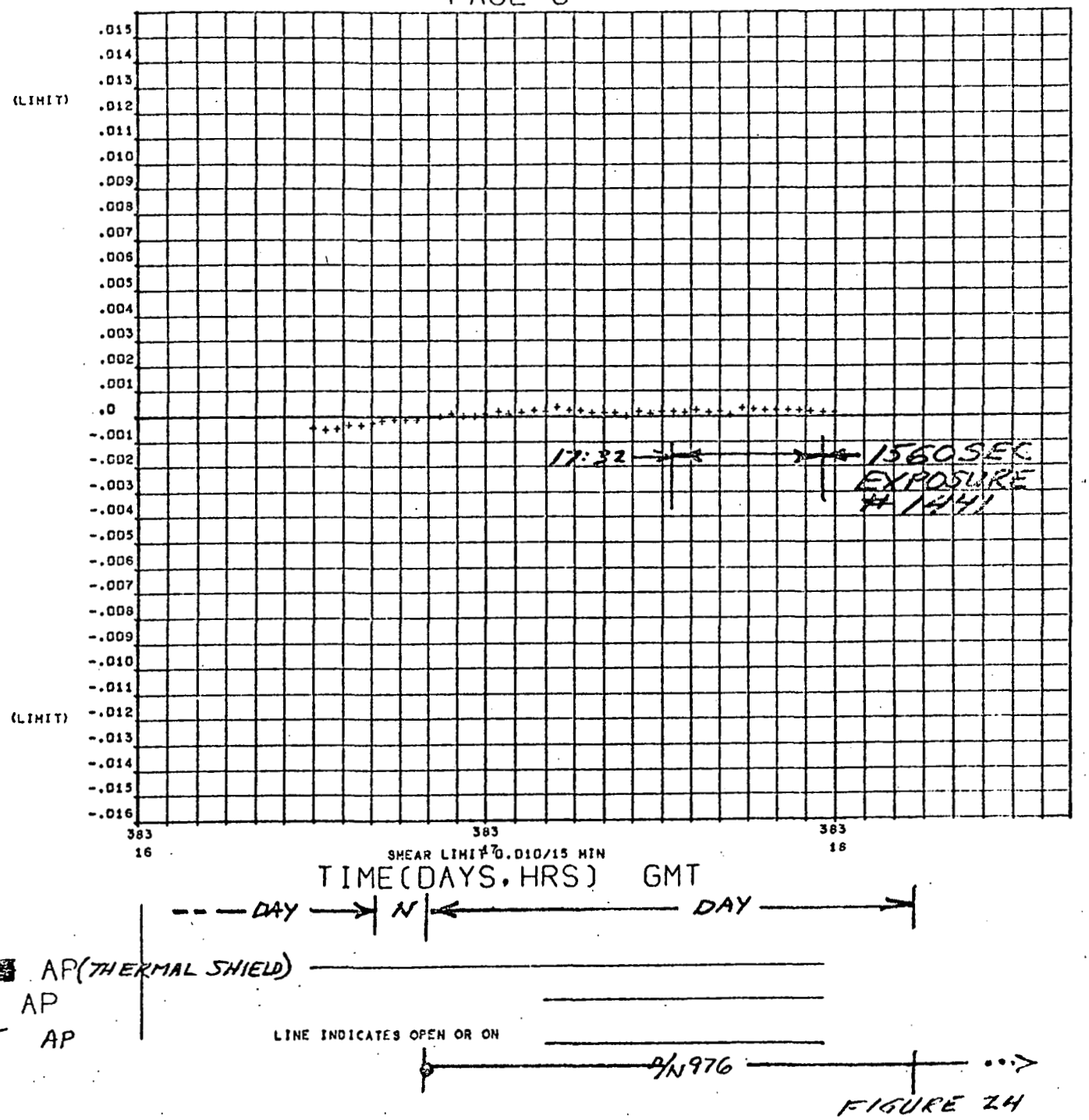
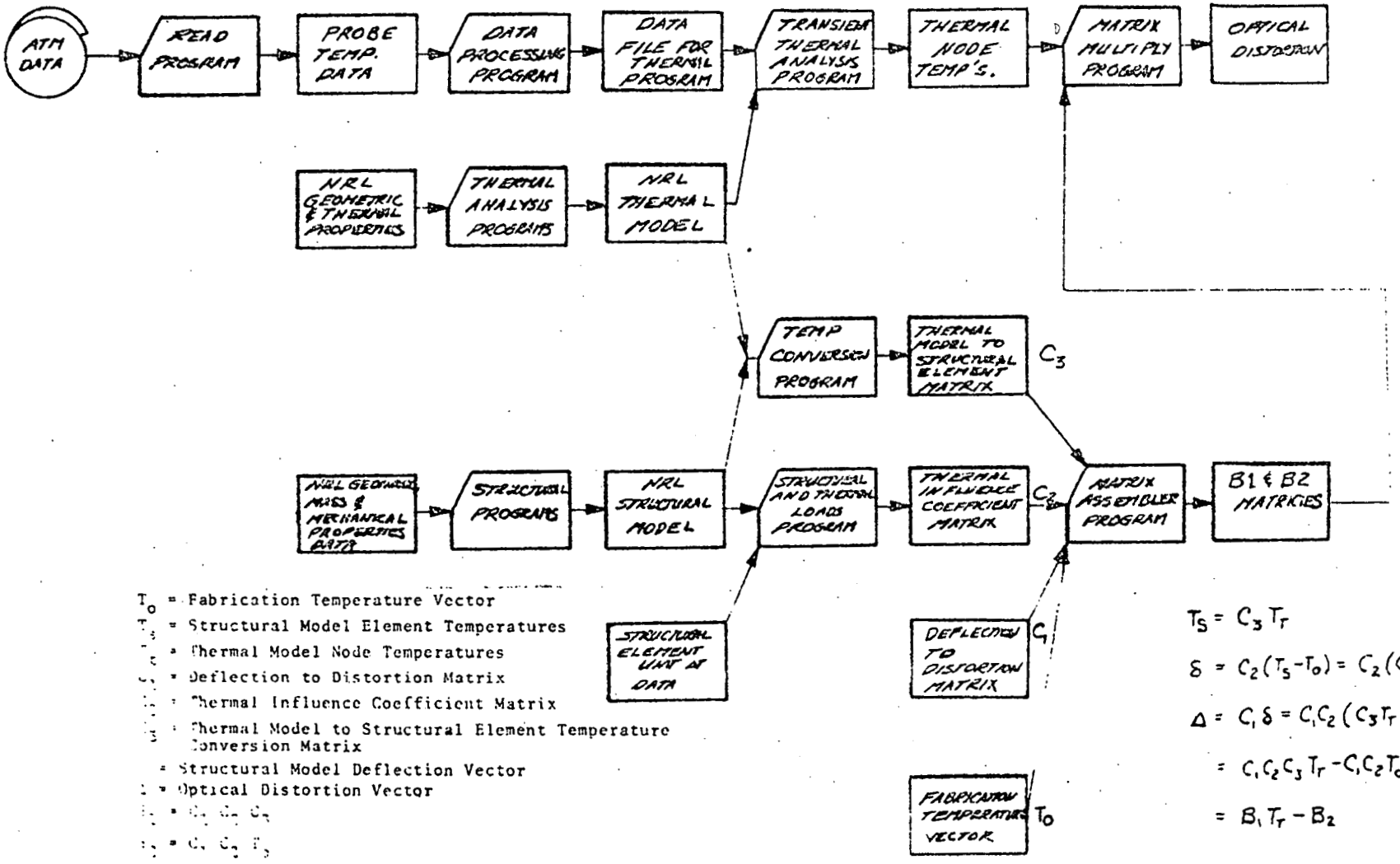


FIGURE 24

NRL THERMAL DISTORTION ANALYSIS



T_o = Fabrication Temperature Vector
T_s = Structural Model Element Temperatures
T_T = Thermal Model Node Temperatures
C_1 = Deflection to Distortion Matrix
C_2 = Thermal Influence Coefficient Matrix
C_3 = Thermal Model to Structural Element Temperature Conversion Matrix
δ = Structural Model Deflection Vector
Δ = Optical Distortion Vector
B_1 = $C_1 C_2 C_3$
B_2 = $C_1 C_2 T_o$

$$T_S = C_3 T_T$$

$$\delta = C_2 (T_S - T_o) = C_2 (C_3 T_T - T_o)$$

$$\Delta = C_1 \delta = C_1 C_2 (C_3 T_T - T_o)$$

$$= C_1 C_2 C_3 T_T - C_1 C_2 T_o$$

$$= B_1 T_T - B_2$$

FIGURE 25

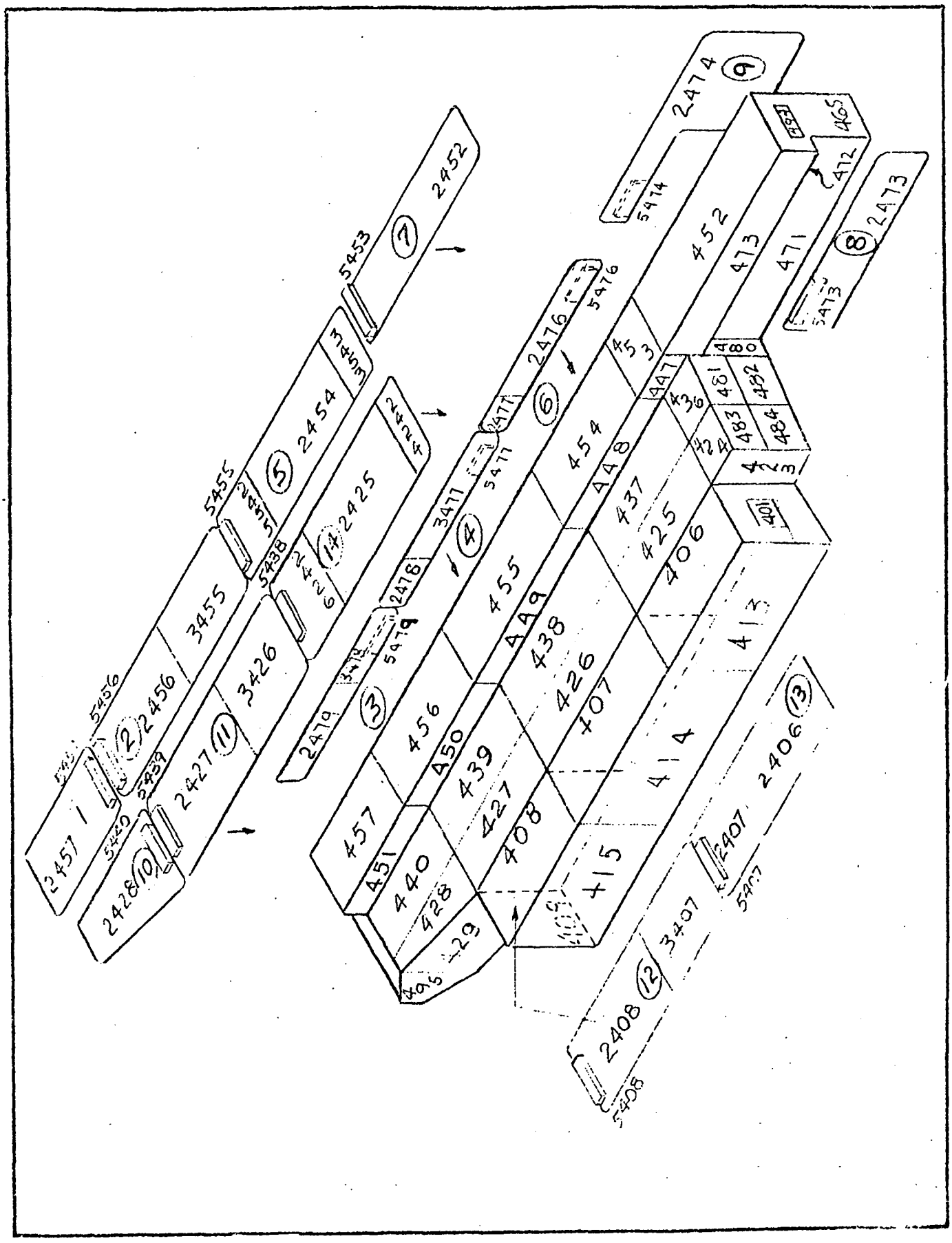


Figure 26 NRL B Spectrograph and XUV Monitor Nodes

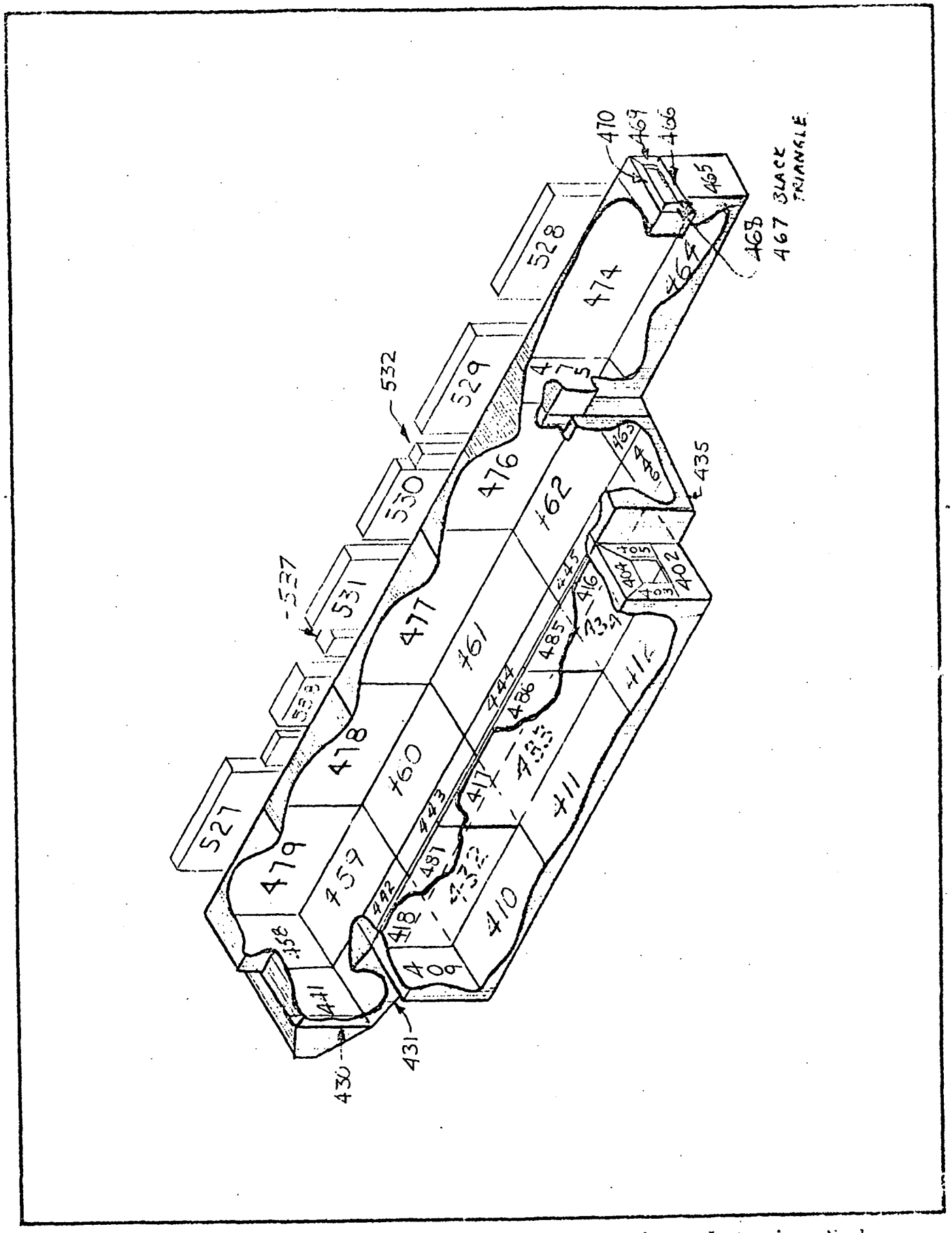


Figure 27 NRL B Spectrograph and XUV Monitor-Interior Nodes

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2-66

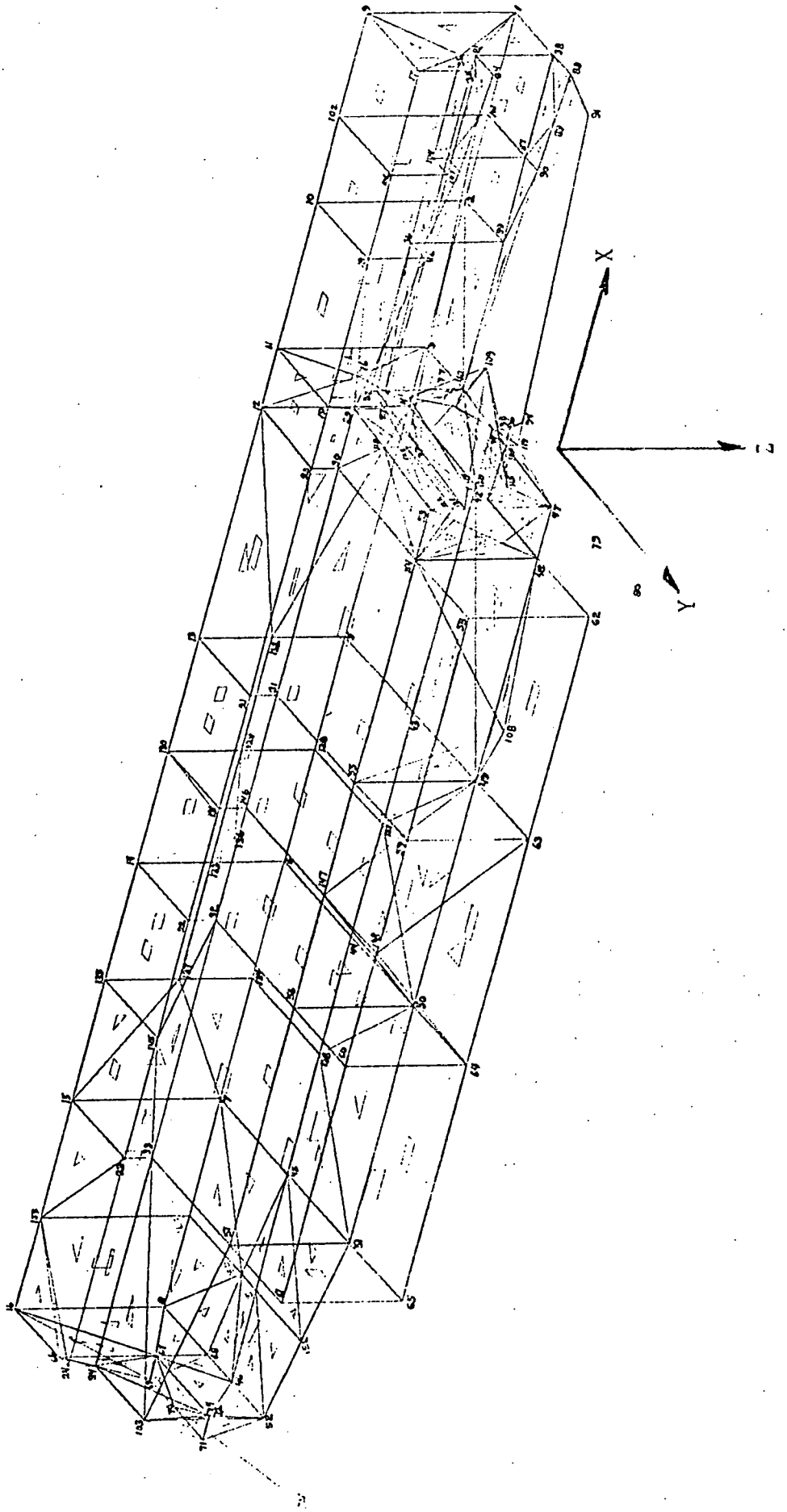

FIGURE 28

NRL-B SPECTROGRAPH AND XUV MONITOR STRUCTURAL MODEL

Appendix B

STRUCTURAL ANALYSIS TASK DESCRIPTION

NRL/ATM

INSTRUMENTS THERMAL DISTORTION

COMPUTER PROGRAM DEVELOPMENT

STRUCTURAL ANALYSIS TASK DESCRIPTION
NRL/ATM
INSTRUMENTS THERMAL DISTORTION
COMPUTER PROGRAM DEVELOPMENT

There are six basic tasks to be accomplished in the structures area in order to generate the optical distortion parameters for any given ATM instrument. These six tasks are listed below followed by a detailed description of both the task itself and the effort required to accomplish the task.

1) Update Structural Model

2) Develop C3 matrix (thermal to structural model conversion matrix).

3) Generate C2 matrix (thermal deflection influence coefficient matrix).

4) Generate C1 matrix (distortion influence coefficient matrix).

5) Combine the above matrices (C1, C2, & C3) to produce the optical distortion parameters and also to form the B1 and B2 matrices.

6) Generate check cases using the finite elements structures program to verify that the C2 matrix was generated correctly and that the multiplication of the matrices gives the correct optical distortions, i.e. $\Delta = C1C2(C3T_t - T_o)$.

Task No. 1 - Update Structural Model

Updating the structural model involves modifying the analytical model used for stress and dynamics analysis. First the model is checked to ascertain that the basic structure conforms to the final drawings with emphasis on obtaining accurate distortions due to thermal gradients in the structure. Where necessary, additional structural detail is added consistent with obtaining the desired optical distortion parameters.

After all of the desired changes have been incorporated in the analytical model an internal loads analysis is conducted with loads applied at each structural degree of freedom. This internal loads analysis is accomplished on the CDC 3800 computer using BBRC's finite element "Loads Program." The purpose for applying a load at each degree of freedom is to verify that the analytical model has structural continuity, i.e., the model is "healthy." A healthy model is indicated by a good balance of applied loads and reactions.

Task No. 2 - Develop C_3 Matrix

The C_3 matrix is used to establish the temperatures of the structural elements based on the temperatures of the effective thermal nodes that surround the element. Only axial and plate elements are considered for thermal distortions because the temperature gradients across beams or torsional elements are considered insignificant. Consequently the thermal model is not modeled in sufficient detail to give temperature gradients across beams or torsional members.

In order to determine which thermal nodes are pertinent in establishing the temperature of a given structural element, stereo plots are made of both the structural and thermal models using the same scale and view angles. The structural and thermal nodes are labeled on the corresponding plots. The plots are then overlayed thereby showing which thermal nodes would be pertinent in establishing the temperature of the structural elements.

In order to determine how effective each of the pertinent thermal nodes are in establishing the structural element temperature two approaches were used. The first approach is based on the element being located in a plane surrounded by four thermal nodes. The element temperature is based on the location of the element within the plane of the four thermal nodes assuming linear temperature gradients. The second approach is based on the thermal node effectiveness being inversely proportional to its distance from the element. This approach was used with two, three or four thermal nodes.

A computer program was written to calculate the effectiveness (coefficients) of the pertinent thermal nodes on each structural element used for thermal distortions. This program generated the C_3 matrix in the form of punch cards. A card was punched for each element and contained the following information:

1) Element number

2) Structural nodes defining the element

3) Pertinent thermal nodes and corresponding coefficients

4) Coefficient of thermal expansion.

Task No. 3 - Generate C_2 Matrix

The C_2 matrix is the thermal deflection influence coefficient matrix. It is obtained by determining all of the structural deflections for a unit temperature differential applied to each of the structural elements used for thermal distortions. If there are 100 structural elements there will be 100 unit solutions in the C_2 matrix and each solution will contain the structural deflection at each degree of freedom in the structural model. The number of elements used for thermal distortions in the ATM structural models range from approximately 300 to 400. The number of degrees of freedom range from approximately 500 to 600. Therefore the C_2 matrix can contain up to 400 x 600 or 240,000 values. Due to the large size of the C_2 matrix it is stored on magnetic tape.

The C_2 matrix is generated using a modified version of the finite element loads program. The program was modified to produce deflections only and to point out the deflections for the 1st, 21st, 41st, 61st----, etc. condition. The printed data is then used for checking purposes as defined in Task No. 6.

Task No. 4 - Generate C_1 Matrix

The C_1 matrix is the distortion influence coefficient matrix. It is a matrix of coefficients such that when these coefficients are multiplied times the pertinent structural deflection the desired optical distortion parameters are obtained. The C_1 matrix coefficients include the effects of image moments due to mirror rotations, translations, changes in coordinate systems, etc.

Task No. 5 - Combine C_1, C_2 & C_3 to Produce Optical Distortion Parameters and Form B_1 & B_2 Matrices

A computer program (Program Distor) was written to perform the operations:

$$\Delta = C_1C_2(C_3T_t - T_o)$$

$$= C_1C_2C_3T_t - C_1C_2T_o$$

$$= B_1T_t - B_2, \text{ definition of } B_1 \text{ \& } B_2$$

Δ = vector of optical distortion parameters

T_t = vector of thermal node temperatures

T_o = fabrication temperature.

The B_1 & B_2 matrices are produced in the form of punched cards. This data is then used to generate data statements for the final computer program to which orbital temperature data is imput and optical distortion parameters are calculated.

Another computer program which combines the matrices to produce the optical distortion plus the structural deflections is also used. The structural deflections which are calculated by $\delta = C_2(C_3T_t - T_o)$ are used for comparison with the check case as defined in Task No. 6.

Task No. 6 - Generate Check Cases

The finite element loads program is used to run check cases for verification of the C_2 matrix and also to verify that the combining of the matrices in Task No. 5 produces the correct optical distortion parameters. One check case is run using the same vector of thermal node temperatures as was used in Task No. 5 and the structural deflections using these two approaches are compared. Also the pertinent structural deflections are then multiplied times the C_1 matrix to verify that the correct optical distortions are being calculated by the "Distor" program as defined in Task No. 5. Other check cases are run by applying a unit temperature differential to the 1st, 21st, 41st, 61st--- etc., elements and then the deflections from these conditions are compared to the deflections obtained during generation of the C_2 matrix as described in Task No. 3.