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INTEROFFICE MEMORANDUM

Date: June 3, 1969

Page 1 of 1 Pages

To: [redacted] Facility: Burlington Total 36 Pages

From: [redacted] Facility: Palo Alto

Subject: Transmittal of 6th Data Analysis Report

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Enclosed are [redacted] copies of the 6th Data Analysis Report in accordance with the contractual requirement. An additional copy is included for [redacted] This report concludes the requirement for six Data Analysis Reports.

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Enclosures (9)

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FLIGHT DATA THERMAL ANALYSIS REPORT - CR-6

MAY 1969

by

[redacted]

for

ITEK CORPORATION
Project [redacted]

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CONTENTS

1. Summary and Conclusions

2. Technical Discussion

2.1 Thermal Math Model
2.2 Surface Finishes
2.3 Temperature Sensor Locations
2.4 Accuracy of Telemetered Temperatures
2.5 Comparison of Predicted with Measured Temperatures
2.5.1 Temperatures as a Function of β
2.5.2 Thermal Behavior of Specific Components

A. Lens Cells
B. Rails and Transports
C. Auxiliary Optics
D. Takeup Cassettes
E. Delta Structure
F. Drum Support Structure
G. Auxiliary Electronics

3. Recommendations

4. References

[redacted]

1. SUMMARY AND CONCLUSIONS

Thermal design features and behavior of the CR-6 payload are discussed. This was the first system to be coated with the "no gold" surface finish which used black paint, aluminum foil tape, and multi-layer superinsulation materials in place of the previous vacuum deposited gold plating and paint finishes. This was the first system to have the lens cell assemblies wrapped in superinsulation. Both these features are incorporated on subsequent payloads.

The overall operating temperatures were lower than those experienced for CR-3, CR-4, and CR-5, and were similar to those of CR-2. The average instrument temperatures ranged from $68^{\circ}F$ to $58^{\circ}F$ over the mission. This is slightly below the general specification limits of $70 \pm 10^{\circ}F$ but presented no mechanical problems. Tape recorded data for the lens cells indicated lesser end-to-end temperature gradients than previously experienced; transient temperature fluctuations of $1^{\circ}F$ or less were noted over a typical revolution as contrasted with $3^{\circ}F$ previously. Laboratory test data indicates that a $\pm 0.5^{\circ}F$ periodic temperature fluctuation will cause a corresponding time dependent change in the focal plane position of $\pm .00026$ inches.

Recommendations are also presented and discussed concerning several areas of potential system improvements. These include recommendations for improving the precision and accuracy of flight temperature data, for obtaining comprehensive thermal data from HIVOS tests, and for reducing in-flight periodic temperature fluctuations of the transport assemblies and IMC support structure.

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2.1 THERMAL MATHEMATICAL MODEL

Temperature predictions for the J-3 camera system have been obtained from a thermal mathematical model of the entire payload section. This model is described in detail in Reference 1. In general, the payload section is represented by 104 isothermal nodes, with the greater detail applied to the lens cells and associated structure, the lesser to the airframe structure and associated black boxes. Other sections of the payload section have been analyzed by "independent" thermal models which take as their boundary conditions outputs of the general thermal model; these include take-up cassette studies, main and auxiliary electronics box assemblies, lens cell temperature gradient studies (References 2, 3), and lens cell transient temperature studies (Ref. 23). For purposes of this report no differentiation will be indicated as to the source of the temperature predictions.

2.2 SURFACE FINISHES

The "no-gold" surface finish was applied to CR-6. This is a radical departure from the finishes used on all previous J-3's and J-1's. Rather than the magnesium barrel sections being gold plated externally and internally, they were left in the Dow 17 process state. The internal radiation shields were "beefed up" with the application of several layers of superinsulation material $\pm 45^{\circ}$ about the Y axis. Ring sections and other exposed internal structure were coated with Mystic 7402 aluminum foil tape to reduce their emissivity. Five layers of superinsulation (aluminized mylar sheet) were wrapped around the lens cell and tail cone in both instruments based on test results presented in Reference 22, The external finish consisted of black paint $\pm 45^{\circ}$ about the Z axis and aluminum foil tape $\pm 45^{\circ}$ about the Y axis. The surface finish is indicated in Figure 1. The "no-gold" finish is typical for CR-6 and subsequent.

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2.3 TEMPERATURE SENSOR LOCATIONS

The 16 CR-6 camera system temperature sensors and their locations are as follows:

Forward Instrument - #1

1 Lens cell - on magnesium casting
2 Lens cell - on tail cone approximately 6 inches from scan head
3 Rear rail - on back of rail near center
4 Auxiliary optics camera - on housing
5 Drive motor - on housing
6 Front rail - on back of rail near center
7 Delta structure - near top support
8 Support structure - on side centered between motor and shuttle

Aft Instrument - #2

1 Lens cell - on magnesium casting
2 Lens cell - on magnesium casting
3 Rear rail - on magnesium casting
4 Auxiliary optics camera - on magnesium casting
5 Drive motor - on magnesium casting
6 Front rail - on magnesium casting
7 Supply casette - on cover
8 Auxiliary electronics box - near power amplifier

Figures 2 and 3 show the instrument sensor locations. In addition to these, temperatures of takeup casettes, payload structure, and "black boxes" were monitored. The tail cone temperature sensor now indicates the approximate average tail cone temperature, making this measurement more directly useful for temperature versus lift calculations, less useful for indicating the lens cell-to-tail cone temperature gradient.

2.4 ACCURACY OF TELEMETERED TEMPERATURES

Before presenting the flight data, an indication of its possible accuracy is in order. Based on an estimated telemetry accuracy of 5% full range and a temperature sensor output of 0 → 5 volts, the voltage reading may be in error as much as 0.25 volt. This corresponds to a temperature range of 5°F.

Because of recorded temperature "differences" between sensors during ground operation under conditions where such differences could not exist, a system of "normalizing" the temperature sensors against each other has been adopted at A/P. This involves establishing "plus" or "minus" temperature corrections for each sensor based on averaged ground readout and then applying this correction to the flight readout. While this technique provides an improved indication of flight temperature gradients, it is far from an ideal system. Unfortunately, temperature fluctuations less than the $5^{\circ}F$ telemetered accuracy have a marked effect on system optical performance.

Thermistors have been specified to replace the existing temperature sensors on the lens cells and tail cones only for CR-7 and up. (Ref 27) The greater stability and sensitivity of the new thermistors will allow greater confidence in telemetered temperatures.

2.5 COMPARISON OF PREDICTED WITH MEASURED TEMPERATURES

2.5.1 Temperatures as a Function of β

The comparison of temperatures predicted with the corrected thermal mathematical model to the measured temperatures are presented in Figures 4 through 11, as a function of the orbit solar incidence angle β. This angle is defined as the angle between the orbit plane and earth-sun line. β is positive if the vehicle appears to be moving counter-clockwise when viewed from the sun, negative if clockwise. This angle is both an indication of the total solar incident flux on the vehicle (increases with higher numerical β's) and the relative position of the maximum flux on the vehicle with respect to the -Z axis.

Measured temperatures in the figures are shown as "x's". Where corresponding temperature data from CR-1, CR-2, CR-3, CR-4, and CR-5, is available, it is presented in these figures as dashed lines and identified by system number. Study of Figures 4 through

11 indicates that the CR-6 instrument temperatures most closely matched those of CR-2, of all the previous J-3 systems. The overall instrument average temperatures ranged from approximately 68°F for β = -33° to 58°F for β = -15° at the end of the mission. Contrary to previous missions, a temperature rise was observed for most temperature sensors after separation of the "A" SRV at β = -25° (Event 1 or E1). The CR-6 system operated below the general specification nominal temperature average of 70°F during the active mission and slightly below the minimum specified temperature of 60°F near the end of the "B" mission phase.

2.5.2 Thermal Behavior of Specific Components

A. Lens Cells

This was the first system flown with the superinsulation installed on the lens and tail cone; the resultant temperature transient fluctuations and gradients are greatly improved from the previous flights. Transients of ±0.5°F were observed in contrast to ±1.5°F previously noted. Tail cone-to-lens cell gradients were reduced from approximately 6°F to less than 3°F at corresponding β angles.

The lens cell and tail cone temperatures for the No. 1 and No. 2 instruments are presented in Figures 4 and 5, for the entire mission. Tape recorded data are presented in Figures 12 through 15 for lens cells and tail cones for revolutions 8, 56, 72, and 137. The latter points are from the vehicle tape recorder.

Figure 4 indicates a temperature rise near the middle of the mission. This occurs after separation of the A SRV at β = 25, and is an opposite effect to the 2 to 5°F temperature drop previously observed. At this time the exact reason for this is unknown. Of the various theories applied, the most reasonable to this writer is that the effect is due to changing internal heat transfer paths upon separation of the "A" SRV. The new vehicle surface finishes and insulation contribute to this. The thermal mathematical models are of little assistance as the uncertainties in temperature prediction ($\pm 12^{O}F$ to $\pm 15^{O}F$) are greater than the noted temperature rise ($\approx 5^{O}F$). In addition, the various models have not been able to predict the previously observed temperature drops.

The observed temperature fluctuations of $\pm 0.5^{O}F$ were input to equation 5-5 of Reference 22 in order to relate the transient focal plane position to the transient temperatures.

The results of this computation indicate that changes in focal plane position remained with $\pm .00026''$ of the set point.

B. Rails

Variations in the rail temperature data (Figure 6) is similar to that experienced on previous missions and is the thermal reaction to day-night variations in incident heat flux to the vehicle exterior. Temperature fluctuations up to $8^{O}F$ over one orbital revolution can be observed from the tape recorded data; a sample of this data is presented in Figures 16 and 17. These fluctuations have not been identified as a problem area, but represent an aspect of the instrument thermal control which could be improved. This improvement would take the form of insulation blankets around the shuttle assemblies. The temperature gradient along the rails, is not measured in flight and must be deduced from other data points and mathematical models. Such deduction indicates a maximum gradient of $13^{O}F$ near the beginning of the mission dropped off to approximately $6^{O}F$ at completion.

C. Auxiliary Optics

As the auxiliary optics are located in proximity to the vehicle exterior skins, a marked variation with β angle changes is expected. This is demonstrated in Figure 7 for the aft A.O., located on the side of the vehicle exposed to periodic solar radiation, and fluctuating over a 6 or $7^{O}F$ temperature range.

As described in general previously, this component rose in temperature approximately 10°F after SRV "A" separation. The subsequent temperature history closely followed the CR-2 data.

D. SRV Take-up Casettes

The "A" SRV takeup casette temperatures indicate that the thermostat activated the heater at 50°F as shown in Figure 8. This sequence is typical of all flights.

The "B" SRV takeup casette operated at a lower temperature level, 65°F, than CR-5 early in the mission, then sought a level approximately 10°F higher after separation of the "A" SRV. As noted in Paragraph A above, the reasons for this rise are not completely understood at this time, although they are obviously associated with the separation.

E. Delta Top

A spread of almost 20°F in this temperature is shown in Figure 9. Temperature fluctuations of 35°F to 40°F over a single revolution have been indicated by tape recorded data from previous flights. The IMC mechanism is attached to the delta structure at this temperature sensor location and the indicated fluctuations, although not identified as a problem area, should be considered for missions where stereo angle is of major consequence.

F. Drum Support Structure

The relatively stable temperatures indicated in Figure 9 are indicative of the average system temperatures. Investigations performed in conjunction with preparation of the CR-5 Data Analysis Report (Ref. 26) indicate that the temperature of this entire structure is nearly uniform, and relative unaffected by the temperature gradients existing across the transport assembly.

G. Auxiliary Electronics Box (AEB)

This temperature sensor is located in proximity to the high efficiency amplifiers and indicated temperatures (78°F to 60°F near mission completion) indicate nominal operation. Temperatures are presented in Figure 10.

H. Supply Casette

The supply casette (Figure 10) operated at approximately 60°F during the "A" mission phase, then at approximately 62°F during the "B" phase. For the "A" phase, this indicates that film was spooled off at 60°F, passed through the 60°F rails, through the 65°F "B" takeup casette, and was ultimately stored at 50°F in the "A" takeup. For the "B" phase, film was spooled off at 62°F, passed through the 62°F rails, and was stored at 75°F in the "B" takeup casette.

These relatively even temperatures are in contrast to the CR-5 mission where, during the "A" phase, film was stored at a temperature of 20° to 30°F lower than supply or peak values. This has not been identified as a problem area, but suggests investigations of temperature effects on film. Such investigations were proposed in Reference 28 and are in process.

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3. RECOMMENDATIONS

3.1 TEMPERATURE DATA

Consideration should be given to improvement of the temperature data attainable from these studies. Presently, the orbital temperature level changes and fluctuations of importance to optical performance are of the same order as the thermal instrumentation accuracy.

Two recommendations have been made to the program office regarding this subject:

A. <u>Improvement to Precision and Accuracy of Existing Temperature Measurement System</u>

The replacement of existing lens cell and tail cone temperature sensors with Fenwal K563 thermistors is being implemented on CR-7 and up. The narrower total temperature range ($\simeq 50^{o}F$ versus $100^{o}F$ previously), the higher sensitivity ($\simeq$ 70 ohms/^{o}F versus $\simeq$ 8 ohms/^{o}F), and the greater stability of the new sensors combine to reduce the uncertainties associated with the indicated flight data. This recommendation was made in Reference 27.

B. <u>Improvement in Thermal Data Obtained from HIVOS "Production" Tests</u>

Improvements in the thermal data obtained from presently scheduled HIVOS tests would add significantly to our knowledge of temperature levels and gradients in the J-3 system. This will require the installation of 30 to 50 calibrated thermocouples to the instruments, associated structure, and shielding. Data would be recorded continuously during operation at 3 simulated β conditions.

In addition to allowing comparisons to be made to flight temperature sensor readings, these tests would produce data relating to thermal behavior where thermal predictions or previous flight data have not and/or cannot provide this information. This includes temperature gradients across the transport assembly,

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transient temperature response of the drum, and others. This recommendation was made in Reference 29. It has not been implemented.

3.2 THERMAL INSULATION OF SHUTTLE ASSEMBLIES

Although not positively identified as contributing to performance degradation, temperature gradients and transient fluctuations exist across and throughout the shuttle assembly, respectively. Gradients up to 20^{o}F have been recorded across the shuttles; sinusoidal transient temperature level changes of $\pm 5^{o}$F typically occur on a single revolution. These adverse temperature excursions obviously have some effect on the position of the rails relative to the scan head. Improved thermal behavior can be obtained by the addition of insulation blankets around the shuttles, reducing the radiant heat exchange between these units and the nearby structure. Such a recommendation has not been formally transmitted to the project office.

3.3 THERMAL INSULATION OF DELTA STRUCTURE

The delta structure, at the point where the IMC mechanism is attached to it, has been observed to fluctuate in temperature with an amplitude of 40^{o}F over a single revolution. While not presently identified as a problem area, thermal expansion of this structure can affect the stereo angle by as much as $\pm 0.5'$.

An error of similar magnitude can also be introduced into the IMC cam constant when the temperature of portions of the linkage differs by as little as 10^{o}F from the delta structure. These should be considered when knowledge of this angle is critical.

The IMC support is near the delta structure attach point and its resultant thermal response is influenced both by conduction heat transfer from the external skins, via the attach point, and by direct thermal radiation heat transfer between the delta structure and adjacent thermal radiation shields. A simple thermal mathematical model of this area indicates that as much as 70% of the observed 40°F temperature swings can be attributed to the thermal radiation effects. The application of low emissivity aluminum foil tape and/or multilayer superinsulation on the delta structure will serve to significantly reduce the observed thermal transients. More analysis and thermal test data (as could be obtained from HIVOS tests) is required to fully define this potential problem area and establish the effectiveness of proposed thermal fixes. No formal recommendation for this effort has been transmitted to the program office.

4. REFERENCES

1. Vidya Report No. 216, Thermal Design Analysis of J-3 System, by [redacted], 1 April 1966.

2. [redacted] Recommended Location for Backup Thermostat; Results of Parametric Thermal Analysis for Faceplate, [redacted] to [redacted] 10 March 1967.

3. [redacted] Predicted Thermal Behavior, Main and Auxiliary Electronics Box Assemblies, [redacted] to [redacted] 19 August 1967.

4. [redacted], Thermal Surface Finish Anomolies; Flight & Test - J-3, [redacted] to [redacted] 5 April 1967.

5. [redacted] Added Thermal Radiation Protection for J-3, [redacted], 2 August 1967.

6. [redacted] Relocation of Temperature Sensors - CR-2 & Up, [redacted] to [redacted] 11 October 1967.

7. [redacted] Relocated Temperature Sensors, [redacted] to [redacted] 14 November 1967.

8. (A/P), J-3 Power Consumption Estimate, [redacted] to [redacted] 14 November 1967.

9. Thermo-Optical Sensitivity CR-1, [redacted] to [redacted] 22 August 1967.

10. [redacted] Proposal-Petzval Lens Cell Thermal/Optical Test Program, by [redacted] 19 August 1967.

11. [redacted] Correlation of Thermal Analysis with CR-1 Thermal Vacuum Test Results for $\beta = 40$, [redacted] to [redacted] 19 August 1967.

References 1 through 11 comprise the list of references from the following document.

12. [redacted] Flight Data Thermal Analysis Report - CR-1, by [redacted] December 1967.

13. ----, Preliminary Radial Gradient Test Result: [redacted] to [redacted] 13 February 1968.

14. [redacted] Worst-Case Temperature Gradients - Petzval Lens Cell, 20 February 1968.

15. [redacted] Addition of Thermal Radiation Insulation to Light Shields - CR-3 and Up, [redacted] to [redacted] 1 March 1967.

16. [redacted] Thermal Modifications to CR-4, [redacted] to [redacted], 1 March 1967.

17. ----. [redacted] Temperature Sensor Summary, [redacted] to [redacted], 8 March 1968.

18. [redacted] Conversations at A/P Regarding CR-2 Behavior After Mission Completion, [redacted] to [redacted] 10 January 1968.

References 1 through 18 comprise the list of references from the following document.

19. [redacted] Flight Data Thermal Analysis Report - CR-2, by [redacted], 12 April 1968.

20. P.A.D. Final Report No. 250, Petzval Lens Cell Thermal/Optical Test Program, By [redacted] et al, 14 June 1968.

References 1 through 20 comprise the list of references from the following document.

21. [redacted] Flight Data Thermal Analysis Report - CR-3, by [redacted] August 1968.

22. P.A.D. Final Report No. 253, Transient & Off-Axis Petzval Lens Cell Thermal/Optical Test Program, by [redacted] October 1968.

23. Interoffice Memo, Mathematical Model of the Petzval Lens, [redacted] to [redacted], 30 October 1968, [redacted]

24. [redacted] Addition of Superinsulation to Lens Cells - CR-6 & Up, by [redacted] to [redacted] October 23, 1968.

References 1 through 24 comprise the list of references from the following document.

25. [redacted] Flight Data Thermal Analysis Report - CR-4, by [redacted] November 1968, to [redacted]

References 1 through 25 comprise the list of references from the following document.

26. [redacted] Flight Data Thermal Analysis Report - CR-5, by [redacted], January 1969.

27. [redacted] Improvement in Precision and Accuracy of Existing Temperature Measurement System, [redacted] to [redacted] January 17, 1969.

28. [redacted] Thermal/Vacuum Testing of Film, 6 March 1969.

29. Interoffice Memo, Thermal Data Improvement, [redacted] to [redacted] January 14, 1969.

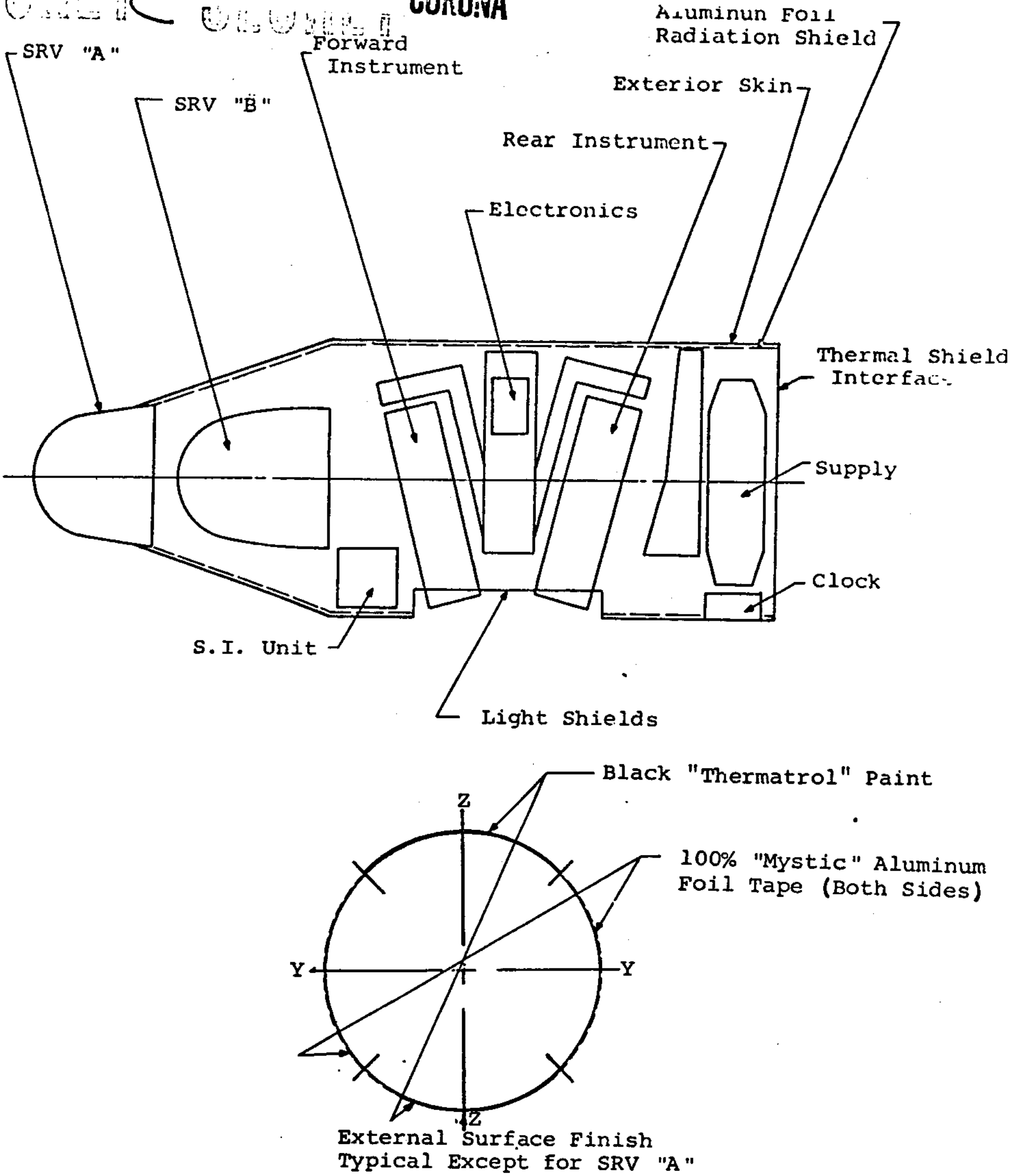

Figure 1 - General Layout and Surface Finish Features

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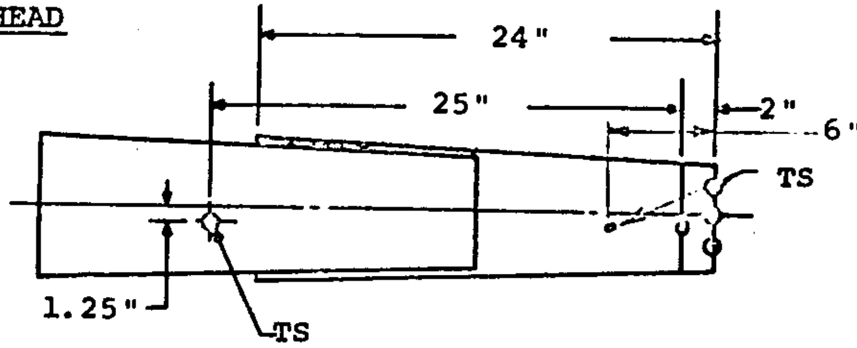
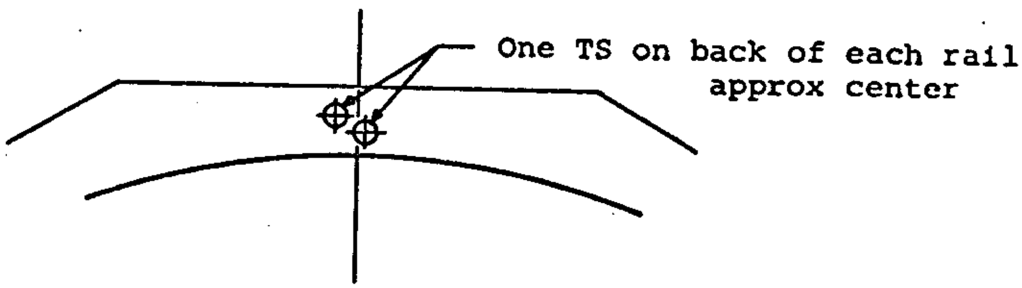
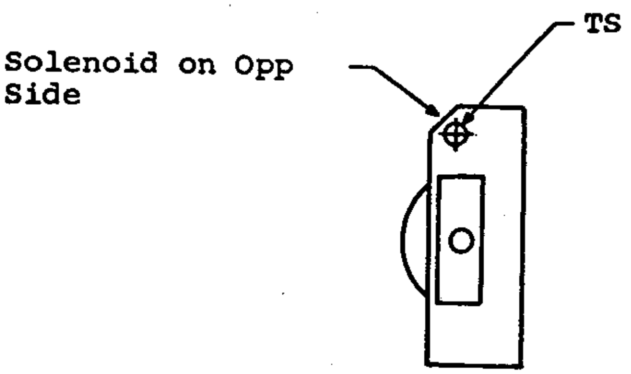
L CELL & S HEAD



RAILS



A.O.



Looking from inside

Figure 2

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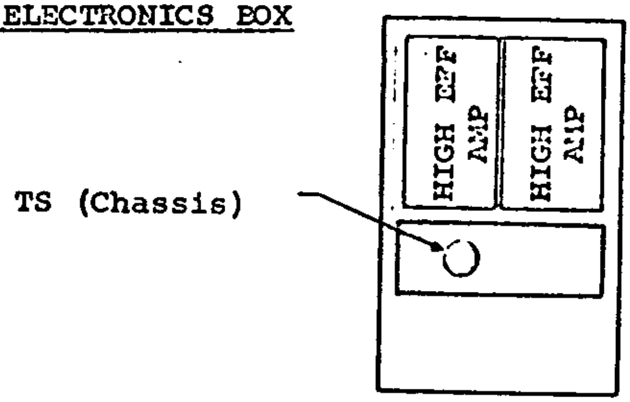
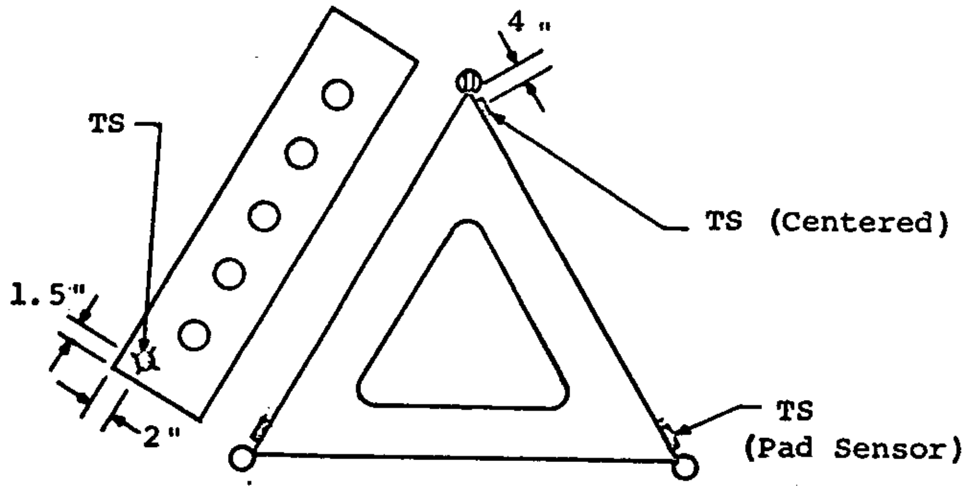
AUXILIARY ELECTRONICS BOX



DELTA



DRIVE HOUSING

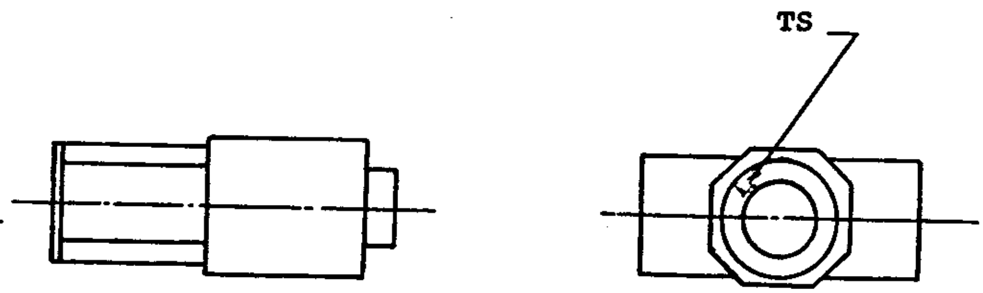


Figure 3

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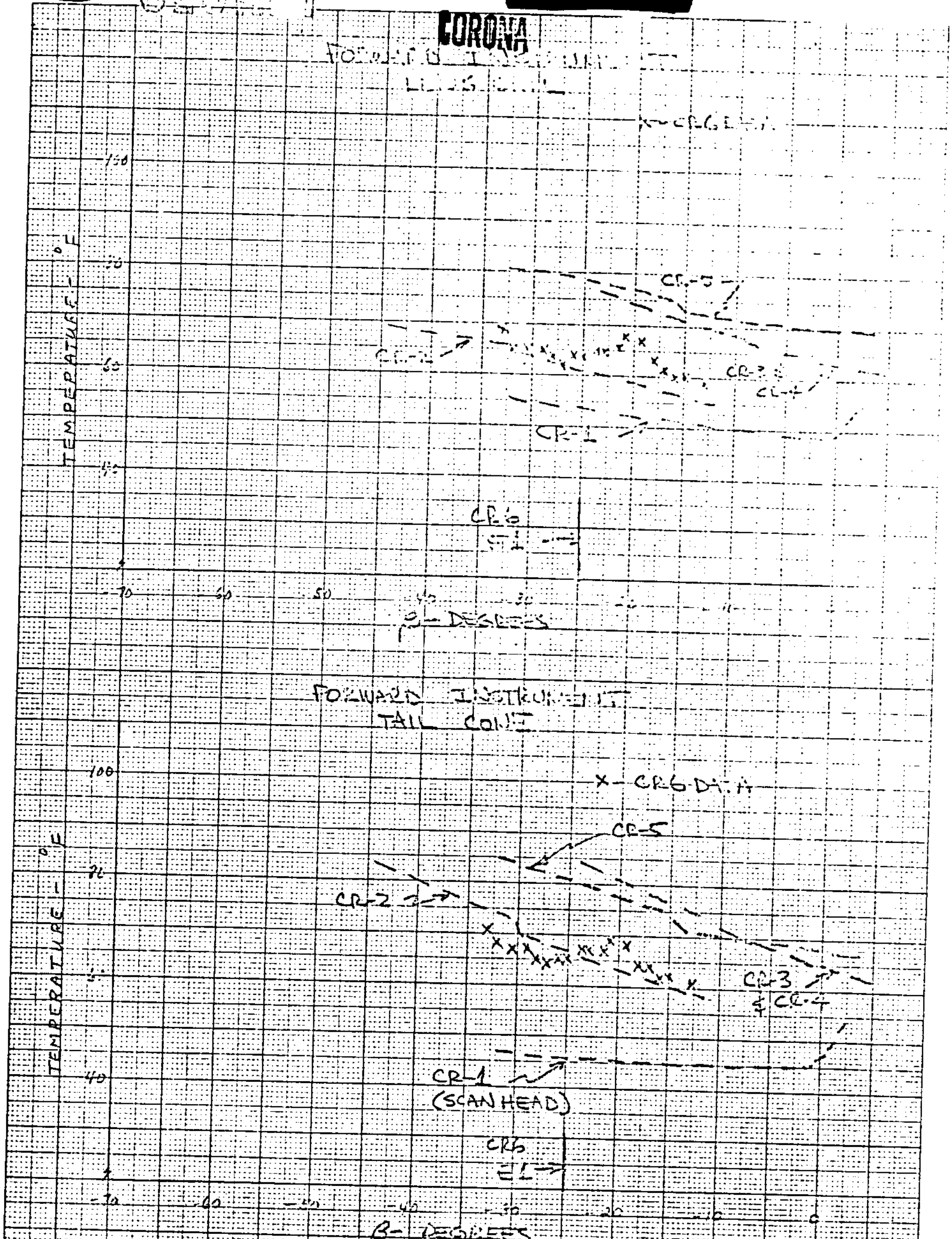

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FIGURE 4

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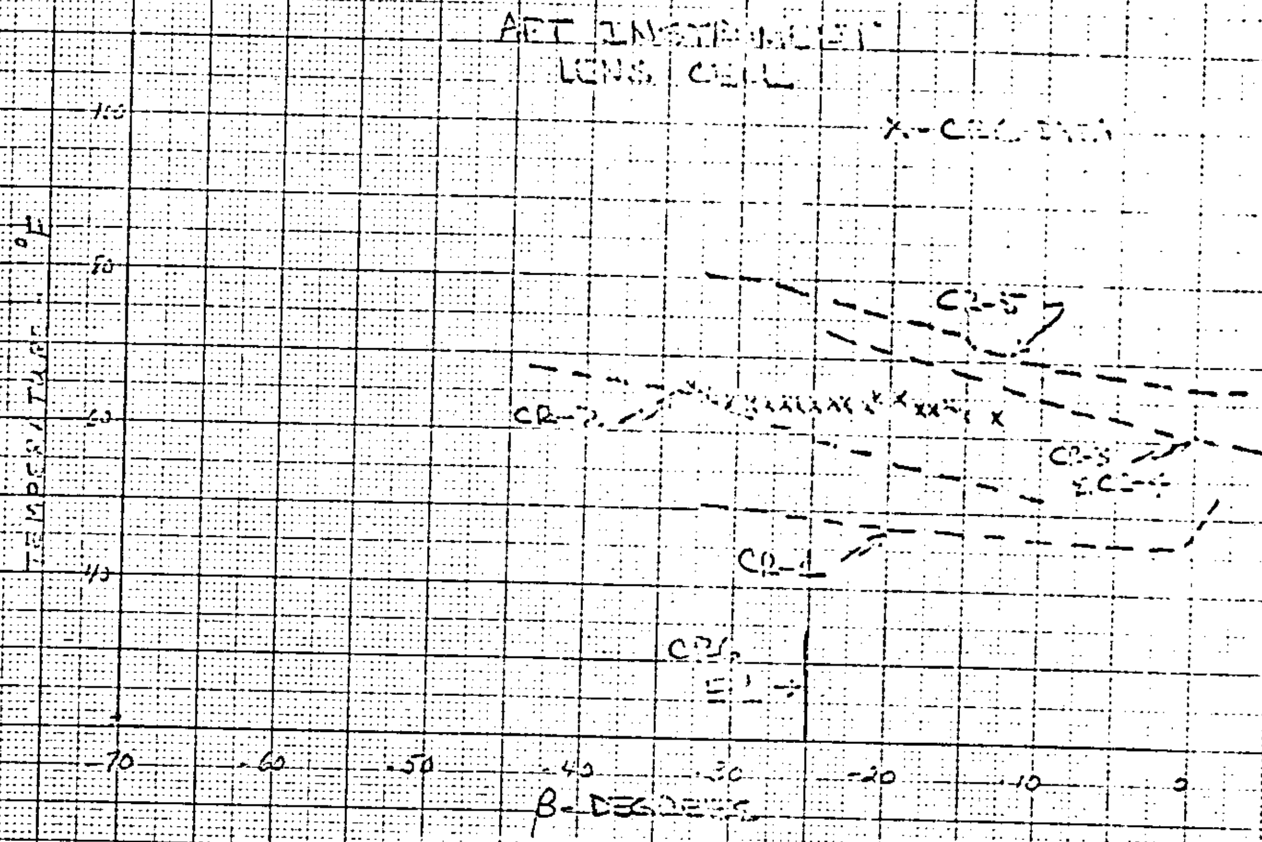

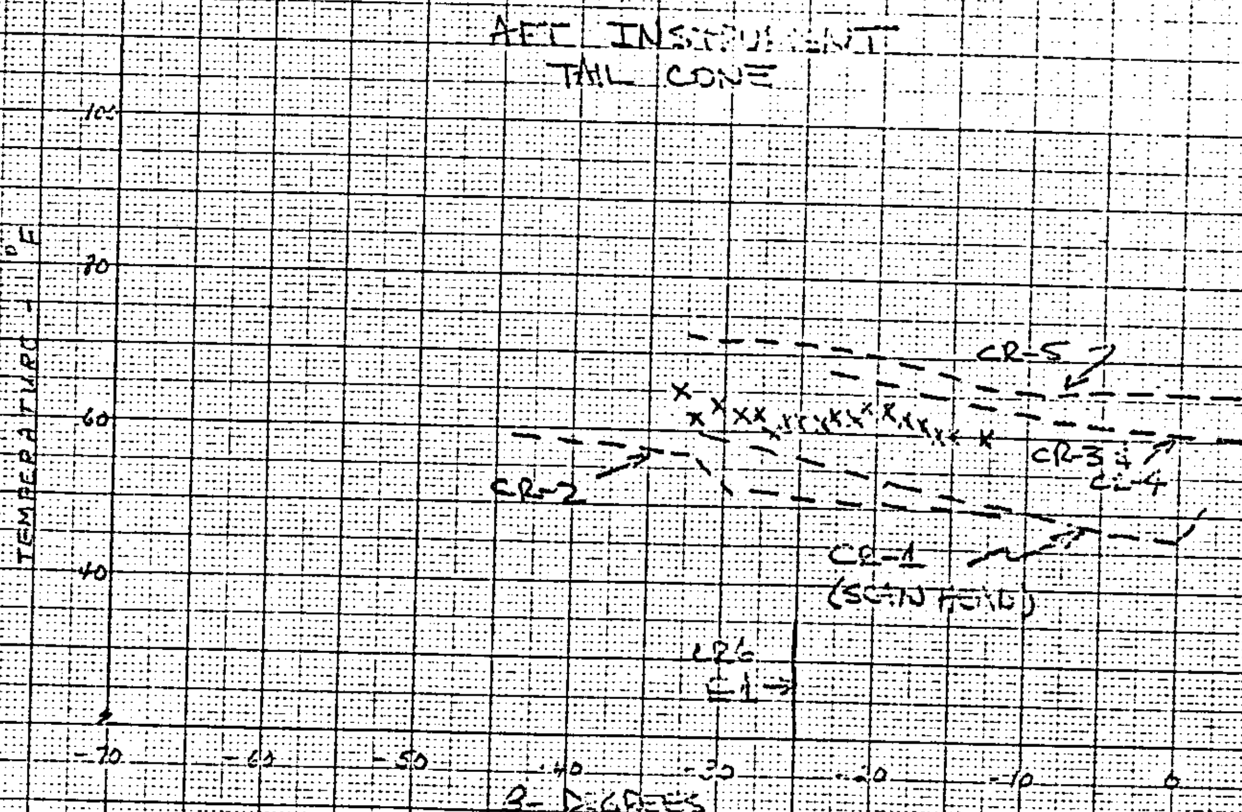

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FIGURE 5

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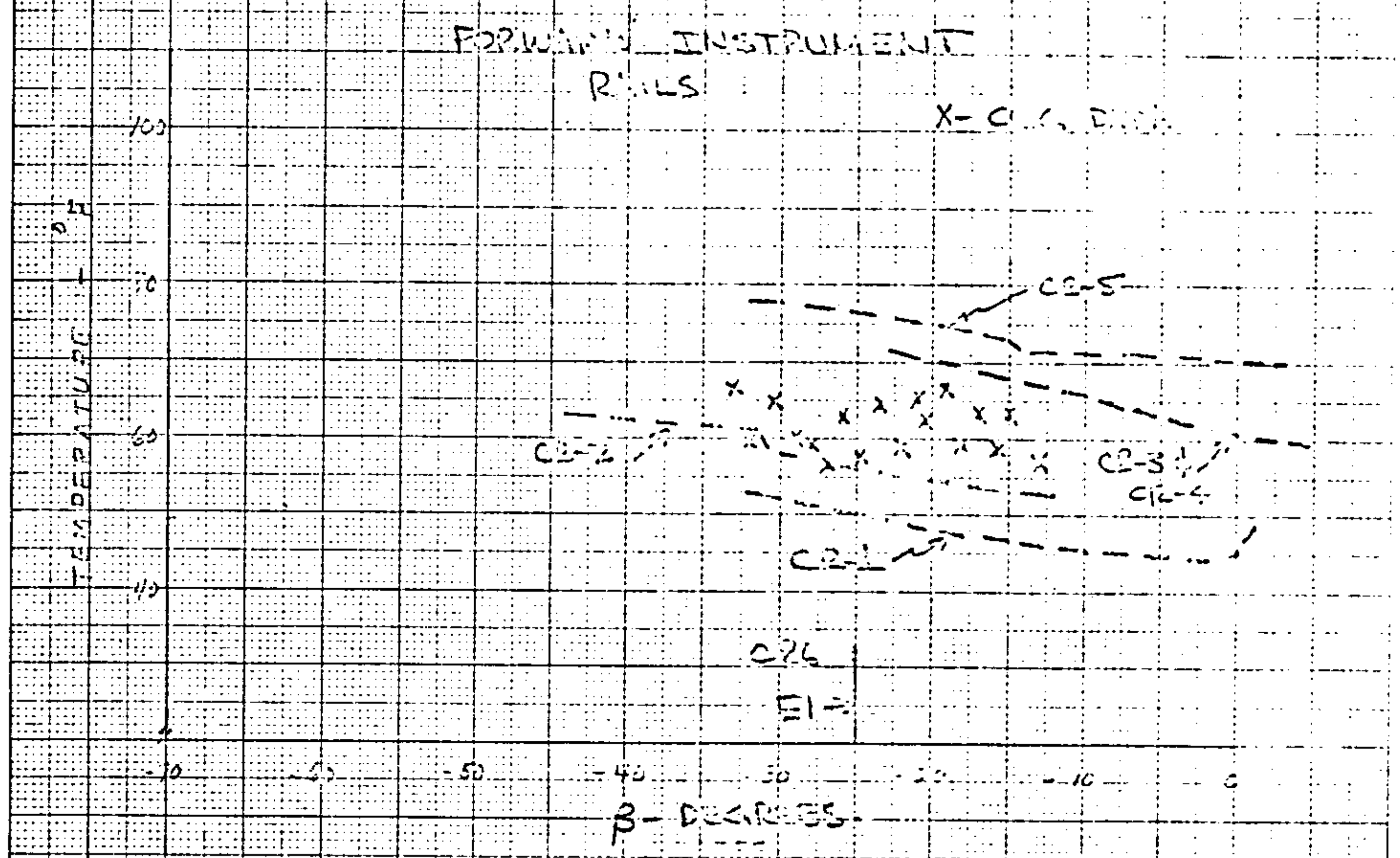

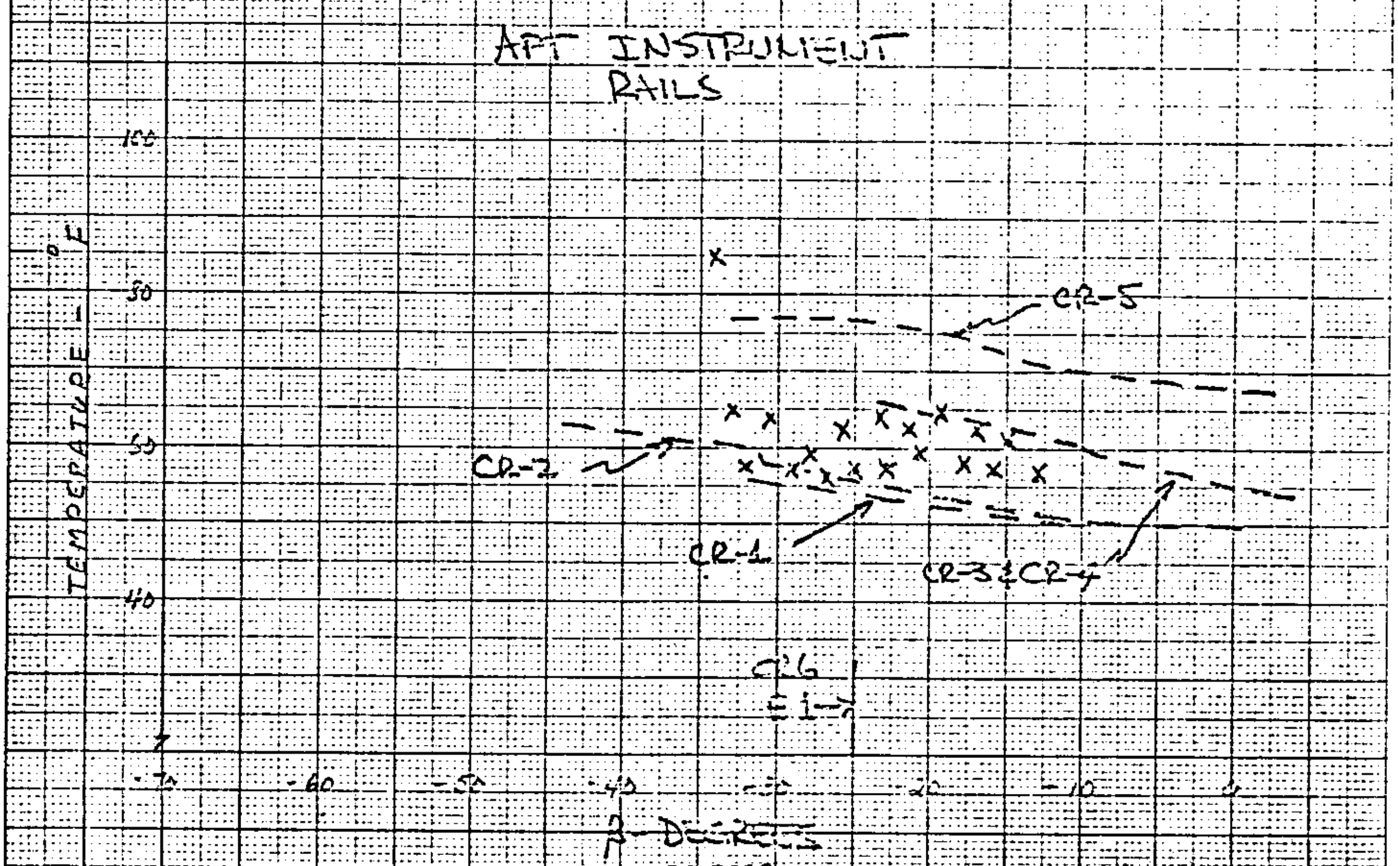

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FIGURE 6

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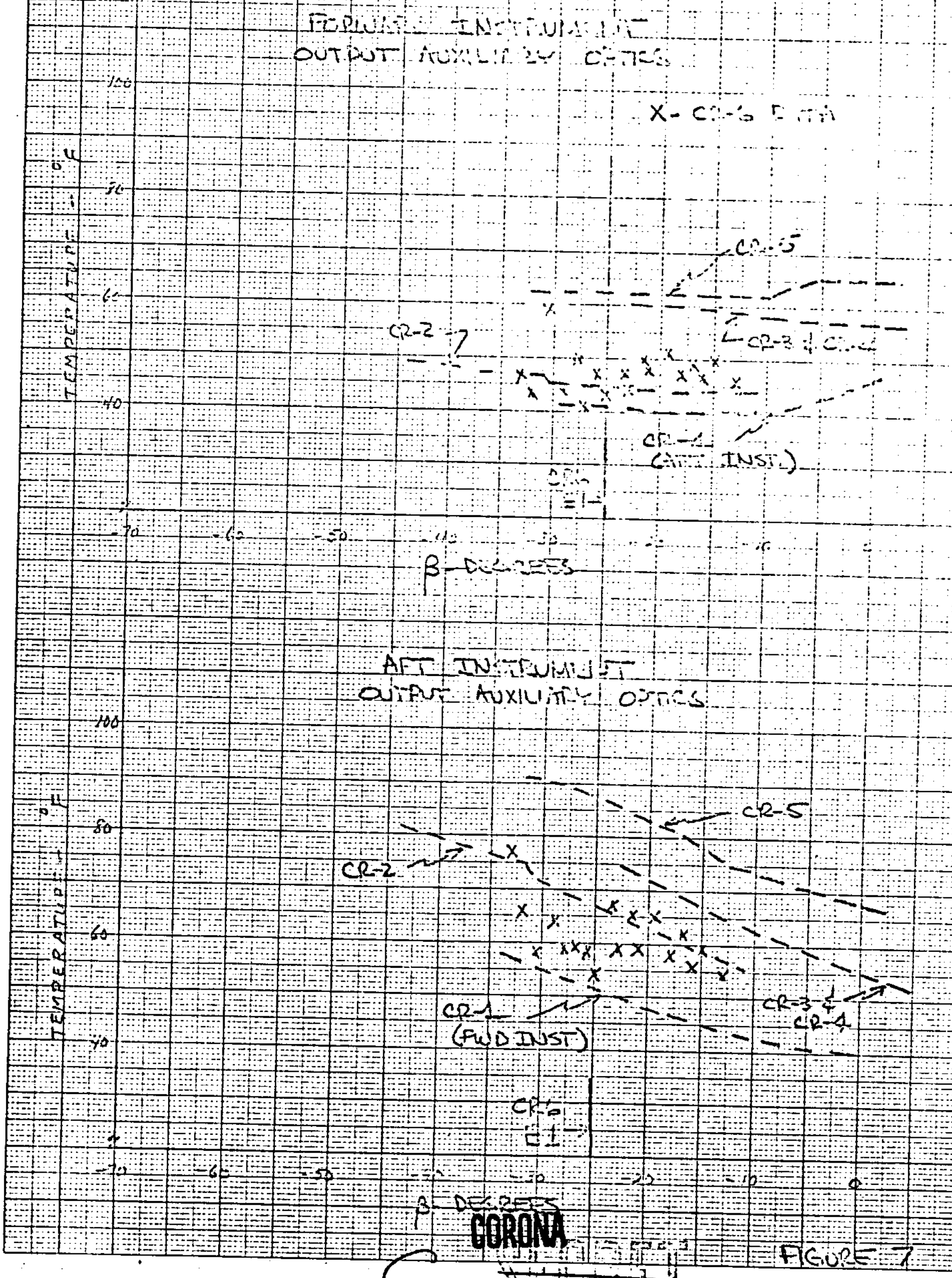

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FIGURE 7

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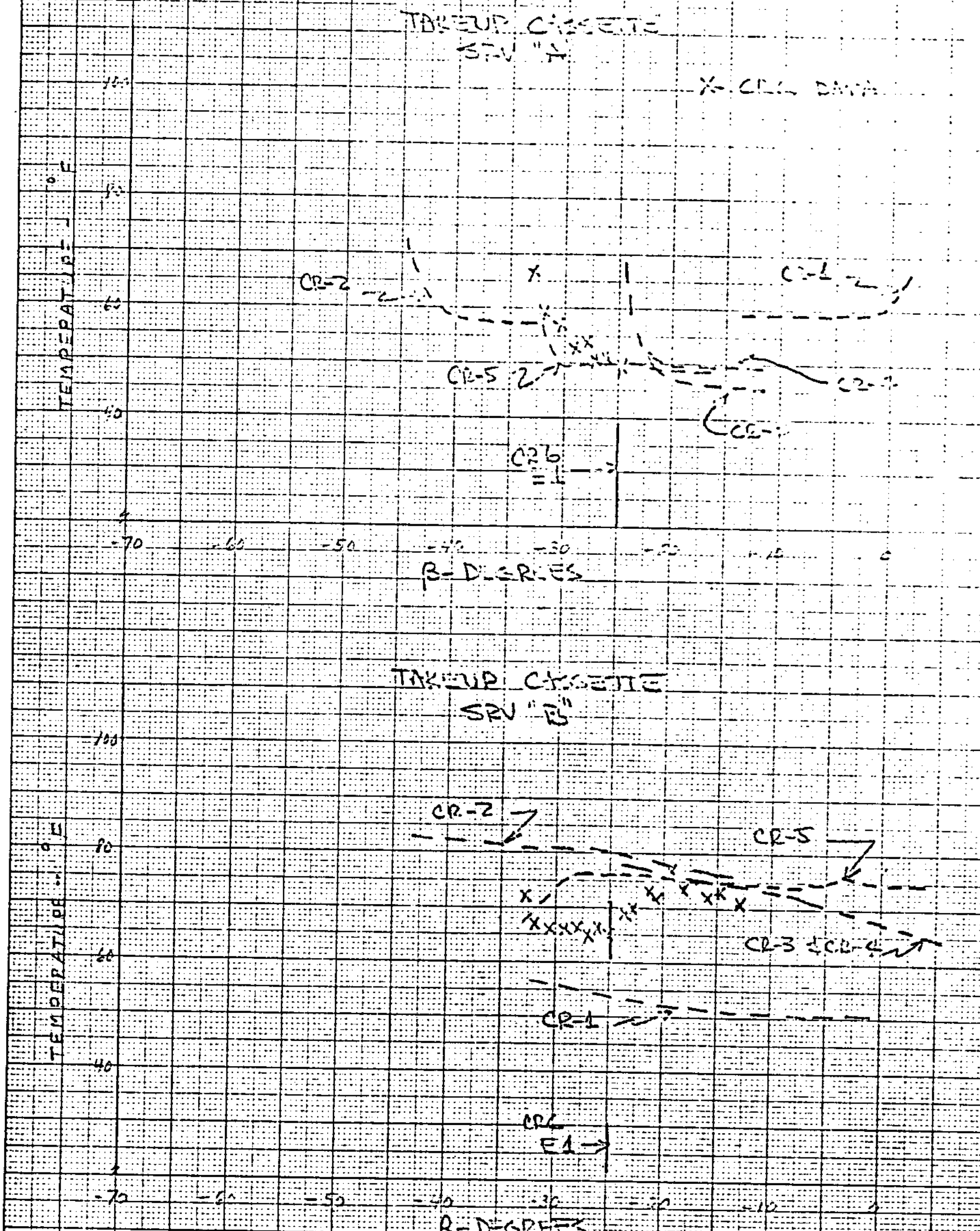

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FIGURE 6

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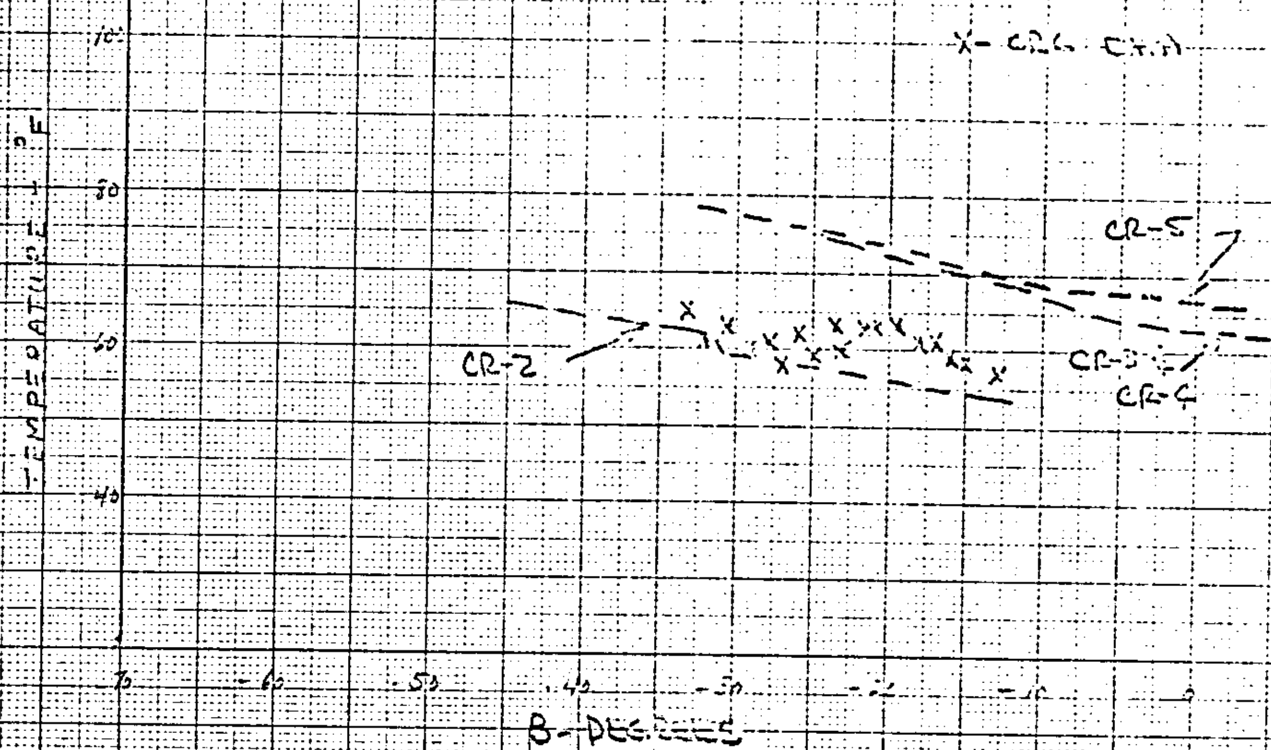
DRUM SUPPORT STRUCTURE



DELTA TOP

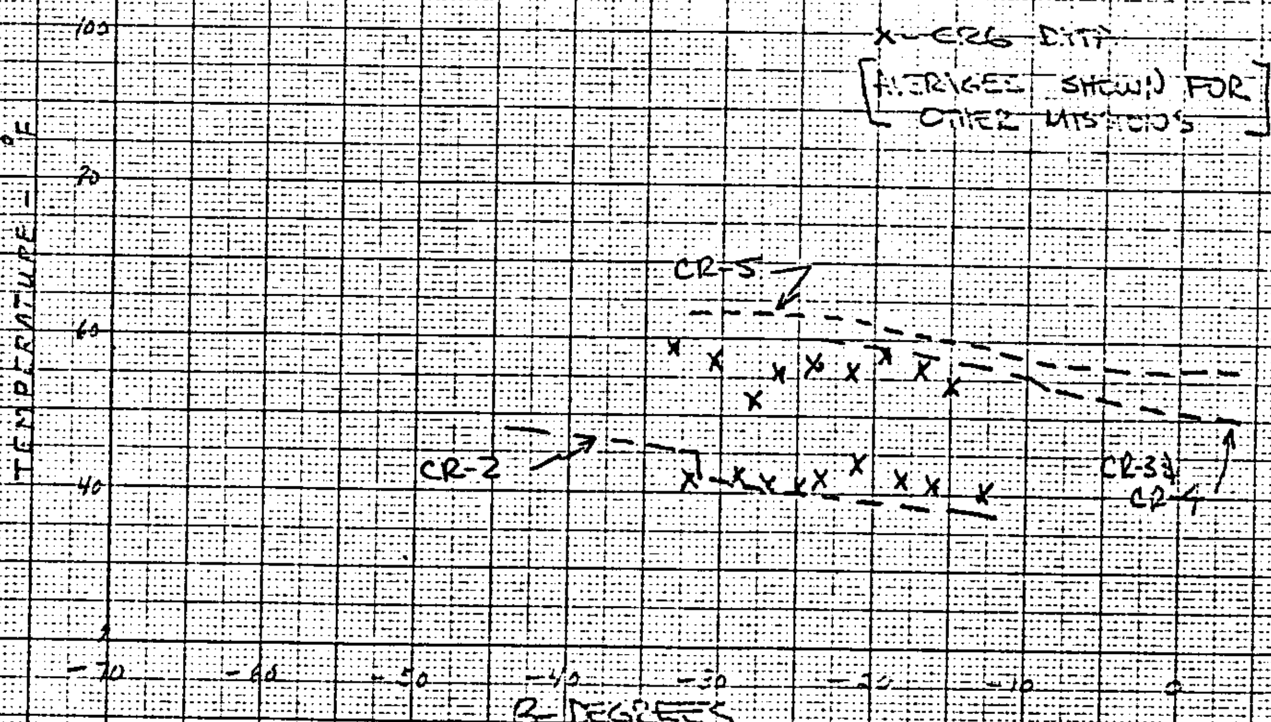


FIGURE 9