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NO. C76-7C4. 51A
DOCUMENT CONTROL

379425

**(TITLE UNCLASSIFIED)
HYBRID PROPULSION SYSTEM
FOR AN ADVANCED
ROCKET-POWERED TARGET MISSILE**

**R. A. Jones
United Technology Center**

**TECHNICAL REPORT
FEBRUARY 1967**

CONTRACT NO. AF 04(611)-11632

Group 4

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**Air Force Rocket Propulsion Laboratory
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UTC 2220-QTR2

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17 February 1967
RAS-18-67-F

Air Force Flight Test Center
Edwards Air Force Base
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Attention: FTMKR-4

Subject: Quarterly Technical Report, UTC 2220-QTR2

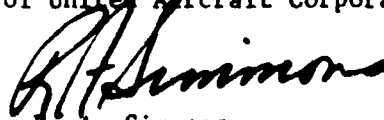
Reference: Contract AF 04(611)-11632, DD Form 1423, Item 40

Gentlemen:

United Technology Center herewith effects transmittal of Quarterly Technical Report, UTC 2220-QTR2, in accordance with the referenced contract.

This report covers the period from 1 October through 31 December 1966.

Very truly yours,
UNITED TECHNOLOGY CENTER
A Division of United Aircraft Corporation


R. A. Simmons
Contract Administrator

RAS:vg

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UTC 2220-QTR 2

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FOREWORD

(U) This is the second quarterly report covering the period from 1 October 1966 to 31 December 1966, and is submitted in compliance with Contract No. AF 04(611)-11632 and in accordance with exhibit B of the Contract Data Requirements List, DD form 1423. The contract was initiated on 1 June 1966 under United Technology Center (UTC) Project 2220, "Hybrid Propulsion System for Advanced Rocket-Powered Target Missile." The work is being administered by the Air Force Rocket Propulsion Laboratory, Edwards Air Force Base, with Mr. F. Mead as the project officer.

(U) This report summarizes the progress made by UTC in the demonstration of the feasibility of using hybrid propulsion systems for advanced rocket-powered target missiles.

(U) Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

F. Mead
Project Officer

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ABSTRACT

The development of a hybrid propulsion system for an advanced rocket-powered target missile has advanced through the seventh program month. During the past 3 months, the heavyweight motor test series was completed successfully, and designs have been finalized for the lightweight thrust chamber assembly components. The results of the final nozzle evaluation tests have shown that the nozzle configuration selected has a nozzle material erosion rate of 0.45 mils/sec. Motor ignition has been demonstrated at -65°F at sea-level conditions and at a simulated altitude of 50,000 ft. The required thrust ratings have been demonstrated at boost and sustain thrust levels for the durations specified, and step thrust operation has been verified over an 8 to 1 range. The lightweight feed system component buildup has been initiated and cold-flow checkout tests will be conducted during the next reporting period. The current status of the program indicates that the hybrid propulsion units to be used in the flight demonstration program will be delivered in accordance with the original schedule.

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ABBREVIATIONS

AFRPL	Air Force Rocket Propulsion Laboratory
c^*	characteristic exhaust velocity
EAFB	Edwards Air Force Base
IRFNA	inhibited red fuming nitric acid
O/F	oxidizer-to-fuel ratio
PG	pyrolytic graphite
TCA	thrust chamber assembly
UTC	United Technology Center

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SECTION I

INTRODUCTION

(U) Under Contract AF 04(611)-11632, initiated in June 1966, UTC is conducting a four-phase program to develop a low-cost hybrid propulsion unit and to provide hybrid propulsion systems to be used in a flight demonstration program to prove the feasibility of an advanced hybrid powered target missile. Contained herein is a description of the work conducted during the 3-month period between 1 October 1966 and 31 December 1966.

(U) During the report period, work has progressed in the areas of interface definition, design, analysis, fabrication, and development testing. Interface definition efforts have been confined to an interchange of information with Beech Aircraft Corporation, which has at this time eliminated all foreseeable interface problems. The design and analysis effort has proceeded through the completion of all heavyweight hardware designs and all major flightweight components. Analysis of the test data has been completed for all tests conducted to date. Appendix I of this report contains reduced test data for those firings conducted over the last 3 months. Fabrication of the heavyweight test hardware has been completed with the expectation of final incremental hardware deliveries to EAFB which are being used in the parallel development conducted by AFRPL. Flightweight hardware fabrication has been initiated and certain small components have been received.

(U) The heavyweight TCA development testing has been successfully completed. Component designs to be used in the flightweight propulsion system have been developed to the required durability levels by a series of design modifications and evaluation tests. Test data obtained from motor firings conducted with the latest hardware modifications have indicated that the performance requirements will be achieved or exceeded.

(U) At this time, the program schedule continues to reflect the assurance that the propulsion systems deliveries will be accomplished on the required dates. Minor delays that have occurred or that are projected to occur have been primarily the result of a variety of procurement problems; however, the rescheduling of the affected tasks has circumvented possible final delivery delays.

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SECTION II

PROGRAM STATUS

1. SCHEDULE

(U) This program is being conducted in four phases: design, development, flight system deliveries, and technical support. The program schedule, figure 1, shows the areas of activity associated with this reporting period.

(U) The schedule shows an extension of the interface definition activity through February 1967. The bulk of the interface definition task was completed during October 1966 as shown; however, it has been found that minor detail changes continue to develop as UTC and Beech continue into the hardware fabrication areas. The schedule extension, therefore, reflects the low level of effort that is required to add these minor changes to the interface control drawing.

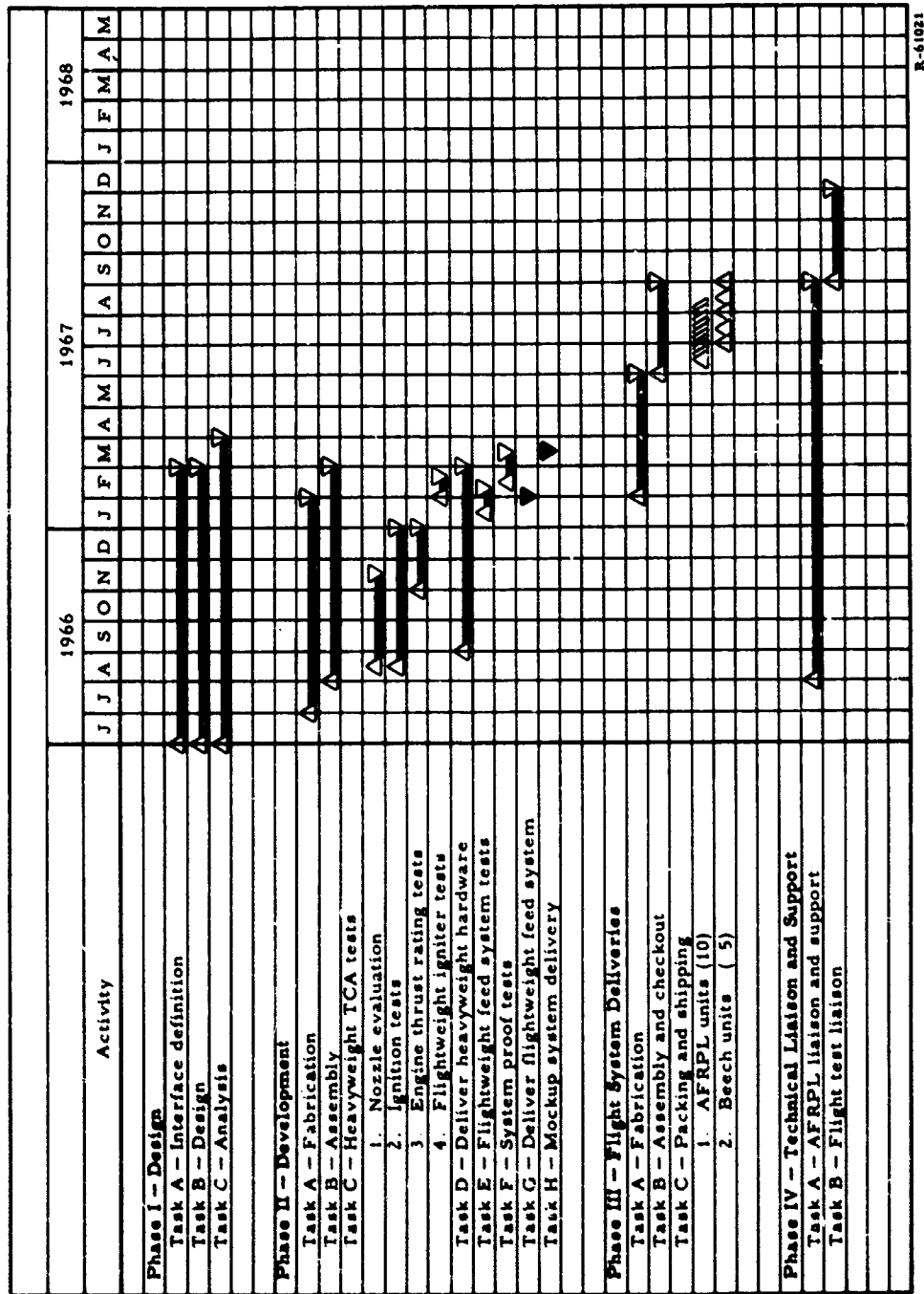
(U) The scheduled activity for design and analysis remains unchanged as this effort continues.

(U) A number of activities have been rescheduled in phase II, primarily because of lightweight feed system hardware procurement delays. The projected feed system test delays allowed a stretchout of the heavyweight TCA tests, which can be shown to be of benefit to the overall program. The TCA test stretchout provided time for at least one more design improvement change and motor firing evaluation. In addition, more test results became available from the parallel development program being conducted by AFRPL and which were integrated into the overall design plans.

(U) Phase III, Flight System Deliveries remains as originally scheduled. The delays in the phase II activity completion dates will not affect the initial fabrication activities go-ahead.

(U) Applicable program mileposts of figure 2 have been changed to reflect the rescheduling of program activities.

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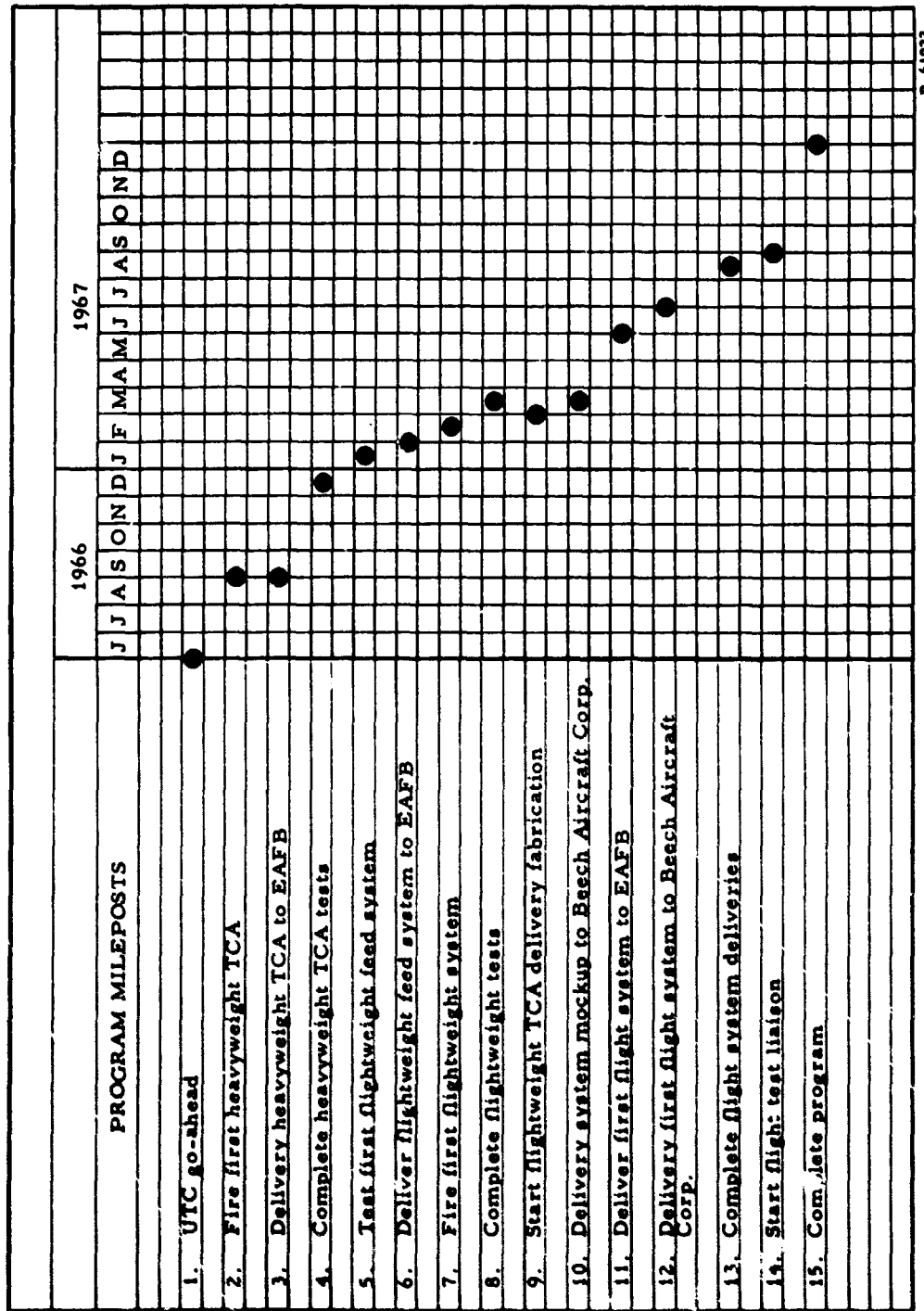


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Figure 1. (U) Hybrid Propulsion System Program Schedule

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Figure 2. (U) Hybrid Propulsion System Milepost Schedule

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2. WORK ACCOMPLISHED

a. Mileposts

(U) During this reporting period, milepost No. 4, Complete Heavyweight TCA Test, was completed. The information gained during this test series will assure that the flightweight hardware to be tested during the system proof tests will satisfy the performance requirements.

b. Interface Definition

(U) Plumbing and fitting details of the flightweight feed system were modified to comply with a Beech Aircraft Corporation revision request. In addition, a minor change to the flightweight thrust chamber design in the vicinity of the chamber aft closure was made to eliminate a possible interference problem. All major revisions were made to the UTC/Beech interface control drawing and it is considered baseline at this time. Minor detail changes are expected throughout the flightweight hardware buildup period; however, these revisions will not affect the UTC or Beech Aircraft Corporation delivery schedule.

c. Design and Analysis

(U) The design and analysis of the heavyweight hardware was completed and several major nozzle design revisions were completed as a result of the hardware evaluation tests. The heavyweight hardware design activity is considered complete.

(U) During this reporting period, the majority of the flightweight hardware components were designed and analyses initiated. The flightweight thrust chamber was designed and a stress analysis was completed and is presented as appendix II. The design was found to be structurally adequate and the weight estimates predict the hardware will fall within the original weight allowance.

(U) The design of the prototype feed system which involves all plumbing and fitting details was completed. Designs have been completed or off-the-shelf hardware selected for other major feed system components such as control valves, regulators, relief valves, fill valves, burst diaphragms, and the dial-a-thrust flow control valve. The final hardware drawings of the flightweight igniter assembly have been completed and a complete procurement package has been prepared.

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(U) Based on the results of the heavyweight TCA motor firings, minor modifications to the flightweight TCA components were made. An assembly drawing of the TCA was prepared and detailed stress and thermal analyses have been initiated.

(U) Test plans are being prepared for the structural and vibration proof tests and the design of the test fixtures has been initiated.

(U) Detailed drawings of the flightweight hardware shipping containers have been completed and formal Interstate Commerce Commission safety classification approval is expected.

d. Heavyweight Hardware Fabrication and Assembly

During this reporting period, the following quantities of heavyweight TCA components were fabricated and assembled for motor firings:

- 12 - Nozzle Assemblies
- 10 - Fuel Grain Assemblies
- 16 - Igniter Assemblies
- 3 - Injector Assemblies

(U) In addition, five nozzle assemblies and five fuel grain assemblies were fabricated and assembled to make up the second incremental delivery of these components to EAFB.

(U) In conjunction with the fabrication of the heavyweight TCA components, various tooling hardware and assembly fixtures were procured or modified to facilitate design changes.

e. Flightweight Hardware Fabrication and Assembly

(U) The fuel grains to be used for the proof test firings were fabricated and are undergoing final inspection.

(U) The flightweight tankage is being fabricated and initial deliveries are expected during the first week of the next reporting period. The remaining feed system components were received with the exception of miscellaneous fittings which are expected momentarily.

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(U) The flightweight thrust chamber procurement has been initiated and the vendor has initiated procurement of long lead-time materials and tooling. Fabrication of chamber components was started the last week of this reporting period and final assembly is scheduled for the first week in February 1967.

(U) The first flightweight flow control valve was fabricated and assembled for initial heavyweight TCA duty cycle tests.

(U) Procurement of the prototype igniter initiator has been started and a fabrication go-ahead will be given during the first month of the next reporting period.

f. Heavyweight TCA Tests

(U) During this reporting period 13 motor firings were conducted, 4 igniter assemblies were fired during open-air tests, and a number of facility cold flow calibrations were run. A summary of these development tests, Nos. 21 through 39, is shown in table I. Detailed test results of motors fired during this reporting period are presented by test number in appendix I.

g. Deliveries and Documentation Transmittals

(U) One nozzle assembly, taken from the second incremental delivery buildup of these components, was delivered to AFRPL.

(U) A set of heavyweight component drawings were transmitted informally to AFRPL. In addition, a revised copy of the UTC coordination drawing has been transmitted to Beech Aircraft Corporation to provide revision details for the Beech/UTC interface control drawings.

h. Technical Liaison and Support

(U) During the second week of November 1966, UTC personnel went to EAFB to provide heavyweight hardware assembly instructions. During the last week of November, UTC personnel in the company of Eglin AFB and Beech Aircraft Corporation personnel, witnessed the first altitude firing of a heavyweight TCA at EAFB. A program review involving informal status presentation by those in attendance was also held at this time.

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TABLE I
(U) HEAVYWEIGHT TCA DEVELOPMENT TESTS SUMMARY

<u>Test No.</u>	<u>Date</u>	<u>Objective</u>	<u>Primary Result</u>	<u>Comment</u>
H3S-21	4 October	Fire heavyweight TCA and evaluate fuel grain insulation material at sustain thrust level.	Performance of the silicon insulation was consistent with results of previous firings.	Test was successful; the 1.0 expansion ratio nozzle withstood 134-sec duration with no erosion.
H3S-22	6 October	Fire heavyweight TCA and evaluate nozzle material at boost thrust level.	The Speer SX4 graphite nozzle coated with silica carbide experienced 4.5 mils/sec erosion during the 95-sec firing. The silica carbide coating was completely removed in the throat regions.	Test was successful.
H3S-23	10 October	Check out facility conditioning box at -65° F.	The conditioning box interior was reduced to -65° F within a brief time period and automatic temperature controls functioned properly.	Detailed test results are available in oscillograph form.
H3S-24	13 October	Fire heavyweight TCA following conditioning at -65° F and evaluate motor ignition.	The TCA was conditioned for 10 hr to achieve an equilibrium temperature of -65° F. Motor ignition occurred within 300 msec.	Test was successful.
H3S-25	14 October	Fire heavyweight TCA and evaluate nozzle material at boost thrust level.	The Speer graphite nozzle coated with zirconium oxide experienced 3.9 mils/sec erosion during the 95-sec firing. The zirconium oxide coating was completely removed in the throat region.	Test was successful.
H3S-26	19 October	Evaluate heavyweight TCA igniter in open-air firing at -65° F.	A modified initiator was used to ignite the igniter propellant charge at -65° F. The initiator provided rapid ignition with moderate overpressure.	Test was successful. Detailed test results available in oscillograph form.
H3S-27	20 October	Fire heavyweight TCA and evaluate motor performance at sustain thrust level using modified injector.	Performance of the motor was satisfactory. The required chamber pressure was achieved and the effects of the modified injector were observed.	Test was successful; the 1.0 expansion ratio nozzle withstood the 155-sec duration with 0.2 mils/sec erosion. The flow control valve was used to maintain oxidizer flow rate setting.
H3S-28	20 October	Evaluate heavyweight TCA igniter in open-air firing at -65° F.	Ignitiator reproducibility was verified at -65° F.	Test was successful; this test was a repeat of test No. H3S-26.
H3S-29	21 October	Evaluate heavyweight TCA igniter in open-air firing at +165° F.	A modified initiator was used to ignite the propellant charges at +165° F. The initiator provided rapid ignition with moderate overpressure.	Tests were successful; these tests involved the same initiator and igniter hardware design used in tests H3S-26 and H3S-28.

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winstood the 100-sec duration with 0.2 mils/sec erosion. The flow control valve was used to maintain oxidizer flow rate setting.

Test was successful; this test was a repeat of test No. H3S-26.

Tests were successful; these tests involved the same initiator and igniter hardware design used in tests H3S-26 and H3S-28.

Test was successful.

Test was successful; the flow control valve was used to maintain oxidizer flow rate setting.

Test was successful; however, an unexpected hot spot required premature shut down. The flow control valve was used to maintain oxidizer flow rate setting.

Test was successful.

Test was partially successful; an unexpected hot spot required premature shut down. The flow control valve was used to maintain oxidizer flow rate setting.

Detailed test results are available in oscillograph form.

Test was successful; the flow control valve was used to maintain oxidizer flow rate setting.

Test was successful; the flow control valve was used to maintain oxidizer flow rate setting.

Test was successful.

and the effects of the mounted injector were observed.

Ignitator reproducibility was verified at -65° F.

A modified initiator was used to ignite the propellant charges at +165° F. The initiator provided rapid ignition with moderate overpressure.

The pyrolytic graphite nozzle insert experienced 0.9 mils/sec erosion during the 95-sec firing.

The pyrolytic graphite nozzle insert experienced 4.8 mils/sec erosion during the 93-sec boost portion. The firing continued an additional 180 sec at sustain for a total duration of 273 sec.

The pyrolytic graphite nozzle insert experienced 0.3 mils/sec erosion during the 93-sec boost operation. The firing continued an additional 147 sec at sustain for a total of 240 sec.

Motor ignition was accomplished and stable operation at boost and sustain thrust levels was demonstrated using the alternate oxidizer (IRFNA).

Following a 93-sec boost phase, the firing continued an additional 36 sec at sustain for a total of 129 sec.

Facility pressure drop characteristics as a function of oxidizer flow rate were determined.

The pyrolytic graphite nozzle insert experienced 0.285 mils/sec erosion during the 93-sec boost operation. The firing continued an additional 180 sec at sustain for a total of 273 sec.

The pyrolytic graphite nozzle insert experienced 0.6 mils/sec erosion during the 95-sec boost operation. The firing continued an additional 300 sec at sustain for a total of 395 sec.

The TCA was conditioned for 12 hr to achieve an equilibrium temperature of -65° F. Motor ignition occurred within 600 msec at a minimum pressure altitude of 50,000 ft.

level using modified injector.

Evaluate heavyweight TCA igniter in open-air firing at -65° F.

Evaluate heavyweight TCA igniter in open-air firing at +165° F.

Fire heavyweight TCA and evaluate nozzle material at boost thrust level.

Fire heavyweight TCA and evaluate mixer redesign during duty cycle at boost and sustain thrust levels.

Fire heavyweight TCA and evaluate mixer redesign during duty cycle at boost and sustain thrust levels.

Fire heavyweight TCA and verify performance of alternate oxidizer.

Fire heavyweight TCA and evaluate duty cycle performance.

Gold flow facility feed system to obtain new calibration curve following system modifications.

Fire heavyweight TCA and evaluate duty cycle performance.

Fire heavyweight TCA and evaluate duty cycle performance.

Fire heavyweight TCA following conditioning at -65° F and evaluate motor ignition at a simulated altitude of 50,000 ft.

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SECTION III

TEST RESULTS DISCUSSION

1. NOZZLE MATERIAL EVALUATION

(U) The nozzle material evaluation was completed and a pyrolytic graphite throat insert has been selected for the flightweight design. A summary of the test results which led to this conclusion is presented in table II.

(U) As discussed in a previous report, it was decided to evaluate an oxidizer-resistant nozzle coating which would protect the graphite substrate in much the same manner as the magnesium oxide buildup had protected the nozzle in previous tests. Both silicon carbide and zirconia oxide were selected for evaluation. A 0.010-in. uniform coating of silicon carbide was applied over the nozzle entrance, throat, and exit cone of a graphite substrate which was selected on the basis of similar thermal expansion characteristics. Test No. H3S-22 was then conducted at boost condition for 95 sec and, as shown in table II, throat erosion averaged 4.5 mils/sec. The silicon carbide coating appeared to have little effect in reducing erosion in the throat region even though the coating remained intact on the nozzle entrance and exit cone surfaces. The zirconia oxide coating was evaluated by applying a 0.10-in. uniform coating on a Speer Carbon graphite nozzle made of the same material previously tested uncoated (H3S-19). Test H3S-25 was then conducted at boost conditions for 95 sec and, as shown in table II, throat erosion averaged 3.9 mils/sec. Again the coating did not reduce the throat erosion. The value of 3.9 compares with the 4.0 value during test H3S-19 for the uncoated material. Further effort with the coating approach could not be justified because of the nozzle cost increases associated with thicker coatings and proprietary coating techniques. Successful coating techniques require extensive structural support of the substrate material to minimize thermal stress, and such requirements could be expected to increase cost and weight. Of the original candidates, only pyrolytic graphite remained to be evaluated, which could now be justified based on the lack of success with inexpensive coatings.

(U) Test No. H3S-31 was then conducted with a pyrolytic graphite (PG) throat insert at boost conditions for 95 sec. As shown in table II, throat erosion averaged 0.96 mils/sec, which was regarded as a new low. The success of this test posed the question of whether or not PG would attract slag similar to the Speer graphite candidate when used in conjunction with

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TABLE II
(U) NOZZLE MATERIAL EVALUATION TEST SUMMARY

<u>Test No.</u>	<u>Chamber Pressure psia</u>	<u>Chamber Pressure psia</u>	<u>Duration sec</u>	<u>Nozzle Erosion mils/sec</u>	<u>Material</u>
H3S-22	490	150	95	4.5	Speer Grade SX4 graphite coated with silicon carbide
H3S-25	480	180	95	3.9	Speer Grade 9139 graphite coated with zirconium oxide
H3S-31	500	470	95	0.96	Pyrolytic graphite insert with ATJ graphite backup
H3S-32	500	170	95	4.8	Pyrolytic graphite insert with ATJ graphite backup (chamber mixer used)
H3S-33	480	515	93	0.3	Pyrolytic graphite insert with ATJ graphite backup (ramped entrance section)

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a mixer. Previous in-house tests conducted with PG throat inserts at boost conditions for durations up to 50 sec indicated no slag buildup with a mixer. The mixer design was therefore modified as shown in figure 3 to incorporate a larger plenum and gradual contours to minimize the flow tripping action previously seen to encourage slag buildup. Test No. H3S-32 was then conducted to boost conditions for 95 sec and, as shown in table II, throat erosion averaged 4.8 mils/sec. The slag buildup did not occur; however, the mixer increased the nozzle erosion rate by a factor of five. The decision was then made to eliminate the mixer on all future tests based on a tradeoff between an expected mixer contribution of 2% improved combustion efficiency and an average thrust coefficient improvement of 10% for a nozzle without a mixer. The thrust coefficient improvement was contributed to by the higher average chamber pressure and nozzle expansion ratio, both of which are obtained with minimum throat erosion. It was also apparent at this juncture that further reduction in nozzle erosion may be obtained by using a very gradual nozzle approach angle with a full radius entrance. Figure 4 shows the modified entrance geometry which produced nozzle erosion as low as 0.3 mils/sec as shown in table II for Test No. H3S-33. The average erosion rate for all the tests conducted to date using this nozzle design has been 0.45 mils/sec.

(U) The selection of the present nozzle configuration for the flightweight design has also been based on the results of the thermal analysis. Continuous boost-sustain firings such as H3S-38, which exceeded a duration of 6.5 min, have provided thermocouple data as shown in figure 5. The results show a maximum skin temperature of 410° F at the end of the firing and a final thermal soak temperature of 600° F after 14 minutes. The analytical results obtained with the thermal model as shown in figure 6 predict maximum skin temperatures of 450° F at the end of the firing, which is slightly conservative. A projection of the thermal model based on these correlations has been used to predict the skin temperature of the flightweight nozzle hardware. These results, shown in figure 7, indicate that a maximum temperature of 1,000° F can be expected at the end of the firing. The stresses developed in the 18-nickel maraging steel by the sustain pressure loads are only 10% of the ultimate strength for this material at 1,000° F, indicating the high margin of safety available with this nozzle configuration.

2. PERFORMANCE

(U) Performance evaluation of the hybrid motor has been accomplished by the "Hybrid Motor Performance Analyzer" computer program presented in appendix III. This program is basically a data reduction program which utilizes the test results as input. The program calculates instantaneous throat area, specific impulse, O/F ratio, fuel flow rate, c^* , c^* efficiency,

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fuel grain port radius, expansion ratio, total oxidizer weight consumed, regression rate, and oxidizer flow rate per unit port area. In addition, options exist which allow the reduced test data to be corrected for altitude operating conditions.

(U) A comparison of recent motor firings at boost conditions has been made, as shown in figure 8. This figure shows the 95-sec boost requirement for the 90,000-ft altitude cruise mission compared with test No. H3S-38. This corrected sea-level data meets or exceeds the boost thrust requirements and represents a typical boost thrust-time curve that can be expected during the flightweight hardware tests.

(U) Sustain thrust performance at altitude conditions, as shown in figure 9, was obtained by correcting the thrust data obtained during sustain firings conducted with a 1.0 expansion ratio nozzle and from the duty cycle tests, by calculating the thrust from chamber pressure measurements. It should be noted that the sustain thrust data shown for the duty cycle tests in appendix I have been measured while the nozzle is flowing in a separated condition. Figure 9 shows the relationship between sustain thrust and the oxidizer flow rate over the range of primary interest. The flow control valve setting may be obtained from the curve for the 80,000-ft cruise requirement, and further data corrections will provide settings for the other cruise altitude requirements. A nozzle expansion ratio of 21 has been referenced on figure 9 to account for the nozzle expansion ratio reduction resulting from throat erosion during boost. At the beginning of a duty cycle, the nozzle expansion ratio is 25 and, depending on the duration of boost, the ratio can be expected to reduce slightly; however, this change is reproducible and does not affect the accuracy of the predetermined sustain thrust settings. Figure 10 shows the variation of nozzle expansion ratio as a function of boost thrust duration as obtained from recent firings using the final nozzle configuration.

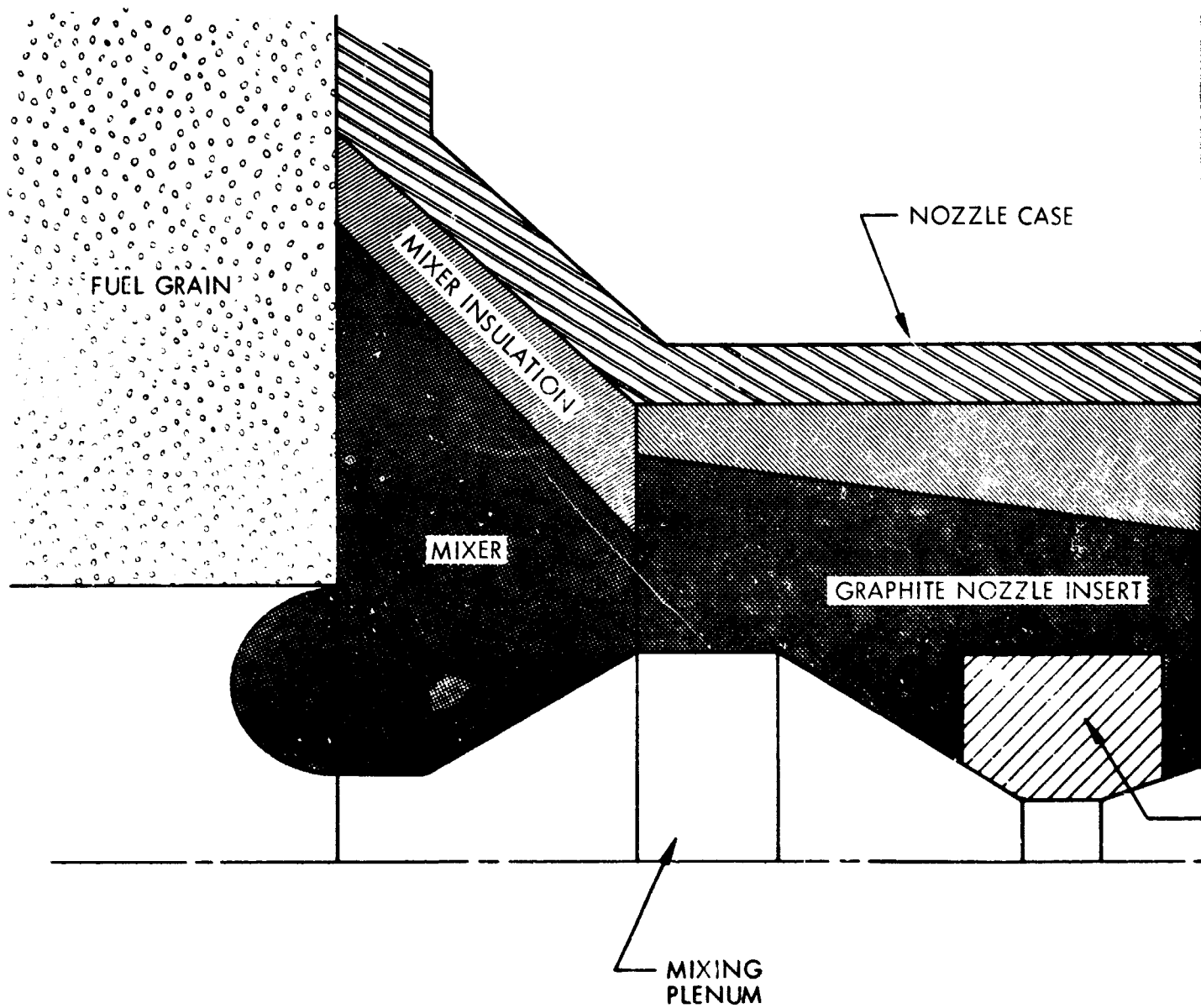
(U) The heavyweight motor firing test data have demonstrated that the required boost thrust levels and sustain thrust durations will be achieved and that flightweight hardware designs based on the final heavyweight motor configuration will satisfy all performance requirements.

3. IGNITER PERFORMANCE

(U) The pyrogen igniter development has been completed and the test results proved that the design is capable of igniting the motor over a temperature range of -65° to $+165^{\circ}$ F.

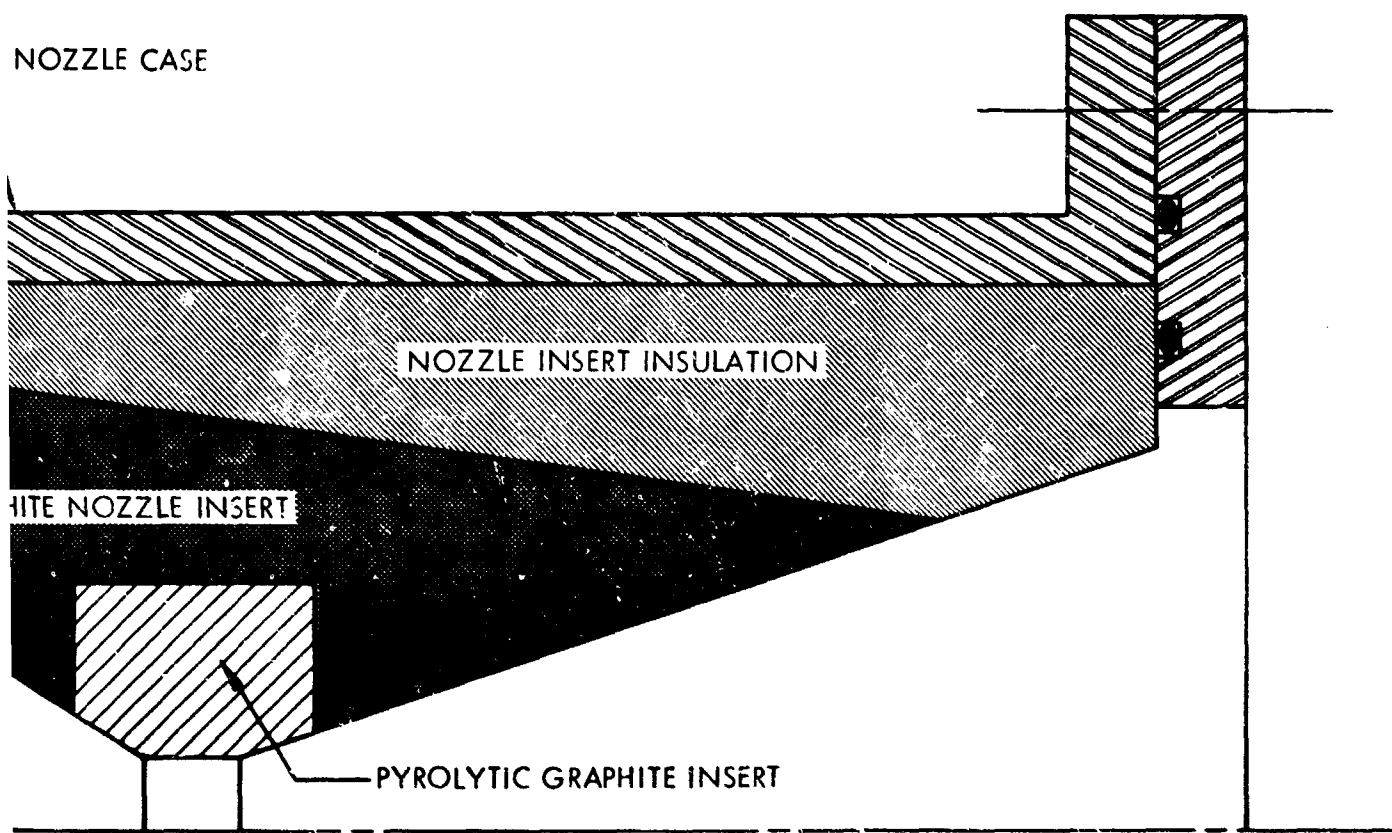
(U) The pyrogen igniter selected has been tested over the required temperature range and produces igniter chamber pressures as shown in figure 11. The pressure-time curves show that the initiator provides ignition

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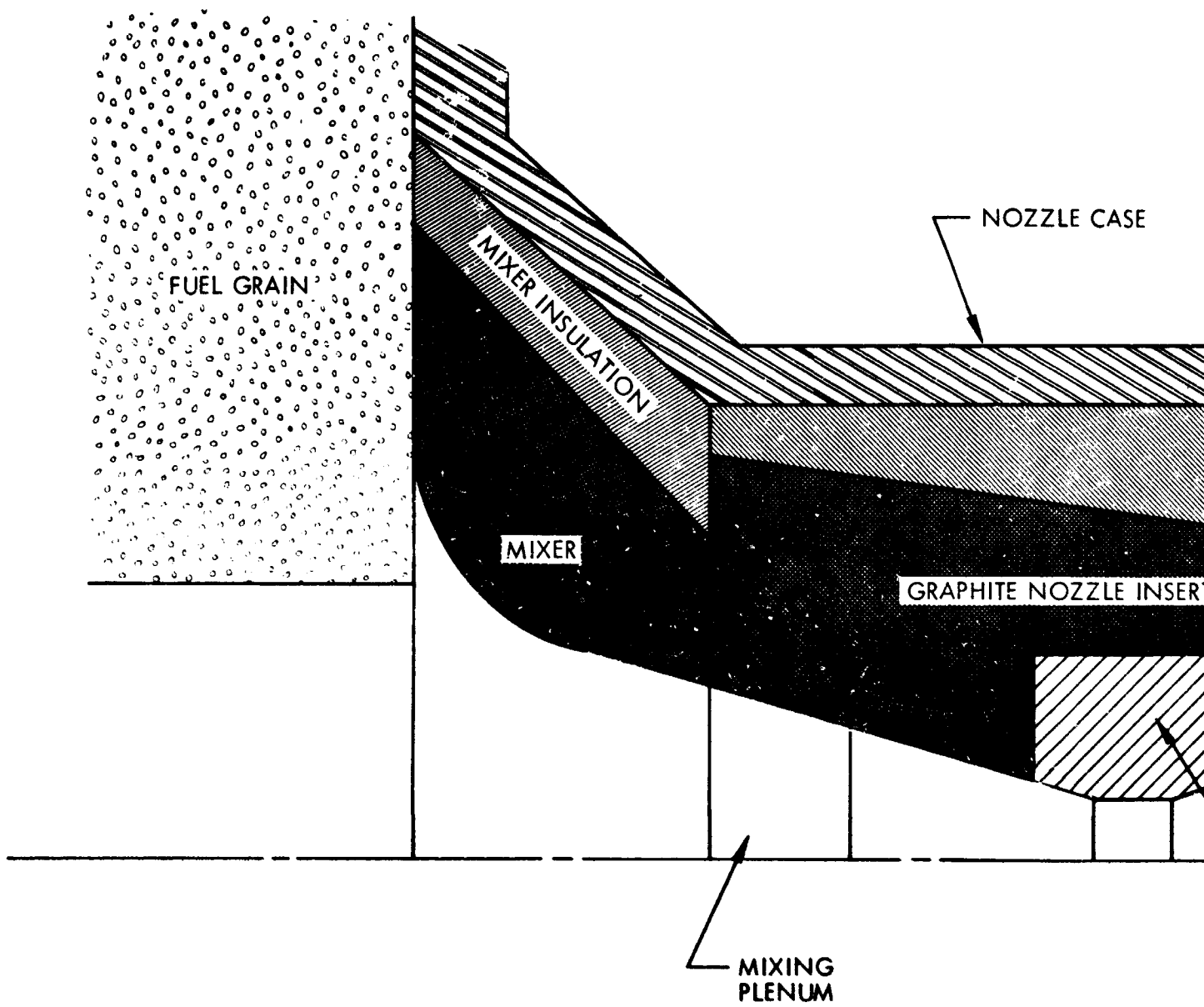
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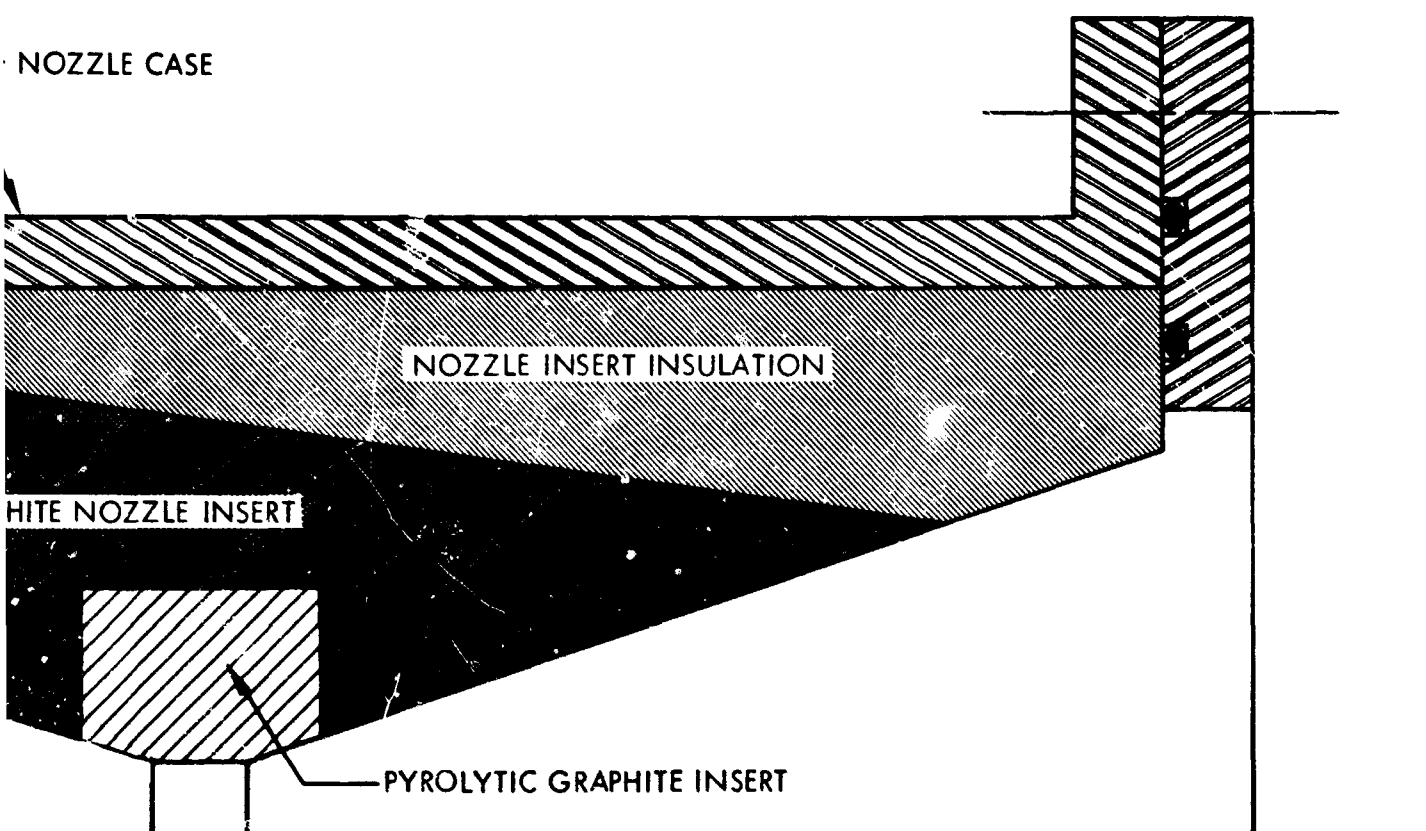
Figure 3. (U) Modified Heavyweight
Nozzle Configuration

2



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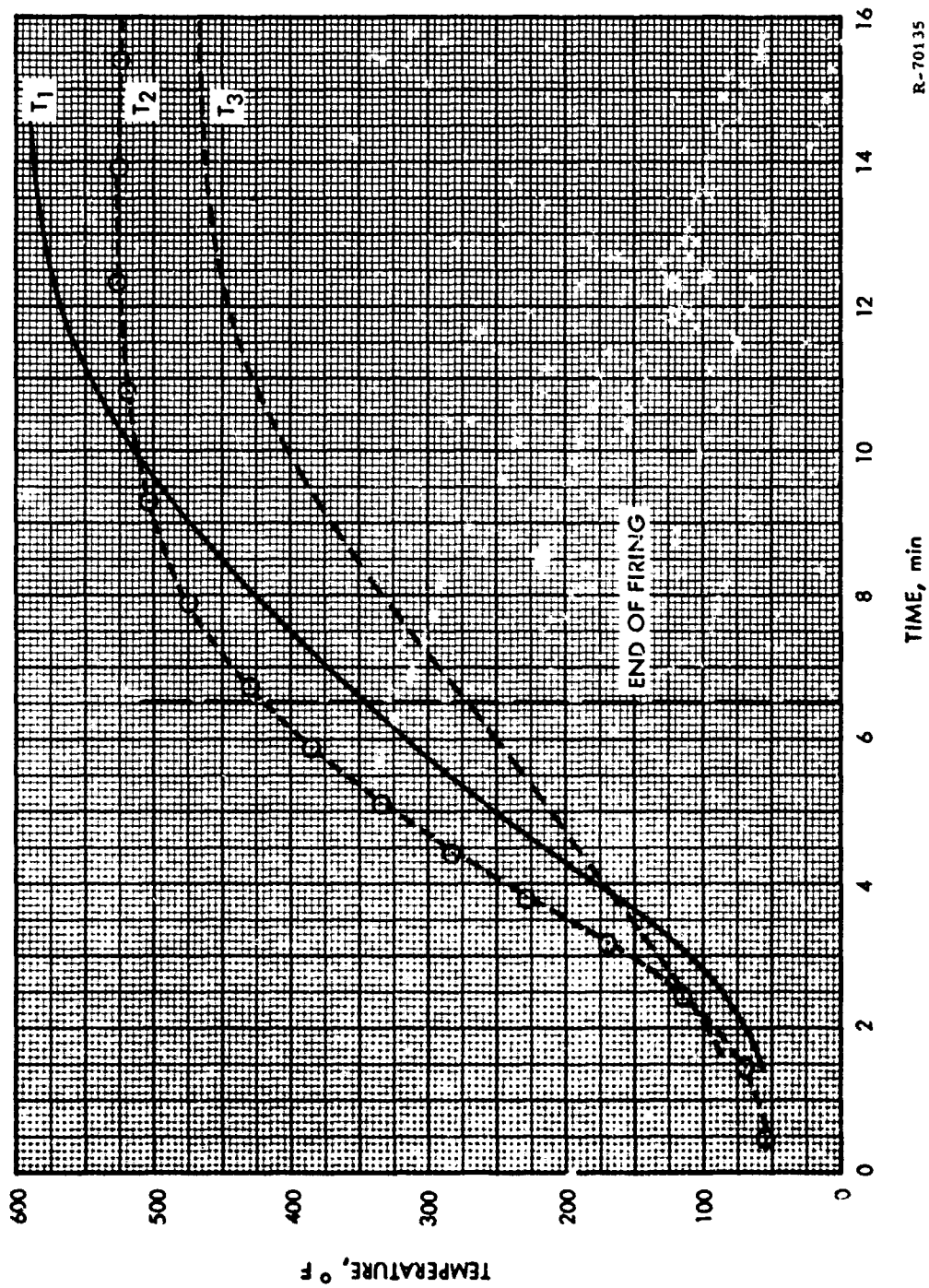


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Figure 4. (U) Modified Entrance
of Modified Heavyweight
Nozzle Configuration

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Figure 5. (U) Thermocouple Response of Test No. H3S-38

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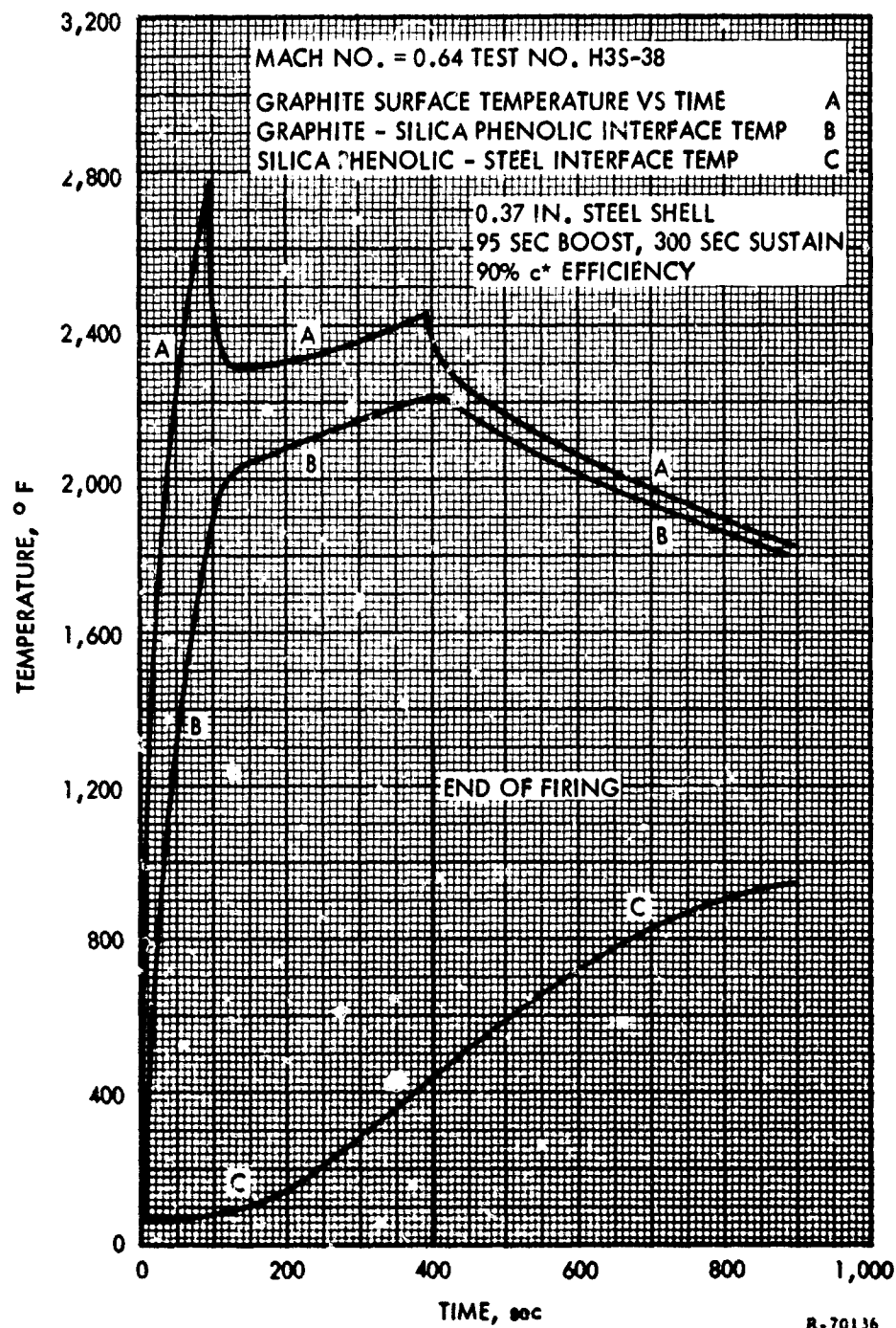


Figure 6. (U) Hybrid Target Missile Thermal Analysis, 0.37-in. Steel Shell

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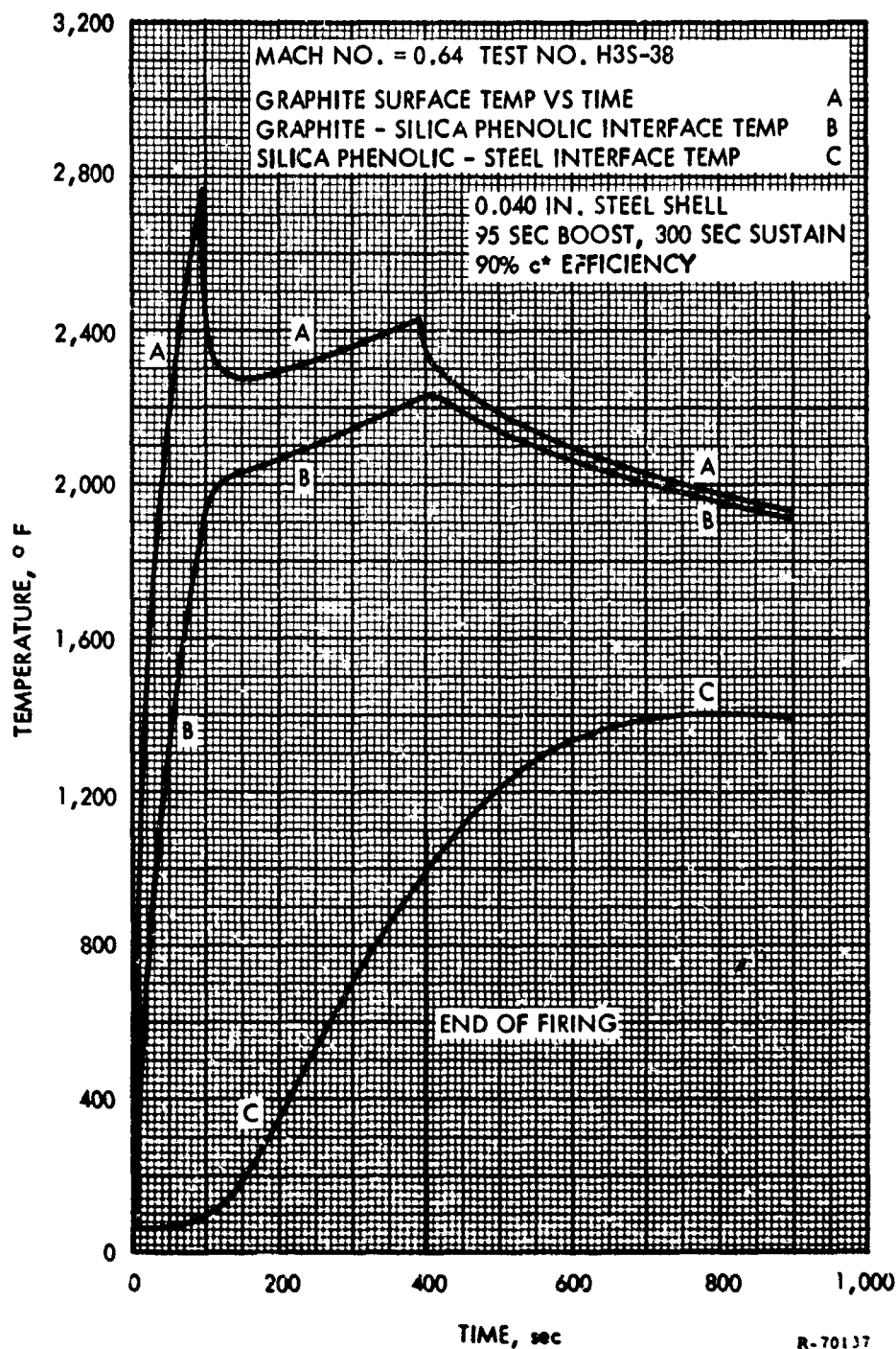
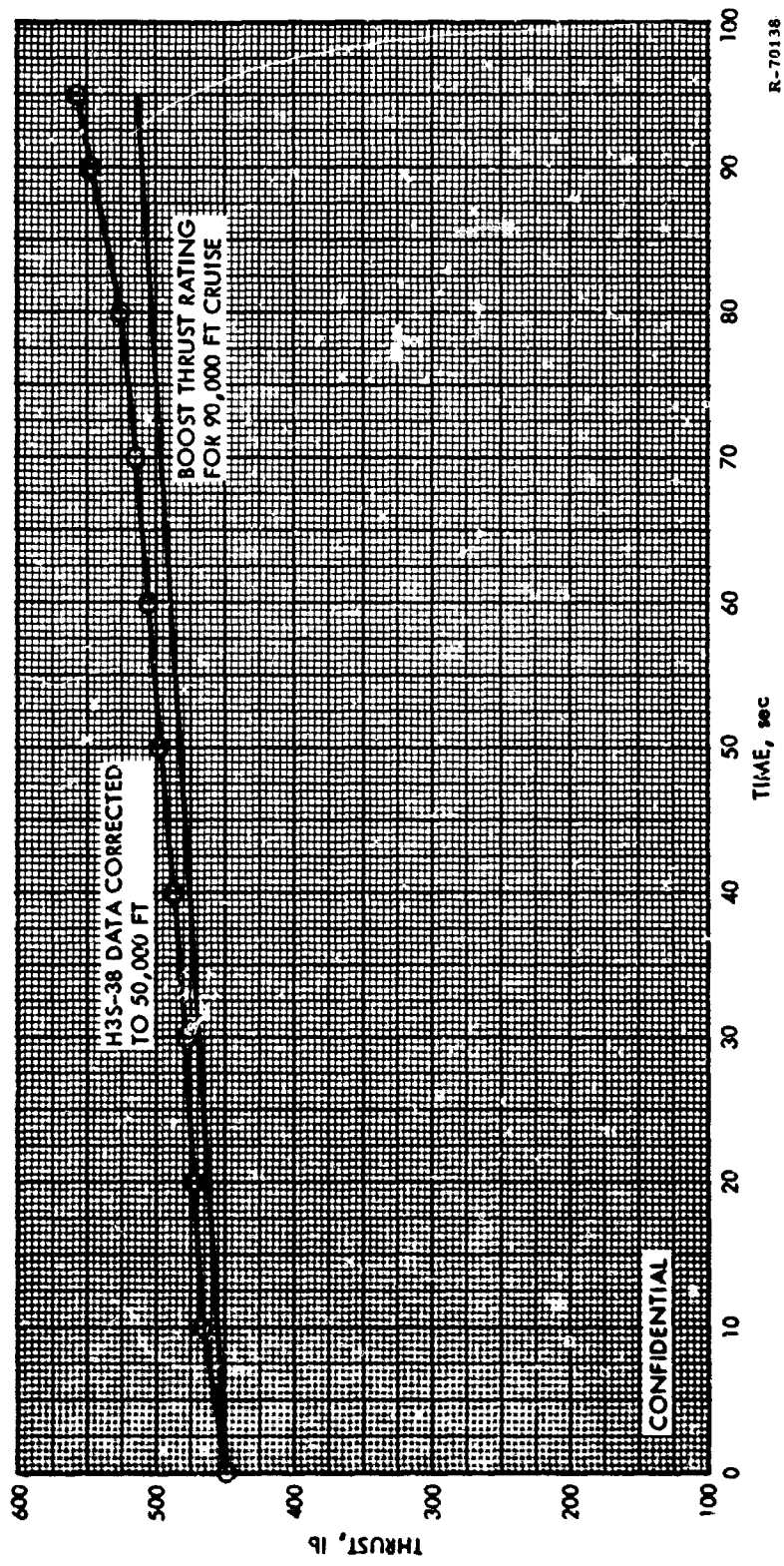


Figure 7. (U) Hybrid Target Missile Thermal Analysis, 0.040-in. Steel Shell

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Figure 8. (U) Comparison of the 90,000-ft Altitude Cruise Boost Thrust Requirements and Data from Test No. H3S-38

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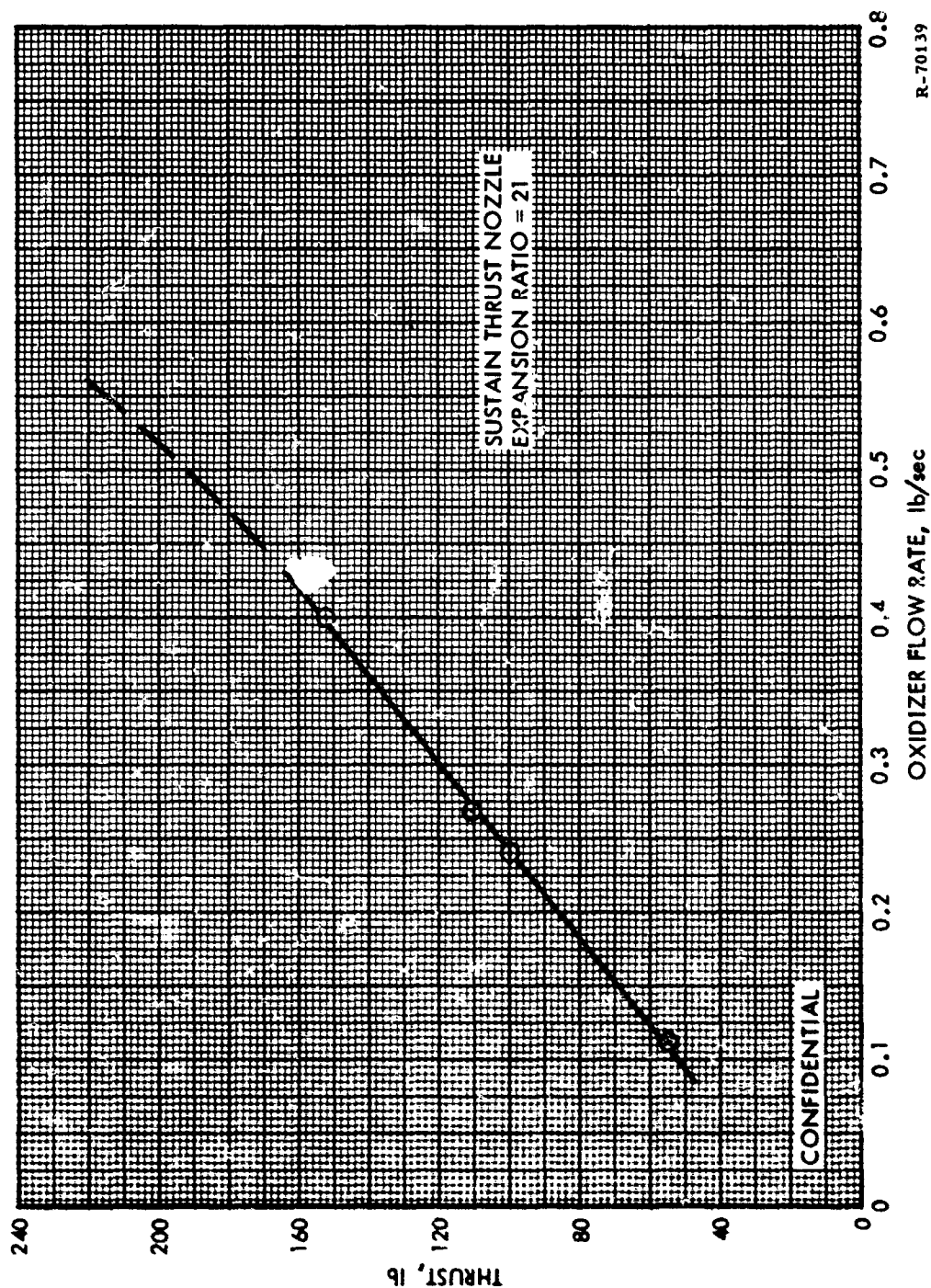
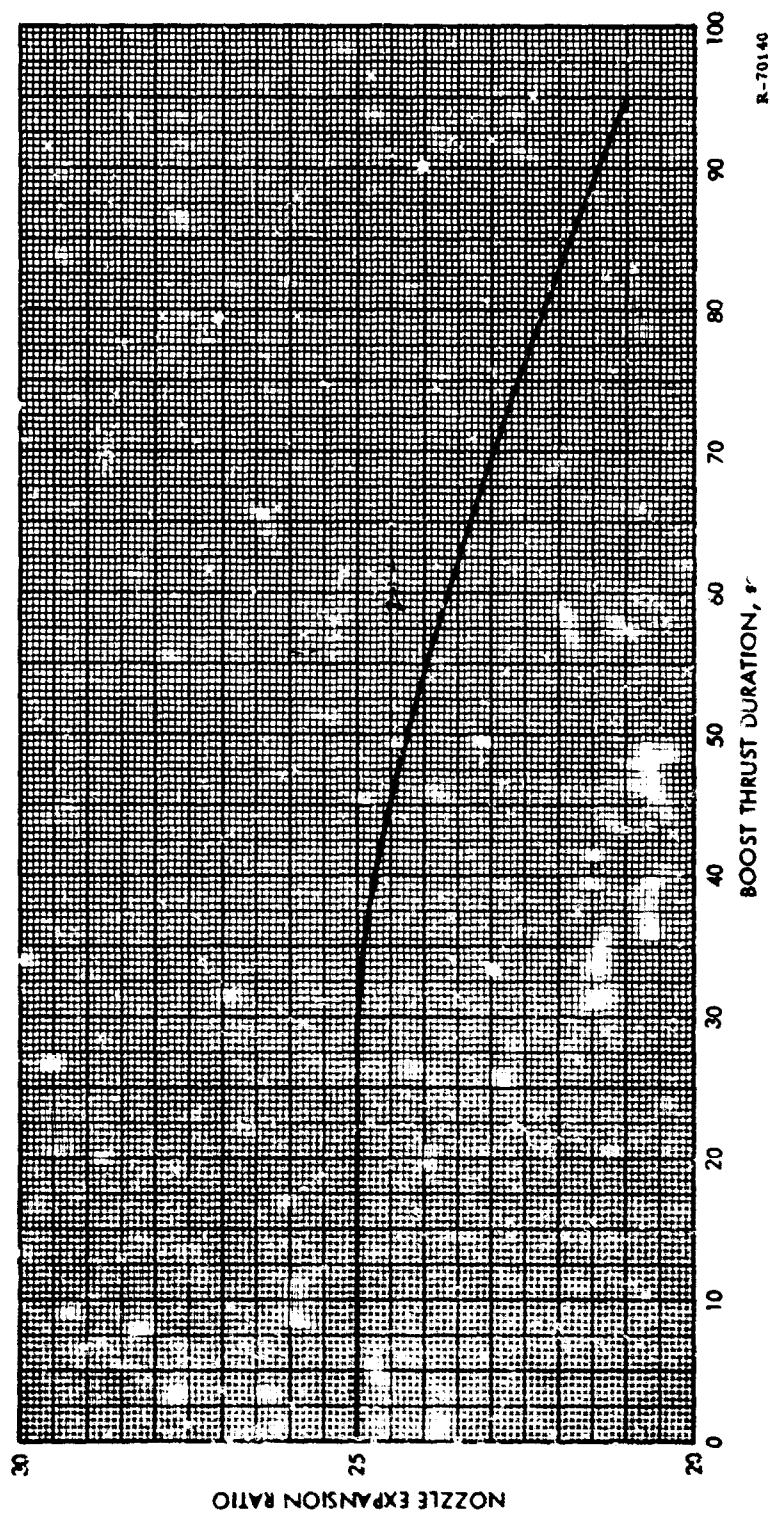


Figure 9. (U) Sea-Level Sustain Performance Corrected to 80,000-ft Altitude

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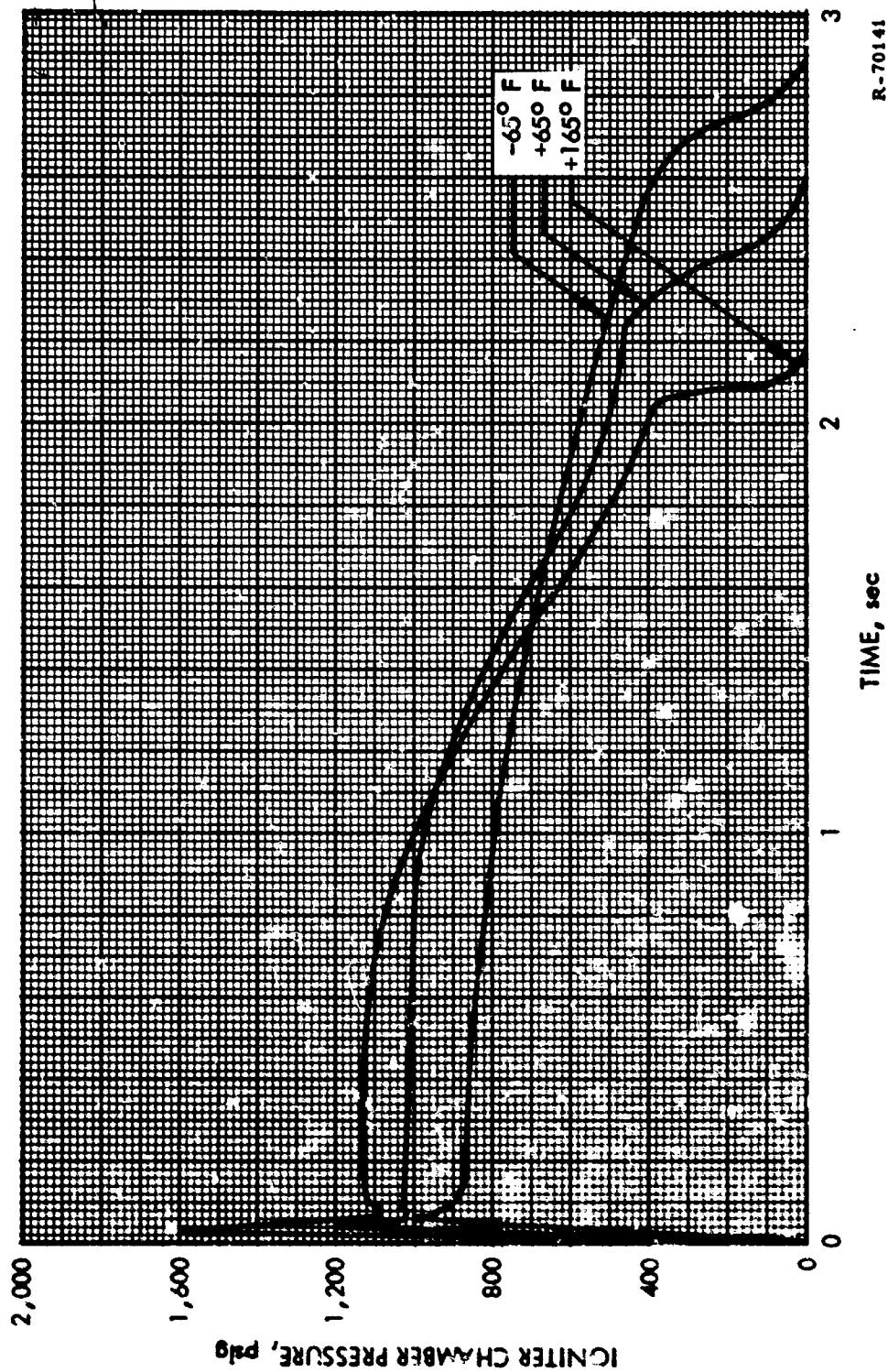
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Figure 10. (U) Nozzle Expansion Ratio Variation as a Function of Boost Time Caused by Nozzle Throat Erosion

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Figure 11. (U) Igniter Open-Air Performance
at Various Conditioning Temperatures

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at -65°F without excessive overpressurization at $+165^{\circ}\text{F}$. A minimum 2-sec action time is provided over the temperature range which provides the required sequencer flexibility during motor ignition.

(U) The performance of the pyrogen igniter in conjunction with the motor has been tested at ambient conditions, (all motors fired to date have used this igniter design), at -65°F , and at -65°F with 50,000-ft simulated altitude conditions. Motor ignition at $+165^{\circ}\text{F}$ has not been considered a development problem and therefore will be evaluated during the flightweight proof test phase. Motor ignition at -65°F was demonstrated during test No. H3S-24 as shown in figure 12. The start sequence provided an igniter leadtime of approximately 1.0 sec followed by the oxidizer valve start signal. The facility oxidizer valve delay and liquid transport time results in a flow rate buildup duration of 100 msec, with full motor chamber pressure developed within 300 msec following the oxidizer start signal. A portion of the facility-supplied oxidizer was conditioned to -65°F during this test to assure that the oxidizer used during the start transient would represent the operation of a complete flight feed system soaked at -65°F . Following the successful ignition at -65°F , an ignition test was then conducted at -65°F in conjunction with a simulated altitude environment of 50,000 ft. The 50,000-ft launch altitude was simulated by an altitude start tank which was able to maintain a near vacuum pressure during the ignition transient. The results of this test are shown in figure 13. The start sequence provided an igniter leadtime of approximately 0.25 sec prior to the oxidizer valve start signal. The facility oxidizer valve delay and liquid transport time required a flow rate buildup duration of 300 msec. Following the arrival of the oxidizer, motor ignition required a delay of 600 msec before achieving full chamber pressure. The effect of a 50,000-ft environment can be seen to delay ignition; however, the igniter performance is well within the acceptable delay limits while being subjected to this combination of -65°F environment and 50,000-ft simulated altitude.

4. FUEL GRAIN INSULATION EVALUATION

(U) During the heavyweight duty cycle tests it was necessary to prematurely terminate some of the tests because of excessive heat on the forward portion of the motor. Slight variations in the test conditions made it difficult to analyze the problem initially; however, based on postfire examinations, it appeared that excessive circulation had suddenly developed at the head end, which attacked the fuel and the forward closure insulation. Hot spots appeared on the forward closure and on the motor case during the tests much earlier than intentional insulation burn throughs had occurred on previous tests and earlier than had been predicted for these tests. This seemed to indicate the possibility that some seemingly minor design change had developed this problem. A careful review of injector design changes

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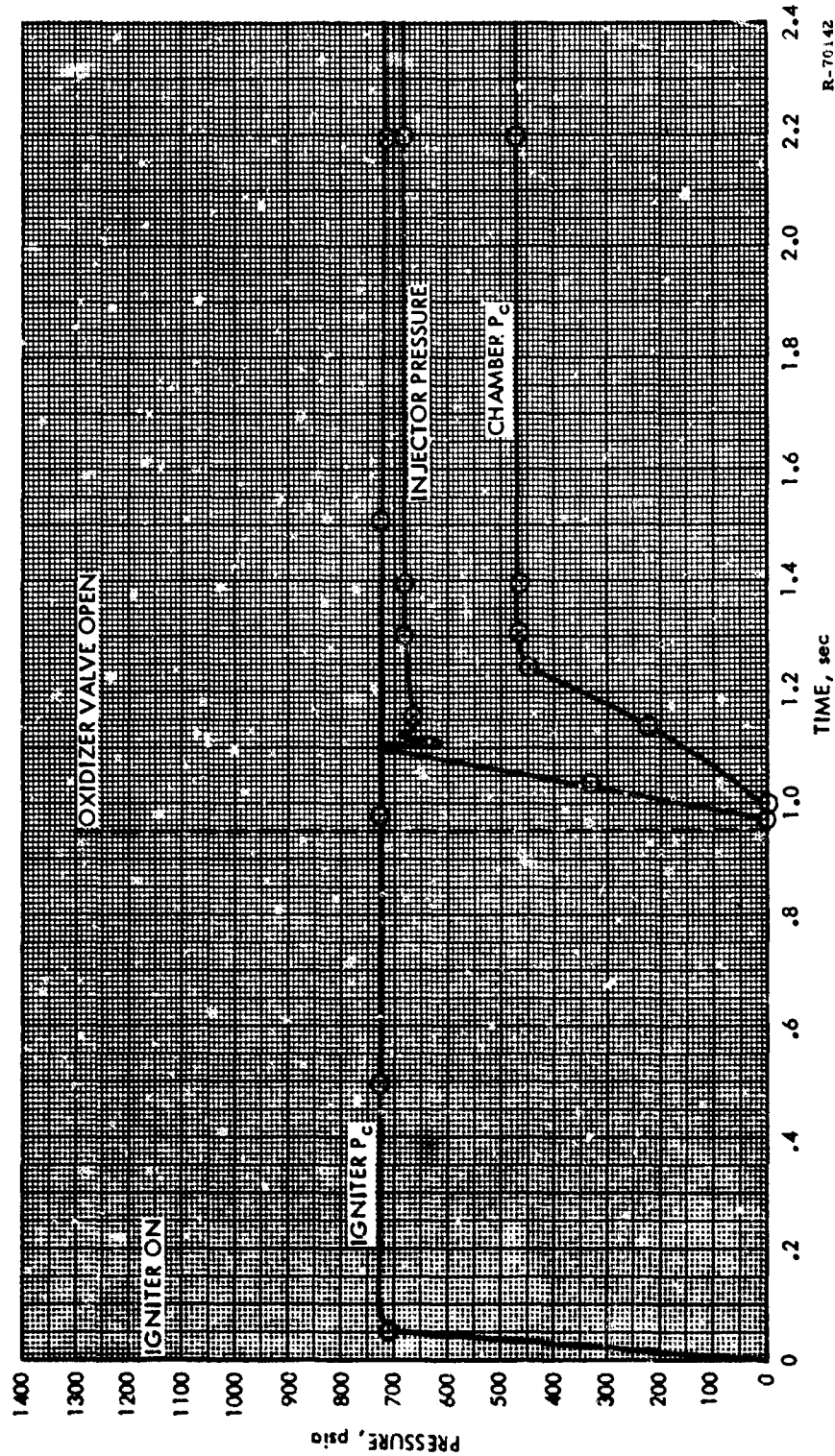


Figure 12. (U) P_{ci} , P_c , P_{io} vs Time, Test No. H3S-24, -65°F

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could not explain this condition until a small piece of deposit built up by the combustion gases, bearing an impression of the injector face, was discovered in the chamber after the test. It could then be seen that some of the injector designs which incorporated a larger exposed surface to the combustion gases might build up deposits which would cling momentarily before being dislodged by the circulation. Before being dislodged, the deposit would deflect the oxidizer to the side, causing excessive fuel utilization and premature insulation burn through. The injector designs having the larger exposed surface areas were of the same internal design as the earlier injectors, the only difference being a method of fabrication change which resulted in a lower projected production unit cost. The low-cost design has now been modified to achieve a minimum amount of exposed surface area by removing more material during the machining operation.

(U) The resolution of this problem did not result in a fuel grain insulation change; however, an additional precaution has been taken on the design of the forward closure insulation. The flightweight hardware forward closure insulation has been thickened by 33% to assure adequate protection for the exposed injector face under the worst conditions of insulation ablation. The thickened insulation provides a recess for the injector early in the firing, thereby diverting the circulating chamber gases away from the injector face. The failures normally occurred during the boost phase or shortly after the beginning of sustain as a result of previous insulation attack during boost. In those tests where the deposits did not deflect the oxidizer, it could be seen that the deposits from the sustain combustion gases were negligible. This reduction during sustain was attributed to a reduced level of combustion gas circulation and a reduced flow rate of cooling oxidizer, resulting in a higher injector face skin temperature. The injector fix is consistent with this reasoning because a reduction in the mass of material near the injector face will increase the surface temperature of the exposed area.

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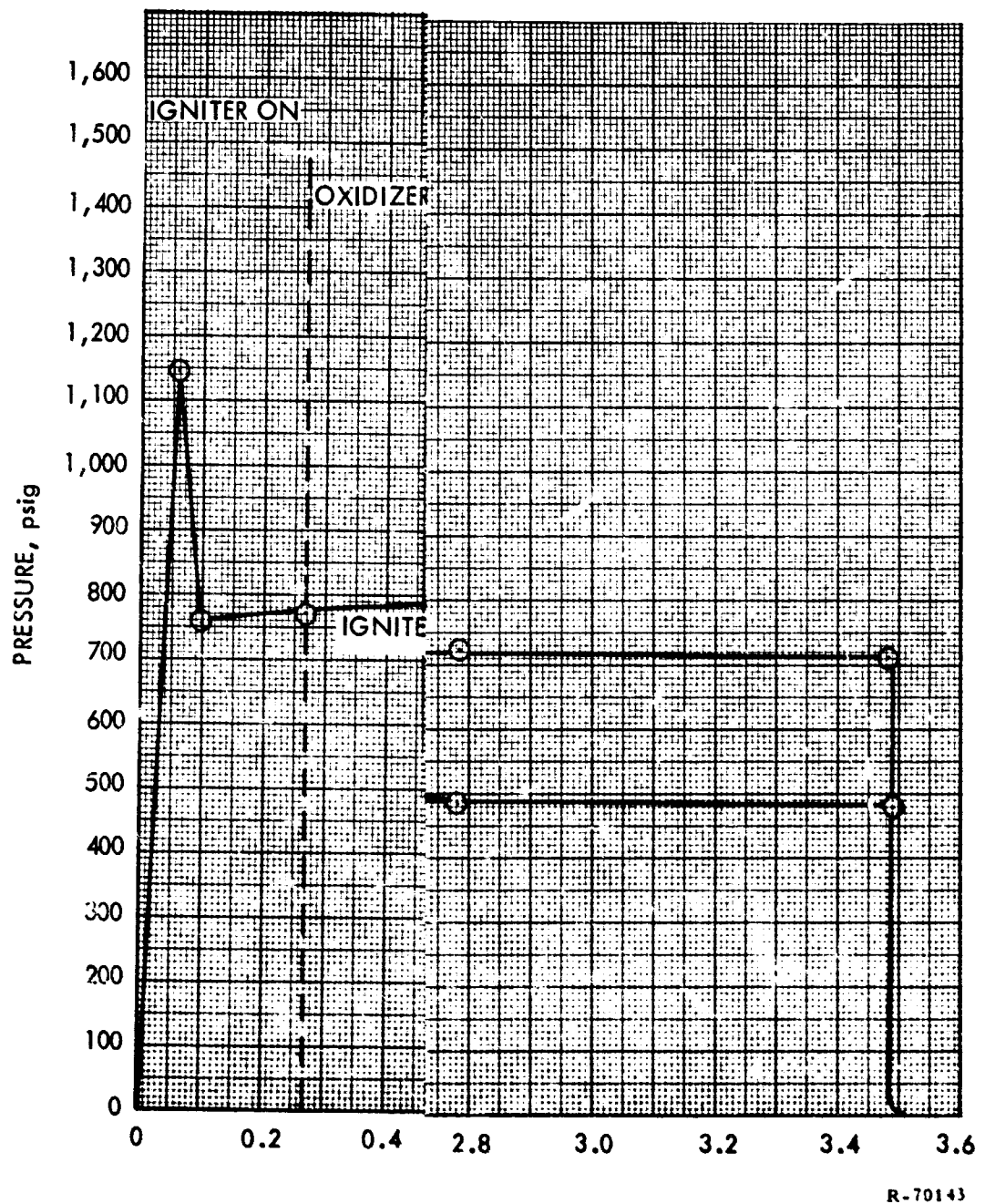
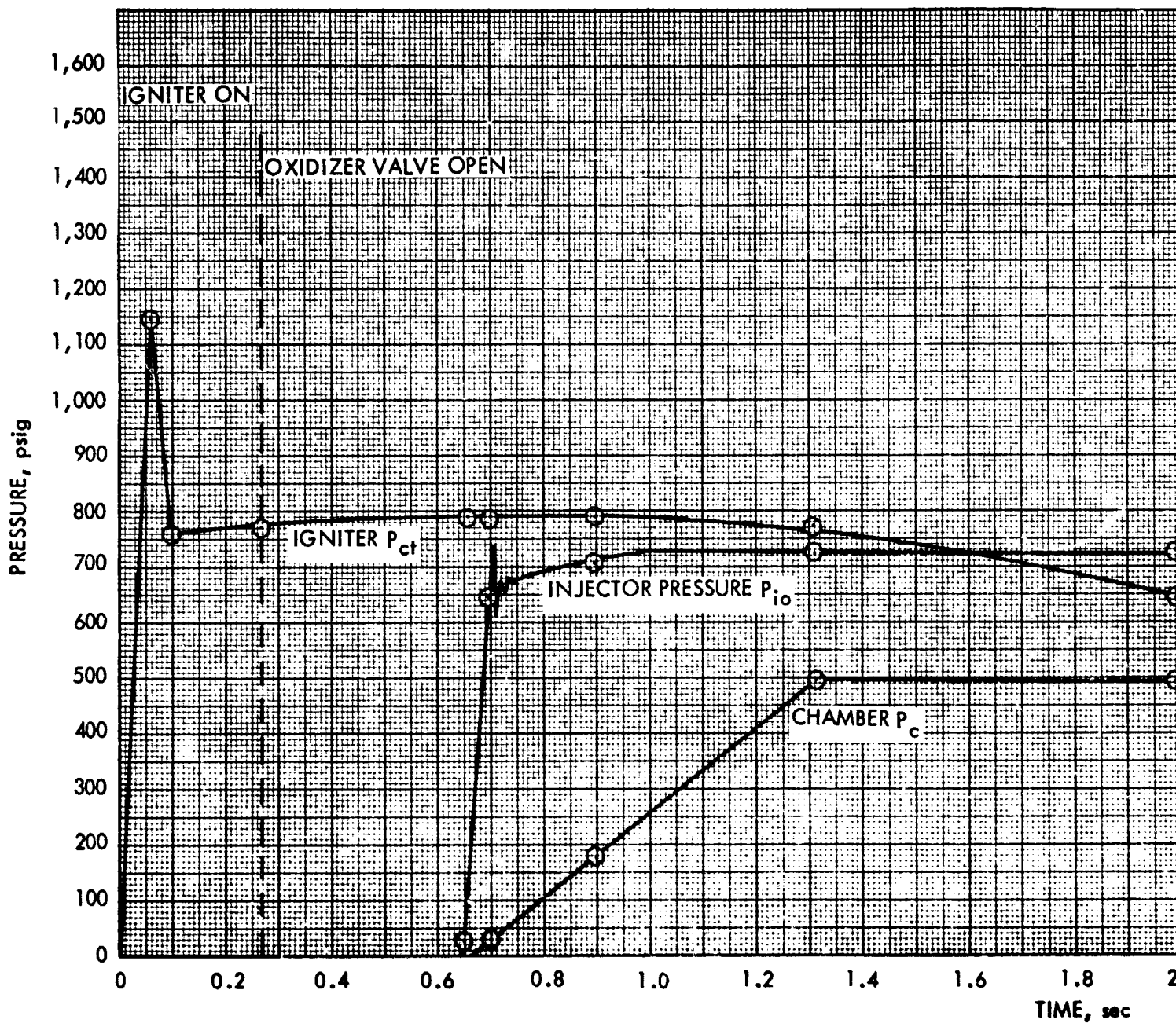


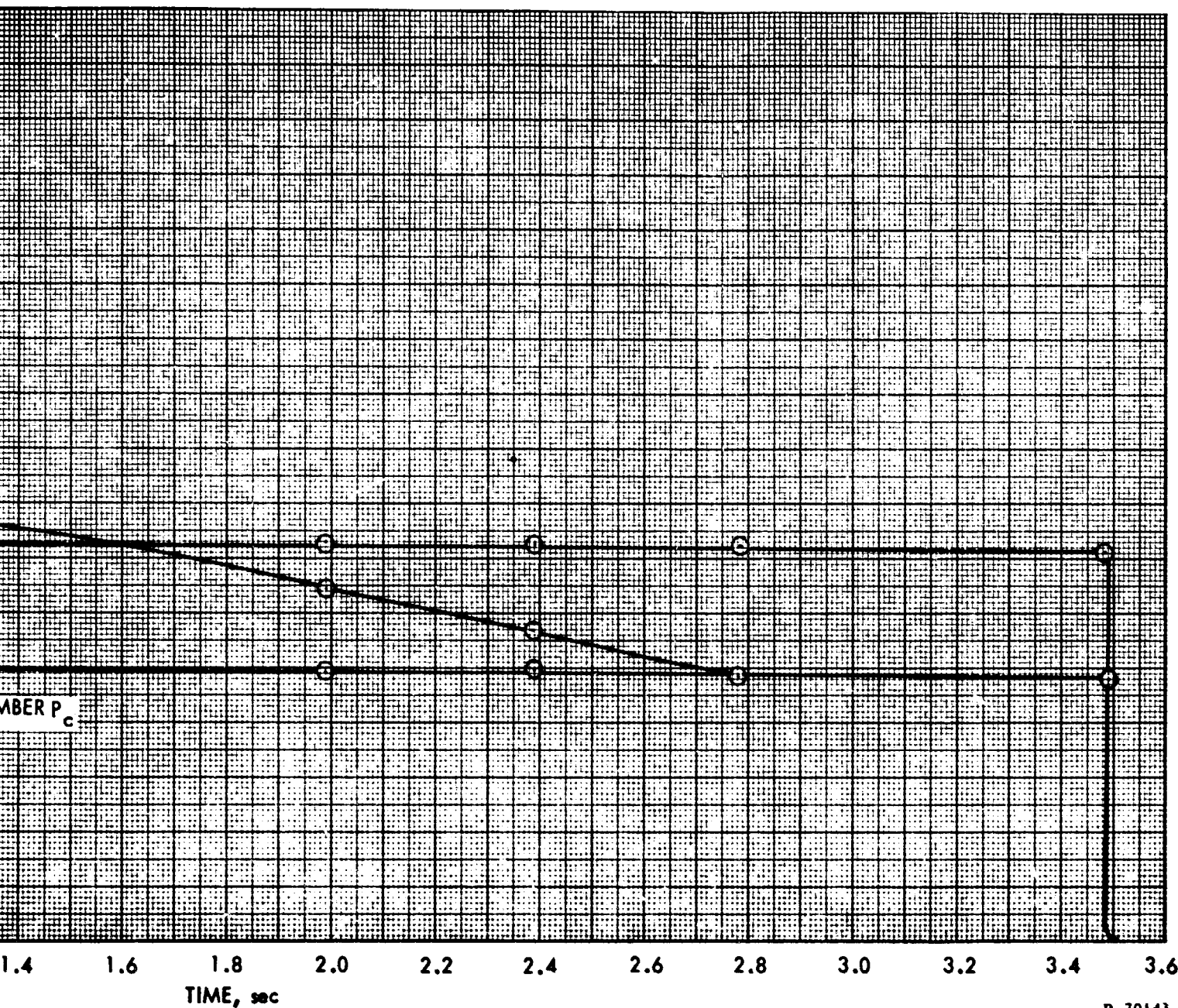
Figure 13. (U) P_{ci} , P_c , P_{io} vs Time,
Test No. H3S-39, 10-in. Hybrid,
-65° F, 50,000-ft Altitude

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Figure 13. (U) P_{ci} , P_c , P_{io} vs Time,
Test No. H3S-39, 10-in. Hybrid,
-65° F, 50,000-ft Altitude

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SECTION IV

FUTURE WORK

(U) During the next reporting period, the flightweight feed system cold flow tests will be completed and final design drawings will be released. The feed system blowdown efficiencies will be determined and pressure drop measurements will allow final injector flow trimming.

(U) Following the feed system cold flow tests, the system tests will begin with an initial shakedown test utilizing the flightweight feed system in conjunction with a heavyweight TCA. The flight system proof tests will then follow in parallel with the structures test and vibration test.

(U) Prior to the actual proof tests, the flightweight igniter assembly will undergo final qualification tests utilizing hardware taken from delivery item production batches.

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APPENDIX I
STRUCTURAL QUALIFICATION OF TCA

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Engineering Department

28 September 1966

UNITED TECHNOLOGY CENTER

Sunnyvale, California

Structural Analysis Report

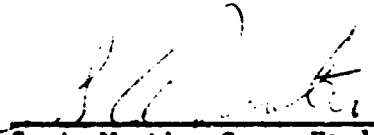
GEN-2

10 INCH HYBRID DRONE, FLIGHT WEIGHT MOTOR CASE

STRUCTURAL ANALYSIS

Prepared by P. F. O'Driscoll
R. D. Bush

Reviewed by:


S. A. Martin, Group Head
Motor Structures

Approved by:

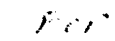

R. A. Jankowski, Section Chief
Structural & Aerothermo Analysis Test

TABLE OF CONTENTS

<u>Section</u>	<u>Page No.</u>
1.0 Introduction	1
2.0 Conclusions	2
3.0 Loads	3
4.0 References	4
5.0 Detailed Calculations	5

Attachment: Outline of Computer Program LI&ZZZ, "Structural
Analysis of Multiple Shell/Ring Structures"

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1.0 INTRODUCTION

This report presents the structural analysis of the 10" Hybrid Drone, Flight-Weight, Thrust Chamber Case. This report includes an analysis of the injector base region, the forward 'Y' ring with and without the aluminum adapter ring in place, the aft closure joint, and the hydro-test closure at the exit plane.

This structural analysis report is made to comply with Section 3.4.2 of reference 1.

This analysis is made for the hydro-test load condition : internal pressure and no loads applied through the skirts. The analysis for internal pressure and flight loads applied concurrently, will be presented in Structural Analysis Report GEN-3, "10 inch Hybrid Drone, Thrust Chamber Assembly, Structural Analysis".

2.0 CONCLUSIONS

All components are shown to have positive margins of safety at ultimate pressure, with or without the aluminum adapter ring in place. Further, since the hydrotest closure plate at the exit plane applied a load virtually identical to that of the nozzle insert, this analysis demonstrates the adequacy of the motor case design for motor operation.

The basic case wall is sized by the minimum manufactured thickness of material, and hence, the basic wall margin of safety is high. The margins of safety for the motor case components are listed below:

Injector Boss region:	+0.98
Forward Closure Y-Ring region: (with aluminum adapter ring)	+0.44
Forward Closure Y-Ring region: (without aluminum adapter ring)	+0.45
Aft Closure region:	+0.55
Aft Closure bolts:	+0.78
Exit Plane Ring region:	+4.45
Aluminum Adapter Ring:	+3.16

A more detailed list of margins of safety is given in Section 5.

3.0 LOADS

Loads are taken from Appendix A, "Preliminary Model Specification for a Hybrid Rocket Engine Propulsion System", Contract AF 04(611)-11632. Values of loads obtained from this appendix are summarized at the start of the detailed calculations for the components to which they apply.

4.0 REFERENCES

1. Attachment #1 to Exhibit "A", Contract AF 04(611)-11632. Appendix A, "Preliminary Model Specification for a Hybrid Rocket Engine Propulsion System"
2. Specification, Steel Forgings, Bars, Plates and Sheets, 18 Percent Nickel Maraging, No. SE 0100. United Technology Center
3. "Allowable Stresses and Interaction Equations for Thin Cylinders," STM #5, Convair (Astronautics) Division, General Dynamics Corporation. 7-29-60
4. Shanley, "Strength of Materials."
5. "Strength of Metal Aircraft Elements," MIL-HDBK-5. D.O.D. March 1961

5.0 DETAILED CALCULATIONS

For analysis purposes, the motor case is divided into four regions, as shown in Figure 1. They are:

- i) Injector boss region
- ii) Forward Closure Y Ring region
- iii) Aft Closure region
- iv) Exit Plane Ring

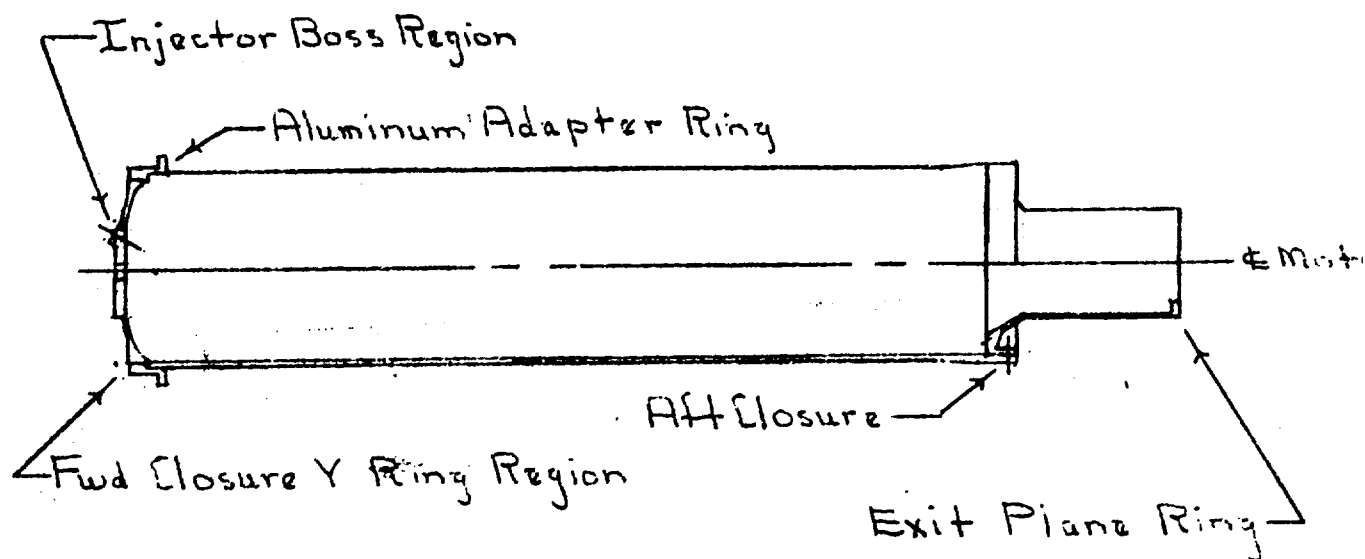
As an approximate analysis for the eccentric injector boss the region is analyzed first as an axi-symmetric shell without a boss, and secondly as an axi-symmetric shell with the boss cross-section included.

The forward Y ring is analyzed both with and without the aluminum adapter ring in place.

The exit plane ring is analyzed with a bearing load on the ring which approximates both the hydrotest closure load and also the throat insert blow-out load.

The method of analysis used for shells is a computer program which is outlined in Appendix A.

The components analyzed are detailed on UTC Drawings No. CO2236, CO2406, CO2177 and CO2219.

10" HYBRID MOTOR COMBUSTION CHAMBERFIGURE 1 NOMENCLATURE

MATERIAL 18 % NICKEL MARAGING STEEL
TYPE I - 200 GRADE

$$F_{tu} = 210,000 \text{ PSI}$$

$$F_{ty} = 200,000 \text{ PSI}$$

United Technology Center, Specification, Steel Forgings, Bars, Plates and Sheets, 18 Percent Nickel Maraging, No. SED100.

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PREPARED BY

P.O'D

DATE 10/19/66

REVIEWED BY

DATE

MARGINS OF SAFETY

ITEM	"S"	t_{max}	TYPE	F_{T0}	M.S.
<u>INJECTOR BOSS REGION</u>					
SHELL 1	.35	54,000	MI	210,000	+ 2.89
SHELL 2	.30	105,000	MO	210,000	+ 1.00
<u>INJECTOR BOSS REGION (NO BOSS AREA)</u>					
SHELL 1	.20	106,000	MO	210,000	+ 0.98
<u>FORWARD CLOSURE 'Y' RING REGION</u>					
SHELL 1	0	57,500	CO	210,000	+ 2.65
SHELL 2	.42	146,000	MI	210,000	+ 0.45
<u>FORWARD CLOSURE 'Y' RING REGION (WITH ALUMINUM ADAPTOR RING)</u>					
SHELL 1	2.9	89,000	MI	210,000	+ 1.36
SHELL 2	.42	146,000	MI	210,000	+ 0.44
<u>AFT CLOSURE</u>					
SHELL 1	2.45	69,500	CO	210,000	+ 2.02
SHELL 2	1.00	80,000	MI	210,000	+ 1.63
SHELL 3	1.20	136,000	CO	210,000	+ 0.55
SHELL 4	0	131,000	CI	210,000	+ 0.60
<u>BOLT</u>					
<u>EXIT PLANE RING</u>					
SHELL 1	1.15	38,500	CO	210,000	+ 4.45

"S" : DISTANCE ALONG SHELL

TYPE : M - MERIDIONAL , C - CIRCUMFERENTIAL

I - INSIDE , O - OUTSIDE



United Technology Center

DIVISION OF UNITED AIRCRAFT CORPORATION

PC

PREPARED BY RDBuch

DATE 9-27-66

REVIEWED BY

DATE

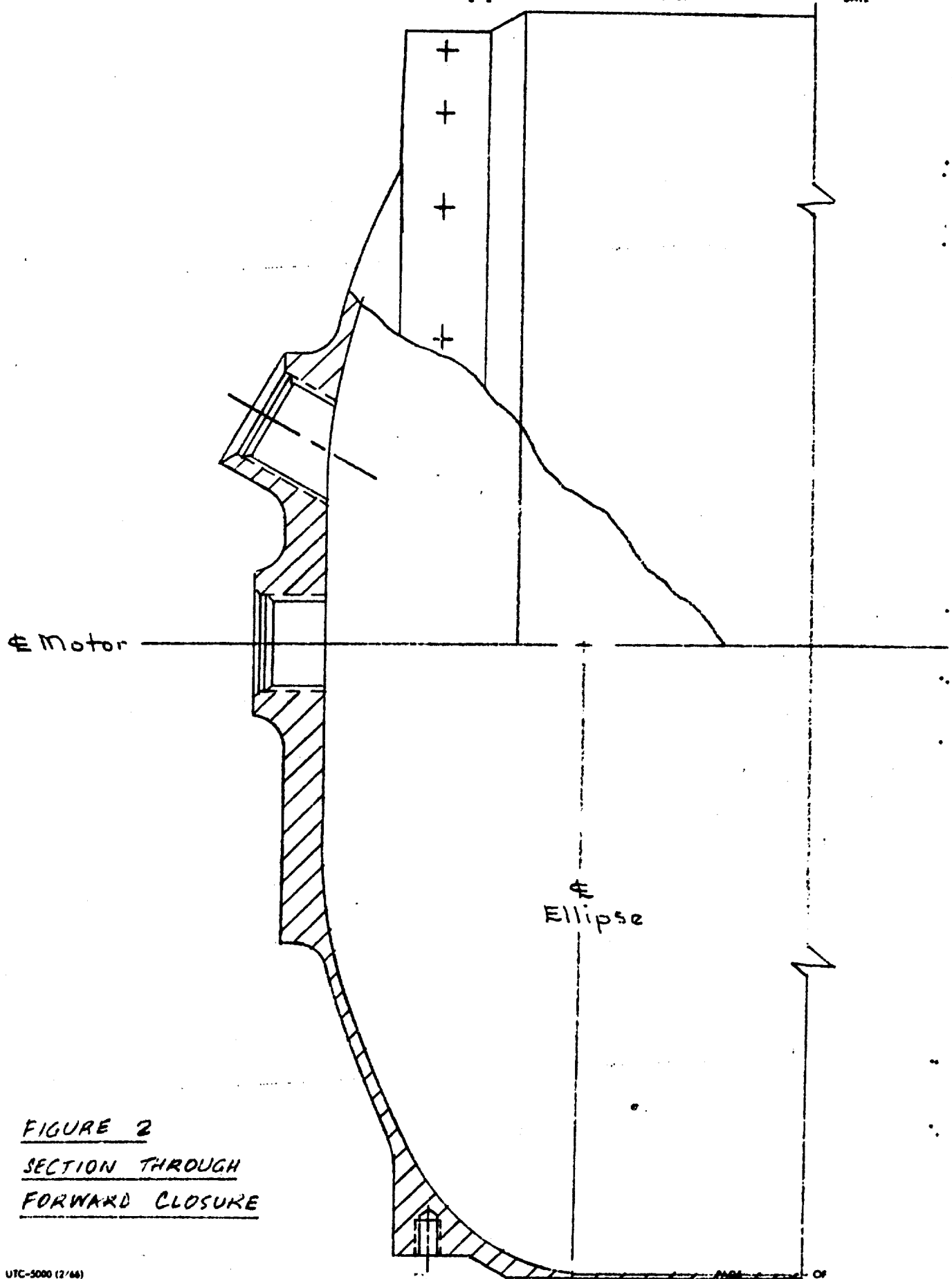


FIGURE 2
SECTION THROUGH
FORWARD CLOSURE

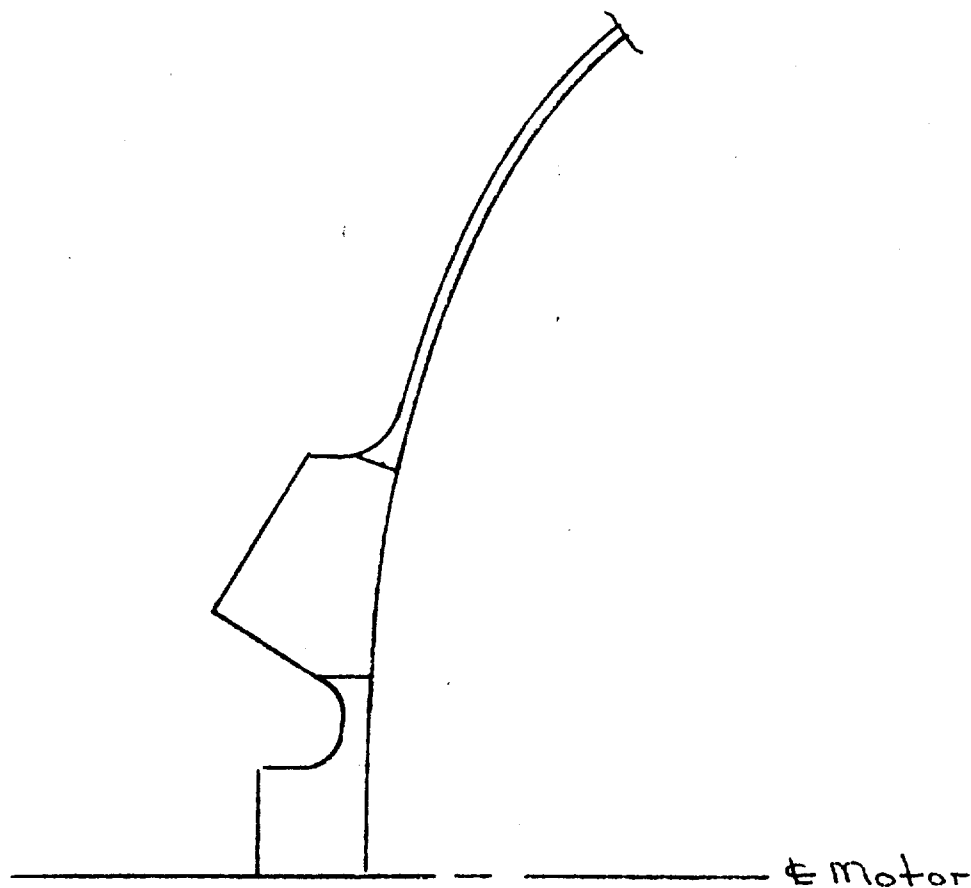


FIGURE 3

INJECTOR BOSS REGION

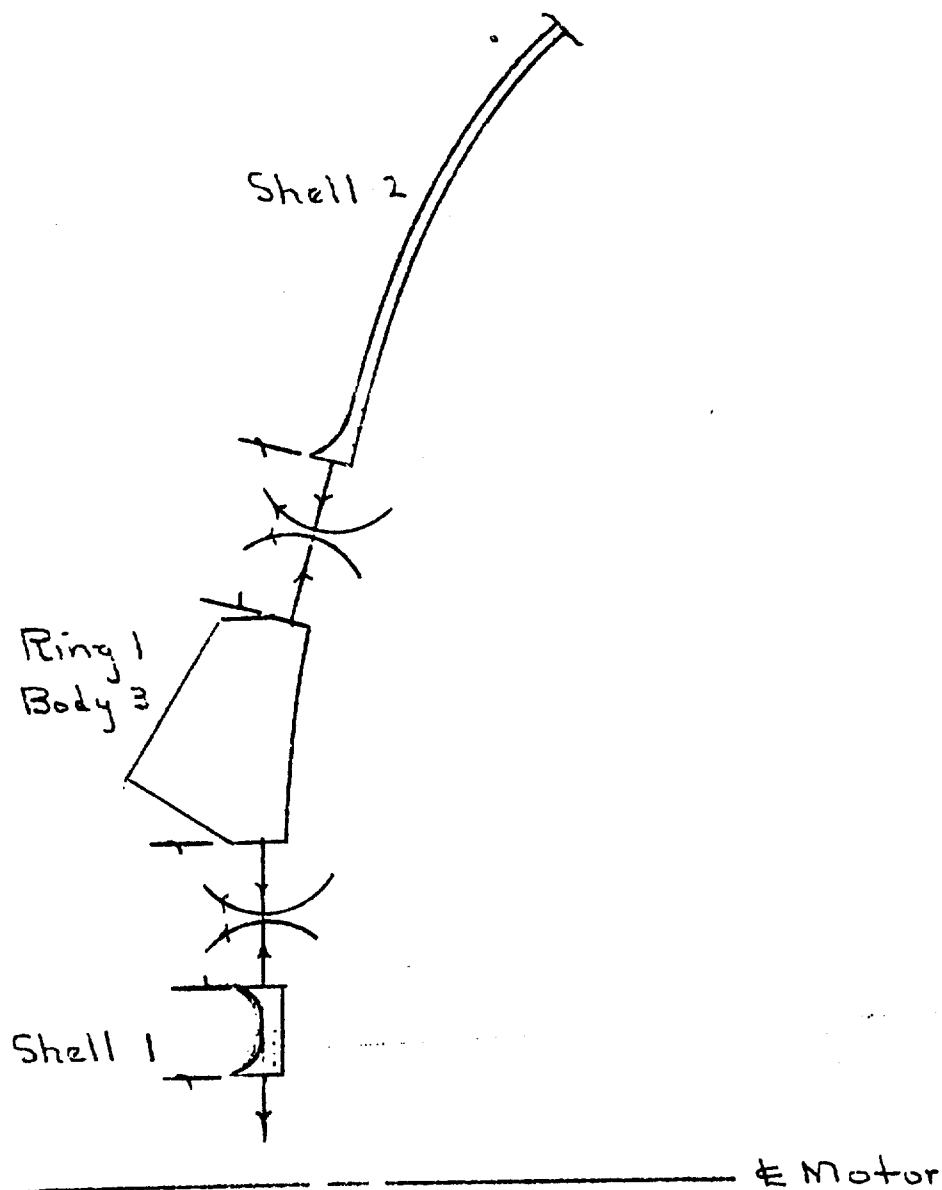


FIGURE 4

INJECTOR BOSS REGION



10 IN HYBRID, THRUST CHAMBER, INJECTOR
BOSS REGION 6 OCT. 66

$$F_x, F_y, M_{cg}, 1106, 0, 0,$$

$$F_x = (2.2600 - 1.0450) \times 910 = 1106 \text{ LB}$$

$$F_y = 0$$

$$M_{cg} = 0$$

B.C.

5,

1, 1, 1,

0, 0, 0,

2, 4, 5,

0, 951, 4997,

2, 2,

1, 1,

3, 4,

0, 0,

$$\beta_1 = 0$$

$$Q_1 = 1.045(910) = 951 \text{ LB}$$

$$N_1 = \frac{PR_2}{2} = \frac{910(10.9827)}{2} = 4997 \text{ LB}$$

THE VALUE OF ULTIMATE PRESSURE IS 910 PSI

THIS IS OBTAINED IN THE FOLLOWING MANNER:

CHAMBER PRESSURE, P_c , FROM TESTS: 550 PSI.

MEOP = $550 \times 1.1 = 605 \text{ PSI}$

ULTIMATE PRESSURE = $605 \times 1.5 = \underline{910 \text{ PSI}}$



INTERNATIONAL JOURNAL OF HART CONSTRUCTION

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PREPARED BY W. D. DAVIS

DATE _____

DATE

INPUT VALUES FOR UNIT ANALYSIS OF AN AXISYMMETRIC THIN SHELL

PROJ. NO. _____

SHELL LENGTH .50 . POISSON'S RATIO 0.3 .

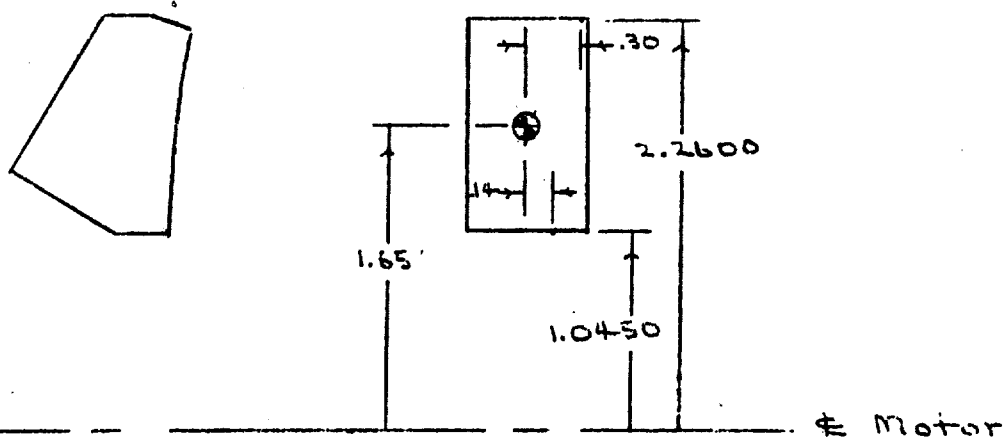
YOUNGS MODULUS 2.65×10^7 NO. TAYLOR SERIES 5 NO. SEGMENTS 50

[illegible]

N-225 (5/63)



INJECTOR BOSS REGION



$$\begin{cases} RLI = 1.0481 \\ PHILI = 5.5505 \\ XLI = -.14 \end{cases}$$

$$\begin{cases} RLO = 0 \\ PHILO = 0 \\ XLO = 0 \end{cases}$$

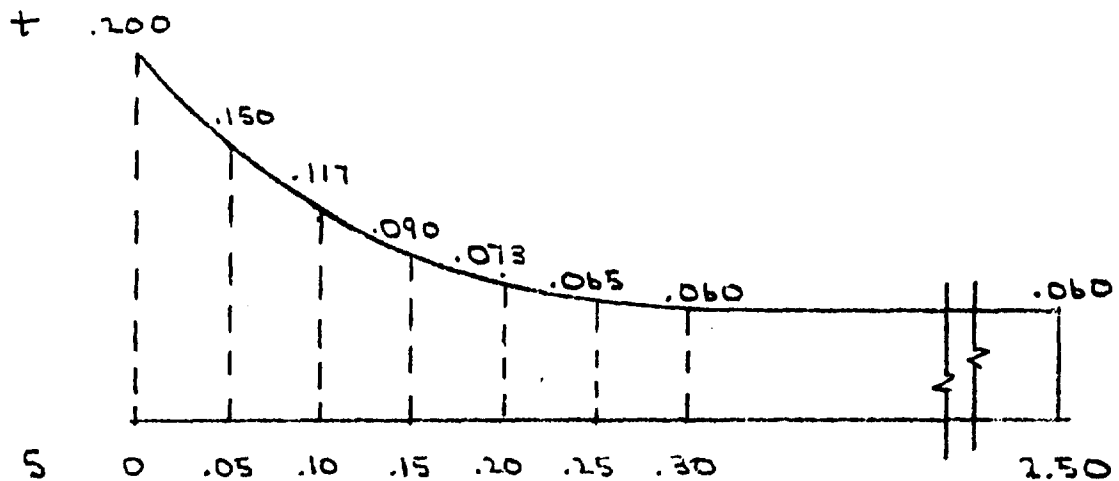
$$\begin{cases} RRI = 0 \\ PHIRI = 0 \\ XRI = 0 \end{cases}$$

$$\begin{cases} RRO = 2.2600 \\ PHIRO = 13.712 \\ XRO = .30 \end{cases}$$

$$\begin{cases} R_{CG} = 1.65 \\ A = 1.17(.64) = .7488 \text{ IN}^2 \\ I = \frac{1.17}{12}(.64)^3 = .02556 \text{ IN}^4 \\ E = 2.65 \times 10^7 \text{ PSI} \end{cases}$$



Shell 2



$$\beta = \frac{1.285}{\sqrt{R_1 t}} = \frac{1.285}{\sqrt{8(0.060)}} = \frac{1.285}{\sqrt{0.48}} = \frac{1.285}{0.692}$$

$$\beta = 1.87$$

$$l = 5.00 / 1.87 = 2.63$$



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INPUT VALUES FOR UNIT ANALYSIS OF AN AXISYMMETRIC THIN SHELL

PROJ. NO. _____

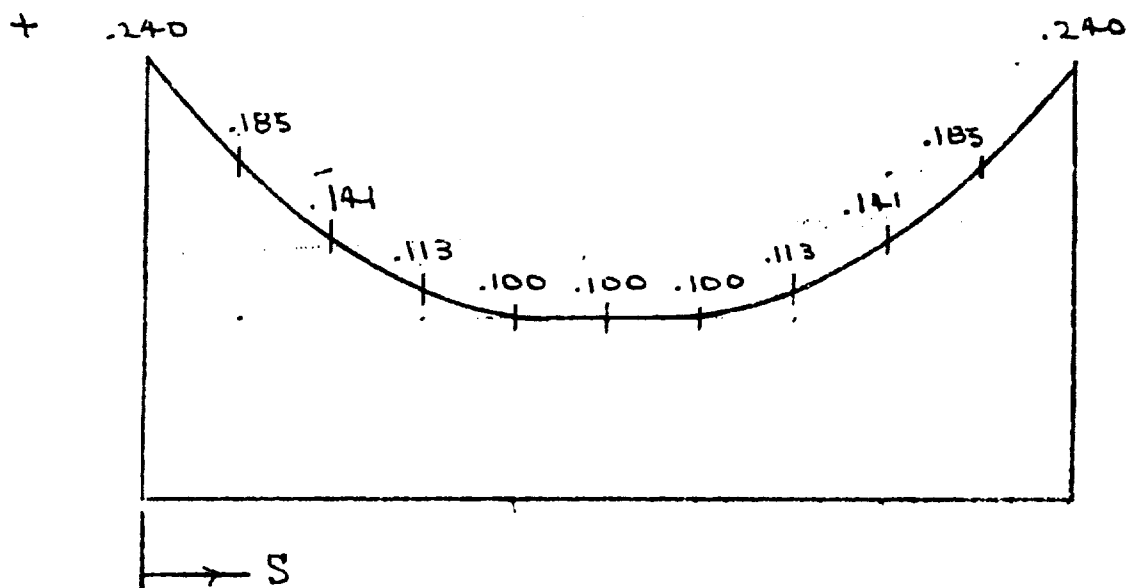
SHELL LENGTH 2.50 . POISSON'S RATIO 0.3 .

YOUNGS MODULUS 2.65×10^7 NO. TAYLOR SERIES 5 NO. SEGMENTS 50.

[illegible]



Shell 1



$$\phi = 13.712^\circ = 13^\circ 42.72'$$

$$\sin 13^\circ 42.72' = .23704$$

$$R_2 = 9.5342$$

$$RRD = R_2 \sin \phi = 9.5342(.23704) = 2.2600$$

10 IN HYBRID THRUST CHAMBER, FWD Y RING ELLIPSE PROPS M.O.D. BUSH 5 AUG 66

INPUT DATA

A = 4.90000 B = 2.30000 X = 2.26000 DELTAS = 0.05000
 GEOMETRIC PROPERTIES - ELLIPSOID OF REVOLUTION

DELTA S	R1	R2	PHI
0.00000000	7.95286696E+00	9.53419701E+00	13.71199071
0.05000000	7.85017765E+00	9.49298317E+00	14.07431601
0.10000000	7.74593771E+00	9.45077773E+00	14.44144222
0.15000000	7.64013309E+00	9.40757438E+00	14.81357223
0.20000000	7.53299104E+00	9.36336672E+00	15.19091806
0.25000000	7.42438007E+00	9.31814823E+00	15.57370140
0.30000000	7.31441003E+00	9.27191234E+00	15.96215430
0.35000000	7.20313207E+00	9.22465237E+00	16.35651974
0.40000000	7.09059873E+00	9.17636160E+00	16.75705243
0.45000000	6.97486390E+00	9.12703326E+00	17.16401948
0.50000000	6.86198291E+00	9.07666054E+00	17.57770129
0.55000000	6.74601253E+00	9.02523663E+00	17.99839239
0.60000000	6.62901099E+00	8.97275471E+00	18.42640239
0.65000000	6.51103601E+00	8.91920802E+00	18.86205699
0.70000000	6.39215487E+00	8.86458983E+00	19.30569909
0.75000000	6.27242438E+00	8.80889353E+00	19.75768995
0.80000000	6.15191099E+00	8.75211262E+00	20.21841046
0.85000000	6.03068076E+00	8.69424076E+00	20.68826252
0.90000000	5.90880142E+00	8.63527185E+00	21.16767049
0.95000000	5.78634243E+00	8.57520004E+00	21.65706281
1.00000000	5.66337498E+00	8.51401979E+00	22.15697371
1.05000000	5.53997207E+00	8.45172597E+00	22.66784506
1.10000000	5.41620853E+00	8.38831392E+00	23.19022835
1.15000000	5.29216106E+00	8.32377950E+00	23.72468690
1.20000000	5.16790832E+00	8.25811924E+00	24.27181816
1.25000000	5.04353090E+00	8.19133042E+00	24.83225625
1.30000000	4.91911145E+00	8.12341119E+00	25.40667464
1.35000000	4.79473469E+00	8.05436073E+00	25.99578925
1.40000000	4.67048745E+00	7.98417938E+00	26.60036130
1.45000000	4.54645876E+00	7.91286885E+00	27.22120103
1.50000000	4.42273987E+00	7.84043240E+00	27.85917124
1.55000000	4.29942436E+00	7.76687508E+00	28.51519123
1.60000000	4.17660812E+00	7.69220398E+00	29.19024107
1.65000000	4.05434947E+00	7.61642853E+00	29.88536611
1.70000000	3.93284920E+00	7.53956084E+00	30.60168178
1.75000000	3.81215063E+00	7.46161609E+00	31.34037879
1.80000000	3.69233966E+00	7.38261291E+00	32.10272851
1.85000000	3.57354485E+00	7.30257392E+00	32.89008868
1.90000000	3.45587743E+00	7.22152623E+00	33.70390942
1.95000000	3.33945144E+00	7.13950212E+00	34.54573935
2.00000000	3.22433836E+00	7.05653967E+00	35.41723194
2.05000000	3.11079383E+00	6.97268361E+00	36.32015181
2.10000000	2.99880447E+00	6.88798616E+00	37.25638098
2.15000000	2.88854104E+00	6.80250806E+00	38.22792482
2.20000000	2.78013212E+00	6.71631971E+00	39.23691746
2.25000000	2.67376900E+00	6.62950235E+00	40.28562627
2.30000000	2.56940610E+00	6.54214953E+00	41.37645514
2.35000000	2.46734607E+00	6.45436862E+00	42.51194563
2.40000000	2.36771306E+00	6.36628249E+00	43.69477685
2.45000000	2.27060611E+00	6.27603140E+00	44.92775491

2.50000000
2.50000000
2.50000000
2.60000000
2.65000000
2.70000000
2.75000000
2.80000000
2.85000000
2.90000000
2.95000000
3.00000000
3.05000000
3.10000000
3.15000000
3.20000000
3.25000000
3.30000000
3.35000000
3.40000000
3.45000000
3.50000000
1.05905730

2.17618558+00
2.08459974+00
1.99599920+00
1.91053670+00
1.82836675+00
1.74964525+00
1.67452903+00
1.60317524+00
1.53578069+00
1.47238103+00
1.41324978+00
1.35849733+00
1.30826966+00
1.26270700+00
1.22194242+00
1.18610017+00
1.15529411+00
1.12962598+00
1.10918380+00
1.09404032+00
1.08425160+00
2.63094227+00

6.18977494+00
6.10169426+00
6.01399418+00
5.92690561+00
5.84068773+00
5.75563021+00
5.67205512+00
5.59031845+00
5.51081096+00
5.43395812+00
5.36021889+00
5.29008292+00
5.22406580+00
5.16270222+00
5.10653677+00
5.05611185+00
5.01195391+00
4.97455732+00
4.94436727+00
4.92176257+00
4.90703972+00
6.75698913+00

46.21382596
47.55602049
48.95747161
50.42136410
51.95089646
53.54922581
55.21939733
56.96425611
58.78633970
60.68775035
62.67000720
64.73388072
66.87921409
69.10473964
71.40790184
73.78470215
76.22958365
78.73537496
81.29331132
83.89314664
86.52336228
38.75697992

PROCESSOR: 0.090 MINUTES
INPUT/OUTPUT: 0.121 MINUTES
ELAPSED TIME: 0.112 MINUTES

STRUCTURAL ANALYSIS OF MULTIPLE SPALL/RING STRUCTURES

UNITED TECHNOLOGY CENTER

6 OCT 1966

10 IN HYBRID, THRUST CHAMBER, INJECTION BOSS REGION 6 OCT. 1966

SHELL #1 END PLATE

SHELL UNIT ANALYSIS

SHELL NO. 1, CONFIGURATION NO. 1

INPUT IS:

RAYLUMS SERIES EXPANSIONS OF 5 TERMS ARE USED TO SOLVE THE DIFFERENTIAL EQUATIONS SIMULTANEOUSLY.
THE 0.5000 INCH LONG SHELL SECTION IS DIVIDED INTO 50 SEGMENTS EACH OF WHICH IS 0.0100 INCHES LONG.

MODULUS OF ELASTICITY, E = 2.650000E+07
POISSON'S RATIO, MU = 0.3000

MENTIONALLY VARYING PARAMETER FUNCTIONS:

RADIUS 1 = 1.0874E+01 1.0844E+01 1.0810E+01 1.0774E+01 1.0735E+01 1.0694E+01 1.0650E+01
S = 0.0000E+00 5.0000E-02 1.0000E-01 1.5000E-01 2.0000E-01 2.5000E-01 3.0000E-01

RADIUS 2 = 1.0983E+01 1.0972E+01 1.0961E+01 1.0949E+01 1.0936E+01 1.0922E+01 1.0907E+01
S = 0.0000E+00 5.0000E-02 1.0000E-01 1.5000E-01 2.0000E-01 2.5000E-01 3.0000E-01
1.0891E+01 1.0874E+01 1.0856E+01 1.0838E+01
3.5000E-01 4.0000E-01 4.5000E-01 5.0000E-01

THICKNESS = 2.4000E-01 1.8500E-01 1.4100E-01 1.1300E-01 1.0000E-01 1.0000E-01 1.0000E-01
S = 0.0000E+00 5.0000E-02 1.0000E-01 1.5000E-01 2.0000E-01 2.5000E-01 3.0000E-01
1.1300E-01 1.4100E-01 1.8500E-01 2.4000E-01
3.5000E-01 4.0000E-01 4.5000E-01 5.0000E-01

PMI = 2.8691E+00 3.1324E+00 3.3975E+00 3.6629E+00 3.9292E+00 4.1965E+00 4.4649E+00
S = 0.0000E+00 5.0000E-02 1.0000E-01 1.5000E-01 2.0000E-01 2.5000E-01 3.0000E-01
4.7344E+00 5.0051E+00 5.2771E+00 5.5505E+00
3.5000E-01 4.0000E-01 4.5000E-01 5.0000E-01

SHELL #2 CLOSURE DOME (ELLIPTICAL)

SHELL UNIT ANALYSIS

SHELL NO. 2, CONFIGURATION NO. 1

INPUT ISI

TAYLORS SERIES EXPANSIONS OF 5 TERMS ARE USED TO SOLVE THE DIFFERENTIAL EQUATIONS SIMULTANEOUSLY.
THE 2.5000 INCH LONG SHELL SECTION IS DIVIDED INTO 50 SEGMENTS EACH OF WHICH IS 0.0500 INCHES LONG.

MODULUS OF ELASTICITY, E = 2.650000E+07
POISSON'S RATIO, MU = 0.3000

MEMORIDUALLY VARIING PARAMETER FUNCTIONS:

RADIUS 1 =	7.9529E+00	7.6502E+00	7.7459E+00	7.6402E+00	7.5330E+00	7.4244E+00	7.3144E+00
S =	0.0000E+00	5.0000E-02	1.0000E-01	1.5000E-01	2.0000E-01	2.5000E-01	3.0000E-01
	7.0906E+00	6.8620E+00	6.6290E+00	6.3922E+00	6.1519E+00	5.9088E+00	5.6634E+00
	4.0000E-01	5.0000E-01	6.0000E-01	7.0000E-01	8.0000E-01	9.0000E-01	1.0000E+00
	5.4162E+00	5.1679E+00	5.0435E+00	4.9191E+00	4.7947E+00	4.6705E+00	4.5465E+00
	1.1000E+00	1.2000E+00	1.2500E+00	1.3000E+00	1.3500E+00	1.4000E+00	1.4500E+00
	4.4227E+00	4.1766E+00	3.9329E+00	3.6923E+00	3.4559E+00	3.2244E+00	2.9988E+00
	1.5000E+00	1.6000E+00	1.7000E+00	1.8000E+00	1.9000E+00	2.0000E+00	2.1000E+00
	2.7801E+00	2.5694E+00	2.3677E+00	2.1762E+00			
	2.2000E+00	2.3000E+00	2.4000E+00	2.5000E+00			

RADIUS 2 =	9.5342E+00	9.4430E+00	9.4508E+00	9.4076E+00	9.3634E+00	9.3181E+00	9.2719E+00
S =	0.0000E+00	5.0000E-02	1.0000E-01	1.5000E-01	2.0000E-01	2.5000E-01	3.0000E-01
	9.1744E+00	9.0767E+00	8.9728E+00	8.8646E+00	8.7521E+00	8.6353E+00	8.5140E+00
	4.0000E-01	5.0000E-01	6.0000E-01	7.0000E-01	8.0000E-01	9.0000E-01	1.0000E+00
	8.3883E+00	8.2541E+00	8.1913E+00	8.1234E+00	8.0548E+00	7.9842E+00	7.9129E+00
	1.1000E+00	1.2000E+00	1.2500E+00	1.3000E+00	1.3500E+00	1.4000E+00	1.4500E+00
	7.4404E+00	7.4422E+00	7.4394E+00	7.3826E+00	7.2215E+00	7.0565E+00	6.8880E+00
	1.5000E+00	1.6000E+00	1.7000E+00	1.8000E+00	1.9000E+00	2.0000E+00	2.1000E+00
	6.7163E+00	6.5421E+00	6.3643E+00	6.1898E+00			
	2.2000E+00	2.3000E+00	2.4000E+00	2.5000E+00			

THICKNESS =
 S =
 2.0000E-01 1.5000E-01 1.1700E-01 9.0000E-02 7.3000E-02 6.5000E-02 6.0000E-02
 0.0000E+00 5.0000E-02 1.0000E-01 1.5000E-01 2.0000E-01 2.5000E-01 3.0000E-01
 4.0000E-02
 2.5000E+00

PM1 =
 S =
 1.3712E+01 1.4074E+01 1.4441E+01 1.4814E+01 1.5191E+01 1.5574E+01 1.5952E+01
 0.0000E+00 5.0000E-02 1.0000E-01 1.5000E-01 2.0000E-01 2.5000E-01 3.0000E-01
 1.6757E+01 1.7578E+01 1.8426E+01 1.9306E+01 2.0218E+01 2.1168E+01 2.2157E+01
 4.0000E-01 5.0000E-01 6.0000E-01 7.0000E-01 8.0000E-01 9.0000E-01 1.0000E+00
 2.3190E+01 2.4272E+01 2.5407E+01 2.5996E+01 2.6600E+01 2.7221E+01 2.7221E+01
 1.1000E+00 1.2000E+00 1.2500E+00 1.3000E+00 1.3500E+00 1.4000E+00 1.4500E+00
 2.7859E+01 2.9190E+01 3.0602E+01 3.2103E+01 3.3704E+01 3.5417E+01 3.7256E+01
 1.5000E+00 1.6000E+00 1.7000E+00 1.8000E+00 1.9000E+00 2.0000E+00 2.1000E+00
 3.9237E+01 4.1377E+01 4.3695E+01 4.6214E+01
 2.2000E+00 2.3000E+00 2.4000E+00 2.5000E+00

SHELL/RING BOUNDARY CONDITIONS AND FORCES

CASE NO. 1, CONFIGURATION NO. 1

SHELL NO. 1

HET-L = 0.0000E+00
Q-L = 9.5100E+02
N-L = 0.0000E+00
PRESSURE = 9.1000E+02

SHELL NO. 2

M-R = 0.0000E+00
Q-R = 0.0000E+00
PRESSURE = 9.1000E+02

RING NO. 1

FX = 1.1060E+03
FY = 0.0000E+00
MCG = 0.0000E+00

SHELL/RING DISCONTINUITY REFORMATION AND FORCE SOLUTIONS

CASE NO. 1, CONFIGURATION NO. 1

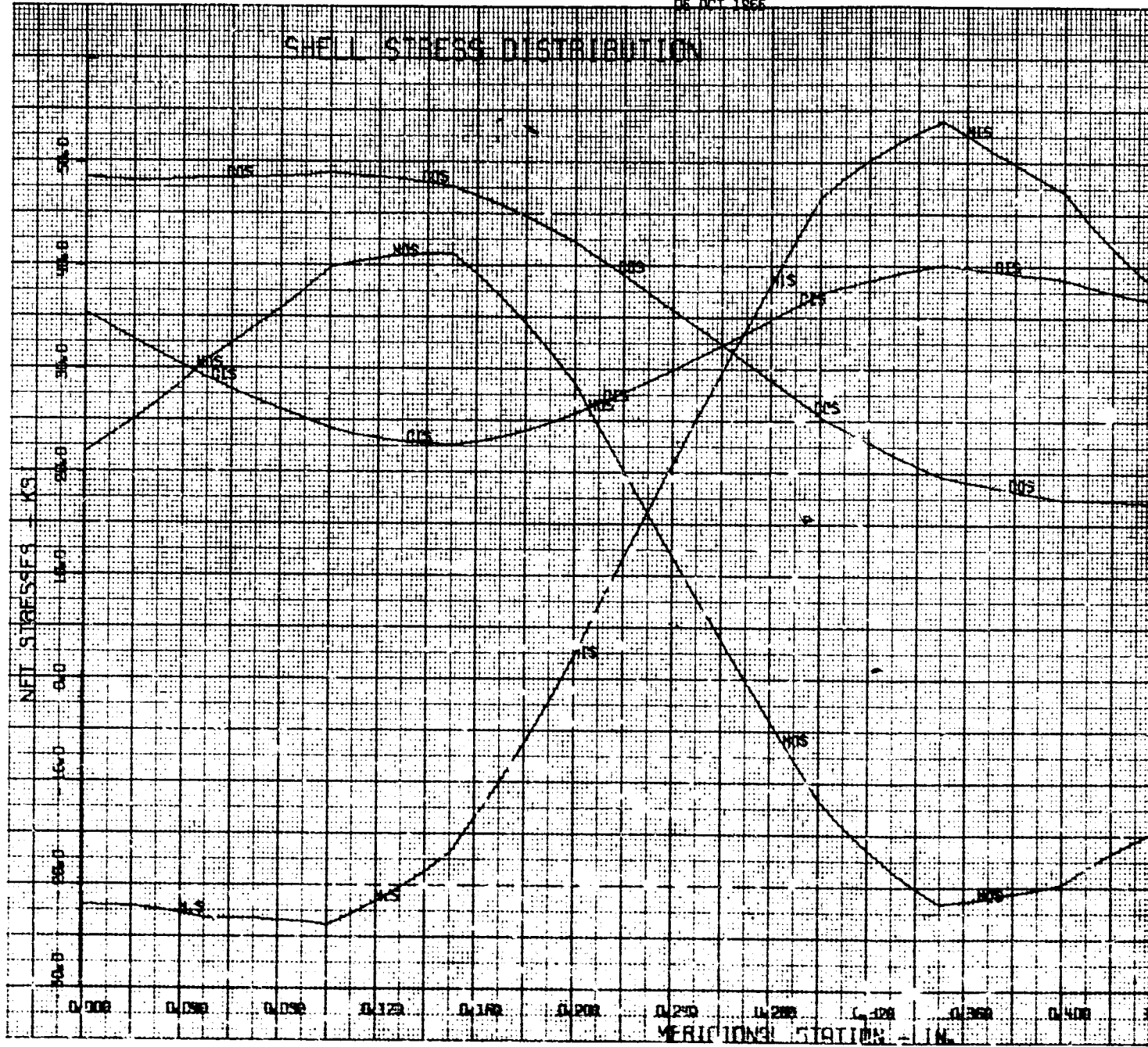
SHELL NO. 1	LEFT END	RIGHT END
DELTA	8.711263E-04	8.819095E-04
ETA	0.000000E+00	1.229704E-03
M	-2.108973E+02	1.677798E+02
Q	9.510000E+02	6.109375E+02
N	0.000000E+00	2.231925E+03

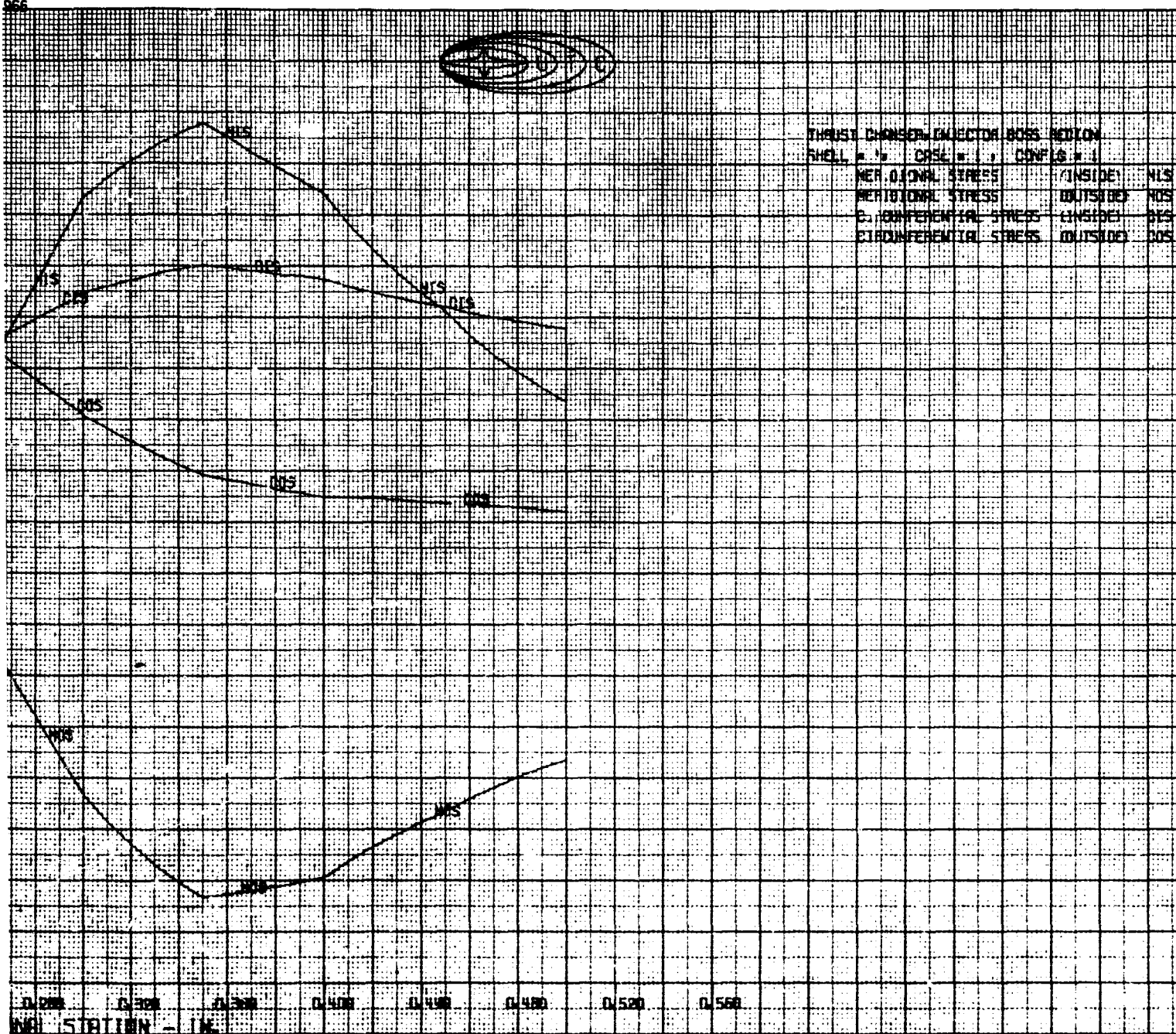
SHELL NO. 2	LEFT END	RIGHT END
DELTA	1.078662E-03	-9.823903E-03
ETA	1.229704E-03	-1.726450E-02
M	-2.534049E+01	0.000000E+00
Q	3.149838E+01	0.000000E+00
N	4.926721E+03	2.934761E+03

RING NO. 1	LEFT INSIDE	LEFT OUTSIDE	RIGHT INSIDE	RIGHT OUTSIDE
DELTA	8.610095E-04	0.000000E+00	0.000000E+00	1.078662E-03
ETA	1.229704E-03	0.000000E+00	0.000000E+00	1.229704E-03
M	1.677798E+02	0.000000E+00	0.000000E+00	-2.534049E+01
Q	4.309375E+02	0.000000E+00	0.000000E+00	3.149838E+01
N	2.231925E+03	0.000000E+00	0.000000E+00	4.926721E+03
DEL-CG	7.097509E-04	RETA-CG = 1.229704E-03		
M-NET	3.059423E+02	Q-NET = 5.173087E+03		

05 OCT 1966

SHELL STRESS DISTRIBUTION

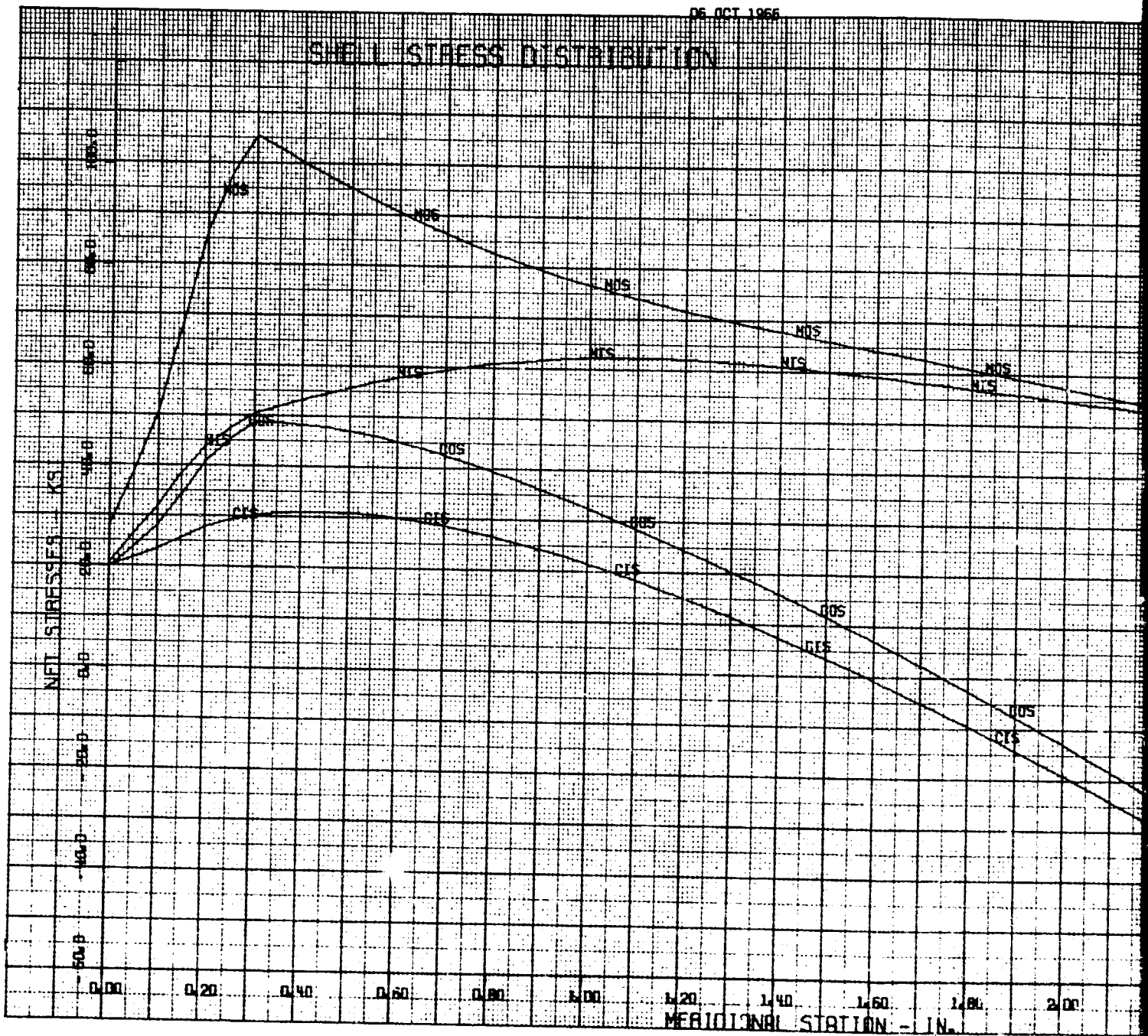




2

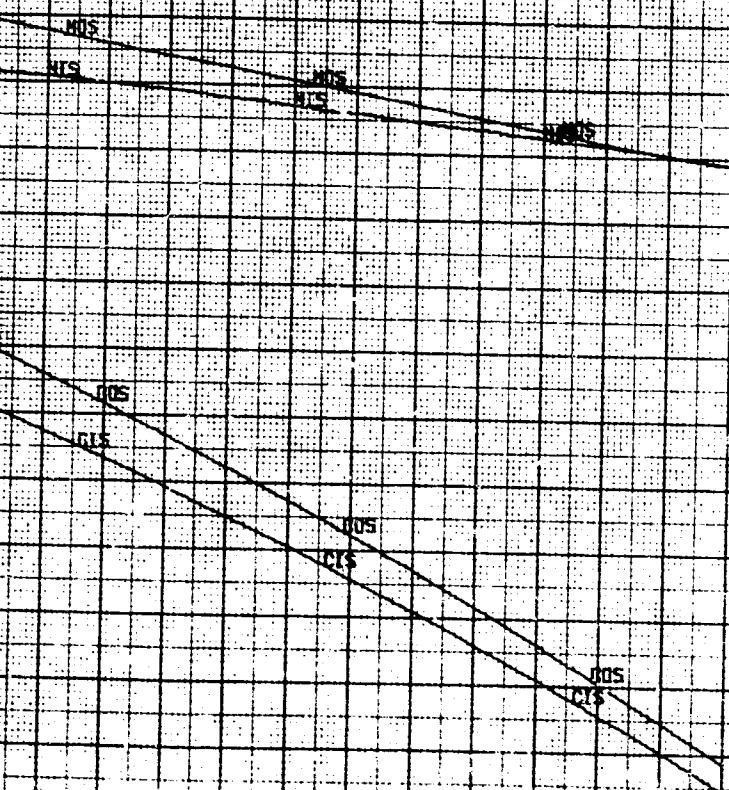
06 OCT 1966

SHELL STRESS DISTRIBUTION





THICK CHAMBER INJECTOR ROSS REFIN
SHELL # 2 CASE # 11 CONFER # 1
MERIDIONAL STRESS INSIDE MIS
MERIDIONAL STRESS OUTSIDE MIS
CIRCUMFERENTIAL STRESS INSIDE MIS
CIRCUMFERENTIAL STRESS OUTSIDE MIS



1.40 1.60 1.80 2.00 2.20 2.40 2.60 2.80
INCH STATION - IN.

2



United Technology Center

DIVISION OF UNITED AIRCRAFT CORPORATION

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PREPARED BY

R D Bush

DATE

10-5-66

REVIEWED BY

DATE

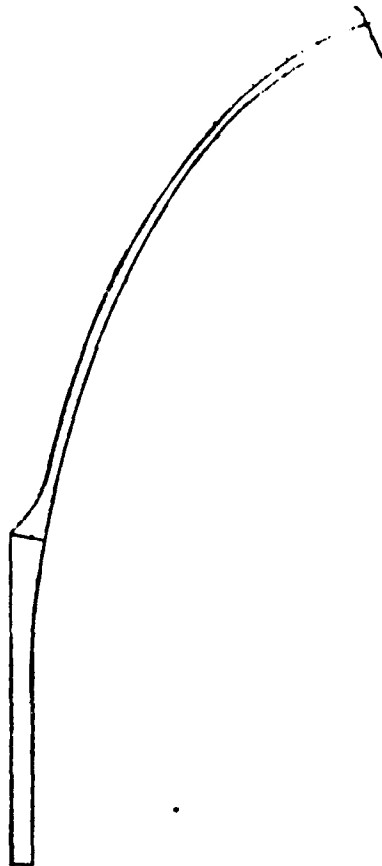


FIGURE 5
INJECTOR BOSS REGION (NO BOSS)

Motor

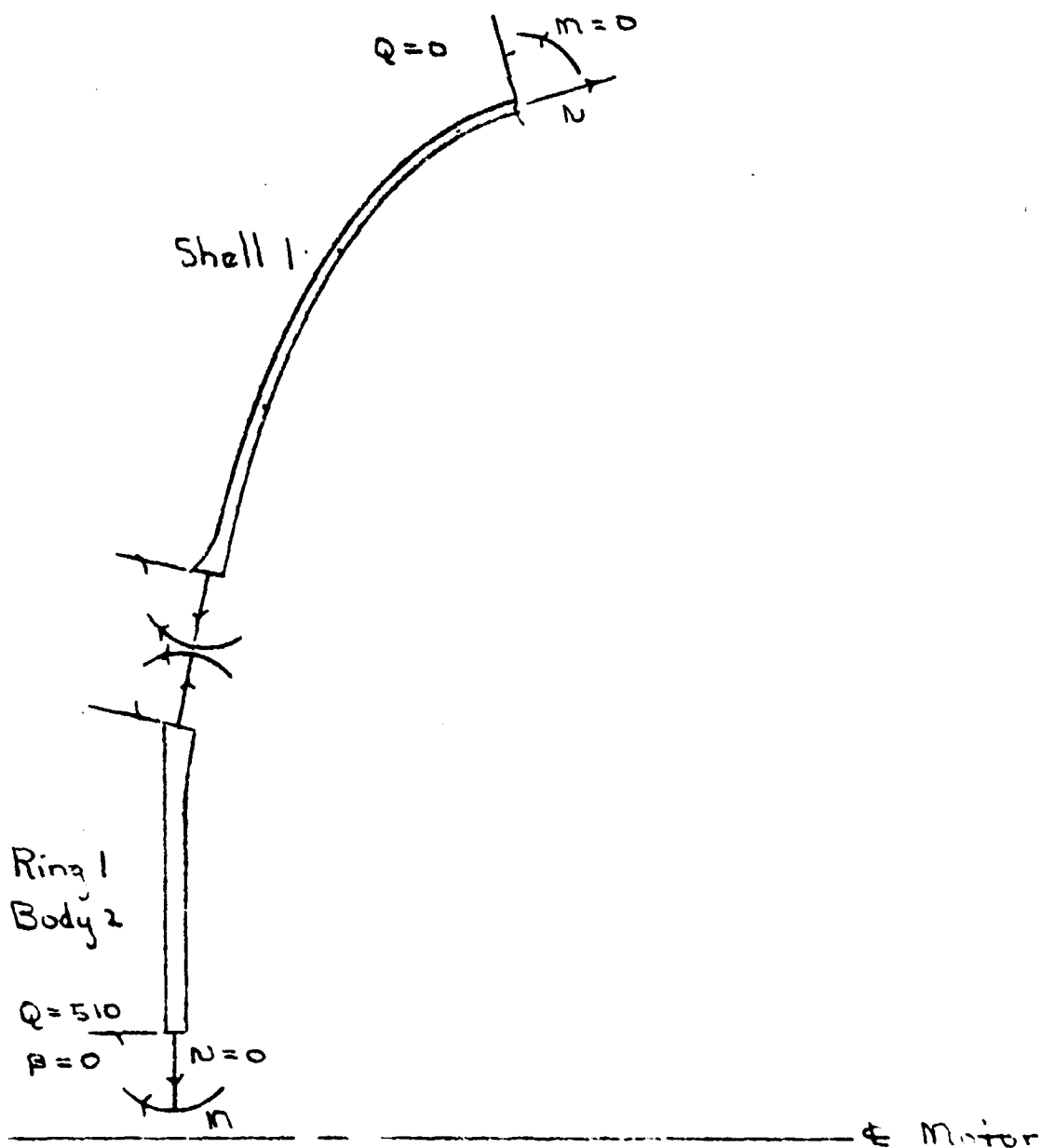


FIG. 6: INJECTOR BOSS REGION (NO BOSS)



10 IN HYBRID, COMBUSTION CHAMBER, INJECTOR
BOSS REGION (NO EDGE) - OCT. 66

Ring 1, Body 2

$$\begin{cases} RLI = .56 \\ PHILI = 1.0 \\ XLI = 0 \end{cases}$$

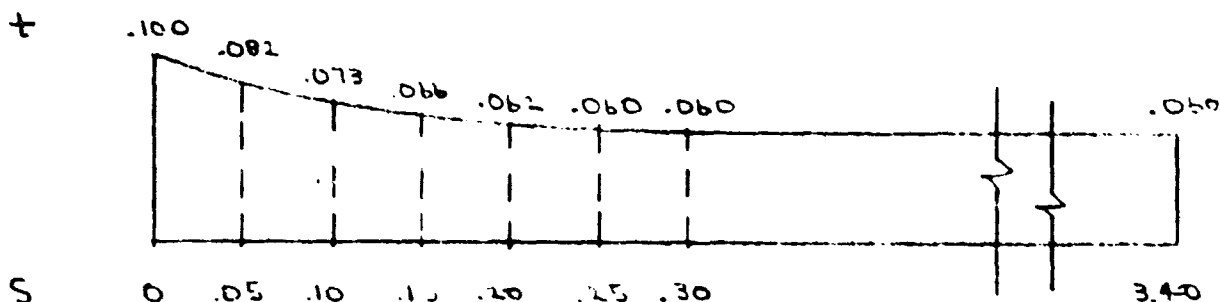
$$\begin{cases} RLO = 0 \\ PHILO = 0 \\ XLO = 0 \end{cases}$$

$$\begin{cases} RRI = 0 \\ PHIRRI = 0 \\ XRI = 0 \end{cases}$$

$$\begin{cases} RRO = 2.34 \\ PHIRO = 13.5278 \\ XRO = .050 \end{cases}$$

$$\begin{cases} R_{CG} = 1.450 \\ A = 1.78(.10) = .178 \text{ in}^2 \\ I_{yy} = \frac{1.78}{12}(.10)^3 = .0001483 \text{ in}^4 \\ E = 2.65 \times 10^7 \text{ PSI} \end{cases}$$

Shell 1



NJ, 1,
NJ Sets, 2, 1,
Location, 3, 0,
No. of B.C., 5,
Body No., 1, 1, 2, 2, 2,
Location, 1, 1, 0, 0, 0,
B.C. No., 3, 4, 2, 4, 5
Value, 0, 0, 0, 510, 0,

$$\begin{cases} N_2 = 0 \\ Q_2 = .56 p = .56(910) = 510 \text{ LB} \\ \beta = 0 \end{cases}$$

Shell 1 Closure Dome (Elliptical)

$$a = 4.950$$

$$b = 2.220$$

$$x_1 = 2.34$$

$$\tan \phi = \frac{b}{a} \frac{x}{\sqrt{a^2 - x^2}}$$

$$\tan \phi = \frac{2.220}{4.950} \frac{2.34}{\sqrt{(4.95)^2 - (2.34)^2}} = \frac{1.0475}{\sqrt{17.027}}$$

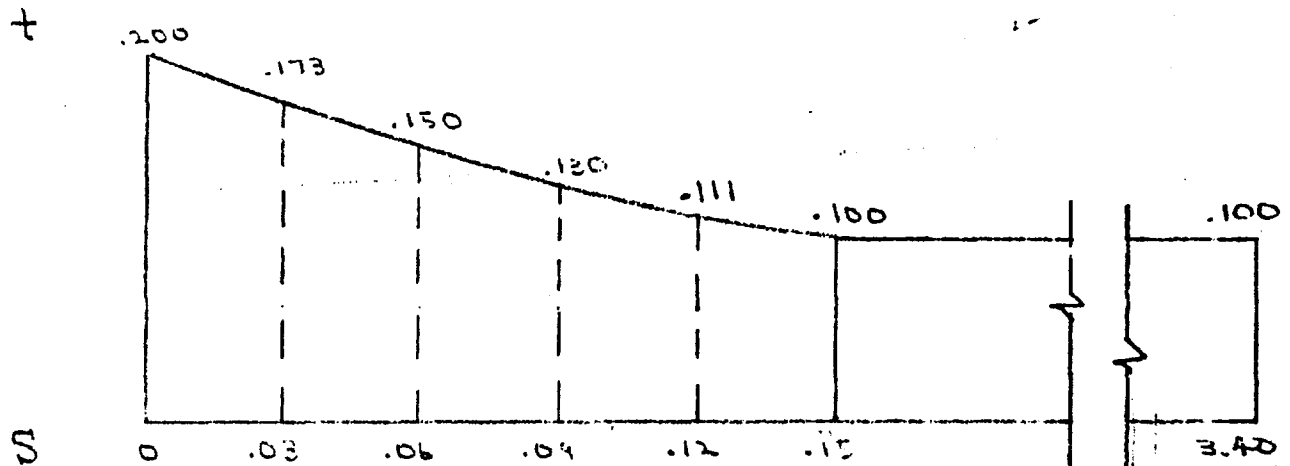
$\begin{array}{r} 24.503 \\ - 5.476 \\ \hline \end{array}$

$$\tan \phi = \frac{1.0475}{4.36} = .24071$$

$$\phi = 13^\circ 32' = 13.5333^\circ$$



Shell 1 Closure Dome (Elliptical)



S	t
0	.200
.03	.173
.06	.150
.09	.130
.12	.111
.15	.100
3.40	.100



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PREPARED BY 12W Bush DATE 9-28-66

REVIEWED BY

DATE

INPUT VALUES FOR UNIT ANALYSIS
OF AN AXISYMMETRIC THIN SHELL

PROJ. NO. _____

SHELL LENGTH 3.400 POISSON'S RATIO 0.3YOUNGS MODULUS 2.65×10^7 NO. TAYLOR SERIES 5 NO. SEGMENTS 50

MERIDIONAL STATION	R_1	R_2	THICKNESS	PHI
0	8.2177	10.0036		13.5278
.10	7.9920	9.9112		14.2342
.20	7.7602	9.8144		14.9611
.30	7.5526	9.7132		15.7104
.40	7.2797	9.6075		16.4829
.50	7.0319	9.4972		17.2839
.60	6.7197	9.3823		18.1129
.70	6.5231	9.2627		18.9733
.80	6.2644	9.1383		19.8637
.90	6.0023	9.0090		20.8021
1.00	5.7331	8.8748		21.7772
1.10	5.4722	8.7356		22.7903
1.20	5.2057	8.5914		23.8413
1.30	4.9389	8.4421		24.9307
1.40	4.6727	8.2876		26.0596
1.50	4.4078	8.1279		27.2291
1.60	4.1451	7.9631		28.4394
1.70	3.8854	7.7932		29.6915
1.80	3.6296	7.6183		31.0866
1.90	3.3787	7.4385		32.5267
2.00	3.1326	7.2542		35.1271
2.10	2.8955	7.0656		37.0253
2.20	2.6653	6.8733		39.0834
2.30	2.4446	6.6780		41.3231
2.40	2.2342	6.4806		43.7693
2.50	2.0356	6.2826		46.4252
2.60	1.8501	6.0856		49.2960
2.70	1.6790	5.8917		52.38401
2.80	1.5238	5.7045		55.6956
2.90	1.3860	5.5270		60.1511
3.00	1.2669	5.3640		64.7671
3.10	1.1680	5.2206		69.5551
3.20	1.0905	5.1024		74.5205
3.30	1.0333	5.0052		79.6474
3.40	1.0028	4.9263		84.9001

N-225 (5/63),

INPUT DATA

A = 4.95000 R = 2.22000 X = 2.34000 DELTAS = 0.05000
 GEOMETRIC PROPERTIES - ELLIPSOID OF REVOLUTION

NDELTA5	R1	R2	PHI
0.00000000	8.217713770+00	1.000357620+01	13.52775383
0.05000000	8.105673480+00	9.997905120+00	13.87651701
0.10000000	7.992039370+00	9.911152390+00	14.23419102
0.15000000	7.876661360+00	9.863309990+00	14.59498674
0.20000000	7.760190710+00	9.814369710+00	14.96112497
0.25000000	7.642080100+00	9.764323150+00	15.33283717
0.30000000	7.522583610+00	9.713161800+00	15.71036609
0.35000000	7.401756770+00	9.660876980+00	16.09396658
0.40000000	7.279656600+00	9.607459890+00	16.48390636
0.45000000	7.156341630+00	9.552901590+00	16.88046695
0.50000000	7.031671920+00	9.497193060+00	17.28394454
0.55000000	6.906309120+00	9.440325160+00	17.69465108
0.60000000	6.779716480+00	9.382288720+00	18.11291535
0.65000000	6.652158910+00	9.323074490+00	18.53908417
0.70000000	6.523702990+00	9.262673210+00	18.97352366
0.75000000	6.394417050+00	9.201075650+00	19.41662065
0.80000000	6.264371170+00	9.13872610+00	19.86878421
0.85000000	6.133637240+00	9.074254970+00	20.33044728
0.90000000	6.002289040+00	9.009013770+00	20.80206842
0.95000000	5.870402220+00	8.942540220+00	21.28413377
1.00000000	5.738054400+00	8.874825780+00	21.77715916
1.05000000	5.605325220+00	8.805862250+00	22.28169232
1.10000000	5.472296350+00	8.735641810+00	22.79831544
1.15000000	5.339051600+00	8.664157170+00	23.32764750
1.20000000	5.205676960+00	8.591401600+00	23.87034870
1.25000000	5.072260650+00	8.517369140+00	24.42712070
1.30000000	4.938823180+00	8.442054670+00	24.99871301
1.35000000	4.805667440+00	8.365454090+00	25.58592529
1.40000000	4.672678750+00	8.287564540+00	26.18961176
1.45000000	4.540024940+00	8.208384560+00	26.81068565
1.50000000	4.407806400+00	8.127914360+00	27.45012401
1.55000000	4.276126190+00	8.046156090+00	28.10897300
1.60000000	4.145090090+00	7.963114130+00	28.78835355
1.65000000	4.014806700+00	7.878795520+00	29.48946756
1.70000000	3.885387510+00	7.793210290+00	30.21367451
1.75000000	3.756946960+00	7.706372020+00	30.96214863
1.80000000	3.629602580+00	7.618298310+00	31.73658659
1.85000000	3.503475020+00	7.529014500+00	32.53851567
1.90000000	3.378688150+00	7.438539130+00	33.36965250
1.95000000	3.255369140+00	7.346915250+00	34.23184214
2.00000000	3.133648570+00	7.254180860+00	35.12706770
2.05000000	3.013660450+00	7.160385240+00	36.05746011
2.10000000	2.895542320+00	7.065587100+00	37.02530804
2.15000000	2.779435310+00	6.969856010+00	38.03306768
2.20000000	2.665844180+00	6.873273920+00	39.08337203
2.25000000	2.553837360+00	6.775937020+00	40.17903916
2.30000000	2.444646950+00	6.677957720+00	41.32307901
2.35000000	2.338046870+00	6.579466910+00	42.51669759
2.40000000	2.234262120+00	6.480616520+00	43.76929777
2.45000000	2.133339080+00	6.381582270+00	45.07847508

2.50000000
2.55000000
2.60000000
2.65000000
2.70000000
2.75000000
2.80000000
2.85000000
2.90000000
2.95000000
3.00000000
3.05000000
3.10000000
3.15000000
3.20000000
3.25000000
3.30000000
3.35000000
3.40000000

2.03561899E+00
1.94111851E+00
1.85006127E+00
1.76267260E+00
1.67894007E+00
1.59931295E+00
1.52380155E+00
1.45262640E+00
1.38594726E+00
1.32400194E+00
1.26690491E+00
1.21884574E+00
1.16798732E+00
1.1268381E+00
1.09047860E+00
1.06010193E+00
1.03546870E+00
1.01667613E+00
1.00388172E+00

6.28256678E+00
6.18380281E+00
6.08555679E+00
5.98813280E+00
5.89187416E+00
5.79717088E+00
5.7045843E+00
5.61422215E+00
5.52699756E+00
5.44336959E+00
5.36396936E+00
5.28946800E+00
5.22056681E+00
5.15798338E+00
5.10243328E+00
5.05460812E+00
5.01515016E+00
4.98462500E+00
4.96349506E+00

46.45000679
47.88783208
49.39682058
50.97872609
52.64012183
54.38431311
56.21522331
58.13644915
60.15108242
62.26149691
64.46910259
66.77407363
69.17586269
71.66892128
74.25045324
76.91223437
79.64453428
82.43537339
85.27073826

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STRUCTURAL ANALYSIS OF MULTIPLE SHELL/RING STRUCTURES

UNITED TECHNOLOGY CENTER

6 OCT 1966

10 IN HYBRID COMBUSTION CHAMBER, INJECTOR BOSS REGION (NO BOSS) 6 OCT. 66

SHELL #1 CLUSURE DOME (ELLIPTICAL)

SHELL UNIT ANALYSIS

INPUT IS:

SHELL NO. 1, CONFIGURATION NO. 1

TAYLORS SERIES EXPANSIONS OF 5 TERMS ARE USED TO SOLVE THE DIFFERENTIAL EQUATIONS SIMULTANEOUSLY.
THE 3.4000 INCH LONG SHELL SECTION IS DIVIDED INTO 50 SEGMENTS EACH OF WHICH IS 0.0680 INCHES LONG.

MODULUS OF ELASTICITY, E = 2.65000E+07

POISSON S RATIO, MU = 0.3000

MEMIDIONALLY VARIING PARAMFTER FIUNCTIONS:

RADIUS 1 =	0.2177E+00	7.9920E+00	7.7602E+00	7.5526E+00	7.2797E+00	7.0319E+00	6.7797E+00
S =	0.0000E+00	1.0000E-01	2.0000E-01	3.0000E-01	4.0000E-01	5.0000E-01	6.0000E-01
	6.5237E+00	6.2644E+00	6.0023E+00	5.7381E+00	5.4723E+00	5.2057E+00	4.9389E+00
	7.0000E-01	8.0000E-01	9.0000E-01	1.0000E+00	1.1000E+00	1.2000E+00	1.3000E+00
	4.6727E+00	4.4078E+00	4.1451E+00	3.8854E+00	3.6296E+00	3.3787E+00	3.1336E+00
	1.4000E+00	1.5000E+00	1.6000E+00	1.7000E+00	1.8000E+00	1.9000E+00	2.0000E+00
	2.8955E+00	2.6655E+00	2.4446E+00	2.2343E+00	2.0356E+00	1.8501E+00	1.6790E+00
	2.1000E+00	2.2000E+00	2.3000E+00	2.4000E+00	2.5000E+00	2.6000E+00	2.7000E+00
	1.5238E+00	1.3860E+00	1.2669E+00	1.1680E+00	1.0905E+00	1.0355E+00	1.0038E+00
	2.8000E+00	2.9000E+00	3.0000E+00	3.1000E+00	3.2000E+00	3.3000E+00	3.4000E+00

RADIUS 2 =	1.0004E+01	9.9112E+00	9.8144E+00	9.7132E+00	9.6075E+00	9.4972E+00	9.3823E+00
S =	0.0000E+00	1.0000E-01	2.0000E-01	3.0000E-01	4.0000E-01	5.0000E-01	6.0000E-01
	9.2627E+00	9.1383E+00	9.0090E+00	8.8748E+00	8.7356E+00	8.5914E+00	8.4421E+00
	7.0000E-01	8.0000E-01	9.0000E-01	1.0000E+00	1.1000E+00	1.2000E+00	1.3000E+00
	8.2876E+00	8.1279E+00	7.9631E+00	7.7932E+00	7.6183E+00	7.4385E+00	7.2542E+00
	1.4000E+00	1.5000E+00	1.6000E+00	1.7000E+00	1.8000E+00	1.9000E+00	2.0000E+00
	7.0656E+00	6.8733E+00	6.6780E+00	6.4806E+00	6.2826E+00	6.0856E+00	5.8919E+00
	2.1000E+00	2.2000E+00	2.3000E+00	2.4000E+00	2.5000E+00	2.6000E+00	2.7000E+00
	5.7045E+00	5.5270E+00	5.3640E+00	5.2206E+00	5.1024E+00	5.0152E+00	4.9635E+00
	2.8000E+00	2.9000E+00	3.0000E+00	3.1000E+00	3.2000E+00	3.3000E+00	3.4000E+00

THICKNFSS =
S =

1.0000E-01	8.2000E-02	7.3000E-02	6.6000E-02	6.2000E-02	6.0000E-02	6.0000E-02
0.0000E+00	5.0000E-02	1.0000E-01	1.5000E-01	2.0000E-01	2.5000E-01	3.4000E+00

PHI =
S =

1.3528E+01	1.4234E+01	1.4941E+01	1.5710E+01	1.6488E+01	1.7284E+01	1.8113E+01
0.0000E+00	1.0000E-01	2.0000E-01	3.0000E-01	4.0000E-01	5.0000E-01	6.0000E-01
1.8973E+01	1.9869E+01	2.0802E+01	2.1777E+01	2.2798E+01	2.3870E+01	2.4999E+01
7.0000E-01	8.0000E-01	9.0000E-01	1.0000E+00	1.1000E+00	1.2000E+00	1.3000E+00
2.6190E+01	2.7450E+01	2.8788E+01	3.0214E+01	3.1737E+01	3.3370E+01	3.5127E+01
1.4000E+00	1.5000E+00	1.6000E+00	1.7000E+00	1.8000E+00	1.9000E+00	2.0000E+00
3.7025E+01	3.9083E+01	4.1323E+01	4.3769E+01	4.6450E+01	4.9396E+01	5.2640E+01
2.1000E+00	2.2000E+00	2.3000E+00	2.4000E+00	2.5000E+00	2.6000E+00	2.7000E+00
5.6215E+01	6.0151E+01	6.4469E+01	6.9175E+01	7.4251E+01	7.9645E+01	8.5271E+01
2.8000E+00	2.9000E+00	3.0000E+00	3.1000E+00	3.2000E+00	3.3000E+00	3.4000E+00

RING UNIT ANALYSIS

RING NO. 1, CONFIGURATION NO. 1

INPUT IS:

LI 0.560 PHI, DEG. 1.000 X, IN. 0.000
LU 0.000 0.000 0.000
RI 0.000 0.000 0.000
RU 2.340 13.528 0.050
RCG = 1.450 A = 0.178 IYY = 0.000 E = 2.650e+07

OUTPUT IS:

	QNET	MNET	AXIAL EQUIL
M-LI	0.0000e+00	-3.6421e-01	0.0000e+00
Q-	6.7402e-03	-3.4367e-01	5.5991e-01
N-	-3.8615e-01	-5.9986e-03	9.7733e-03
M-LU	0.0000e+00	0.0000e+00	0.0000e+00
Q-	0.0000e+00	0.0000e+00	0.0000e+00
N-	0.0000e+00	0.0000e+00	0.0000e+00
M-RI	0.0000e+00	0.0000e+00	0.0000e+00
Q-	0.0000e+00	0.0000e+00	0.0000e+00
N-	0.0000e+00	0.0000e+00	0.0000e+00
M-RU	0.0000e+00	1.6138e+00	0.0000e+00
Q-	-3.7749e-01	-1.4153e+00	-2.2751e+00
N-	1.5690e+00	-2.5752e-01	-5.4737e-01
FA	0.0000e+00	0.0000e+00	1.4500e+00
FY	1.0000e+00	0.0000e+00	0.0000e+00
MCG	0.0000e+00	1.0000e+00	0.0000e+00

DEL-CG = 0.4573e-07 x Q-VFT DELTA-CG = 5.3499e-04 x M-NFT

SHELL/RING BOUNDARY CONDITIONS AND FORCES

CASE NO. 1, CONFIGURATION NO. 1

SHELL NO. 1

M-R = 0.0000E+00
Q-R = 0.0000E+00
PRESSURE = 9.1000E+02

RING NO. 1

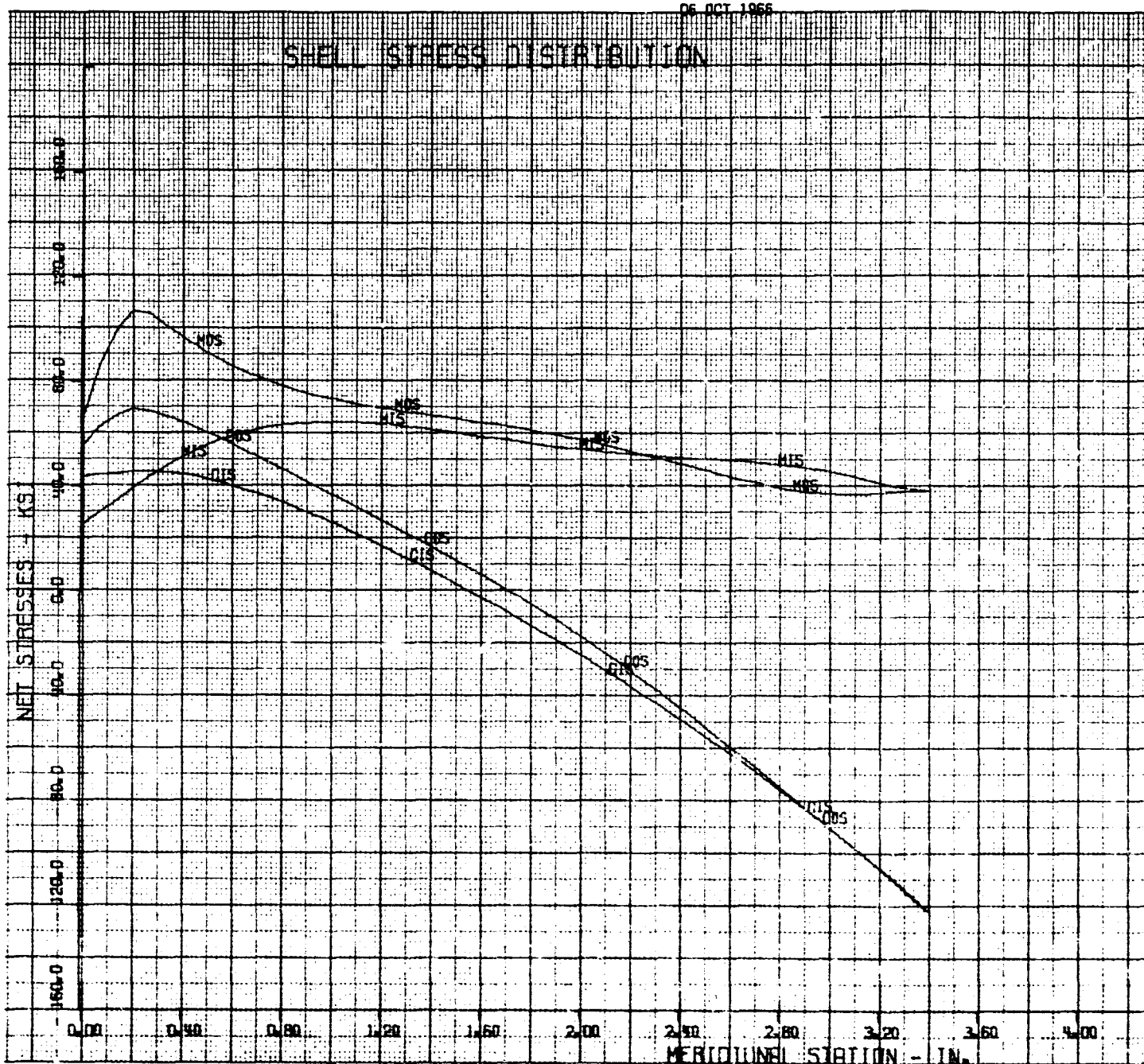
WET-LI = 0.0000E+00
W-LI = 5.1000E+02
N-LI = 0.0000E+00
PX = 1.6200E+01

FY = 0.0000E+00 MCG = 0.0000E+00

SHELL/WING DISCONTINUITY DEFORMATION AND FORCE SOLUTIONS

SHELL NO. 1	LEFT FND	RIGHT END			
	DELTA 3.183585E-03	-2.495461E-02			
	BETA 2.323848E-11	-1.676157E-02			
	M -3.326043E+01	0.000000E+00			
	Q 5.985496E+01	0.000000E+00			
	N 4.564371E+03	2.286358E+03			
WING NO. 1	LEFT INSIDE	LEFT OUTSIDE	RIGHT INSIDE	RIGHT OUTSIDE	
	DELTA 3.183585E-03	0.000000E+00	0.000000E+00	3.183585E-03	
	BETA 0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	
	M -3.855630E+03	0.000000E+00	0.000000E+00	-3.326045E+01	
	Q 5.100000E+02	0.000000E+00	0.000000E+00	5.98549	
	N 0.000000E+00	0.000000E+00	0.000000E+00	4.564371E+03	
	DEL-CG = 3.183585E-03		DELTA-CG = 0.000000E+00		
	M-NET = 0.000000E+00		Q-NET = 7.142435E+03		

SHELL STRESS DISTRIBUTION





INJECTOR BOSS SECTION AND BORE			
SHELL x 1/2	CASE x 1/2	CONFID x 1/2	
MERIDIONAL STRESS		(INSIDE)	MIS
MERIDIONAL STRESS		(OUTSIDE)	MOS
CIRCUMFERENTIAL STRESS		(INSIDE)	BIS
CIRCUMFERENTIAL STRESS		(OUTSIDE)	BOS

1/15
1/15

1/15
1/15

0.00 3.20 3.60 4.00 4.40 4.80 5.20 5.60
STATION - IN.

2



Ret. - Convair (Aeronautics) Division
General Dynamics Corp., Structures
Technical Memorandum No. 8

$M = 69,600 \text{ in-lb (Limit)} = 104,400 \text{ in-lb (UL)}$
Att Launch Fin
Captive Flight

$$L = 48.75 \text{ in}$$

$$L/R = 48.75 / 5.020 = 9.711$$

$$R = 5.020 \text{ in}$$

$$R/t = 5.020 / .040 = 125.5$$

$$t = .040 \text{ in}$$

$$F_b = \frac{M}{\pi R^2 t} = \frac{104,400}{\pi (5.020)^2 (.040)} = 34,042 \text{ psi}$$

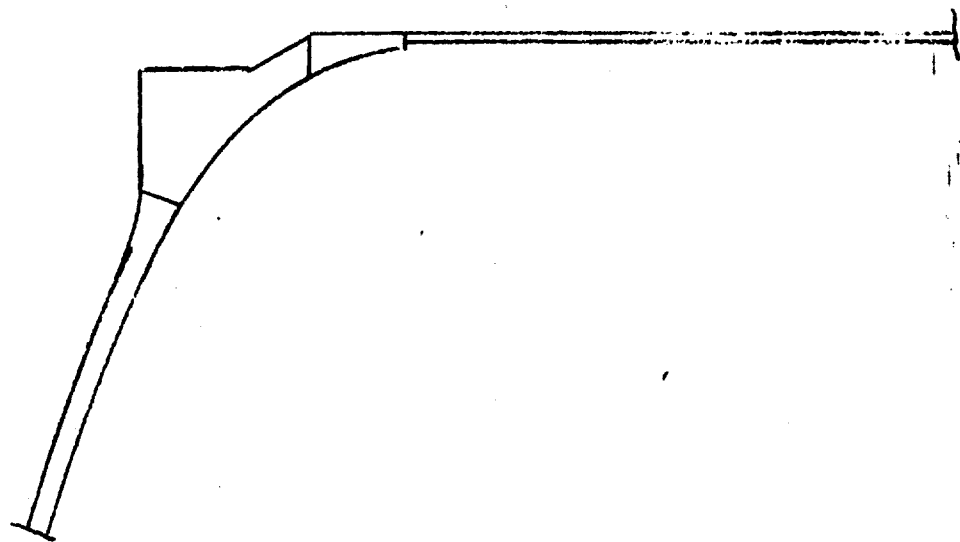
Pure Bending of Unpressurized Unstiffened
Circular Cylinder, Clamped Ends (Page 2)

$$\frac{F_{c1}}{E} \times 10^3 = 1.35$$

$$F_{c1} = \frac{28.5 \times 10^3 (1.35)}{1.0} = 38,475 \text{ psi}$$

$$M/S = \frac{F_{c1}}{F_b} = 1 = \frac{38,475}{34,042} = 1.13$$

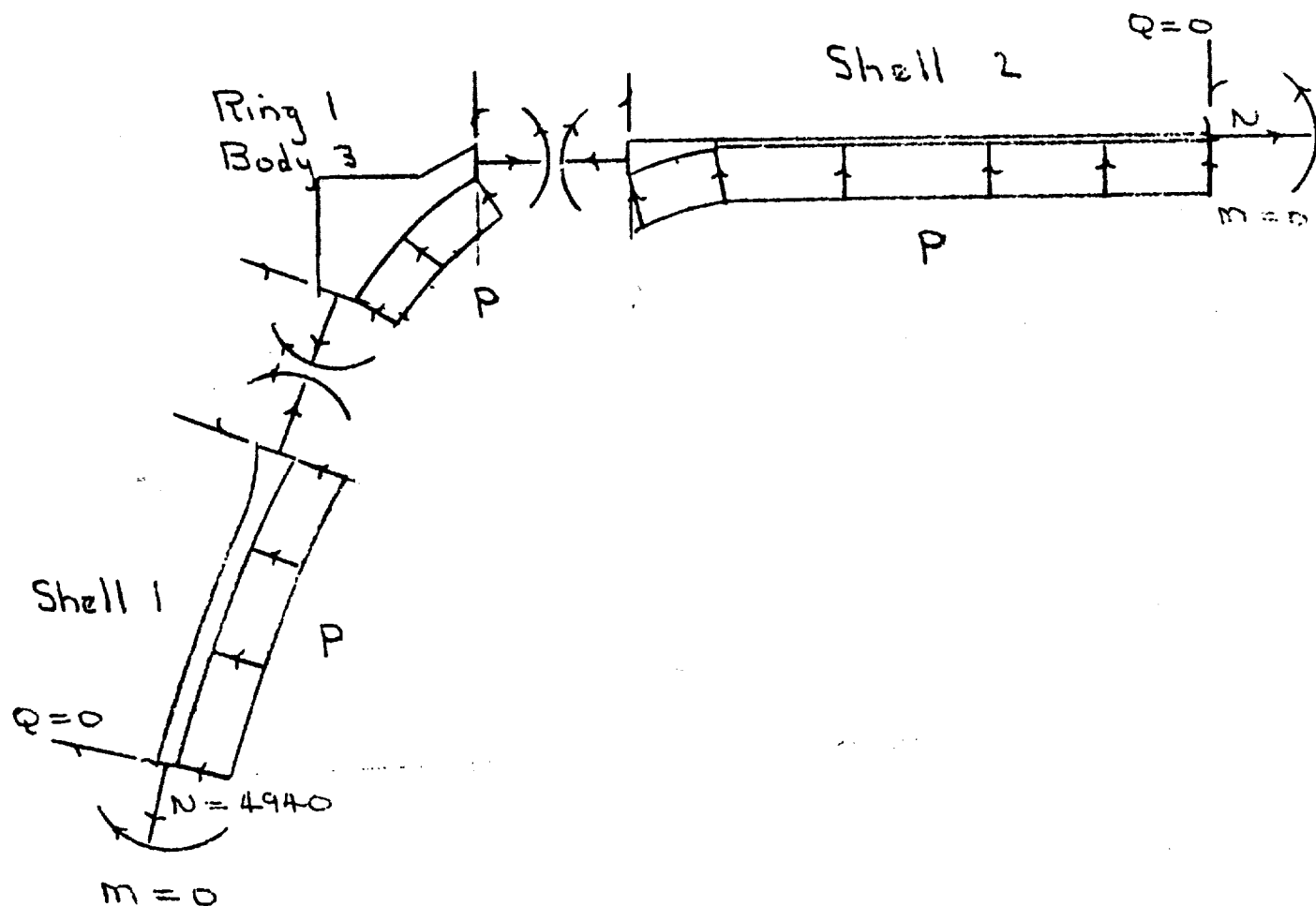
NOTE : SINCE THE GRAIN WILL BE IN PLACE AND
BEARING ON THE CASE UNDER EXTERNAL LOADS
THIS ANALYSIS IS HIGHLY CONSERVATIVE.



E Motor

FIGURE 7

FWD CLOSURE, Y RING REGION



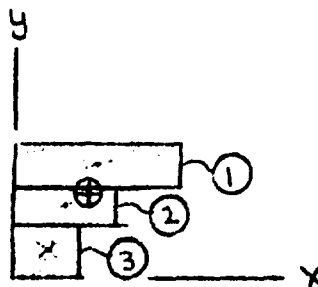
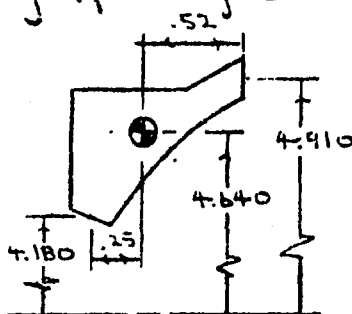
& Motor

FIGURE 8

FWD CLOSURE, Y RING REGION



Ring 1, Body 3



$$A = .2400 + .1007 + .0707 = .4107 \text{ IN}^2$$

$$A_y = .13920 + .03625 + .00980 = .18525 \text{ IN}^3$$

$$A_x = .12000 + .02669 + .00675 = .15344 \text{ IN}^3$$

$$A_x^2 = .06000 + .00707 + .00109 = .06816 \text{ IN}^4$$

$$I_{oy} = .02000 + .00236 + .00036 = .02272 \text{ IN}^4$$

$$\bar{x} = .15344 / .4107 = .3735 \text{ IN}$$

$$\bar{y} = .18525 / .4107 = .4511 \text{ IN}$$

$$I_{yy} = .06816 + .02272 - .4107(.3735)^2 = .03204 \text{ IN}^4$$

$$F_x = .67(910) = 610 \text{ LB}$$

$$F_y = .67(910) = 610 \text{ LB}$$

$$M_{cg} = .947(910)0 = 0$$

$$\begin{cases} RLI = 4.180 \\ PHLI = 35.26180 \\ XLI = .25 \end{cases}$$

$$\begin{cases} RLO = 0 \\ PHLO = 0 \\ XLO = 0 \end{cases}$$

$$\begin{cases} RRI = 0 \\ PHRI = 0 \\ XRI = 0 \end{cases}$$

$$\begin{cases} RRO = 4.940 \\ PHRO = 90 \\ XRO = .52 \end{cases}$$

$$\begin{cases} R_{cg} = 4.640 \\ A = .4107 \\ I_{yy} = .03204 \\ E = 26.5 \times 10^6 \end{cases}$$

STRUCTURAL ANALYSIS OF MULTIPLE SHELL/RING STRUCTURES

UNITED TECHNOLOGY CENTER

29 SEPT 1966

COMBUSTION CHAMBER, 10 IN HYBRID C02219 R.D.BUSH

SHELL #1 CLOSURE DOME (ELLIPTICAL)

SHELL UNIT ANALYSIS

INPUT 151

SHELL NO. 1, CONFIGURATION NO. 1

TAYLORS SERIES EXPANSIONS OF 5 TERMS ARE USED TO SOLVE THE DIFFERENTIAL EQUATIONS SIMULTANEOUSLY.
THE 3.3679 INCH LONG SHELL SECTION IS DIVIDED INTO 50 SEGMENTS EACH OF WHICH IS 0.0678 INCHES LONG.

MODULUS OF ELASTICITY, E = 2.65000E+07

POISSON'S RATIO, MU = 0.3000

MEMORIANALLY VARYING PARAMETER FUNCTIONS:

RADIUS 1 =	1.0503E+01	1.0393E+01	1.0272E+01	1.0142E+01	1.0002E+01	9.8532E+00	9.6949E+00
S =	0.0000E+00	1.0000E-01	2.0000E-01	3.0000E-01	4.0000E-01	5.0000E-01	6.0000E-01
	9.5276E+00	9.3517E+00	9.1674E+00	8.9749E+00	8.7747E+00	8.5649E+00	8.3520E+00
	7.0000E-01	8.0000E-01	9.0000E-01	1.0000E+00	1.1000E+00	1.2000E+00	1.3000E+00
	8.1303E+00	7.9021E+00	7.6680E+00	7.4282E+00	7.1833E+00	6.9338E+00	6.6801E+00
	1.4000E+00	1.5000E+00	1.6000E+00	1.7000E+00	1.8000E+00	1.9000E+00	2.0000E+00
	6.4227E+00	6.1622E+00	5.8992E+00	5.6343E+00	5.3681E+00	5.1014E+00	4.8347E+00
	2.1000E+00	2.2000E+00	2.3000E+00	2.4000E+00	2.5000E+00	2.6000E+00	2.7000E+00
	4.5449E+00	4.3048E+00	4.0432E+00	3.7847E+00	3.5309E+00	3.2821E+00	3.0300E+00
	2.8000E+00	2.9000E+00	3.0000E+00	3.1000E+00	3.2000E+00	3.3000E+00	3.4000E+00
	3.1159E+00						
	3.3679E+00						

RADIUS 2 =	1.0856E+01	1.0618E+01	1.0776E+01	1.0730E+01	1.0681E+01	1.0627E+01	1.0570E+01
S =	0.0000E+00	1.0000E-01	2.0000E-01	3.0000E-01	4.0000E-01	5.0000E-01	6.0000E-01
	1.0509E+01	1.0444E+01	1.0375E+01	1.0302E+01	1.0225E+01	1.0143E+01	1.0058E+01
	7.0000E-01	8.0000E-01	9.0000E-01	1.0000E+00	1.1000E+00	1.2000E+00	1.3000E+00
	9.9480E+00	9.6738E+00	9.3753E+00	9.0724E+00	8.7645E+00	8.4524E+00	8.1361E+00
	1.4000E+00	1.5000E+00	1.6000E+00	1.7000E+00	1.8000E+00	1.9000E+00	2.0000E+00
	9.2140E+00	9.0883E+00	8.9571E+00	8.8210E+00	8.6799E+00	8.5336E+00	8.3823E+00
	2.1000E+00	2.2000E+00	2.3000E+00	2.4000E+00	2.5000E+00	2.6000E+00	2.7000E+00

8.2250E+00 8.0641E+00 7.6973E+00 7.7254E+00 7.5486E+00 7.3670E+00 7.2745E+00
 2.8000E+00 2.9000E+00 3.0000E+00 3.1000E+00 3.2000E+00 3.3000E+00 3.3500E+00
 7.2804E+00
 3.3459E+00

THICKNESS =
 S =

1.0000E-01 1.0000E-01 1.0400E-01 1.3000E-01 1.7500E-01 2.0000E-01 2.0000E-01
 0.0000E+00 3.0000E+00 3.1000E+00 3.2000E+00 3.3000E+00 3.3500E+00 3.3679E+00

PHI =
 S =

5.2771E+00 5.8253E+00 6.3796E+00 6.9407E+00 7.5093E+00 8.0862E+00 8.6721E+00
 0.0000E+00 1.0000E-01 2.0000E-01 3.0000E-01 4.0000E-01 5.0000E-01 6.0000E-01
 9.2680E+00 9.6747E+00 1.0493E+01 1.1124E+01 1.1770E+01 1.2430E+01 1.3107E+01
 7.0000E-01 8.0000E-01 9.0000E-01 1.0000E+00 1.1000E+00 1.2000E+00 1.3000E+00
 1.3802E+01 1.4516E+01 1.5251E+01 1.6010E+01 1.6793E+01 1.7604E+01 1.8445E+01
 1.4000E+00 1.5000E+00 1.6000E+00 1.7000E+00 1.8000E+00 1.9000E+00 2.0000E+00
 1.9314E+01 2.0229E+01 2.1178E+01 2.2171E+01 2.3211E+01 2.4304E+01 2.5457E+01
 2.1000E+00 2.2000E+00 2.3000E+00 2.4000E+00 2.5000E+00 2.6000E+00 2.7000E+00
 2.6674E+01 2.7963E+01 2.9335E+01 3.0797E+01 3.2361E+01 3.4041E+01 3.4929E+01
 2.8000E+00 2.9000E+00 3.0000E+00 3.1000E+00 3.2000E+00 3.3000E+00 3.3500E+00
 3.5262E+01
 3.3679E+00

SHELL OF CYLINDER WALL

SHELL UNIT ANALYSIS

INPUT IS:

SHELL NO. 2, CONFIGURATION NO. 1

TAYLORS SERIES EXPANSIONS OF 5 TERMS ARE USED TO SOLVE THE DIFFERENTIAL EQUATIONS SIMULTANEOUSLY.

THE 3.0000 INCH LONG SHELL SECTION IS DIVIDED INTO 50 SEGMENTS EACH OF WHICH IS 0.0600 INCHES LONG.

MODULUS OF ELASTICITY, E = 2.65000E+07

POISSON'S RATIO, MU = 0.3000

ARBITRARILY VARYING PARAMETER FUNCTIONS:

RADIUS 1 = 1.0000E+10 1.0000E+10
S = 0.0000E+00 3.0000E+00

RADIUS 2 = 4.9400E+00 4.9625E+00 4.9825E+00 5.0000E+00 5.0400E+00 5.0200E+00 5.0200E+00
S = 0.0000E+00 1.0000E-01 2.0000E-01 3.0000E-01 4.0000E-01 5.0000E-01 5.0000E-01
5.0200E+00
3.0000E+00

THICKNESS = 2.0000E-01 1.5500E-01 1.1500E-01 8.0000E-02 5.2000E-02 4.0000E-02 4.0000E-02
S = 0.0000E+00 1.0000E-01 2.0000E-01 3.0000E-01 4.0000E-01 5.0000E-01 5.0000E-01
4.0000E-02
3.0000E+00

PHI = 9.0000E+01 9.0000E+01
S = 0.0000E+00 3.0000E+00

WING 1.0000 3

WING UNIT ANALYSIS

RING NO. 1, CONFIGURATION NO. 1

INPUT IS:

LI	RADIUS, IN.	PHI, DEG.	X, IN.
	4.180	35.262	0.250
LU	0.000	0.000	0.000
RI	0.000	0.000	0.000
RU	4.940	90.000	0.520
WCG =	4.640	A = 0.411	IYY = 0.032
			E = 2.650E+07

OUTPUT IS:

	UNET	UNET	AXIAL EQUIL
M-LI	0.0000E+00	-9.0086E-01	0.0000E+00
Q-	5.2008E-01	-4.6438E-01	3.4131E+00
N-	-7.3557E-01	-5.5143E-02	2.4132E+00
M-LU	0.0000E+00	0.0000E+00	0.0000E+00
Q-	0.0000E+00	0.0000E+00	0.0000E+00
N-	0.0000E+00	0.0000E+00	0.0000E+00
M-RI	0.0000E+00	0.0000E+00	0.0000E+00
Q-	0.0000E+00	0.0000E+00	0.0000E+00
N-	0.0000E+00	0.0000E+00	0.0000E+00
M-RU	0.0000E+00	1.0447E+00	0.0000E+00
Q-	-1.0647E+00	-5.5362E-01	-8.8420E-09
N-	1.9056E-09	-3.1949E-01	-4.9400E+00
FA	0.0000E+00	0.0000E+00	4.6400E+00
IY	1.0000E+00	0.0000E+00	0.0000E+00
UG	1.0000E+00	1.0000E+00	0.0000E+00

UNIT = 1.0742E-04 = 0.0001 FT RATA-CG = 2.5357E-05 X "NFT

SHELL/RING BOUNDARY CONDITIONS AND FORCES

CASE NO. 1, CONFIGURATION NO. 1

SHELL NO. 1

M=L = 0.0000E+00
Q=L = 0.0000E+00
N=L = 4.9400E+03
PRESSURE = 9.1000E+02

SHELL NO. 2

M=R = 0.0000E+00
Q=R = 0.0000E+00
PRESSURE = 9.1000E+02

RING NO. 1

FX = 6.1000E+02
FY = 6.1000E+02
MCG = 0.0000E+00

SHELL/RING DISCONTINUITY DEFORMATION AND FORCE SOLUTIONS

SHELL NO. 1 LEFT END RIGHT END

DELTA 1.334225E-03 -9.940170E-04

BETA -5.491030E-03 -3.859829E-03

M 0.000000E+00 1.360678E+01

Q -5.518115E-08 -2.495141E+01

N 4.940000E+03 3.344054E+03

SHELL NO. 2 LEFT END RIGHT END

DELTA -3.964086E-03 1.850549E-02

BETA -3.859829E-03 7.500069E-05

M 2.620343E+02 0.000000E+00

Q -8.194997E+02 0.000000E+00

N 2.189273E+03 2.189274E+03

WING NO. 1 LEFT INSIDE LEFT OUTSIDE RIGHT INSIDE RIGHT OUTSIDE

DELTA -9.940170E-04 0.000000E+00 0.000000E+00 -3.964085E-03

BETA -3.859829E-03 0.000000E+00 0.000000E+00 -3.859829E-03

M 1.360678E+01 0.000000E+00 0.000000E+00 2.620343E+02

Q -2.495141E+01 0.000000E+00 0.000000E+00 -8.194997E+02

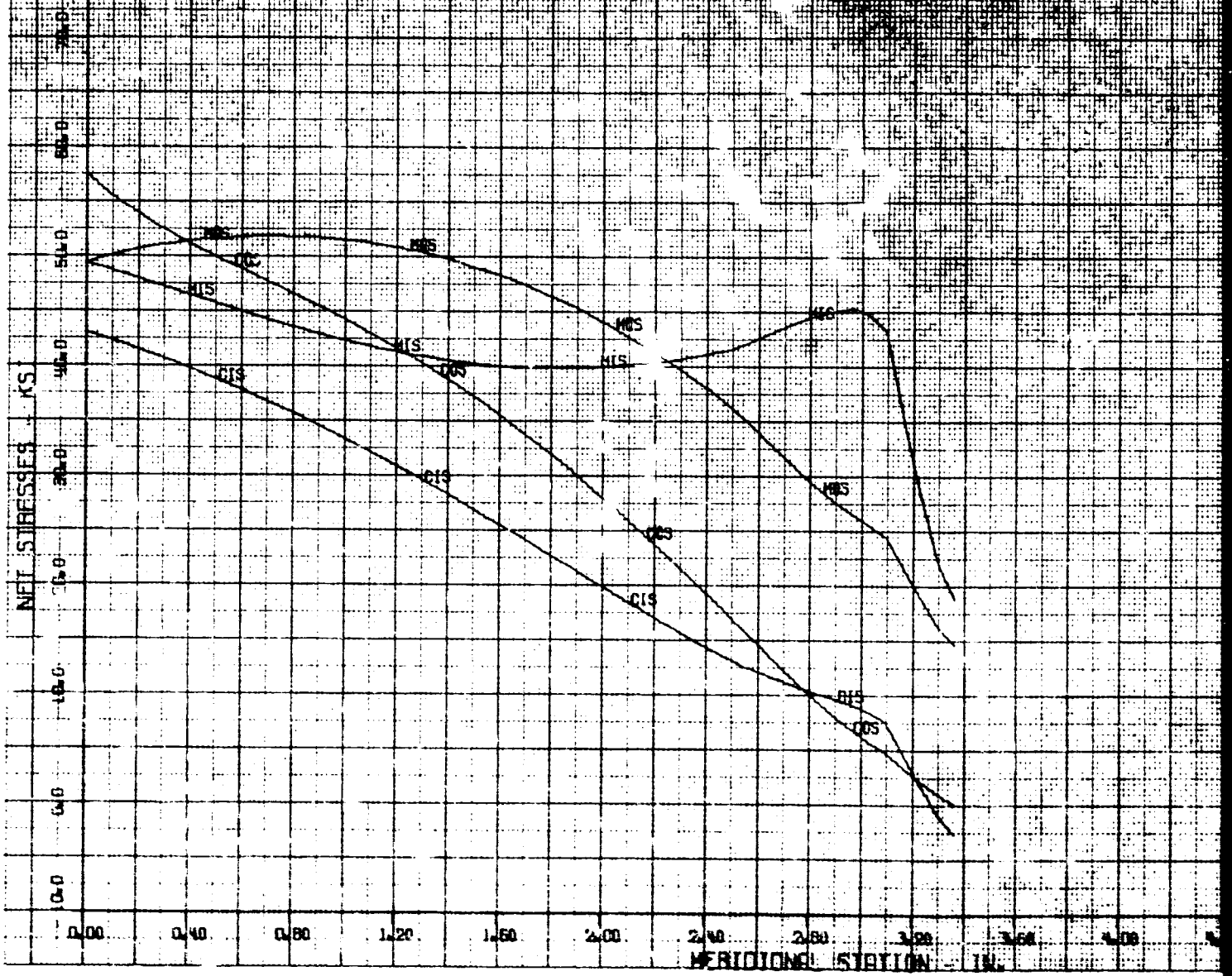
N 3.344054E+03 0.000000E+00 0.000000E+00 2.189273E+03

DEL-CG = -1.954974E-03 DELTA-CG = -3.859829E-03

Q-NET = -1.522104E+02 Q-NET = -9.902921E+02

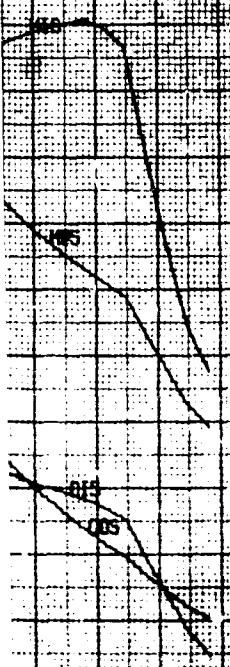
29 SEP 1965

SOIL STRESS DISTRIBUTION





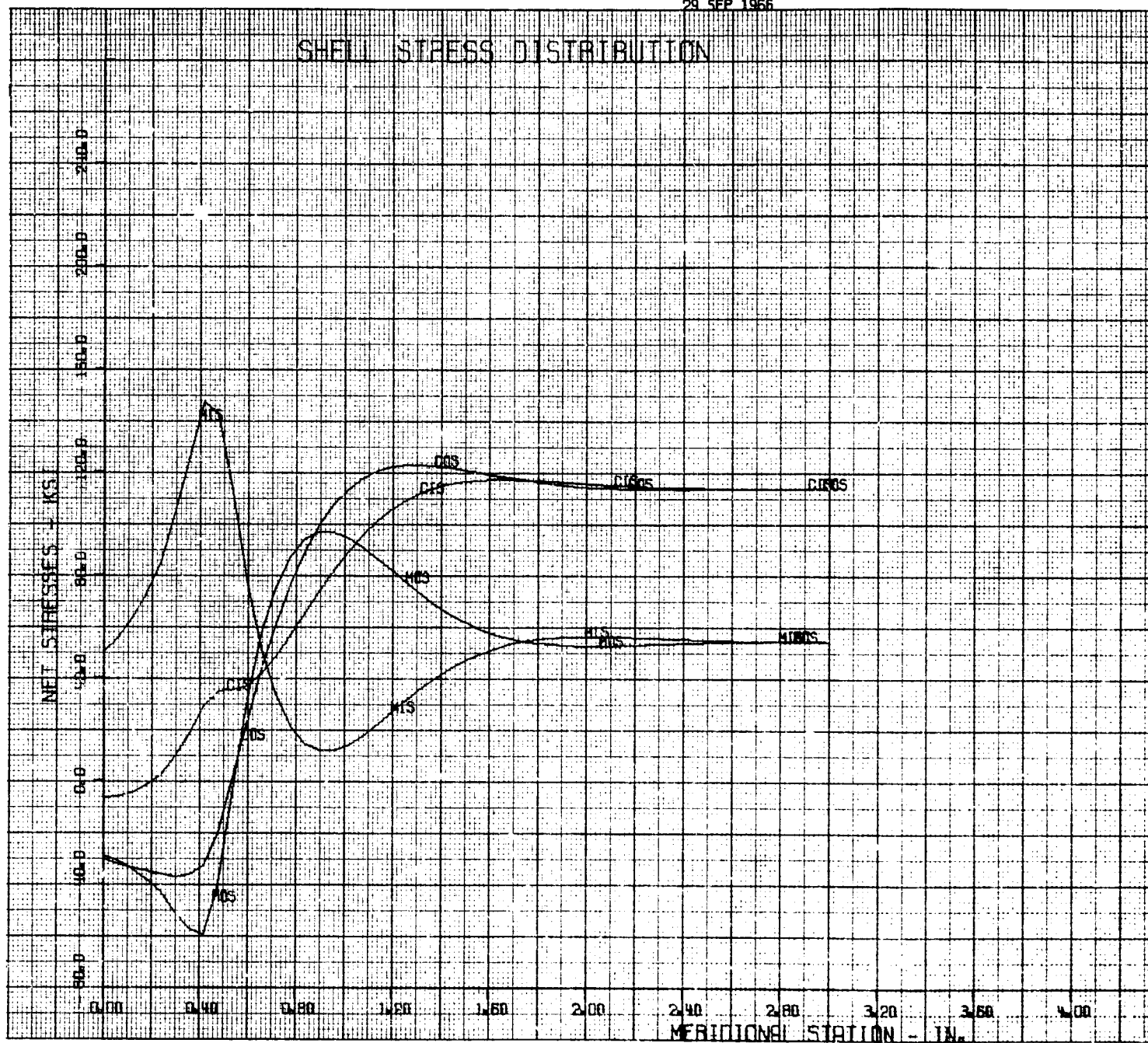
CONCRETE CHAMBER WALL IN HYBRID			
SHELL # 1	ORSE # 2	CONFID # 1	
MERIDIONAL STRESS	INSIDE	MLS	
MERIDIONAL STRESS	OUTSIDE	MOS	
DIRENFERENTIAL STRESS	INSIDE	DOS	
DIRENFERENTIAL STRESS	OUTSIDE	DOS	



2.00 1.00 0.00 -1.00 -2.00 -3.00 -4.00 -5.00
STATION - IN.

2

29 SEP 1966



1966



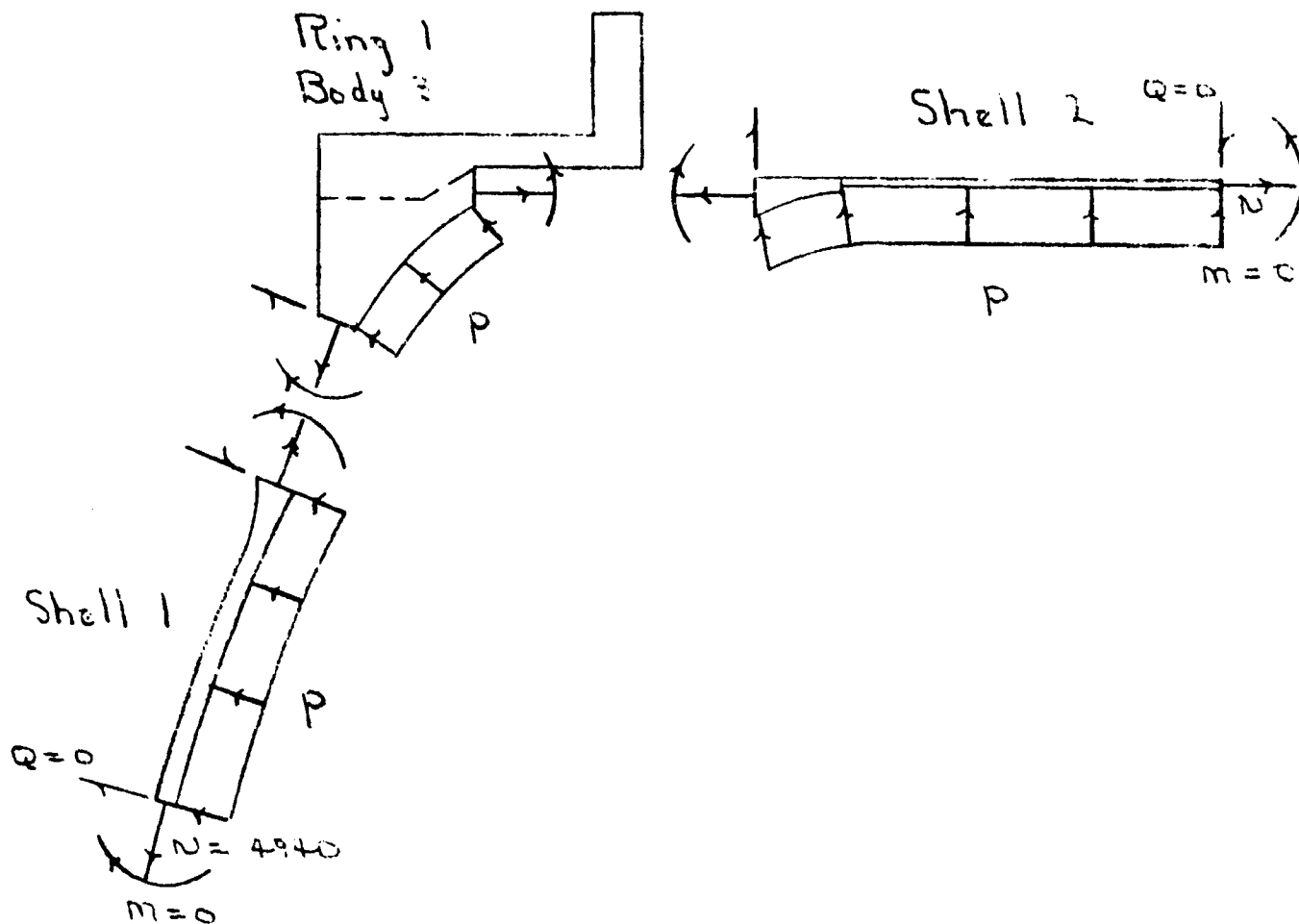
CONSTRUCTION		IN HYBRID	
SHELL # 2	CASE # 1	CONF # 1	
MERIDIONAL STRESS		(INSIDE)	MS
MERIDIONAL STRESS		(OUTSIDE)	MS
CIRCUMFERENTIAL STRESS		(INSIDE)	CS
CIRCUMFERENTIAL STRESS		(OUTSIDE)	CS

CROSS

ADDS

2.80 3.20 3.60 4.00 4.40 4.80 5.20 5.60
 INEL STATION - IN.

2

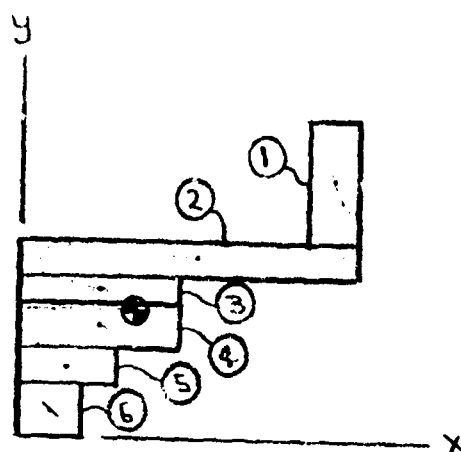
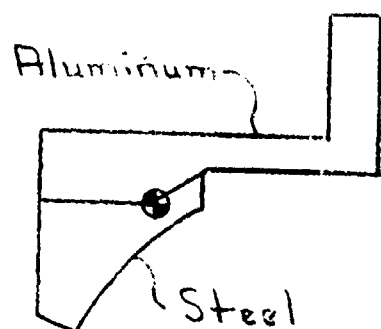


Motor

FIGURE 9

FWD CLOSURE Y RING REGION
(Aluminum Adapter Ring)

Ring 1, Body 3



E_i = Modulus of Elasticity for Material of Element i , Psi

E_0 = Modulus of Elasticity for Selected Base Material, Psi

$$E_0 = 26.5 \times 10^6 \text{ Psi}$$

$$E_i = 10.5 \times 10^6 \text{ Psi}$$

$$n_i = \frac{E_i}{E_0} = \frac{10.5 \times 10^6}{26.5 \times 10^6} = .396$$

Strength of Materials, Shanley, Page 310.



Ring 1, Body 3

Item	b	h	A _i	A _{tr} _i	x	y
1	.27	.65	.1755	.0675	1.730	1.370
2	1.88	.18	.3304	.1341	.740	.950
3	1.00	.14	.1400	.0547	.500	.780
4	1.00	.24	.2400	.2400	.500	.580
5	.53	.19	.1007	.1007	.265	.360
6	.25	.28	.0700	.0700	.125	.140
				.6690		

Item	A _{tr} _i y	A _{tr} _i x	A _{tr} _i x ²	I _y _{tr}		
1	.09322	.12024	.20802	.00042		
2	.12740	.12605	.11841	.03949		
3	.04267	.07022	.21243	.00462		
4	.13720	.12000	.06000	.12000		
5	.03625	.02669	.00707	.00236		
6	.00980	.00875	.00109	.00036		
	.45054	.42303	.40553	.06725		

$$(I_y')_{tr} = \sum (A_{tr,i} x_i^2) + \sum (I_{y, tr})$$

$$(I_y')_{tr} = .40553 + .06725 = .47278 \text{ in}^4$$

$$\bar{x} = .42303 / .6690 = .6314 \text{ in}$$

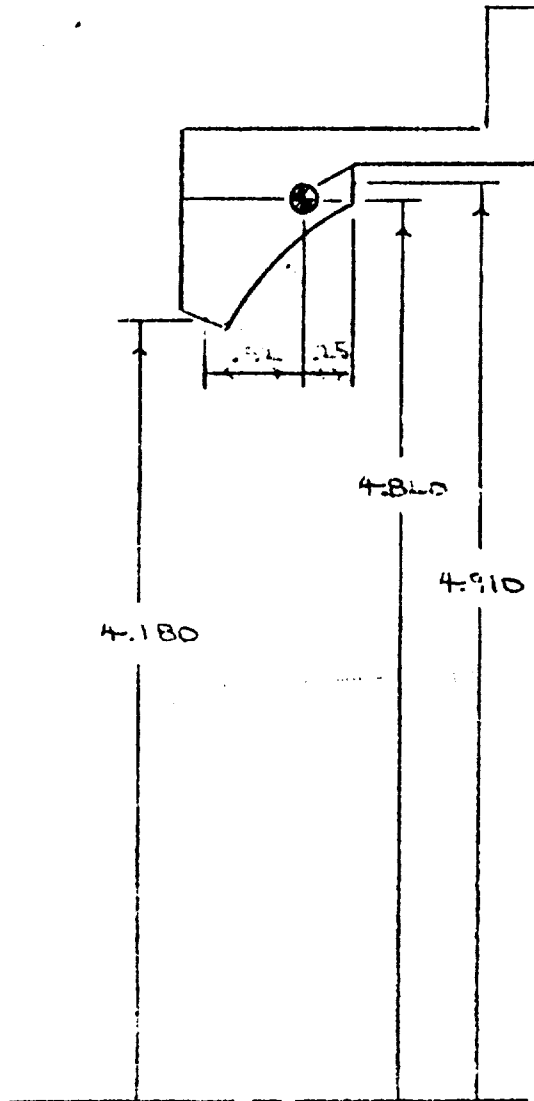
$$\bar{y} = .45054 / .6690 = .6735 \text{ in}$$

$$I_{yy} = (I_y')_{tr} - \sum A_{tr,i} \bar{x}^2$$

$$I_{yy} = .47278 - .0690 (.6314)^2 = .2001 \text{ in}^4$$



RING 1, BODY 2



$$F_x = .67 p = .67(910) = 610 \text{ LB}$$

$$F_y = .67 p = .67(910) = 610 \text{ LB}$$

$$M_{CG} = -.947 p(.30) = -.284(910)$$

$$M_{CG} = -258$$

$$\begin{cases} RLI = 4.180 \\ PHLI = 35.26180 \\ XLI = .520 \end{cases}$$

$$\begin{cases} RLO = 0 \\ PHLO = 0 \\ XLO = 0 \end{cases}$$

$$\begin{cases} RRI = 0 \\ PHRI = 0 \\ XRO = 0 \end{cases}$$

$$\begin{cases} RRO = 4.940 \\ PHRO = 90 \\ XRO = .25 \end{cases}$$

$$R_{CG} = 4.820$$

$$A = .6690$$

$$I_{yy} = .20025$$

$$E = 26.5 \times 10^6$$

Shz.1 Closure Dome (Elliptical)

10 IN HYPERBOLIC CHAMBER, FWD R-D, ELLIPSE PROPS M.D. BUSH 22 AUG 66

INPUT DATA

A = 4.95000 B = 2.22000 X = 0.00000 DELTAS = 0.05000
 GEOMETRIC PROPERTIES - ELLIPSOID OF REVOLUTION

DELTA	R1	R2	PHI
0.00000000	1.10371622E+01	1.10371622E+01	0.00000000
0.05000000	1.10350120E+01	1.10367124E+01	0.25956752
0.10000000	1.10317652E+01	1.10353629E+01	0.51919535
0.15000000	1.10250207E+01	1.10331135E+01	0.77894704
0.20000000	1.10155818E+01	1.10299640E+01	1.03888628
0.25000000	1.10034515E+01	1.10259138E+01	1.29907698
0.30000000	1.09886339E+01	1.10209623E+01	1.55958330
0.35000000	1.09711341E+01	1.10151088E+01	1.82046982
0.40000000	1.09509577E+01	1.10083522E+01	2.08180150
0.45000000	1.09281117E+01	1.10006916E+01	2.34364383
0.50000000	1.09026035E+01	1.09921258E+01	2.60606291
0.55000000	1.08744417E+01	1.09826533E+01	2.86912547
0.60000000	1.08436357E+01	1.09722726E+01	3.13289902
0.65000000	1.08101959E+01	1.09609822E+01	3.39745188
0.70000000	1.07741314E+01	1.09487801E+01	3.66285329
0.75000000	1.07354804E+01	1.09356644E+01	3.92917351
0.80000000	1.06941898E+01	1.09216330E+01	4.19648387
0.85000000	1.06503358E+01	1.09066836E+01	4.46485689
0.90000000	1.06039130E+01	1.08908138E+01	4.73436639
0.95000000	1.05549373E+01	1.08740210E+01	5.00508756
1.00000000	1.05034255E+01	1.08563025E+01	5.27709705
1.05000000	1.04493952E+01	1.08376553E+01	5.55047314
1.10000000	1.03928650E+01	1.08180764E+01	5.82529580
1.15000000	1.03338545E+01	1.07975626E+01	6.10144681
1.20000000	1.02723842E+01	1.07761104E+01	6.37960990
1.25000000	1.02084756E+01	1.07537164E+01	6.65927067
1.30000000	1.01421511E+01	1.07303768E+01	6.94071771
1.35000000	1.00734342E+01	1.07060878E+01	7.22404078
1.40000000	1.00023494E+01	1.06808452E+01	7.50933289
1.45000000	9.92892197E+00	1.06546449E+01	7.79668953
1.50000000	9.85317848E+00	1.06274825E+01	8.08620897
1.55000000	9.77514637E+00	1.05993534E+01	8.37799247
1.60000000	9.69485412E+00	1.05702528E+01	8.67214446
1.65000000	9.61233127E+00	1.05401759E+01	8.96877268
1.70000000	9.52760844E+00	1.05091175E+01	9.26798846
1.75000000	9.44071727E+00	1.04770724E+01	9.56990688
1.80000000	9.35169051E+00	1.04440351E+01	9.87444701
1.85000000	9.26056200E+00	1.04100000E+01	10.18233215
1.90000000	9.16736668E+00	1.03745612E+01	10.49309808
1.95000000	9.07214061E+00	1.03389128E+01	10.80705335
2.00000000	8.97492102E+00	1.03018485E+01	11.12435555
2.05000000	8.87574625E+00	1.02637620E+01	11.44515161
2.10000000	8.77465584E+00	1.02246468E+01	11.76957814
2.15000000	8.67169052E+00	1.01844959E+01	12.09779378
2.20000000	8.56692208E+00	1.01433026E+01	12.42995956
2.25000000	8.46030405E+00	1.01010597E+01	12.76624331
2.30000000	8.35197048E+00	1.00577599E+01	13.10682007
2.35000000	8.24193714E+00	1.00133958E+01	13.45187253
2.40000000	8.13025122E+00	9.96795955E+00	13.80159157
2.45000000	8.01694037E+00	9.92144345E+00	14.15617671

2.50000000	7.90211481E+00	9.87383944E+00	14.51583673
2.55000000	7.78576532E+00	9.82513935E+00	14.88079021
2.60000000	7.66796425E+00	9.77533483E+00	15.25126623
2.65000000	7.54876538E+00	9.72441740E+00	15.62750502
2.70000000	7.42622393E+00	9.67237839E+00	16.00975871
2.75000000	7.30639658E+00	9.61920904E+00	16.39829216
2.80000000	7.18334154E+00	9.56490045E+00	16.79338378
2.85000000	7.05911851E+00	9.50944359E+00	17.19532649
2.90000000	6.93378882E+00	9.45282388E+00	17.60442871
2.95000000	6.80741534E+00	9.39504862E+00	18.02101544
3.00000000	6.68006264E+00	9.33609210E+00	18.44542947
3.05000000	6.55179691E+00	9.27595055E+00	18.87803258
3.10000000	6.42269611E+00	9.21461473E+00	19.31920698
3.15000000	6.29279993E+00	9.15207542E+00	19.76935674
3.20000000	6.16220987E+00	9.08832350E+00	20.22890944
3.25000000	6.03098928E+00	9.02334996E+00	20.69831791
3.30000000	5.89921340E+00	8.95714596E+00	21.17806209
3.35000000	5.76695943E+00	8.88970292E+00	21.66865113
3.40000000	5.63430653E+00	8.82101254E+00	22.17062563
3.45000000	5.50133596E+00	8.75106592E+00	22.68456003
3.50000000	5.36813105E+00	8.67985864E+00	23.21106526
3.55000000	5.23477730E+00	8.60738084E+00	23.75079166
3.60000000	5.10136244E+00	8.53362738E+00	24.30443204
3.65000000	4.96797648E+00	8.45859295E+00	24.87272513
3.70000000	4.83471178E+00	8.38227321E+00	25.45645925
3.75000000	4.70166313E+00	8.30466501E+00	26.05647637
3.80000000	4.56892779E+00	8.22576856E+00	26.67367642
3.85000000	4.43660561E+00	8.14557769E+00	27.30902211
3.90000000	4.30479905E+00	8.06410010E+00	27.96354404
3.95000000	4.17361328E+00	7.98133768E+00	28.63834635
4.00000000	4.04315630E+00	7.89729678E+00	29.33461271
4.05000000	3.91353804E+00	7.81198682E+00	30.05361290
4.10000000	3.78487500E+00	7.72542053E+00	30.79670985
4.15000000	3.65728133E+00	7.63761458E+00	31.56536720
4.20000000	3.53087748E+00	7.54859019E+00	32.36115739
4.25000000	3.40578743E+00	7.45837380E+00	33.18577023
4.30000000	3.28213762E+00	7.36699787E+00	34.04102198
4.35000000	3.16005706E+00	7.27450183E+00	34.92886480
4.36793424	3.11586941E+00	7.24043581E+00	35.26179687

PROCESSOR: 0.109 MINUTES
INPUT/OUTPUT: 0.119 MINUTES
ELAPSED TIME: 0.258 MINUTES



United Technology Center

DIVISION OF UNITED AIRCRAFT CORPORATION

U
A

PREPARED BY KID 13456

DATE 9-25-65

RECEIVED BY

DATE

Shell 1

INPUT VALUES FOR UNIT ANALYSIS
OF AN AXISYMMETRIC THIN SHELL

PROJ. NO. _____

SHELL LENGTH 4.3679, POISSON'S RATIO 0.3.YOUNGS MODULUS 26.5×10^6 , NO. TAYLOR SERIES 5, NO. SEGMENTS 50.

	MERIDIONAL STATION	R_1	R_2	THICKNESS	PHI
	0	11.0372	11.0372		0
	.10	11.0318	11.0354		.51920
	.20	11.0156	11.0350		1.03389
	.30	10.9886	11.0210		1.53708
	.40	10.9510	11.0084		2.03190
	.50	10.9026	10.9921		2.50606
	.60	10.8436	10.9723		3.00092
	.70	10.7741	10.9483		3.46295
	.80	10.6942	10.9216		4.00648
	.90	10.6039	10.8900		4.72437
0	1.00	10.5034	10.8563		5.27710
.1	1.10	10.3927	10.8181		5.82230
.2	1.20	10.2724	10.7761		6.37131
.3	1.30	10.1422	10.7304		6.94072
.4	1.40	10.0023	10.6806		7.52733
.5	1.50	9.8532	10.6275		8.12001
.6	1.60	9.6949	10.5703		8.72114
.7	1.70	9.5276	10.5091		9.32799
.8	1.80	9.3517	10.4440		9.94055
.9	1.90	9.1674	10.3750		10.54801
1.0	2.00	8.9747	10.3018		11.12436
1.1	2.10	8.7747	10.2246		11.76039
1.2	2.20	8.5669	10.1432		12.44296
1.3	2.30	8.3520	10.0578		13.16055
1.4	2.40	8.1302	9.9680		13.90339
1.5	2.50	7.9021	9.8732		14.67054
1.6	2.60	7.6677	9.7753		15.46127
1.7	2.70	7.4271	9.6734		16.27470
1.8	2.80	7.1803	9.5674		17.11053
1.9	2.90	6.9275	9.4576		17.96843
2.0	3.00	6.6691	9.3441		18.84790

N-225 (5-63)



DIVISION OF UNITED AIRCRAFT CORPORATION

PREPARED BY RD Bush

DATE 9-23-66

REVIEWED BY

DATE _____

INPUT VALUES FOR UNIT ANALYSIS OF AN AXISYMMETRIC THIN SHELL

PROJ. NO. _____

SHELL LENGTH 4.3679. POISSON'S RATIO 0.3.

YOUNGS MODULUS 26.5×10^6 . NO. TAYLOR SERIES 5. NO. SEGMENTS 50.

N-225 (5/63)



COMBUSTION CHAMBER - 10 IN HYPERS
(CO 2219)

$$M = 10 NS + 4 NR + 5 NRJ$$

$$M = 10 \overset{20}{(2)} + 4 \overset{4}{(1)} + 5 \overset{10}{(2)} = 34$$

NC, NS, 1, 2,

P₁, P₂, 910, 910,

NJ, 2,

NJ sets, 1, 3, 3, 2,

Location, 1, 0, 3, 0,

No. of B.C., 5,

Body No., 1, 1, 2, 2, 2,

Location, 0, 0, 1, 1, 1,

B.C. No., 3, 4, 3, 4, 5,

Value, 0, 0, 0, 0, 4940,

$$N_1 = \frac{PR_2}{2} = \frac{910}{2} (10.8863) = 4940$$



COMBUSTION CHAMBER, FWD, 10 IN HYBRID
CD 2219

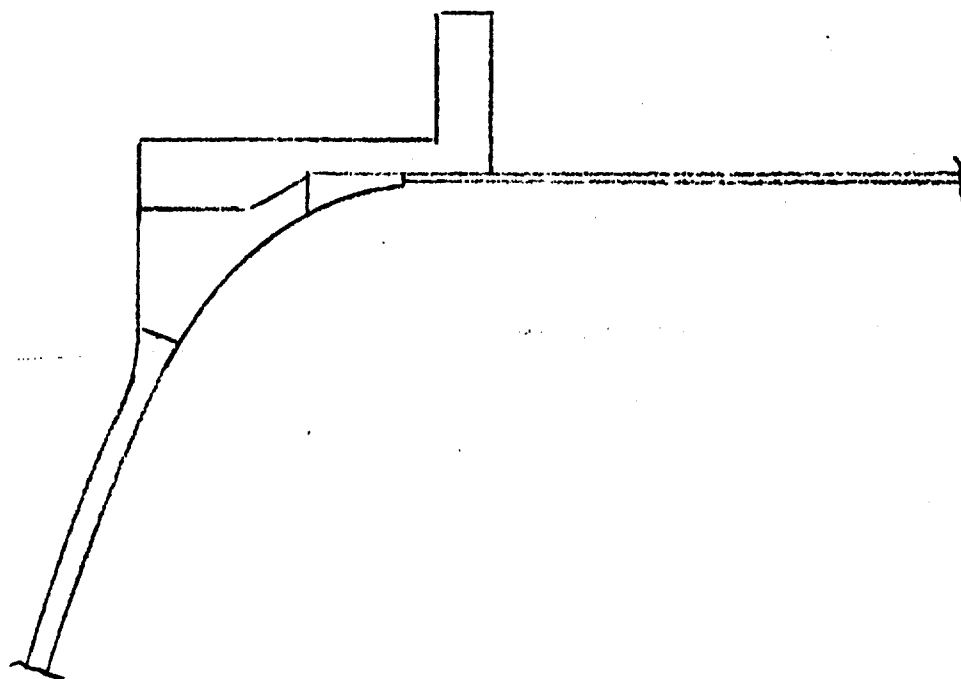
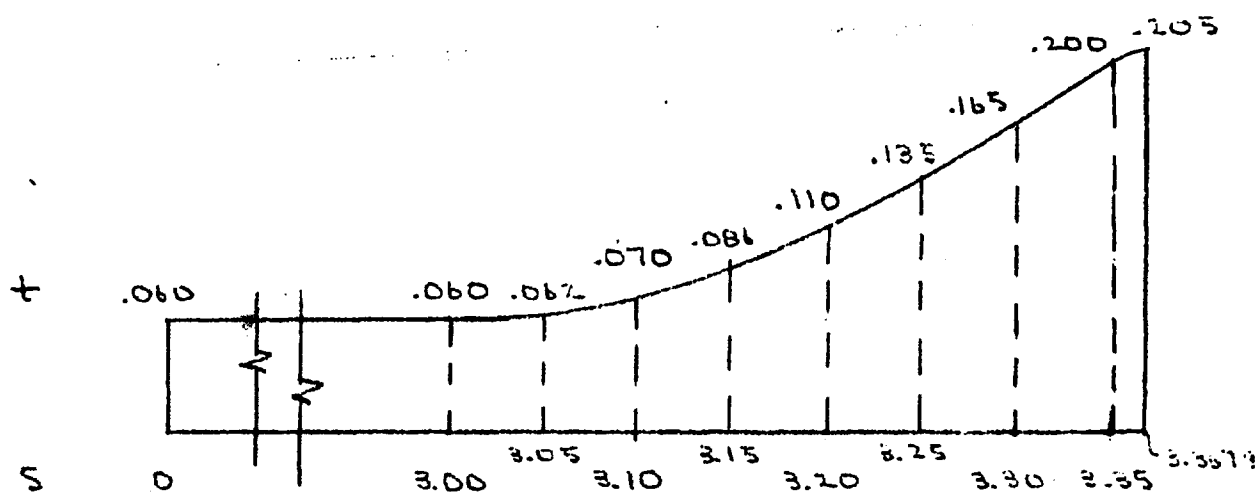


FIGURE 10

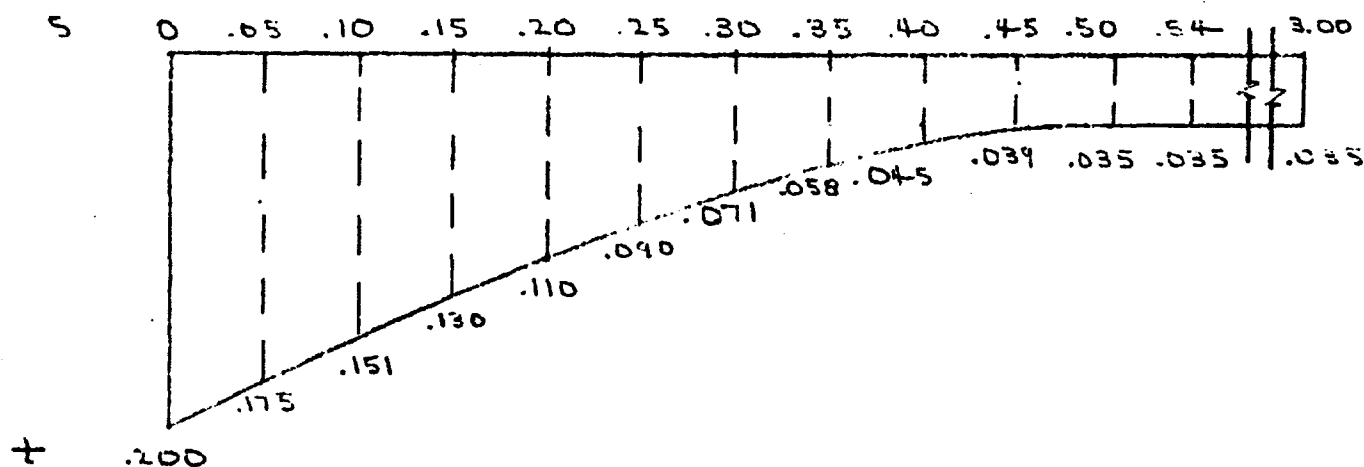
FWD CLOSURE, Y RING REGION
(Aluminum Adapter Ring)

10 IN HYBRID, COMBUSTION CHAMBER, FWD
CLOSURE, Y RING REGION, ALUM. RING,
6 OCT. 66

Shell 1



Shell 2





Shell 2

S	R ₁	t	t/2	R ₂	Φ
0	∞	.200	.1000	4.9460	90
.05		.175	.0875	4.9520	
.10		.151	.0753	4.9643	
.15		.130	.0650	4.9750	
.20		.110	.0550	4.9820	
.25		.090	.0450	4.9950	
.30		.071	.0353	5.0043	
.35		.058	.0290	5.0110	
.40		.045	.0225	5.0173	
.45		.039	.0195	5.0203	
.50		.033	.0173	5.0223	
.54		.033	.0173	5.0223	
3.00	∞	.033	.0173	5.0223	90

STRUCTURAL ANALYSIS OF MULTIPLE SHELL/RING STRUCTURES

UNITED TECHNOLOGY CENTER

6 OCT 1966

10 IN HYBRID COMBUSTION CHAMBER, FWD CLOSURE, Y RING SECTION, 6 OCT. 66

SHELL #1 CLOSURE DOME (ELLIPTICAL)

SHELL UNIT ANALYSIS

INPUT IS:

SHELL NO. 1, CONFIGURATION NO. 1

TAYLORS SERIES EXPANSIONS OF 5 TERMS ARE USED TO SOLVE THE DIFFERENTIAL EQUATIONS SIMULTANEOUSLY.

THE 3.3679 INCH LONG SHELL SECTION IS DIVIDED INTO 50 SEGMENTS EACH OF WHICH IS 0.0674 INCHES LONG.

MODULUS OF ELASTICITY, E = 2.65000e+07

POISSON S RATIO, MU = 0.3000

MERIDIONALLY VARIING PARAMETER FUNCTIONS:

RADIUS 1 =	1.0503e+01	1.0393e+01	1.0272e+01	1.0142e+01	1.0002e+01	9.8532e+00	9.6949e+00
S =	0.0000e+00	1.0000e-01	2.0000e-01	3.0000e-01	4.0000e-01	5.0000e-01	6.0000e-01
	9.5276e+00	9.3517e+00	9.1674e+00	8.9749e+00	8.7747e+00	8.5669e+00	8.3520e+00
	7.0000e-01	8.0000e-01	9.0000e-01	1.0000e+00	1.1000e+00	1.2000e+00	1.3000e+00
	8.1303e+00	7.9021e+00	7.6680e+00	7.4282e+00	7.1833e+00	6.9338e+00	6.6801e+00
	1.4000e+00	1.5000e+00	1.6000e+00	1.7000e+00	1.8000e+00	1.9000e+00	2.0000e+00
	6.4227e+00	6.1622e+00	5.8992e+00	5.6343e+00	5.3681e+00	5.1014e+00	4.8347e+00
	2.1000e+00	2.2000e+00	2.3000e+00	2.4000e+00	2.5000e+00	2.6000e+00	2.7000e+00
	4.5689e+00	4.3048e+00	4.0432e+00	3.7849e+00	3.5309e+00	3.2821e+00	3.1601e+00
	2.8000e+00	2.9000e+00	3.0000e+00	3.1000e+00	3.2000e+00	3.3000e+00	3.3500e+00
	3.1259e+00						
	3.3679e+00						

RADIUS 2 =	1.0856e+01	1.0816e+01	1.0776e+01	1.0730e+01	1.0681e+01	1.0627e+01	1.0570e+01
S =	0.0000e+00	1.0000e-01	2.0000e-01	3.0000e-01	4.0000e-01	5.0000e-01	6.0000e-01
	1.0509e+01	1.0444e+01	1.0375e+01	1.0302e+01	1.0225e+01	1.0143e+01	1.0058e+01
	7.0000e-01	8.0000e-01	9.0000e-01	1.0000e+00	1.1000e+00	1.2000e+00	1.3000e+00
	9.9680e+00	9.8738e+00	9.7753e+00	9.6724e+00	9.5649e+00	9.4528e+00	9.3361e+00
	1.4000e+00	1.5000e+00	1.6000e+00	1.7000e+00	1.8000e+00	1.9000e+00	2.0000e+00
	9.2146e+00	9.0653e+00	8.9571e+00	8.8210e+00	8.6799e+00	8.5336e+00	8.3823e+00
	2.1000e+00	2.2000e+00	2.3000e+00	2.4000e+00	2.5000e+00	2.6000e+00	2.7000e+00

8.2258e+00	8.0641e+00	7.8973e+00	7.7254e+00	7.5486e+00	7.3670e+00	7.2745e+00
2.8000e+00	2.9000e+00	3.0000e+00	3.1000e+00	3.2000e+00	3.3000e+00	3.3500e+00
7.2404e+00						
3.3679e+00						

THICKNESS =	6.0000e-02	6.0000e-02	6.2000e-02	7.0000e-02	8.6000e-02	1.1000e-01	1.3500e-01
S =	0.0000e+00	3.0000e+00	3.0500e+00	3.1000e+00	3.1500e+00	3.2000e+00	3.2500e+00
	1.6500e-01	2.0000e-01	2.0500e-01				
	3.3000e+00	3.3500e+00	3.3679e+00				

PHI =	5.2771e+00	5.8253e+00	6.3796e+00	6.9407e+00	7.5093e+00	8.0862e+00	8.6721e+00
S =	0.0000e+00	1.0000e-01	2.0000e-01	3.0000e-01	4.0000e-01	5.0000e-01	6.0000e-01
	9.2680e+00	9.8747e+00	1.0493e+01	1.1124e+01	1.1770e+01	1.2430e+01	1.3107e+01
	7.0000e-01	8.0000e-01	9.0000e-01	1.0000e+00	1.1000e+00	1.2000e+00	1.3000e+00
	1.3802e+01	1.4516e+01	1.5251e+01	1.6010e+01	1.6793e+01	1.7604e+01	1.8445e+01
	1.4000e+00	1.5000e+00	1.6000e+00	1.7000e+00	1.8000e+00	1.9000e+00	2.0000e+00
	1.9319e+01	2.0229e+01	2.1178e+01	2.2171e+01	2.3211e+01	2.4304e+01	2.5457e+01
	2.1000e+00	2.2000e+00	2.3000e+00	2.4000e+00	2.5000e+00	2.6000e+00	2.7000e+00
	2.6674e+01	2.7963e+01	2.9335e+01	3.0797e+01	3.2361e+01	3.4041e+01	3.4929e+01
	2.8000e+00	2.9000e+00	3.0000e+00	3.1000e+00	3.2000e+00	3.3000e+00	3.3500e+00
	3.5262e+01						
	3.3679e+00						

SHELL #2 CYLINDER WALL

SHELL UNIT ANALYSIS

SHELL NO. 2, CONFIGURATION NO. 1

INPUT IS:

TAYLORS SERIES EXPANSIONS OF 5 TERMS ARE USED TO SOLVE THE DIFFERENTIAL EQUATIONS SIMULTANEOUSLY.
THE 3.0000 INCH LONG SHELL SECTION IS DIVIDED INTO 50 SEGMENTS EACH OF WHICH IS 0.0600 INCHES LONG.

MODULUS OF ELASTICITY, E = 2.65000E+07

POISSON S RATIO, MU = 0.3000

MERIDIONALLY VARIING PARAMETER FUNCTIONS:

RADIUS 1 = 1.0000E+10 1.0000E+10
S = 0.0000E+00 3.0000E+00

RADIUS 2 = 4.9400E+00 4.9525E+00 4.9645E+00 4.9750E+00 4.9850E+00 4.9950E+00 5.0045E+00
S = 0.0000E+00 5.0000E-02 1.0000E-01 1.5000E-01 2.0000E-01 2.5000E-01 3.0000E-01
5.0110E+00 5.0175E+00 5.0205E+00 5.0225E+00 5.0225E+00 5.0225E+00
3.5000E-01 4.0000E-01 4.5000E-01 5.0000E-01 5.4000E-01 5.0000E+00

THICKNESS = 2.0000E-01 1.7500E-01 1.5100E-01 1.3000E-01 1.1000E-01 9.0000E-02 7.1000E-02
S = 0.0000E+00 5.0000E-02 1.0000E-01 1.5000E-01 2.0000E-01 2.5000E-01 3.0000E-01
5.8000E-02 4.5000E-02 3.9000E-02 3.5000E-02 3.5000E-02 3.5000E-02
3.5000E-01 4.0000E-01 4.5000E-01 5.0000E-01 5.4000E-01 5.0000E+00

PHI = 9.0000E+01 9.0000E+01
S = 0.0000E+00 3.0000E+00

RING 1, BODY 3

RING UNIT ANALYSIS

RING NO. 1, CONFIGURATION NO. 1

INPUT IS:

LI	RADIUS, IN.	PHI, DEG.	X, IN.
	4.180	35.262	0.520
LO	0.000	0.000	0.000
HI	0.000	0.000	0.000
RU	4.940	90.000	0.250
RCG =	4.820	A = 0.469	IYY = 0.200
			E = 2.650E+07

OUTPUT IS:

	QNET	WNET	AXIAL EQUIL
M-LI	0.0000E+00	-8.6722E-01	0.0000E+00
Q-	5.0066E-01	-7.1353E-01	3.4131E+00
N-	-7.0810E-01	4.7798E-02	2.4132E+00
M-LU	0.0000E+00	0.0000E+00	0.0000E+00
Q-	0.0000E+00	0.0000E+00	0.0000E+00
N-	0.0000E+00	0.0000E+00	0.0000E+00
M-HI	0.0000E+00	0.0000E+00	0.0000E+00
Q-	0.0000E+00	0.0000E+00	0.0000E+00
N-	0.0000E+00	0.0000E+00	0.0000E+00
M-RU	0.0000E+00	1.0249E+00	0.0000E+00
Q-	-1.0249E+00	-2.5622E-01	-6.8420E-09
N-	1.8384E-09	-1.2799E-01	-4.9400E+00
FA	0.0000E+00	0.0000E+00	4.8200E+00
FY	1.0000E+00	0.0000E+00	0.0000E+00
FC	0.0000E+00	1.0000E+00	0.0000E+00

LI-CG = 1.3105E-04 X CG-YI HETA-CG = 4.3752E-06 X M-NET

SHELL/HING BOUNDARY CONDITIONS AND FORCES

CASE NO. 1, CONFIGURATION NO. 1

SHELL NO. 1

M-L = 0.0000E+00
 Q-L = 0.0000E+00
 N-L = 4.9400E+01
 PRESSURE = 9.1000E+02

SHELL NO. 2

M-R = 0.0000E+00
 Q-R = 0.0000E+00
 PRESSURE = 9.1000E+02

HING NO. 1

FX = 6.1000E+02 FY = 6.1000E+02 MCG = -2.5800E+02

CASE NO. 1, CONFIGURATION NO. 1

SHELL/RING DISCONTINUITY DEFORMATION AND FORCE SOLUTIONS

SHELL NO. 1 LEFT END RIGHT END

DELTA 2.164964E-03 -1.315241E-03

BETA -7.657346E-03 -2.512526E-04

 M 0.000000E+00 2.646410E+01

 U 3.314354E-06 1.410456E+01

 N 4.940000E+03 3.208743E+03

SHELL NO. 2 LEFT END RIGHT END

DELTA -1.508746E-03 2.115773E-02

BETA -2.512527E-04 8.29A568E-05

 M 1.916103E+02 0.000000E+00

 U -5.935138E+02 0.000000E+00

 N 2.211520E+03 2.211520E+03

RING NO. 1 LEFT INSIDE LEFT OUTSIDE RIGHT INSIDE RIGHT OUTSIDE

DELTA -1.315241E-03 0.000000E+00 0.000000E+00 -1.50A746E-03

BETA -2.512526E-04 0.000000E+00 0.000000E+00 -2.512527E-04

 M 2.646410E+01 0.000000E+00 0.000000E+00 1.916103E+02

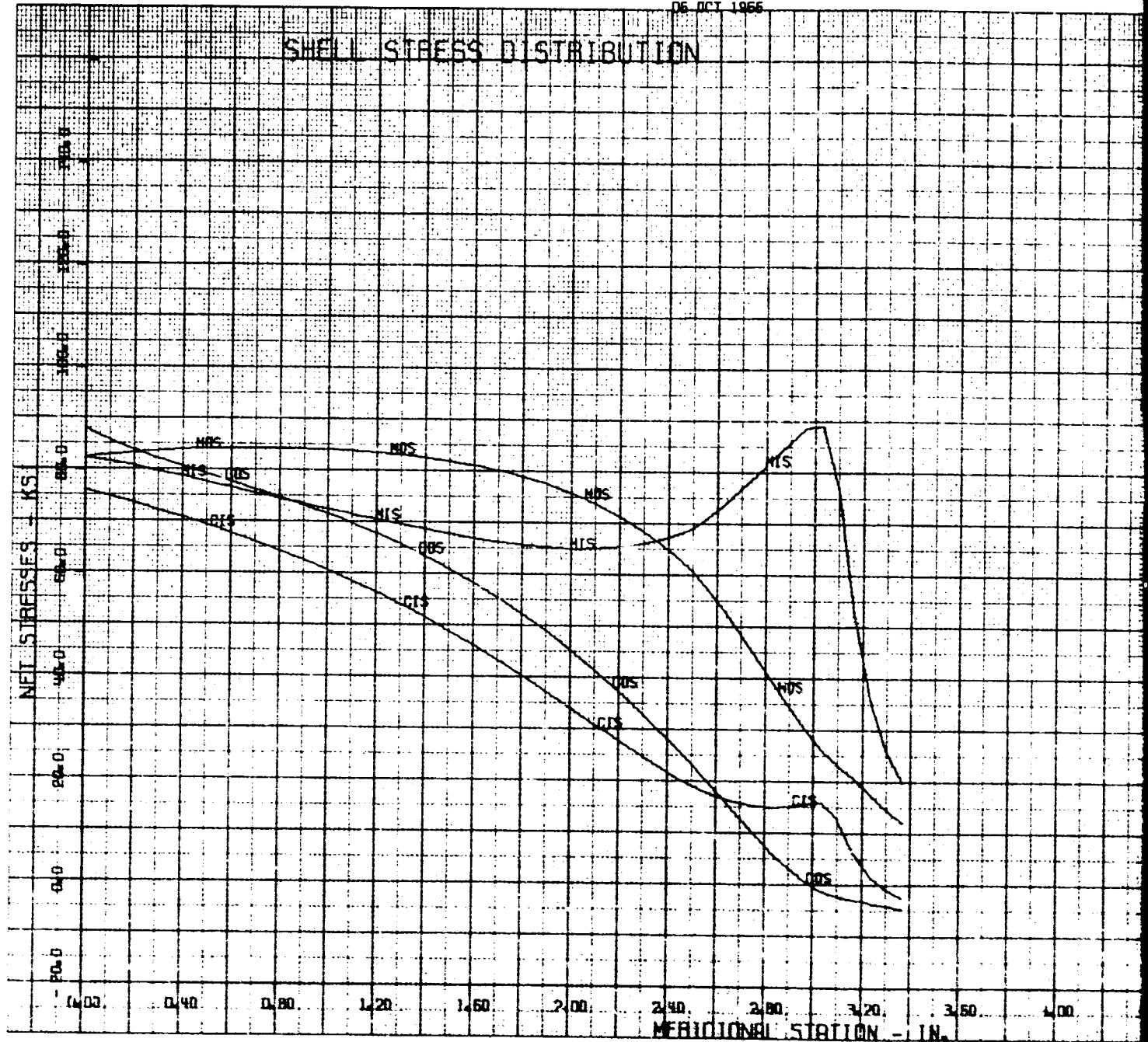
 U 1.410456E+01 0.000000E+00 0.000000E+00 -5.935138E+02

 N 3.208743E+03 0.000000E+00 0.000000E+00 2.211520E+03

DEL-CG = -1.44593E-03 DELTA-CG = -2.512526E-04

U-NET = -5.742709E+01 Q-NET = -1.103382E+03

SHELL STRESS DISTRIBUTION

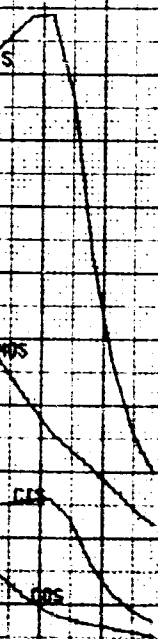




END CLOSURE Y-RING SECTION

SHELL = 10 CASE = 11 CONFIG = 1

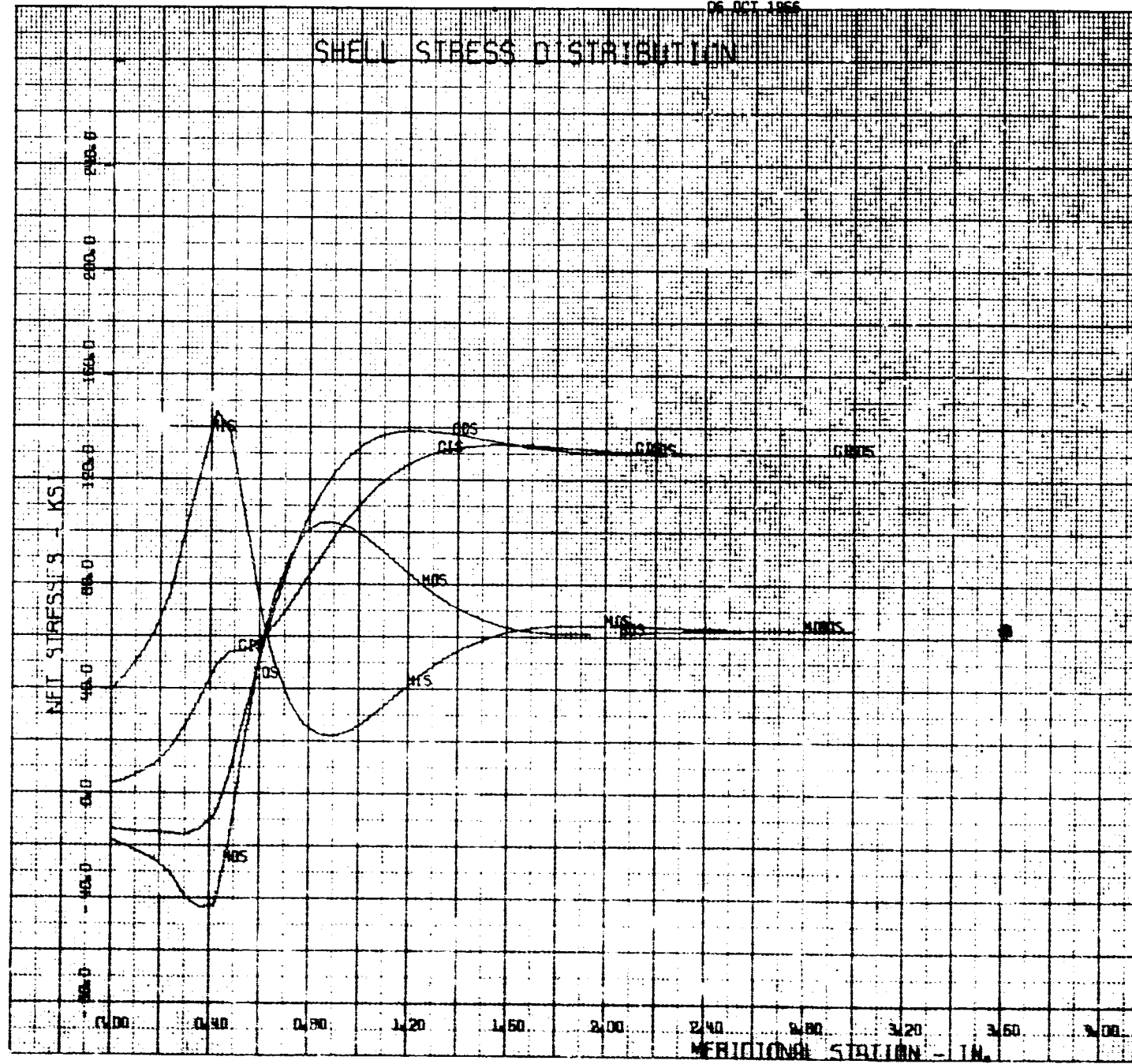
MERIDIONAL STRESS	'INSIDE'	NIS
MERIDIONAL STRESS	'OUTSIDE'	NPS
CIRCUMFERENTIAL STRESS	'INSIDE'	SIS
CIRCUMFERENTIAL STRESS	'OUTSIDE'	POS



STATION - IN. 3.20 3.60 4.00 4.40 4.80 5.20 5.60

06 OCT 1966

SHELL STRESS DISTRIBUTION



7-1855



END CLOSURE Y-RING SECTION
 SHELL # 26 CIRC # 1, CONFIG # 1
 MERIDIONAL STRESS (INSIDE) MES
 MERIDIONAL STRESS (OUTSIDE) MOS
 CIRCUMFERENTIAL STRESS (INSIDE) CES
 CIRCUMFERENTIAL STRESS (OUTSIDE) COS

3.80 3.20 2.60 2.00 1.40 0.80 0.20 0.60
 TONG STATION - IN.

2

ADAPTER RING

$$M_{NET} = -57 \text{ in lb}$$

$$Q_{NET} = -1100 \text{ lb}$$

$$A_{RING} = 0.654 \text{ in}^2$$

$$(I_{yy})_{RING} :$$

Item	b	h	A _i	x	y
1	.27	.65	.176	1.73	1.37
2	1.88	.18	.338	.94	.95
3	1.00	.14	.140	.50	.70
			.654		

Item	A _i x	A _i x ²	I _{yy=0}
1	.304	.526	.00
2	.317	.298	.0775
3	.070	.035	.0116
	.691	.859	.0891

$$\bar{x} = \frac{.691}{.654} = 1.06 "$$

$$I_{yy} = .089 + .859 + (.654)(1.06^2)$$

$$= .255 \text{ in}^4$$



∴ CIRCUMFERENTIAL STRESS σ_c :

$$\begin{aligned}\sigma_c &= \frac{-MR(x)}{I_{yy}} + \frac{-QR}{A} \\ &= \frac{-(-57)(5)(1.06)}{.255} + \frac{-(-1100)(5)}{.654} \\ &= +1128 + 8420 \\ &= \underline{+9608 \text{ psi}}\end{aligned}$$

MATERIAL : AL ALLOY 2024 - T4

UTS (MIN.) = 60 KSI

YS (MIN.) = 40 KSI.

$$M.S. = \frac{40}{9.6} - 1 = + \underline{3.16}$$



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U
C

PREPARED BY R. O. Bush

DATE 10-1-66

REVIEWED BY

DATE

Motor

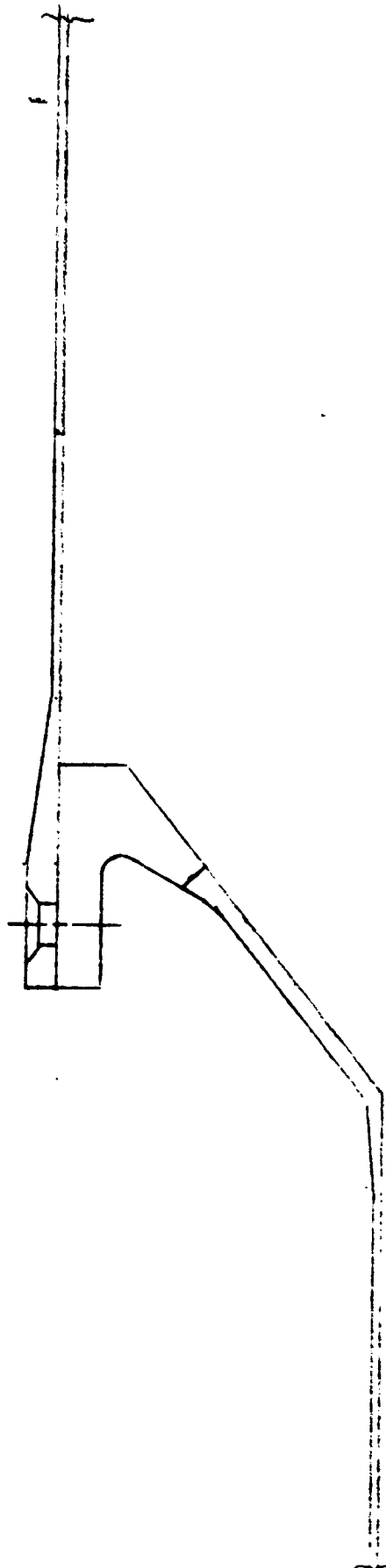


FIGURE 10 AFT CLOSURE REGION



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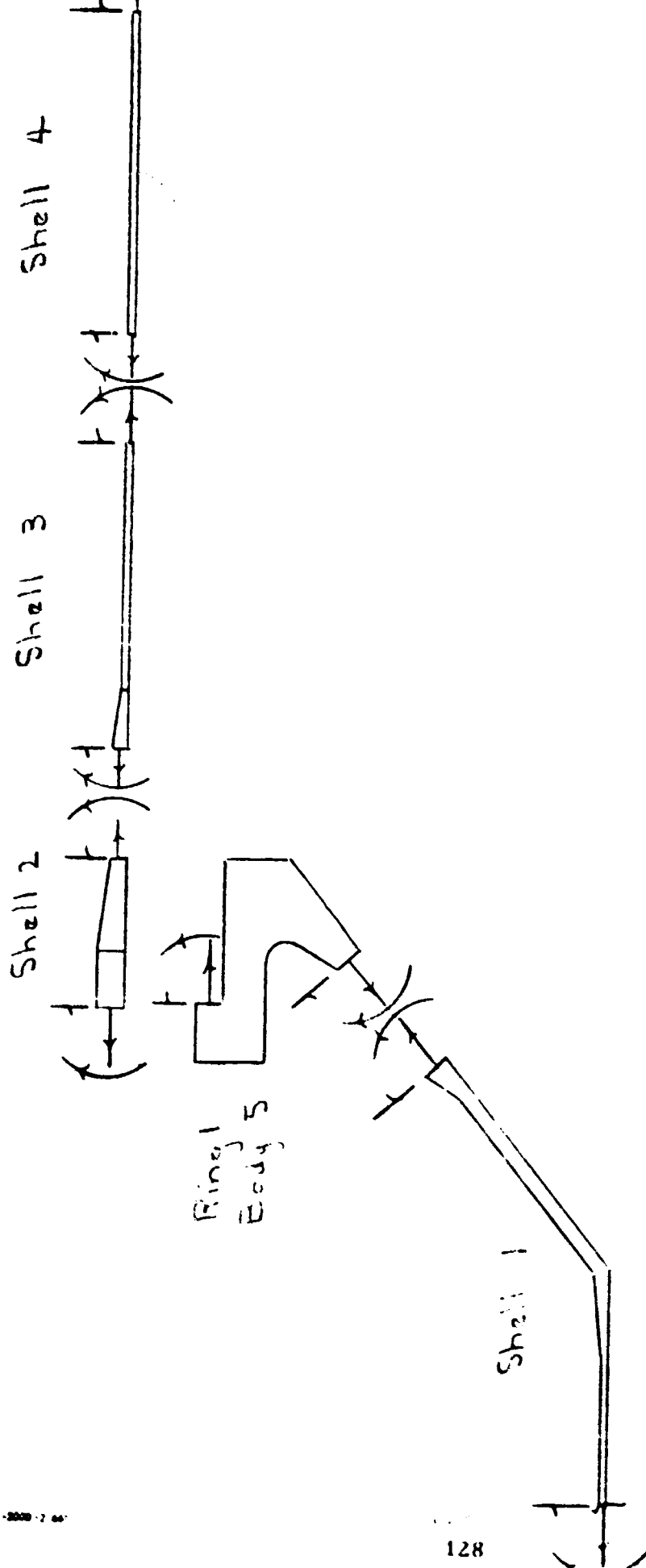
DC

PREPARED BY 12-13-68

REVIEWED BY

DATE

DATE

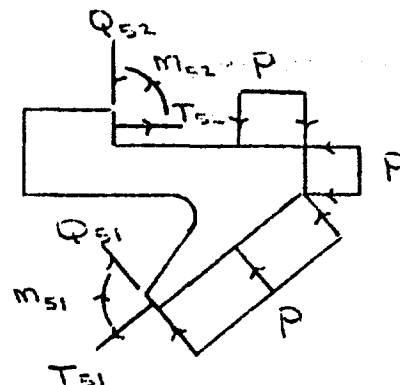
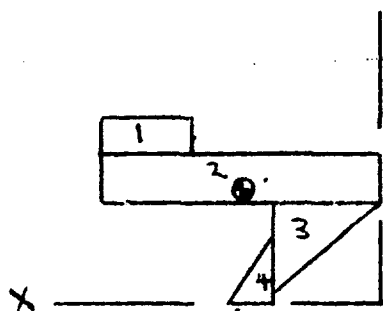


Motor

FIGURE 11 AFT CLOSURE REGION
ANALYSIS RATE BODIES



Ring 1, Body 5



Item	b	h	A	x	y	Ay
1	.48	.20	.0960	1.23	.87	.08544
2	1.48	.24	.3632	.72	.67	.23778
3	.55	.48/2	.1320	.37	.26	.04752
4	.23	.34/2	.0391	.65	.11	.00430
			.6223			.37524

Item	Ax	Ax ²	I _{xy}			
1	.11808	.14524	.00164			
2	.25574	.18413	.02488			
3	.04884	.01807	.00241			
4	.02542	.01652	.00011			
	.44808	.36196	.06506			

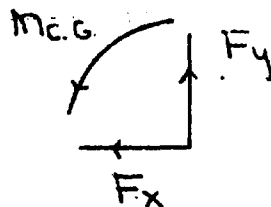
$$\bar{y} = .37524 / .6223 = .603$$

$$\bar{x} = .44808 / .6223 = .720$$

$$I_{y-y} = .36196 + .06506 - .6223(.720)^2 = .10832$$



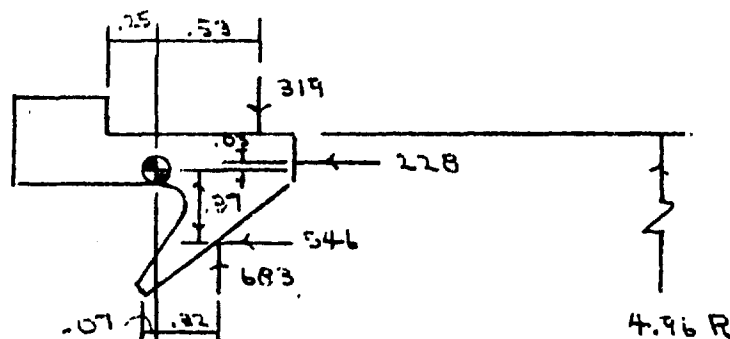
Ring 1, Body 5



$$P = 650 \text{ PSI (Operating)}$$

$$P = 650(1.1) = 715 \text{ PSI (Proof)}$$

$$P = 650(1.4) = 910 \text{ PSI (Burst)}$$



$$P_1 = 910(.250) = 228$$

$$P_2 = 910(.600) = 546$$

$$P_3 = 910(.750) = 683$$

$$P_4 = 910(.350) = 319$$

$$F_x = 546 + 228 = 774$$

$$F_y = 683 - 319 = 364$$

$$M_{C.G.} = 228(.03) + 683(.32) - 319(.53) - 546(.37)$$

$$= 226 - 371 = -145$$

$$\begin{cases} R_{LI} = 4.150 \\ P_{HLLI} = 50 \\ X_{LLI} = .07 \end{cases}$$

$$\begin{cases} R_{LO} = 0 \\ P_{HILO} = 0 \\ X_{LO} = 0 \end{cases}$$

$$\begin{cases} R_{TC} = 4.96 - .18 = 4.78 \\ A = .6223 \\ I_{yy} = .10832 \\ E = 3 \times 10^7 \end{cases}$$

$$\begin{cases} R_{RI} = 0 \\ P_{HRI} = 0 \\ X_{RI} = 0 \end{cases}$$

$$\begin{cases} R_{RO} = 5.060 \\ P_{HIR} = 90 \\ X_{RO} = -.25 \end{cases}$$



Shell 1

$$\beta = \frac{1.285}{\sqrt{R_2 t}} = \frac{1.285}{\sqrt{2.92(.040)}} = \frac{1.285}{\sqrt{.1168}} = \frac{1.285}{.342}$$

$$\beta = 3.76$$

$$\beta t = 5.00 \quad t = \frac{5.00}{3.76} = 1.33 \text{ in}$$

It	S	R ₁	R	φ	sin φ	R ₂	t
1	0	∞	2.920	90	1.00	2.9200	.040
2	2.00	∞	2.920	90	1.00	2.9200	.040
3	2.44	∞	2.9400	90	1.00	2.9400	.085
4	2.46	-.25	2.9420	82.5	.9914	2.9675	.090
5	2.48	-.25	2.9460	75.5	.9799	3.0054	.090
6	2.50	-.25	2.9540	73.0	.9585	3.0801	.090
7	2.52	-.25	2.9600	68.5	.9304	3.1814	.075
8	2.54	-.25	2.9660	63	.8949	3.3143	.100
9	2.56	-.25	2.9800	58	.8526	3.475	.100
10	2.58	∞	2.9800	50	.7660	3.9135	.100
11	4.37	∞	4.1500	50	.7660	5.4178	.100



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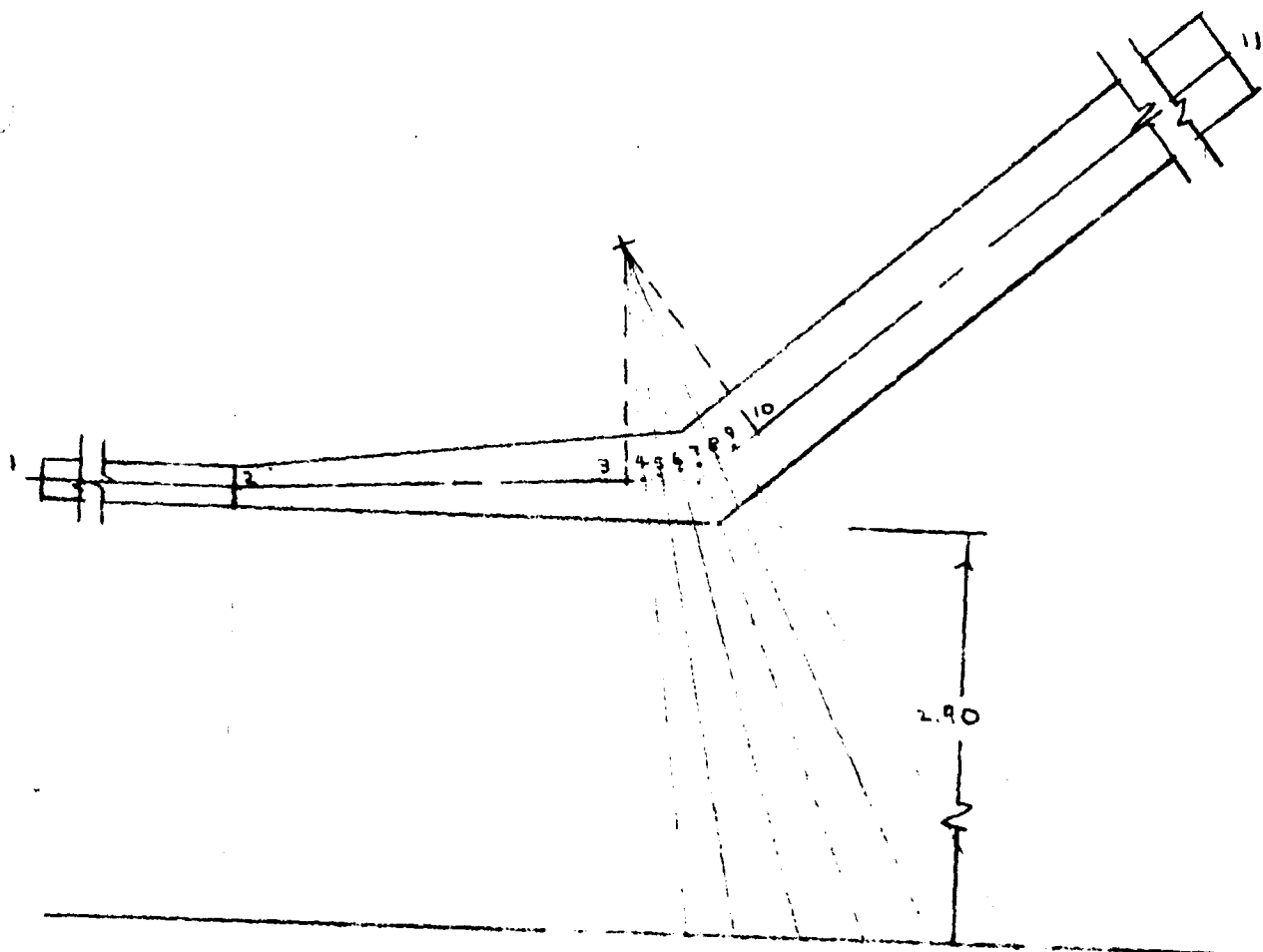
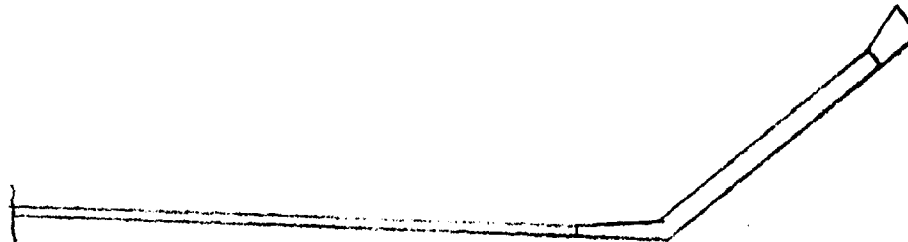
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U
A

PREPARED BY RDBush
REVIEWED BY

10-1-66
DATE
DATE

Shell 1





Shell 2



S	R ₁	t	t/2	R ₂	φ
0	∞	.2150	.10750	5.10750	90
.375	∞	.2150	.10750	5.10750	90
1.000	∞	.1025	.05125	5.05125	90

Shell 3



S	R ₁	t	t/2	R ₂	φ
0	∞	.1025	.05125	5.05125	90
.625	∞	.0350	.01750	5.01750	90
2.000	∞	.0350	.01750	5.01750	90

Shell 4



S	R ₁	t	t/2	R ₂	φ
0	∞	.0350	.01750	5.01750	90
2.0	∞	.0350	.01750	5.01750	90

STRUCTURAL ANALYSIS OF MULTIPLE SHELL/RING STRUCTURES

UNITED TECHNOLOGY CENTER

8 OCT 1966

10 IN HYBRID, THRUST CHAMBER, AFT V RING, ZERO SKIRT LOAD 7 OCT 66

SHELL #1 CYLINDER-CONE CLOSURE

SHELL UNIT ANALYSIS

INPUT IS:

SHELL NO. 1, CONFIGURATION NO. 1

TAYLORS SERIES EXPANSIONS OF 5 TERMS ARE USED TO SOLVE THE DIFFERENTIAL EQUATIONS SIMULTANEOUSLY.

THE 4.3700 INCH LONG SHELL SECTION IS DIVIDED INTO 50 SEGMENTS EACH OF WHICH IS 0.0874 INCHES LONG.

MODULUS OF ELASTICITY, E = 2.65000E+07

POISSON S RATIO, MU = 0.3000

MERIDIONALLY VARIING PARAMETER FUNCTIONS:

RADIUS 1 =
S =

1.0000E+10 1.0000E+10 1.0000E+10 -2.5000E-01 -2.5000E-01 -2.5000E-01 -2.5000E-01
0.0000E+00 2.0000E+00 2.4000E+00 2.4600E+00 2.4800E+00 2.5000E+00 2.5200E+00
-2.5000E-01 -2.5000E-01 1.0000E+10 1.0000E+10 1.0000E+10
2.5000E+00 2.5600E+00 2.5800E+00 4.3700E+00

RADIUS 2 =
S =

2.9200E+00 2.9200E+00 2.9400E+00 2.9675E+00 3.0064E+00 3.0809E+00 3.1814E+00
0.0000E+00 2.0000E+00 2.4000E+00 2.4600E+00 2.4800E+00 2.5000E+00 2.5200E+00
3.3143E+00 3.4952E+00 3.9138E+00 5.4178E+00
2.5400E+00 2.5600E+00 2.5800E+00 4.3700E+00

THICKNESS =
S =

4.0000E-02 4.0000E-02 4.5000E-02 9.0000E-02 9.0000E-02 9.0000E-02 9.5000E-02
0.0000E+00 2.0000E+00 2.4000E+00 2.4600E+00 2.4800E+00 2.5000E+00 2.5200E+00
1.0000E-01 1.0000E-01 1.0000E-01 1.0000E-01
2.5400E+00 2.5600E+00 2.5800E+00 4.3700E+00

PHI =
S =

9.0000E+01 9.0000E+01 9.0000E+01 8.2500E+01 7.3500E+01 7.3000E+01 6.8500E+01
0.0000E+00 2.0000E+00 2.4000E+00 2.4600E+00 2.4800E+00 2.5000E+00 2.5200E+00
4.3000E+01 5.4000E+01 5.0000E+01 5.0000E+01
2.5400E+00 2.5600E+00 2.5800E+00 4.3700E+00

SHELL #2 CYLINDER WALL

SHELL UNIT ANALYSIS

SHELL NO. 2, CONFIGURATION NO. 1

INPUT 151

TAYLORS SERIES EXPANSIONS OF δ TERMS ARE USED TO SOLVE THE DIFFERENTIAL EQUATIONS SIMULTANEOUSLY.
THE 1.0000 INCH LONG SHELL SECTION IS DIVIDED INTO 50 SEGMENTS EACH OF WHICH IS 0.0200 INCHES LONG.

MODULUS OF ELASTICITY, $E = 2.650000E+07$

POISSON'S RATIO, $\mu = 0.3000$

MERIDIONALLY VARIING PARAMETER FUNCTIONS:

RADIUS 1 = 1.0000E+10 1.0000E+10
S = 0.0000E+00 1.0000E+00

RADIUS 2 = 5.1075E+00 5.1075E+00 5.0513E+00
S = 0.0000E+00 3.7500E-01 1.0000E+00

THICKNESS = 2.1500E-01 2.1500E-01 1.0250E-01
S = 0.0000E+00 3.7500E-01 1.0000E+00

PHI = 9.0000E+01 9.0000E+01
S = 0.0000E+00 1.0000E+00

SHELL #3 CYLINDER WALL

SHELL UNIT ANALYSIS

SHELL NO. 3, CONFIGURATION NO. 1

INPUT IS:

TAYLORS SERIES EXPANSIONS OF 5 TERMS ARE USED TO SOLVE THE DIFFERENTIAL EQUATIONS SIMULTANEOUSLY.
THE 2.0000 INCH LONG SHELL SECTION IS DIVIDED INTO 50 SEGMENTS EACH OF WHICH IS 0.0400 INCHES LONG.

MODULUS OF ELASTICITY, E = 2.65000E+07

POISSON'S RATIO, MU = 0.3000

MERIDIONALLY VARYING PARAMETER FUNCTIONS:

RADIUS 1 = 1.0000E+10 1.0000E+10
S = 0.0000E+00 2.0000E+00

RADIUS 2 = 5.0513E+00 5.0175E+00 5.0175E+00
S = 0.0000E+00 6.2500E-01 2.0000E+00

THICKNESS = 1.0250E-01 3.5000E-02 3.5000E-02
S = 0.0000E+00 6.2500E-01 2.0000E+00

PHI = 9.0000E+01 9.0000E+01
S = 0.0000E+00 2.0000E+00

SHELL 4

SHELL UNIT ANALYSIS

INPUT IS:

SHELL NO. 4, CONFIGURATION NO. 1

TAYLOR'S SERIES EXPANSIONS OF 5 TERMS ARE USED TO SOLVE THE DIFFERENTIAL EQUATIONS SIMULTANEOUSLY.
THE 2.0000 INCH LONG SHELL SECTION IS DIVIDED INTO 50 SEGMENTS EACH OF WHICH IS 0.0400 INCHES LONG.

MODULUS OF ELASTICITY, $E = 2.650000E+07$

POISSON'S RATIO, $\mu = 0.3000$

MENTIONALLY VARYING PARAMETER FUNCTIONS:

RADIUS 1 = 1.0000E+10 1.0000E+10
S = 0.0000E+00 2.0000E+00

RADIUS 2 = 5.0175E+00 5.0175E+00
S = 0.0000E+00 2.0000E+00

THICKNESS = 3.5000E-02 3.5000E-02
S = 0.0000E+00 2.0000E+00

PHI = 9.0000E+01 9.0000E+01
S = 0.0000E+00 2.0000E+00

WING UNIT ANALYSIS

RING NO. 1, CONFIGURATION NO. 1

INPUT IS:

LI	RADIUS, IN.	PMI, DEG.	X, IN.
	8.150	50.000	0.070
LN	0.000	0.000	0.000
RI	0.000	0.000	0.000
RO	5.108	90.000	-0.250
RCG	4.780	A = 0.422	IVY = 0.108
			E = 2.650E+07

OUTPUT IS:

	QNET	WNET	AXIAL EQUIL
M-LI	0.0000E+00	-8.6420E-01	0.0000E+00
Q-	6.6508E-01	-3.9414E-01	2.6676E+00
N-	-5.5407E-01	-3.7094E-01	3.1791E+00
M-LU	0.0000E+00	0.0000E+00	0.0000E+00
Q-	0.0000E+00	0.0000E+00	0.0000E+00
N-	0.0000E+00	0.0000E+00	0.0000E+00
M-RI	0.0000E+00	0.0000E+00	0.0000E+00
Q-	0.0000E+00	0.0000E+00	0.0000E+00
N-	0.0000E+00	0.0000E+00	0.0000E+00
M-RU	0.0000E+00	1.0485E+00	0.0000E+00
Q-	-1.0485E+00	2.6713E-01	-9.1418E-09
N-	1.9125E-09	-3.4494E-01	-5.1075E+00
FA	0.0000E+00	0.0000E+00	4.7800E+00
FY	1.0000E+00	0.0000E+00	0.0000E+00
WCG	0.0000E+00	1.0000E+00	0.0000E+00

DEL-CG = 1.3455E+00 X Q=17 HETA-CG = 7.9598E-14 X WNET

SHELL/RING MOUNTING CONDITIONS AND FORCES

CASE NO. 1, CONFIGURATION NO. 1

SHELL NO. 1

M-L = 0.0000E+00
 O-L = 0.0000E+00
 N-L = 1.3420E+03
 PRESSURE = 9.1000E+02

SHELL NO. 2

PRESSURE = 0.0000E+00

SHELL NO. 3

PRESSURE = 9.1000E+02

SHELL NO. 4

M-R = 0.0000E+00
 O-R = 0.0000E+00
 PRESSURE = 9.1000E+02

RING NO. 1

FX = 7.7400E+02
 FY = 3.0400E+02
 MCG = -1.0500E+02

SHELL STRESS DISTRIBUTION

SHELL NO. 1, CASE NO. 1, CONFIGURATION NO. 1

OUTPUT IS:

STATION	MEMBRANE STRESSES		NET STRESSES			
	MERIDIONAL	CIRCUMFERENTIAL	MERIDIONAL		CIRCUMFERENTIAL	
			INSIDE	OUTSIDE	INSIDE	OUTSIDE
0.00000	3.3556635E+04	6.6409542E+04	3.3556635E+04	3.3556635E+04	6.6409542E+04	6.6409542E+04
0.87400	3.3556641E+04	6.6445112E+04	3.35566473E+04	3.3556809E+04	6.6445061E+04	6.6445162E+04
1.74800	3.3556646E+04	6.5313336E+04	3.3875414E+04	3.3237678E+04	6.5408967E+04	6.5217706E+04
2.62200	1.45844857E+04	5.8699125E+04	8.2704873E+03	2.0899227E+04	5.4064772E+04	6.1333477E+04
3.49600	2.0019144E+04	4.2112363E+04	9.5877310E+03	3.0450557E+04	3.8418734E+04	4.5805992E+04
4.37000	2.1120667E+04	8.0930466E+03	2.6585277E+04	1.5656058E+04	7.4600086E+03	8.7260846E+03

SHELL STRESS DISTRIBUTION

SHELL NO. 2, CASE NO. 1, CONFIGURATION NO. 1

OUTPUT IS:

STATION	MEMBRANE STRESSES		NET STRESSES	
	MEMBRANAL	CIRCUMFERENTIAL	MEMBRANAL INSIDE OUTSIDE	CIRCUMFERENTIAL INSIDE OUTSIDE
0.00000	1.6038330E+04	1.4780721E+04	6.9056541E+04 -4.4979881E+04	3.2486104E+04 -2.9247423E+03
0.20000	1.6038330E+04	5.1574550E+03	6.0489169E+04 -4.0412509E+04	2.0292907E+04 -9.9775966E+03
0.40000	1.0252926E+04	-1.0480209E+03	5.2706770E+04 -3.2200918E+04	1.1672132E+04 -1.3800174E+04
0.60000	1.2388143E+04	-3.6804210E+03	5.9553244E+04 -3.4816959E+04	1.0465909E+04 -1.7845152E+04
0.80000	1.5582960E+04	-2.0717040E+03	6.4744714E+04 -3.7578785E+04	1.3876817E+04 -1.8020234E+04
1.00000	2.1056000E+04	5.8540363E+03	7.9513514E+04 -3.7401503E+04	2.3391289E+04 -1.1683217E+04

SHELL STRESS DISTRIBUTION

SHELL N/1. 3, CASE NO. 1, CONFIGURATION NO. 1

OUTPUT IS:

STATION	MEMBRANE STRESSES		NET STRESSES			
	MERIDIONAL	CIRCUMFERENTIAL	MERIDIONAL		CIRCUMFERENTIAL	
			INSIDE	OUTSIDE	INSIDE	OUTSIDE
0.00000	2.1056008E+04	5.8536779E+03	7.9513518E+04	-3.7401503E+04	2.3390931E+04	-1.1683575E+04
0.40000	3.8385291E+04	8.6805185E+04	8.4302962E+04	8.4876208E+03	5.4777486E+04	3.8032884E+04
0.80000	8.1668023E+04	1.0948839E+05	3.3749324E+04	8.9578722E+04	1.0111399E+05	1.1786280E+05
1.20000	8.1668024E+04	1.3262823E+05	4.8399765E+04	7.4928287E+04	1.2864495E+05	1.3660351E+05
1.60000	8.1668024E+04	1.3262823E+05	8.1450597E+04	6.1877461E+04	1.3262320E+05	1.3275126E+05
2.00000	8.1668032E+04	1.3072728E+05	8.2760395E+04	6.0567669E+04	1.3105619E+05	1.3039837E+05

SHELL STRESS DISTRIBUTION

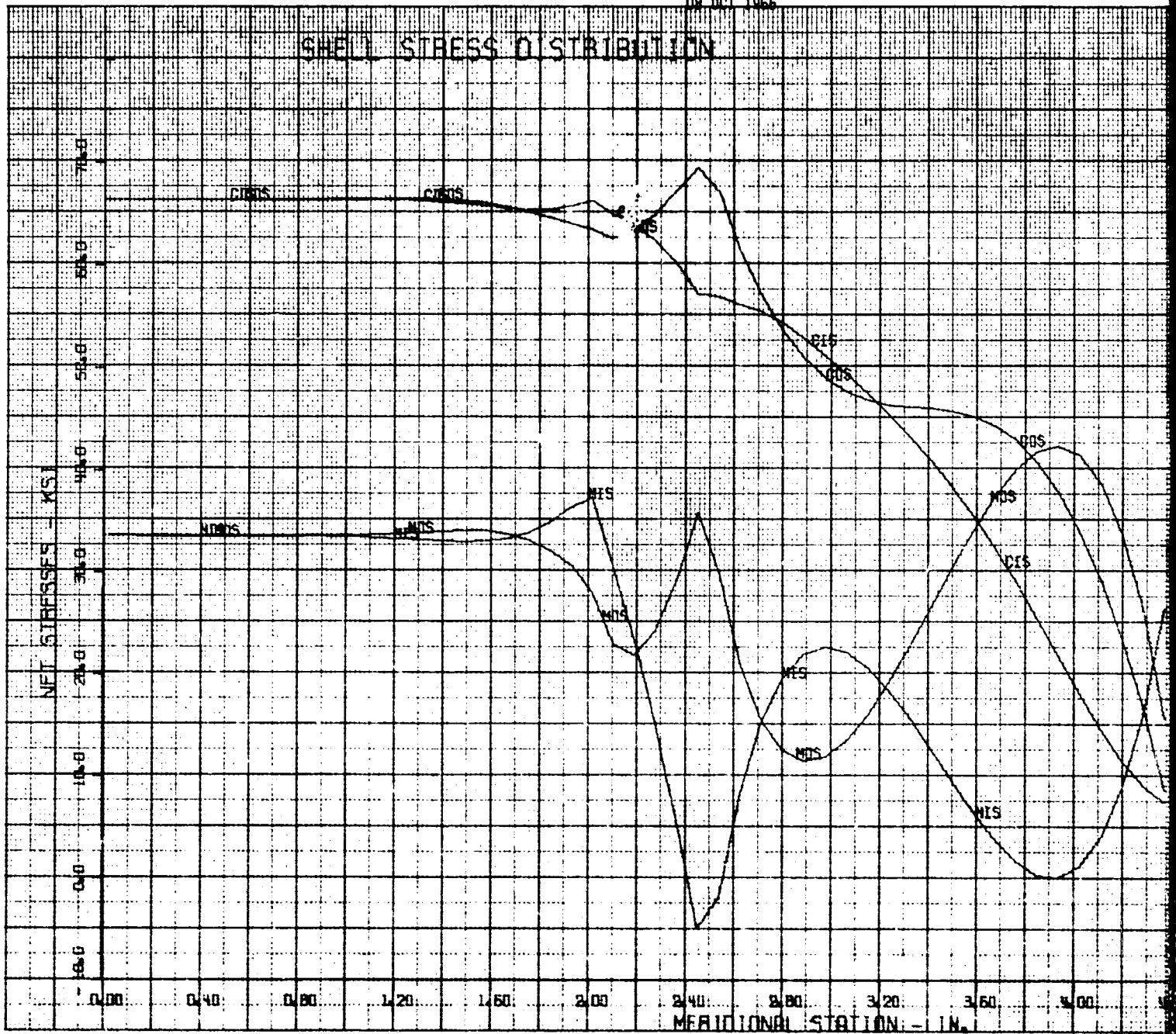
SHELL NO. 4, CASE NO. 1, CONFIGURATION NO. 1

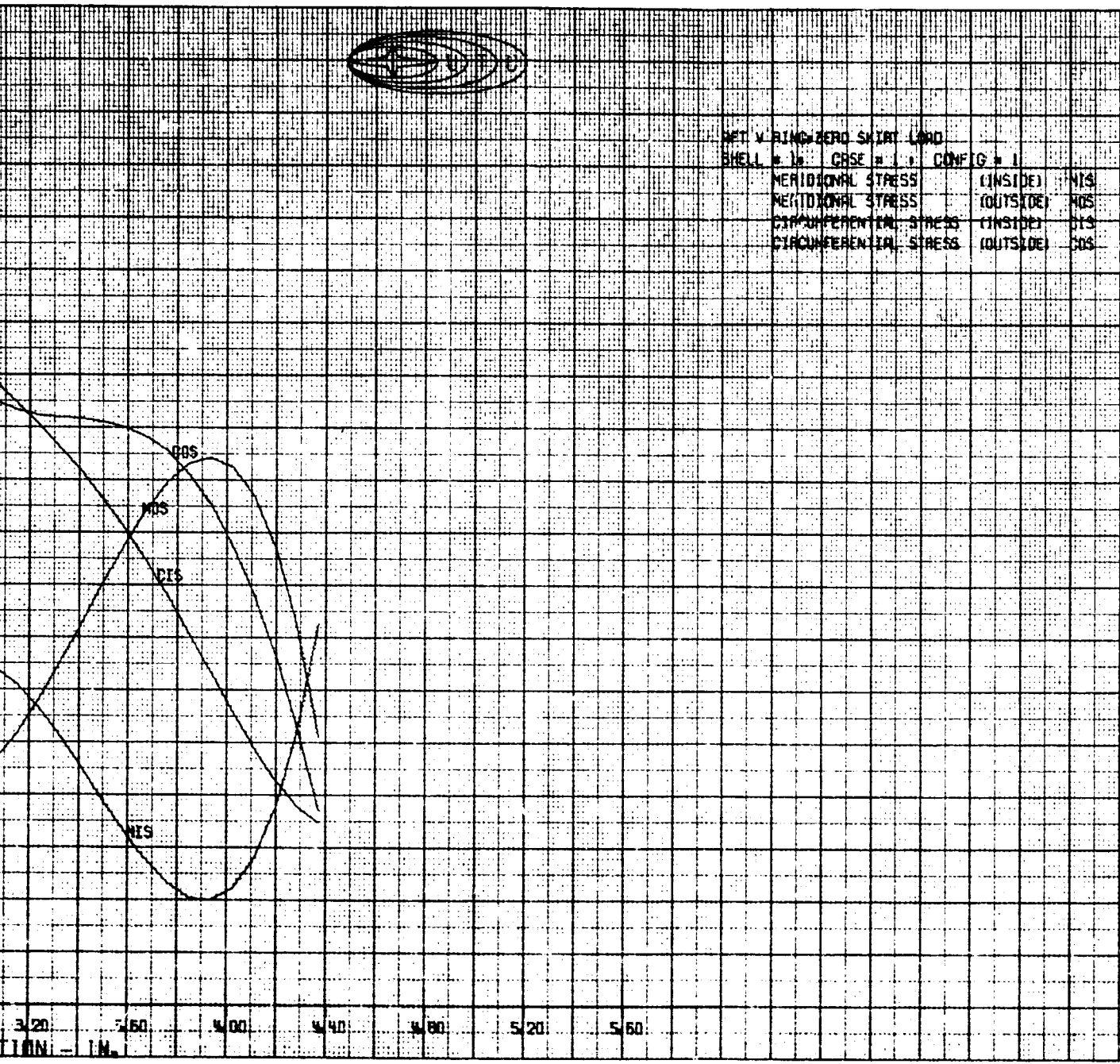
OUTPUT IS:

STATION	MEMBRANE STRESSES		NET STRESSES			
	MERIDIONAL	CIRCUMFERENTIAL	MERIDIONAL		CIRCUMFERENTIAL	
			INSIDE	OUTSIDE	INSIDE	OUTSIDE
0.00000	6.1664032E+04	1.3048968E+05	6.2760395E+04	6.0567670E+04	1.3101859E+05	1.3036078E+05
0.40000	6.1664035E+04	1.3031062E+05	6.1890535E+04	6.1437536E+04	1.3037057E+05	1.3024267E+05
0.80000	6.1664038E+04	1.3040544E+05	6.1614661E+04	6.1713416E+04	1.3039062E+05	1.3042025E+05
1.20000	6.1664042E+04	1.3045692E+05	6.1634762E+04	6.1693321E+04	1.3044814E+05	1.3046570E+05
1.60000	6.1664045E+04	1.3045888E+05	6.1661368E+04	6.1666721E+04	1.3045808E+05	1.3045968E+05
2.00000	6.1664048E+04	1.3045285E+05	6.1664048E+04	6.1664047E+04	1.3045285E+05	1.3045285E+05

08 OCT 1966

SHELL STRESS DISTRIBUTION

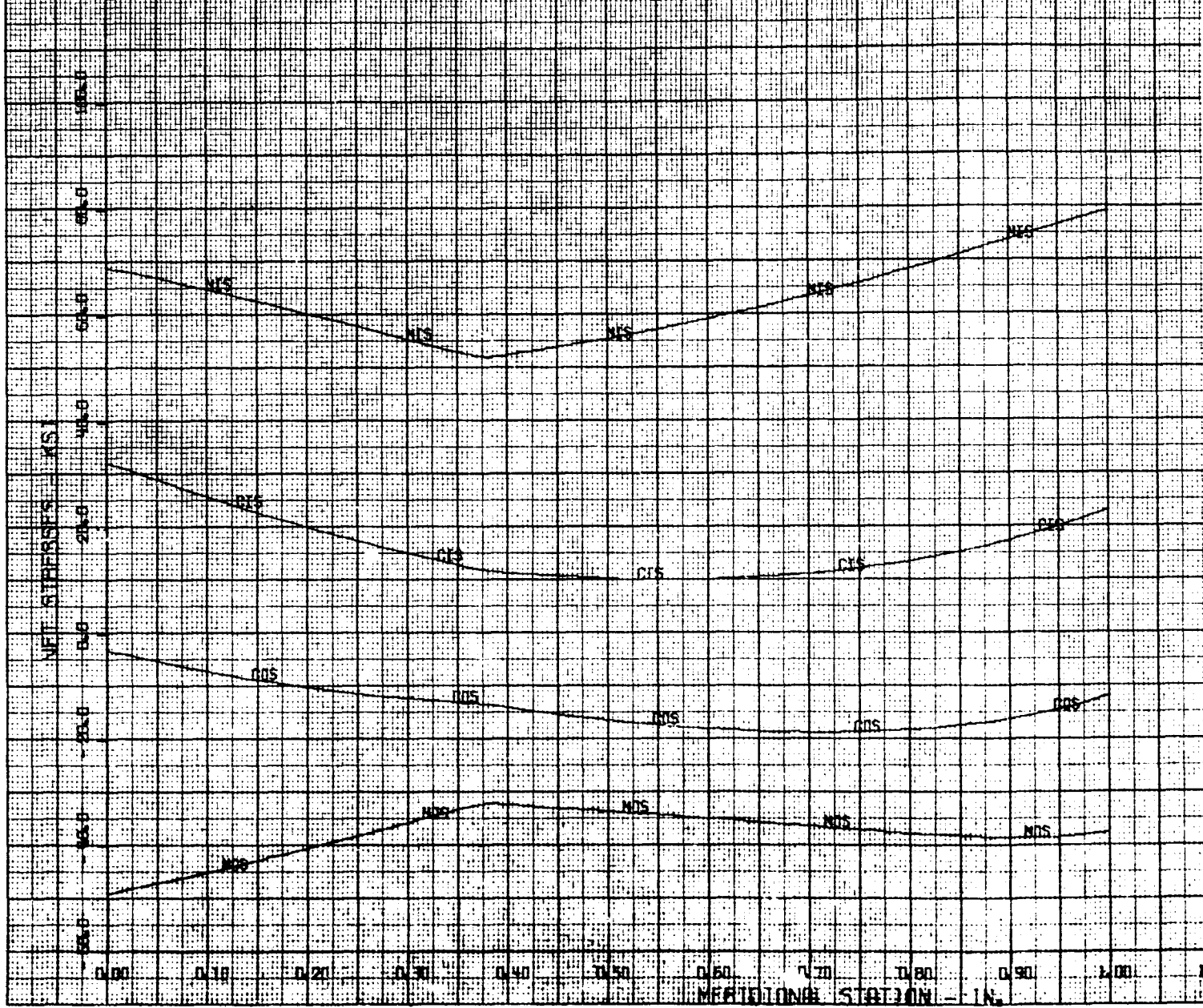


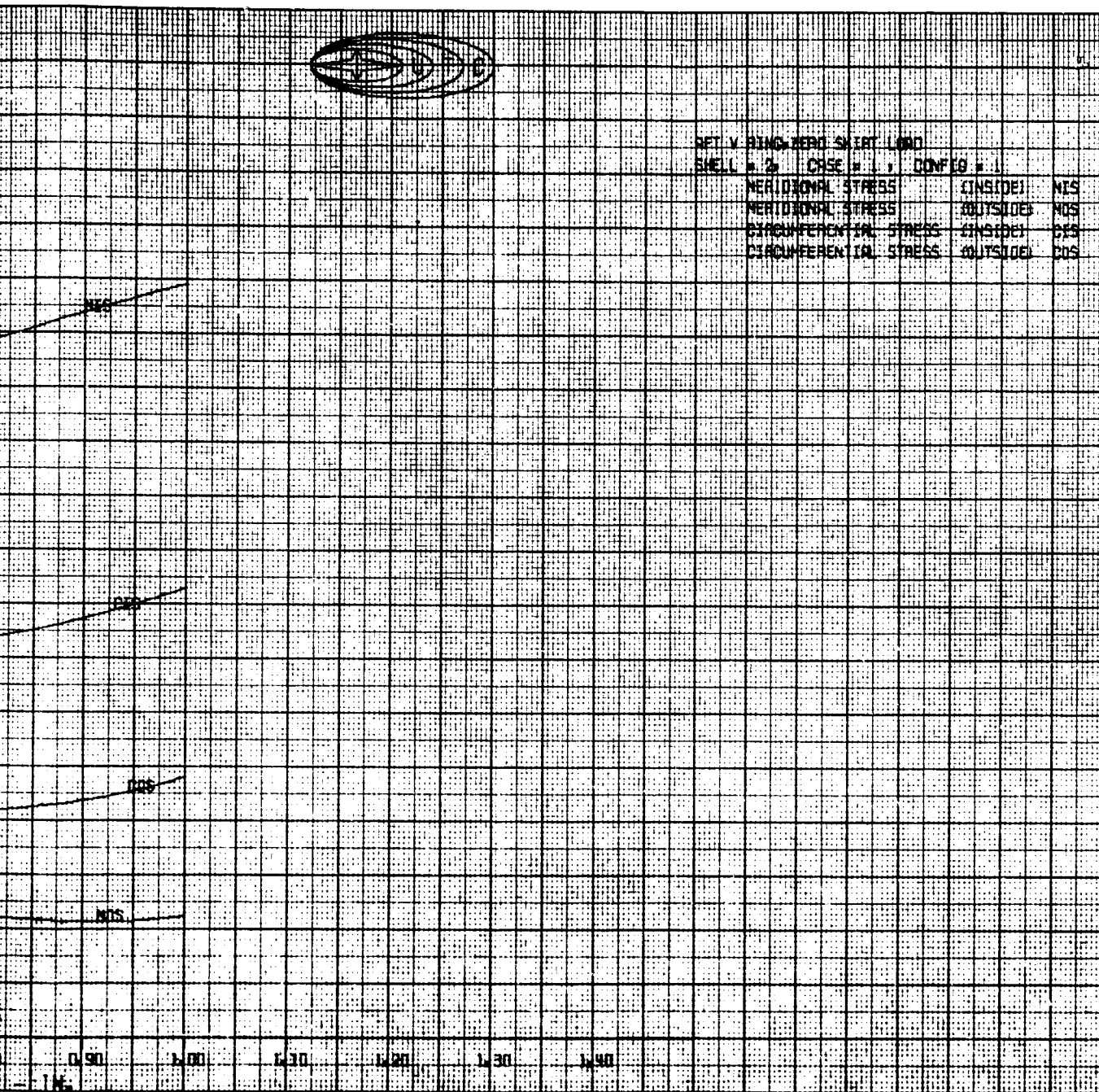


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08 OCT 1966

SHELL STRESS DISTRIBUTION

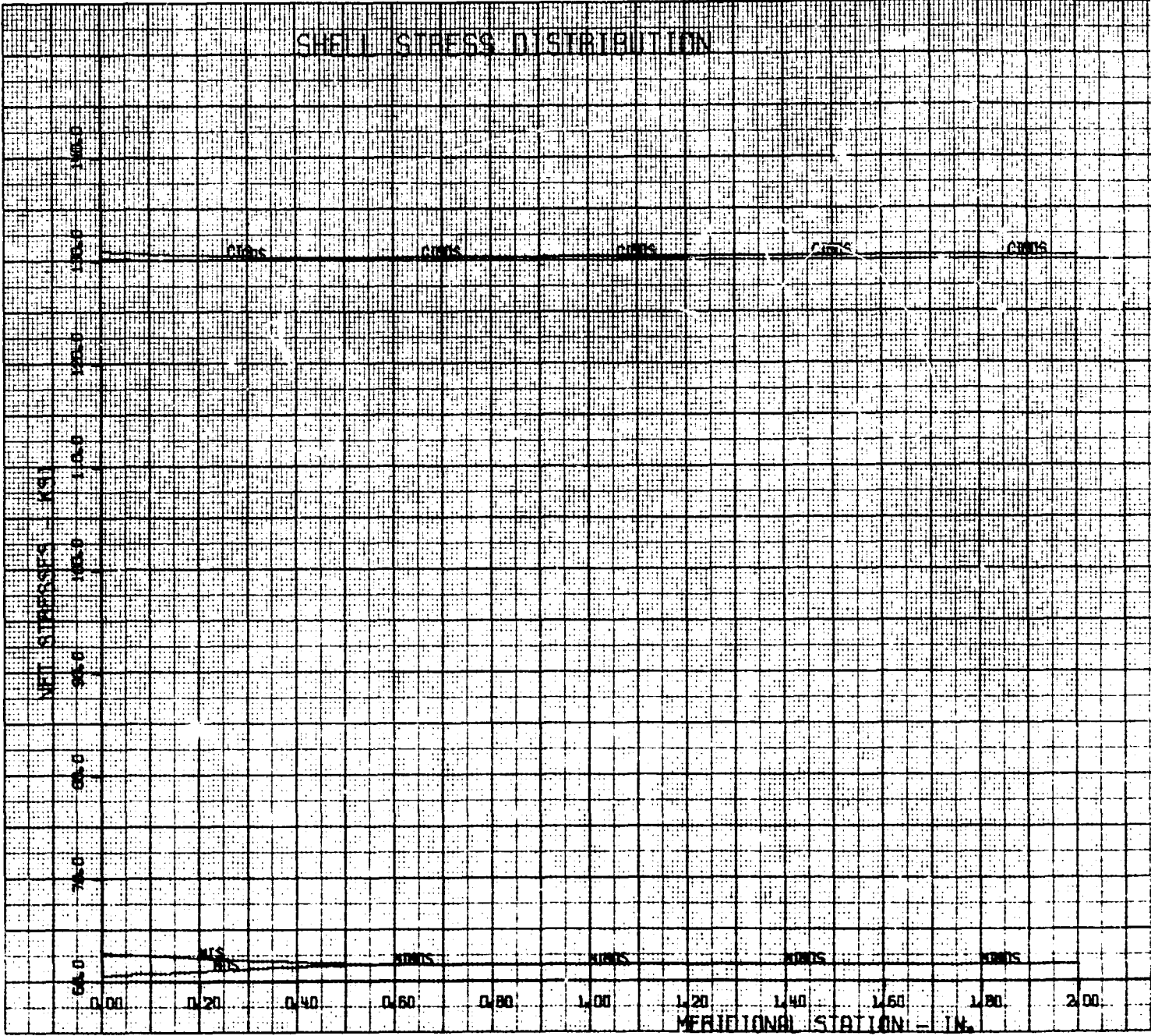




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08 OCT 1956

SHELL STRESS DISTRIBUTION





RET V RING ZERO SKIRT LOAD
SHELL # 4 CASE # 1, CONFIG # 1
MERIDIONAL STRESS (INSIDE) MIS
MERIDIONAL STRESS (OUTSIDE) MOS
CIRCUMFERENTIAL STRESS (INSIDE) DIS
CIRCUMFERENTIAL STRESS (OUTSIDE) DOS

IS CROS

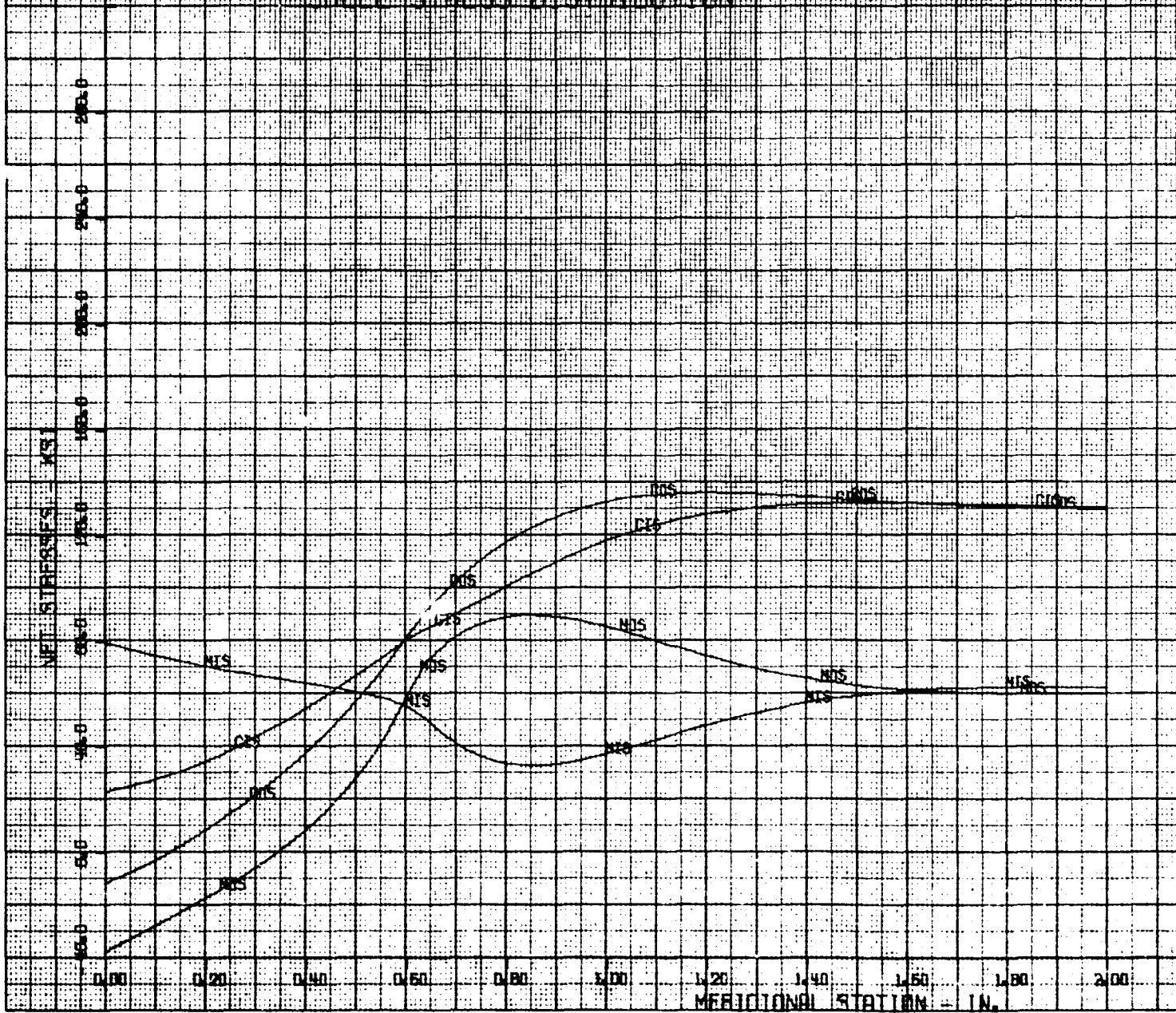
IS CROS

1.60 1.80 2.00 2.20 2.40 2.60 2.80
POSITION IN

2

08 OCT 1966

SHELL STRESS DISTRIBUTION





REF V BING ZERO SWART LOAD

SHELL = 5, CASE = 1, CONFIG = 1

MERIDIONAL STRESS	(INSIDE)	MIS
MERIDIONAL STRESS	(OUTSIDE)	MOS
CIRCUMFERENTIAL STRESS	(INSIDE)	BIS
CIRCUMFERENTIAL STRESS	(OUTSIDE)	BOS

PHYS

MIS

1.50 1.80 2.00 2.20 2.40 2.60 2.80
1.00 1.20 1.40 1.60 1.80 2.00 2.20 2.40 2.60 2.80

2

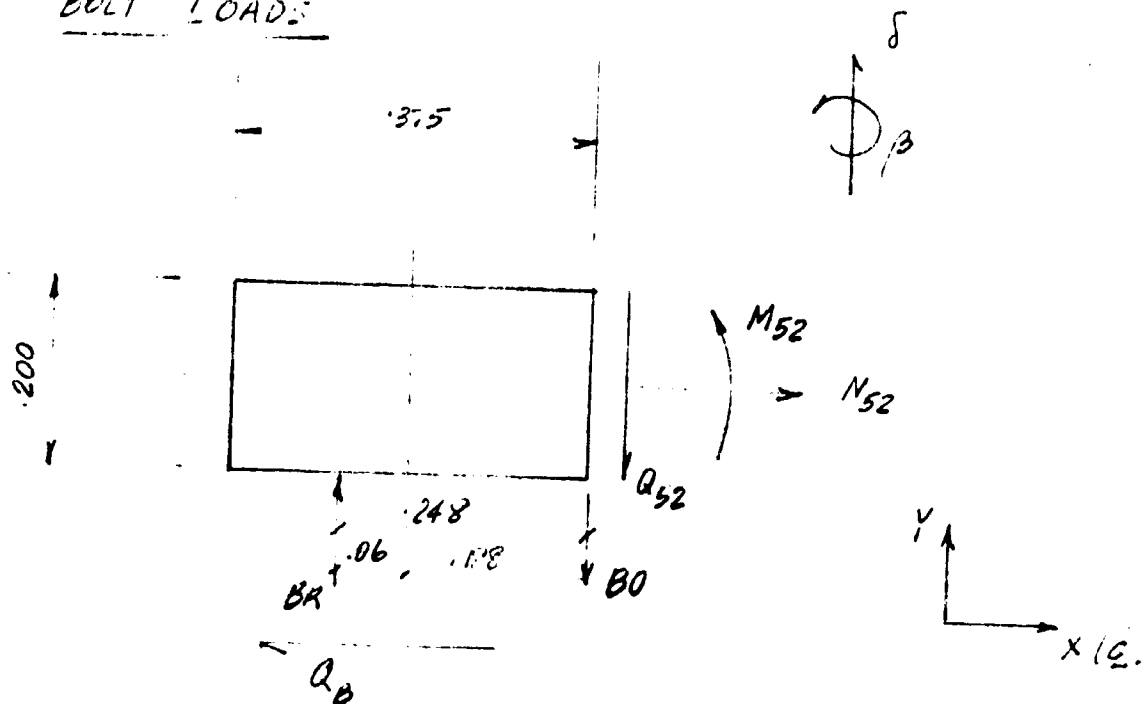
CASE NO. 1, CONFIGURATION NO. 1

SHELL/WING DISCONTINUITY DEFORMATION AND FORCE SOLUTIONS

WING NO. 1	LEFT INSIDE	LEFT OUTSIDE	RIGHT INSIDE	RIGHT OUTSIDE
DELTA	2.751362E-04	0.000000E+00	0.000000E+00	2.268337E-03
BETA	-1.107334E-02	0.000000E+00	0.000000E+00	-1.107334E-02
M	9.107653E+00	0.000000E+00	0.000000E+00	4.546861E+02
U	2.283192E+02	0.000000E+00	0.000000E+00	-2.825901E+02
N	2.112067E+03	0.000000E+00	0.000000E+00	2.158241E+03
DEL-CG	-4.999976E-04		DELTA-CG = -1.107334E-02	
M-NET	-1.391161E+03		O-NET = -3.608758E+02	



BOLT LOADS



B_0 : BOLT LOAD
 B_R : BEARING LOAD
 Q_0 : BOLT SHEAR

FROM LC 11 222

$$\begin{aligned} M_{52} &= 455 \text{ in lbs./in} \\ Q_{52} &= -289 \text{ lbs./in} \\ N_{52} &= 2160 \text{ lbs./in} \\ \delta_R &= 2.27 \times 10^{-3} \text{ in} \\ \beta &= -1.11 \times 10^{-2} \text{ rads} \end{aligned}$$



$$\sum \overset{+}{X} = 0$$

$$-Q_B + N_{S2} = 0$$

$$\therefore Q_B = N_{S2} = 2107 \text{ lb. in.}$$

$$+ \uparrow Q_{NET} = BR - B0 - Q_{S2}$$

$$\delta = \frac{Q_{NET} \bar{R}^2}{EA}$$

$$= \frac{(BR - B0 + 223)(5.0)^2}{(30 \times 10^6)(.375 \times .200)} = 2.27 \times 10^{-2}$$

$$\therefore BR - B0 = -79 \quad (1)$$

$$\begin{aligned} \uparrow M_{NET} &= -.06 BR - .188 B0 - M_{S2} - 1.22 \\ &= -.188 Q_{S2} \end{aligned}$$

$$\beta = \frac{M_{NET} \bar{R}^2}{EI}$$

$$= \frac{[-.06 BR - .188 B0 + 455 - (.1)(2107) - (.188)(2107)](5.0)^2}{(30 \times 10^6)(8.79 \times 10^{-4})}$$

$$= -1.11 \times 10^{-2}$$

$$-.06 BR - .188 B0 = -197.51 \quad (2)$$



From (1) and (2)

$$BR = 736.6$$

$$BO = 815.5$$

BOLTS USED : 100° Close Tolerance Head & Shank,
160 ksi, Short Thread.

NAS 1504-3

MS 21047 K2

24 — 1/4 28 UNF 3A

$$P_T = 4520 \text{ lb. (Ultimate)}$$

$$\begin{aligned} V_{All.} \text{ (Single Shear)} &= 0.4 V_{All.} \text{ (Double Shear)} \\ &= 0.4 (9300) \\ &= 3720 \text{ lb.} \end{aligned}$$

$$BO = 815.5 \text{ lb/in.}$$

$$QB = 2160 \text{ lb/in.}$$

Using an interaction formula (MIL-HDBK. 5
Figure 2.1.1.1)

$$\frac{x^3}{a^3} + \frac{y^2}{b^2} = 1$$

x : Shear Load

y : Tension Load

a : MIL-HDBK. 5, Shear Allowance

b : MIL-HDBK. 5, Tension Allowance



LOADS/BOLT

$$\text{BOLT SPACING} = \frac{\pi(10)}{24} = 1.3 \text{ in.}$$

$$\therefore \text{LOADS/BOLT} = \begin{aligned} (2160)(1.3) &= 2805 \text{ lb. shear} \\ (816)(1.3) &= 1060 \text{ lb. tension} \end{aligned}$$

$$\left(\frac{2805}{3720}\right)^3 + \left(\frac{1060}{4520}\right)^2$$

$$= 0.43 + 0.13 = 0.56$$

$$\therefore MS = \frac{1}{0.56} - 1 = \underline{\underline{+ 0.78}}$$

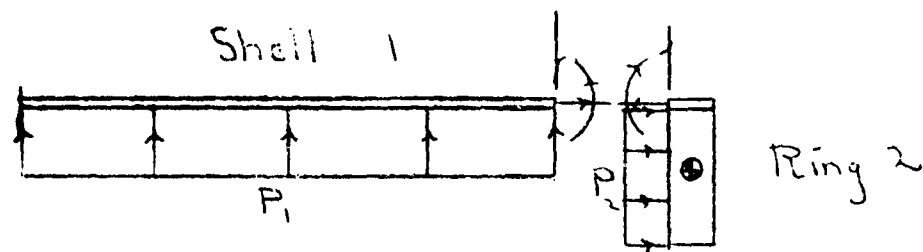
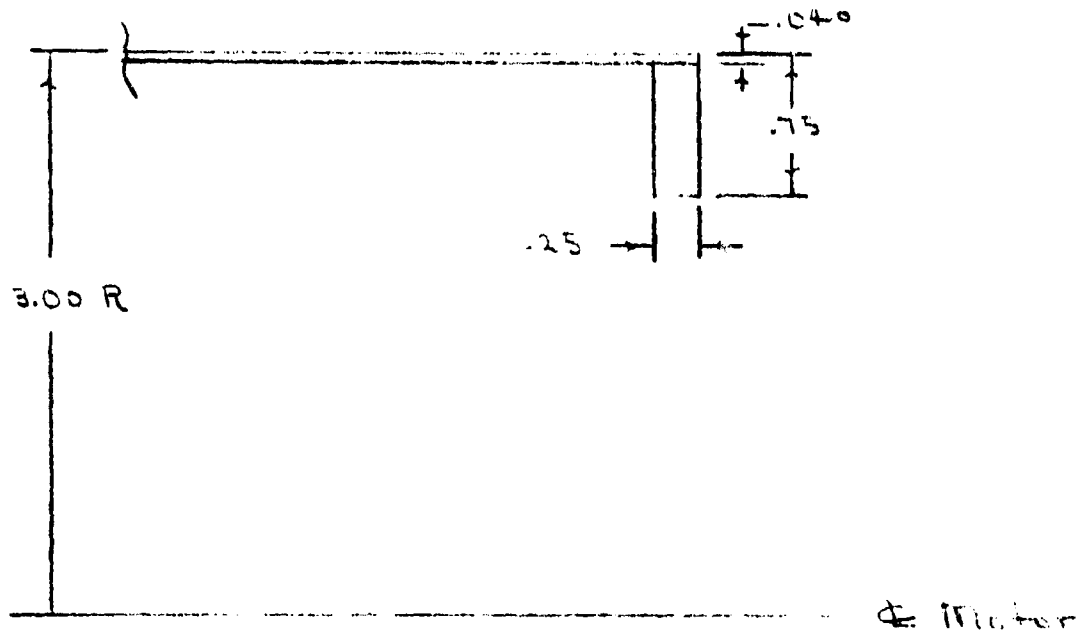


FIGURE 12

EXIT PLANE RING



$$M = 10 NS + 4 NR + 5 NRJ$$

$$M = 10 \overset{10}{(1)} + 4 \overset{4}{(1)} + 5 \overset{5}{(1)} = 19$$

$$NC, NS, 1, 1,$$

$$P_1 \quad 910/2 = 455$$

$$NR \quad 1,$$

$$F_x = -1 p = -.71(910) \left(\frac{27.524}{11.622} \right) = -1530 \text{ LB}$$

$$F_y = 0$$

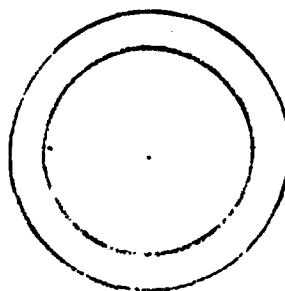
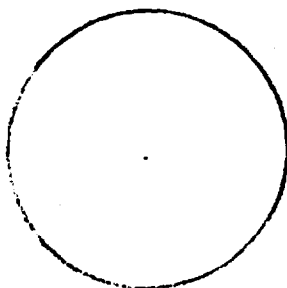
$$M_{CG} = .020(1530) = 30.6 \approx 31$$

S	R ₁	R ₂	φ
0	∞	2.98	90
1.50	∞	2.78	180

$$NJ \quad 1,$$

$$NJ \text{ sets} \quad 1, 2,$$

$$\text{Location} \quad 1, 1,$$



$$A = \frac{\pi}{4} (5.92)^2 = .78520(35.050) = 27.524 \text{ in}^2$$

$$P = pA = 910(27.524) = 25,047 \text{ LB}$$

$$A = \frac{\pi}{4} \left[(5.92)^2 - (4.50)^2 \right] = .78520(14.80) = 11.622$$

$$P_2 = \frac{25,047}{11.622} = 2155 \text{ PSI}$$



EXIT PLANE RING

Ring 1, Body 2

$$\begin{cases} RLI = 2.25 \\ PHLI = 90 \\ XLI = .095 \end{cases}$$

$$\begin{cases} RLO = 2.98 \\ PHLO = 90 \\ XLO = .095 \end{cases}$$

$$\begin{cases} RRI = 0 \\ PHRI = 0 \\ XRI = 0 \end{cases}$$

$$\begin{cases} RRO = 0 \\ PHRO = 0 \\ XRO = 0 \end{cases}$$

$$R_{CG} = 2.625$$

$$A = .75(.19) = .1425 \text{ in}^2$$

$$I_{y-y} = \frac{.75}{12} (.19)^3 = .0004287 \text{ in}^4$$

$$E = 2.65 \times 10^7 \text{ PSI}$$

ATTACHMENT

COMPUTER PROGRAM LI-11-ZZZ

STRUCTURAL ANALYSIS OF
MULTIPLE SHELL/RING STRUCTURES

PAGES NOT FILMED ARE BLANK

STRUCTURAL ANALYSIS OF MULTIPLE SHELL/RING STRUCTURES

UNITED TECHNOLOGY CENTER

6 OCT 1966

10 IN HYBRID, COMBUSTION CHAMBER, EXIT PLANE RING 6 OCT. 66

SHELL #1

SHELL UNIT ANALYSIS

SHELL NO. 1, CONFIGURATION NO. 1

INPUT IS:

TAYLORS SERIES EXPANSIONS OF 5 TERMS ARE USED TO SOLVE THE DIFFERENTIAL EQUATIONS SIMULTANEOUSLY.
THE 1.5000 INCH LONG SHELL SECTION IS DIVIDED INTO 50 SEGMENTS EACH OF WHICH IS 0.0300 INCHES LONG.

MODULUS OF ELASTICITY, E = 2.65000E+07

POISSON'S RATIO, MU = 0.3000

MECHANICALLY VARYING PARAMETER FUNCTIONS:

RADIUS 1 = 1.0000E+10
S = 0.0000E+00 1.5000E+00

RADIUS 2 = 2.9800E+00
S = 0.0000E+00 1.5000E+00

THICKNESS = 4.0000E-02
S = 0.0000E+00 1.5000E+00

PHI = 9.0000E+01
S = 0.0000E+00 1.5000E+00

RING 1-BODY 2

RING UNIT ANALYSIS

RING NO. 1, CONFIGURATION NO. 1

INPUT IS:

LI	RADIUS, IN.	PHI, DEG.	K, IN.
	2.250	90.000	0.095
LU	2.980	90.000	0.095
RI	0.000	0.000	0.000
RU	0.000	0.000	0.000
MCG = 2.650	A = 0.143	IYY = 0.000	E = 2.650E+07

OUTPUT IS:

	QNET	MNET	AXIAL EQUIL
M-LI	0.0000E+00	-6.4906E-01	0.0000E+00
Q-	6.4906E-01	-6.0660E-02	-5.0223E-07
M-	1.8952E-07	-3.3942E-01	2.2500E+00
M-LU	0.0000E+00	-1.1245E+00	0.0000E+00
Q-	1.1245E+00	-1.0683E-01	5.3339E-09
M-	-2.0128E-09	3.7109E-01	2.9800E+00
M-RI	0.0000E+00	0.0000E+00	0.0000E+00
Q-	0.0000E+00	0.0000E+00	0.0000E+00
M-	0.0000E+00	0.0000E+00	0.0000E+00
M-RU	0.0000E+00	0.0000E+00	0.0000E+00
Q-	0.0000E+00	0.0000E+00	0.0000E+00
M-	0.0000E+00	0.0000E+00	0.0000E+00
F2	0.0000E+00	0.0000E+00	2.6500E+00
FY	1.0000E+00	0.0000E+00	0.0000E+00
M-LU	0.0000E+00	1.0000E+00	0.0000E+00

QNET = 1.8594E-04 MNET = 6.1415E-04 AXIAL EQUIL = 0.0000E+00

SHELL/HING BOUNDARY CONDITIONS AND FORCES

CASE NO. 1, CONFIGURATION NO. 1

SHELL NO. 1

M-L = 0.00000E+00
 Q-L = 0.00000E+00
 N-L = 6.78000E+02
 PRESSURE = 4.55000E+02

HING NO. 1

M-LI = 0.00000E+00
 U-LI = 0.00000E+00
 IX = -1.53000E+03

FY = 0.00000E+00

MCG = 3.10000E+01

RING 1, BODY 2

RING UNIT ANALYSIS

RING NO. 1, CONFIGURATION NO. 1

INPUT IS:

LI	RADIUS, IN.	PHI, DEG.	X, IN.
	2.250	90.000	0.095
LU	2.980	90.000	0.095
RI	0.000	0.000	0.000
MU	0.000	0.000	0.000
MC6 =	2.650	A = 0.143	IYY = 0.000
			E = 2.650E+07

OUTPUT IS:

	QALF	MNET	AXIAL EQUIL
M-LI	0.0000E+00	-8.4906E-01	0.0000E+00
Q-	8.4906E-01	-8.0660E-02	-5.0223E-07
M-	1.8952E-07	-3.3962E-01	2.2500E+00
M-LU	0.0000E+00	-1.1245E+00	0.0000E+00
Q-	1.1245E+00	-1.0683E-01	5.3339E-09
M-	-2.0128E-09	3.7109E-01	9800E+00
M-RI	0.0000E+00	0.0000E+00	0.0000E+00
Q-	0.0000E+00	0.0000E+00	0.0000E+00
M-	0.0000E+00	0.0000E+00	0.0000E+00
M-RU	0.0000E+00	0.0000E+00	0.0000E+00
Q-	0.0000E+00	0.0000E+00	0.0000E+00
M-	0.0000E+00	0.0000E+00	0.0000E+00
FA	0.0000E+00	0.0000E+00	2.6500E+00
FY	1.0000E+00	0.0000E+00	0.0000E+00
FLG	0.0000E+00	1.0000E+00	0.0000E+00

QALF = 1.8952E-07 MNET = 0.143 RING NO. 1, CONFIGURATION NO. 1

SHELL/MING BOUNDARY CONDITIONS AND FORCES

CASE NO. 1, CONFIGURATION NO. 1

SHELL NO. 1

M-L = 0.0000E+00
 O-L = 0.0000E+00
 N-L = 6.7800E+02
 PRESSURE = 4.5500E+02

MING NO. 1

M-L = 0.0000E+00
 U-L = 0.0000E+00
 P X = -1.5300E+03

FY = 0.0000E+00 MCG = 3.1000E+01

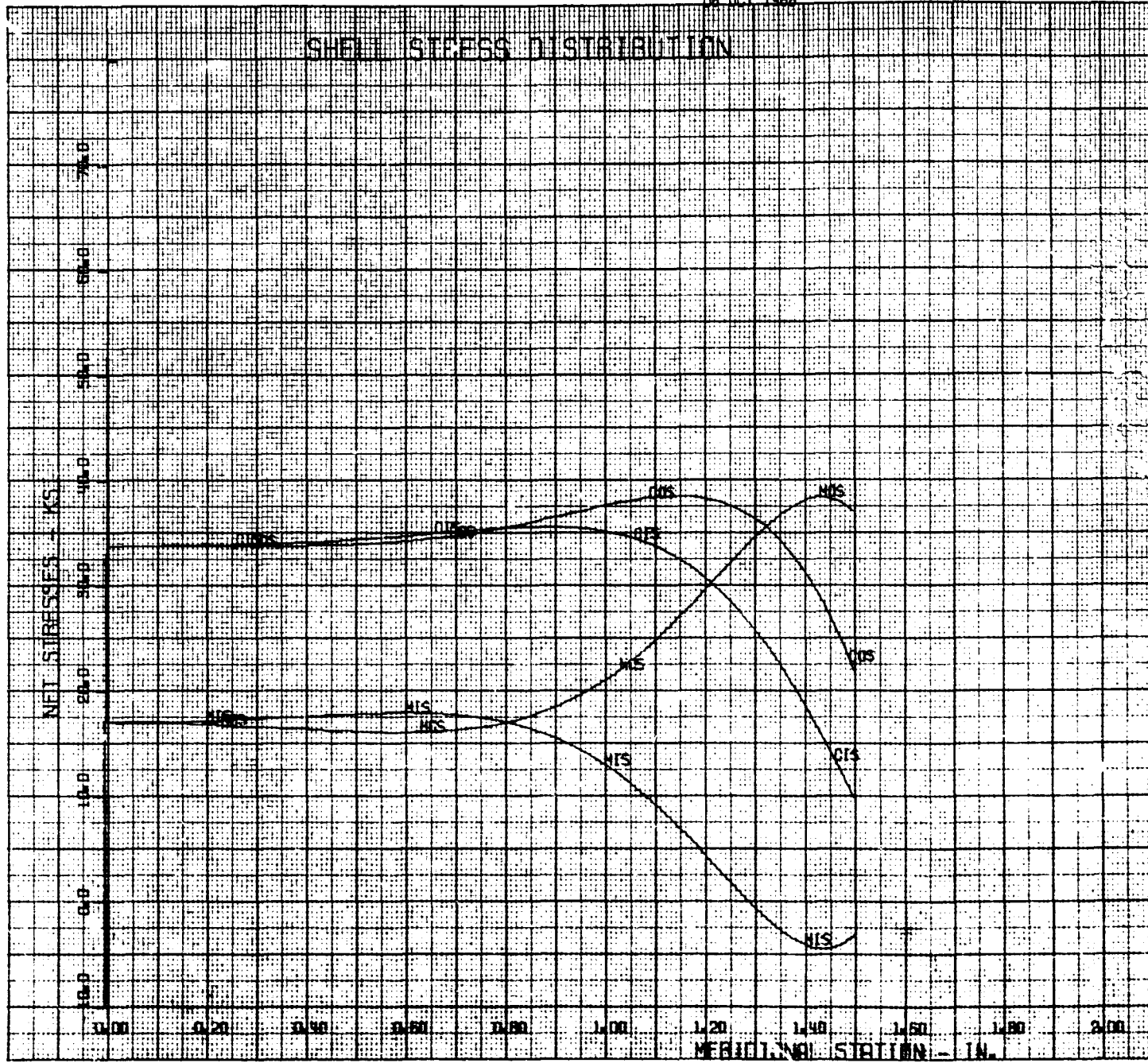
SHELL/RING DISCONTINUITY DEFORMATION AND FORCE SOLUTIONS

SHELL NO. 1	LEFT INSIDE	LEFT OUTSIDE	RIGHT INSIDE	RIGHT OUTSIDE
DELTA	3.219687E-03	1.190480E-03		
BETA	1.987267E-05	-1.224567E-02		
M	0.000000E+00	-5.337419E+00		
Q	0.000000E+00	1.297866E+01		
N	6.780000E+02	6.780002E+02		

RING NO. 1	LEFT INSIDE	LEFT OUTSIDE	RIGHT INSIDE	RIGHT OUTSIDE
DELTA	1.190480E-03	1.190480E-03	0.000000E+00	0.000000E+00
BETA	-1.224567E-02	-1.224567E-02	0.000000E+00	0.000000E+00
M	0.000000E+00	-5.337419E+00	0.000000E+00	0.000000E+00
Q	0.000000E+00	1.297866E+01	0.000000E+00	0.000000E+00
N	9.040264E+02	6.780002E+02	0.000000E+00	0.000000E+00
DEL-CG	2.714164E-05		BETA-CG = -1.224567E-02	
M-WET	-1.981026E+01		Q-WET = 1.459504E+01	

05 OCT 1966

SHELL STRESS DISTRIBUTION





EXIT PLANE RING

SHELL # 1	ORSE # 1	CONF # 1	
VERTICAL STRESS	(INSIDE)	NIS	
VERTICAL STRESS	(OUTSIDE)	NOS	
CIRCUMFERENTIAL STRESS	(INSIDE)	SIS	
CIRCUMFERENTIAL STRESS	(OUTSIDE)	SOS	

STATION - IN. 1.60 1.80 2.00 2.20 2.40 2.60 2.80

2

COMPUTER PROGRAM LI-11-ZZZ

"STRUCTURAL ANALYSIS OF MULTIPLE SHELL/RING STRUCTURES"

Computer program LI-11-ZZZ performs a complete structural analysis of multiple shell/ring structures. The input to the computer program consists of the multiple shell/ring structure geometry description, the shell pressures and ring loads, and the shell/ring boundary or edge conditions. The computer code determines the deformation equations for each shell and ring body, enforces compatibility of deformations and forces at each juncture, and solves the resulting matrix for the redundant deformations and forces at each juncture of the structure. The stress and deflection distributions are then determined for each shell body and output in tabular and graphical form. Additionally, bolt loads are determined for each bolted flange of the structure.

The program will accept multiple cases of shell pressures, ring forces, and boundary conditions for a given configuration.

The following existing UTC computer programs were incorporated as procedures in LI-11-ZZZ.

1. LI-13-ZZZ, Thin Shell Unit Analysis
2. LI-14-ZZZ, Thin Shell Stress Distribution
3. CROSIM procedure to solve NXN linear simultaneous equations.

Additionally, the following procedures were written and programmed for LI-11-ZZZ:

1. Ring Unit Analysis
2. Bolt Loads

The attached pages present the program input, the input for a sample case, and the shell/ring geometry, deformation, and force descriptions.

COMPUTER PROGRAM L111ZZZ
"STRUCTURAL ANALYSIS OF MULTIPLE SHELL/RING STRUCTURES"

— INPUT —

FORMAT: FREE FIELD IN COLUMNS 1 TO 80 EXCEPT TITLE CARDS AND CONTROL CARDS.

1. TITLE CARDS: $1 \leq n \leq 20$ with 9 in Column 73 of last card. Title in Columns 1 to 72.

2. MATRIX SIZE CARD: M,

WHERE:

$$M = 10 NS + 4 NR + 5 NRJ$$

$$= \text{Matrix Size} \leq 108$$

NS = Number of Shells

NR = Number of Rings

NRJ = Total number of ring junctures (all rings combined)

3. NUMBER CASES/SHELLS CARD: NC, NS,

WHERE:

NC = number of cases, $1 \leq NC \leq 10$ (a case is defined as a given set of shell pressures, ring forces, and shell/ring boundary conditions for a fixed configuration)

NS = Number of Shells

4. SHELL PRESSURE CARDS:

$P_1, P_2, P_3, \dots, P_{NS}$

NS shell pressures for each case, starting each case on a new card. Use as many cards for each case as necessary.

5. NUMBER RINGS/RING FORCES CARDS:

Card 1: NR,

Cards 2 to n: FX, FY, MCG, -----,

NR sets of ring forces (FX, FY, MCG) for each case. Repeat cards 2 to n for each case starting each case on a new card. Use as many cards for each case as necessary.

6. SHELL UNIT ANALYSIS

Card 1: title card, Columns 1-78

Card 2: "YES" in Columns 1-3 if influence coefficients are input, else "NO" in Columns 1 and 2.

If "YES" next five cards with influence coefficients in following order:

M-L Q-L M-R Q-R N-R P

DEL-L:

BETA-L:

DEL-R: See L111ZZZ output for typical set

BETA-R:

N-L:

If "NO" input the following shell parameters:

Card 3: Shell length, Poisson's ratio , Young's Modulus,

Card 4: No. of segments, Taylor Series,

Cards 5 to n: Specify the following FGEN'S

Radius 1 vs. S

Radius 2 vs. S

Thickness vs. S

Angle PHI vs. S

The FGEN'S are read in as follows:

Card 1: Header card, i.e., Radius 1 vs. S

Cards 2 to n: No. of pairs, S1, Value 1, S2, Value 2, etc.

This completes the shell unit analysis input, repeat for each shell body for NS sets of input. The input for each shell body must be ordered the same as the shell body numbers.

7. RING UNIT ANALYSIS

Card 1: Title Card, Columns 1-78.

Cards 2 to n: The following cards list the ring geometry.

Use as many cards as needed. Input all values even if zero.

The parameters are: RLI, PHILI, XLI, RLO, PHILO, XLO, RRI, PHIRI, XRI, RRO, PHIRO, XRO, RCG, A, IYY, E

This completes the ring unit analysis input, repeat for each ring body for NR sets of input. The ring bodies must be ordered the same as the ring body numbers and stacked behind the shell unit analysis input.

8. JUNCTURE CARDS

The juncture cards specify the multiple shell/ring junctures, The juncture cards are as follows.

Card 1: Total number of junctures, NJ,

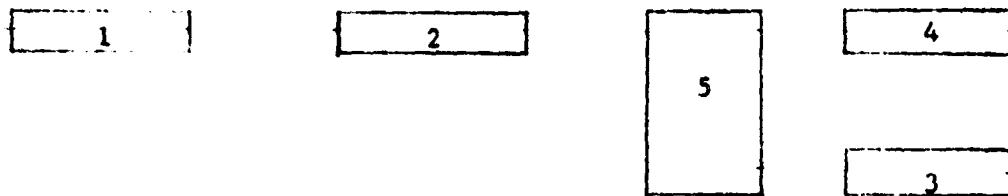
Card 2: NJ sets of 1, j, juncture coordinates.

WHERE: i, j , = Body numbers (either shell or ring) of bodies forming the juncture.

Card 3: Location of juncture for each body of Card 1 using the following code:

Shells: 0=left
 1=right
Rings: 0=left inside
 1=left outside
 2=right inside
 3=right outside

EXAMPLE OF JUNCTURE CARDS



Card 1: 4,

Card 2: 1, 2, 2, 5, 5, 3, 5, 4,

Card 3: 1, 0, 1, 1, 2, 0, 3, 0,

9. BOUNDARY CONDITION CARDS

Each free edge must have a set of two boundary conditions specified. NE sets of boundary conditions must be specified for each shell/ring structure. Where NE = number of free edges. The following sets of boundary conditions are permissible.

1. Delta and Beta
2. M and Q
3. Delta and M
4. Beta and Q

Additionally each shell/ring structure must have (NE-1) Meridional forces (N_L or N_R) specified (this assumes the structure has a single load path). The meridional forces may be specified at the edges or junctures.

The total number of boundary conditions to be specified for each case is then $3NE-1$. The boundary condition cards are as follows.

Card 1: Number of boundary conditions (B.C.) specified.

Card 2: Body number (either shell or ring) for each B.C. in increasing order.

Card 3: Location on body for each B.C. using following code.

Shells: 0 = left

1 = right

Rings: 0 = left inside

1 = left outside

2 = right inside

3 = right outside

Card 4: B.C. Number for each B.C. using following code:

1 = DELTA

2 = BETA

3 = M

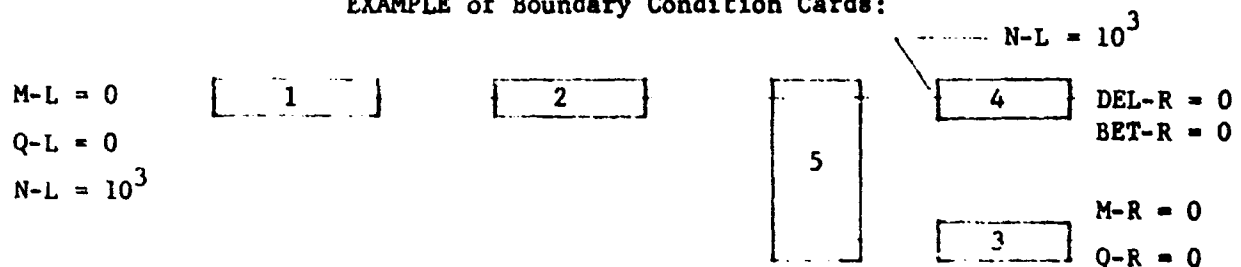
4 = Q

5 = N

Card 5: Value for each B.C., use as many cards as required.

Repeat Cards 1 through 5 for each case.

EXAMPLE of Boundary Condition Cards:



Card 1: 8,

Card 2: 1, 1, 1, 3, 3, 4, 4, 4,

Card 3: 0, 0, 0, 1, 1, 0, 1, 1,

Card 4: 3, 4, 5, 3, 4, 5, 1, 2,

Card 5: 0, 0, @3, 0, 0, @3, 0, 0,

10. SHELL STRESS DISTRIBUTION

Card 1: "YES" in Columns 1 to 3 if stress distributions are to be determined for any of the shell bodies, else "NO" in Columns 1 and 2.

If "YES" input the following

Card 2: NSS, S_1 , S_2 , - - - - , S_n ,

WHERE: NSS = total number of shells for stress distribution.

S_1 , S_2 -- , S_n , = Shell number of each shell for stress distribution. $1 \leq NSS \leq NS$

Cards 3 to n: INPUT FOR FIRST SHELL BODY:

Card 3: Title Card, Columns 1 to 78.

Card 4: Shell length, Poisson's ratio, Young's Modulus,
Print out interval NPR,

NOTE: $NPR \geq 1$

Card 5: Number of segments, Taylor series, plot length.

NOTE: If plots are not desired let plot length = 0.

Cards 6 to n: Specify the following FGEN'S.

Radius 1 vs. S

Radius 2 vs. S

Thickness vs. S

Angle PHI vs. S

The FGEN'S are read in as follows:

Card 1: Header card, i.e., Radius 1 vs. S

Card 2 to n: Number of pairs, S_1 , value 1, S_2 , value 2, etc.

Card n + 1: NCS, C_1 , C_2 , ---, C_n ,

WHERE: NCS = total number of cases for stress distribution,
 $1 \leq NCS \leq NC$

C_1 , C_2 , --, C_n , = Case numbers.

Card n + 2 to n + 2 + NCS: Plot title card for each case if
plot length > 0. Omit if plot length = 0.

() ()

This completes the shell stress distribution input, repeat
cards 3 to n + 2 + NCS for each shell body for NSS sets of
input. The shell bodies must be ordered as indicated on card 2.

If card 1 "NO" go to Bolt Loads.

11. BOLT LOADS

Card 1: "YES" in columns 1 to 3 if bolt loads are to be
determined for any of the ring bodies, else "NO" in columns
1 and 2.

Card 2: NRB, R_1 , R_2 , ---, R_n ,

WHERE: NRB = Total number of rings for bolt load calculations. $1 \leq \text{NRB} \leq \text{NR}$

R_1 , R_2 , --, R_n , = Ring numbers for each ring that requires bolt load calculations.

Cards 3 to n: INPUT FOR FIRST RING BODY:

Card 3: Title card, Columns 1 to 78

Card 3 to n: The following cards list the ring (left flange of the total ring) geometry. Use as many cards as needed. Input all values even if zero. The parameters are:

XLO, XLI, RB, YBO, YBI, XB, RLO, RLI, A, PHILO, PHILI, IYY, E, N, RCG,

WHERE N = total number of bolts

Card n + 1: NCB, C_1 , C_2 , ---, C_n ,

WHERE: NCB = total number of cases for bolt load calculations, $1 \leq \text{NCB} \leq \text{NC}$

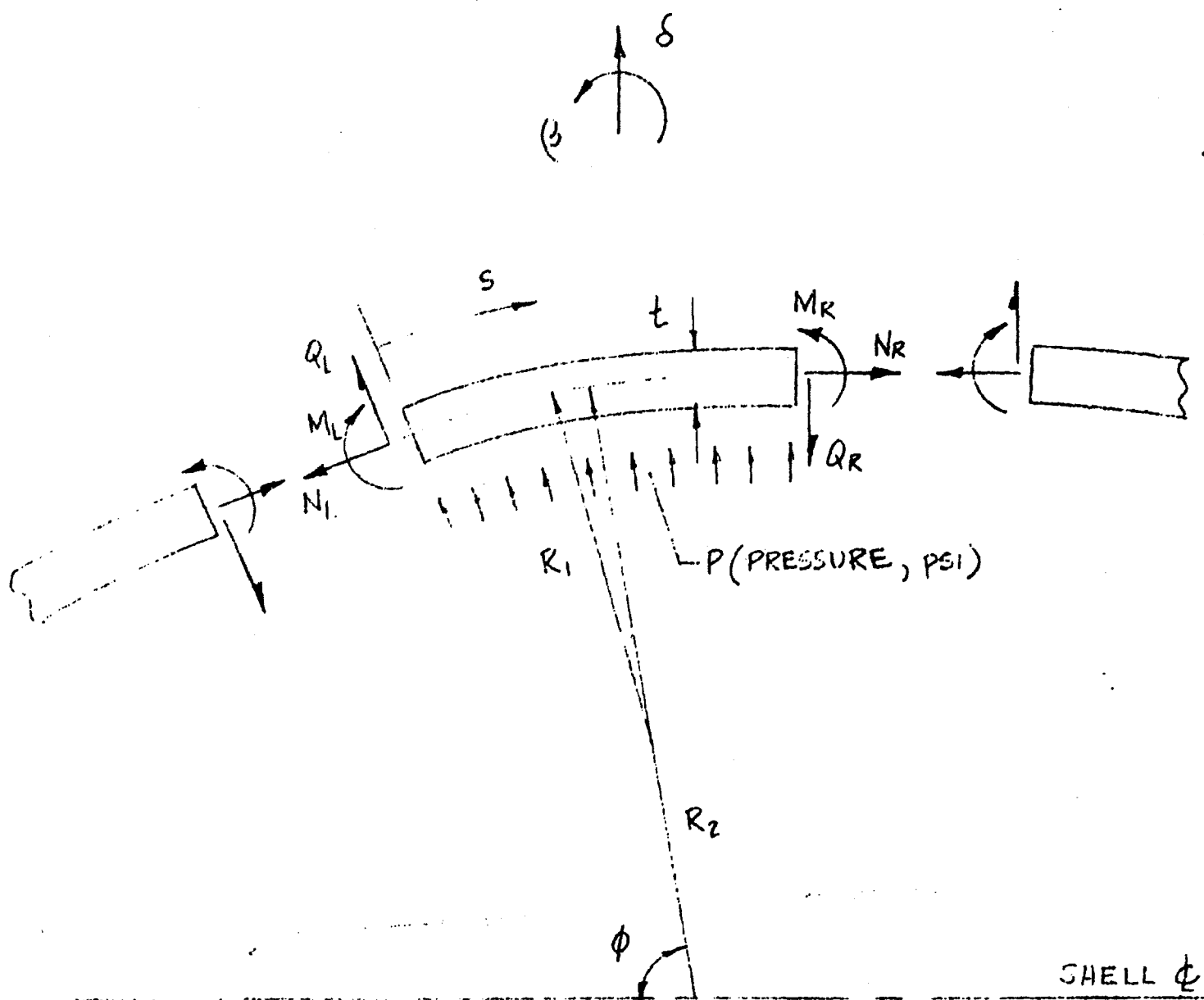
C_1 , C_2 , --, C_n , = Case numbers

Card n + 2: F_X , F_Y , MCG,

NCB sets of ring force Δ (F_X , F_Y , MCG), use as many cards as needed. *Begin each set on a new card*

This completes the bolt load input, repeat Cards 3 to n + 2 for each ring body for NRB sets of input. The ring bodies must be ordered as indicated on card 2.

IF Card 1 "NO", THAT'S ALL.



GEOMETRY AND FORCES FOR TYPICAL SHELL BODY

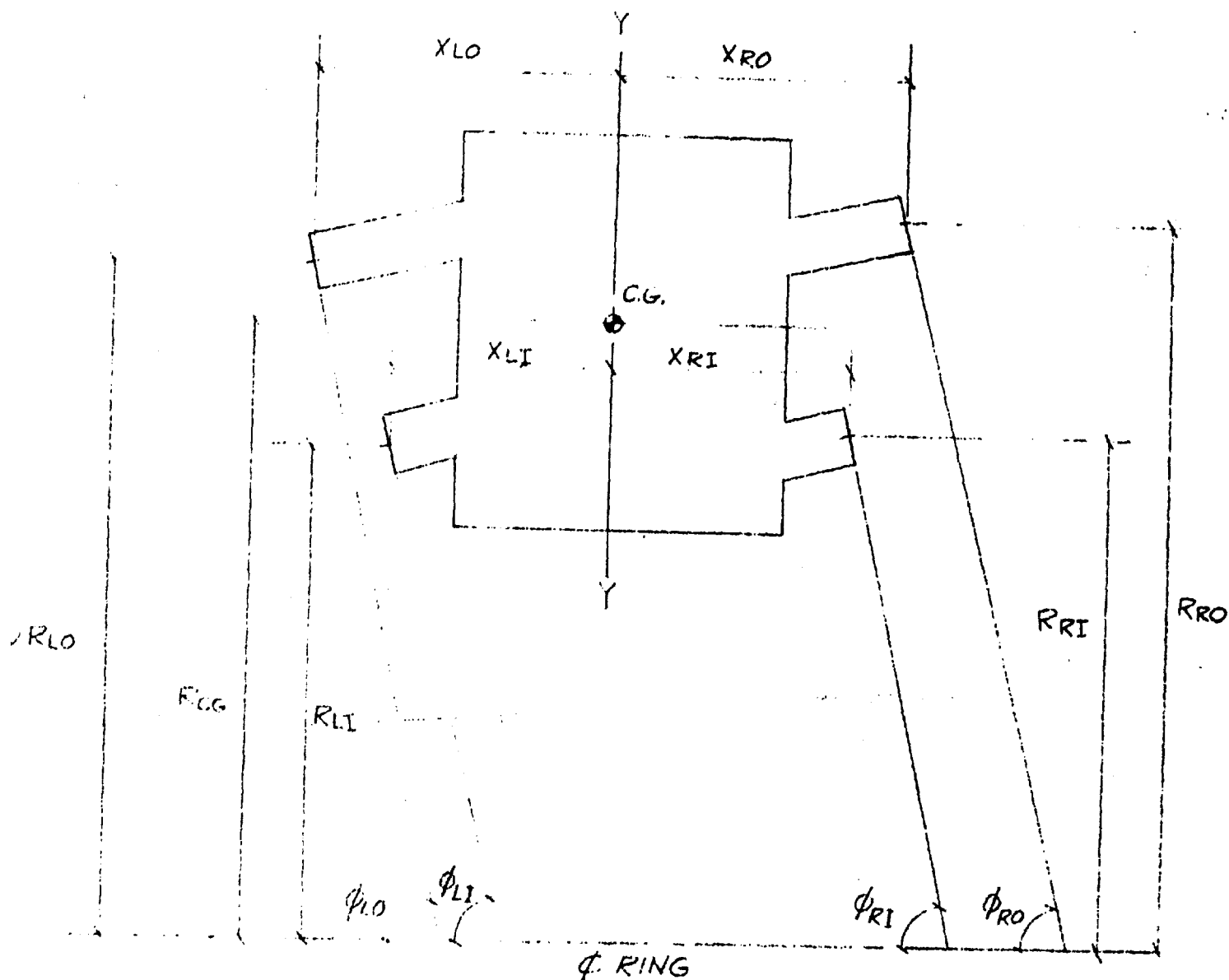
NOTE: ALL DIMENSION IN INCHES,
ANGLES IN DEGREES.

N, Q IN LB/IN.

M IN IN-LB/IN

s IN INCHES

ϕ IN RADIANS



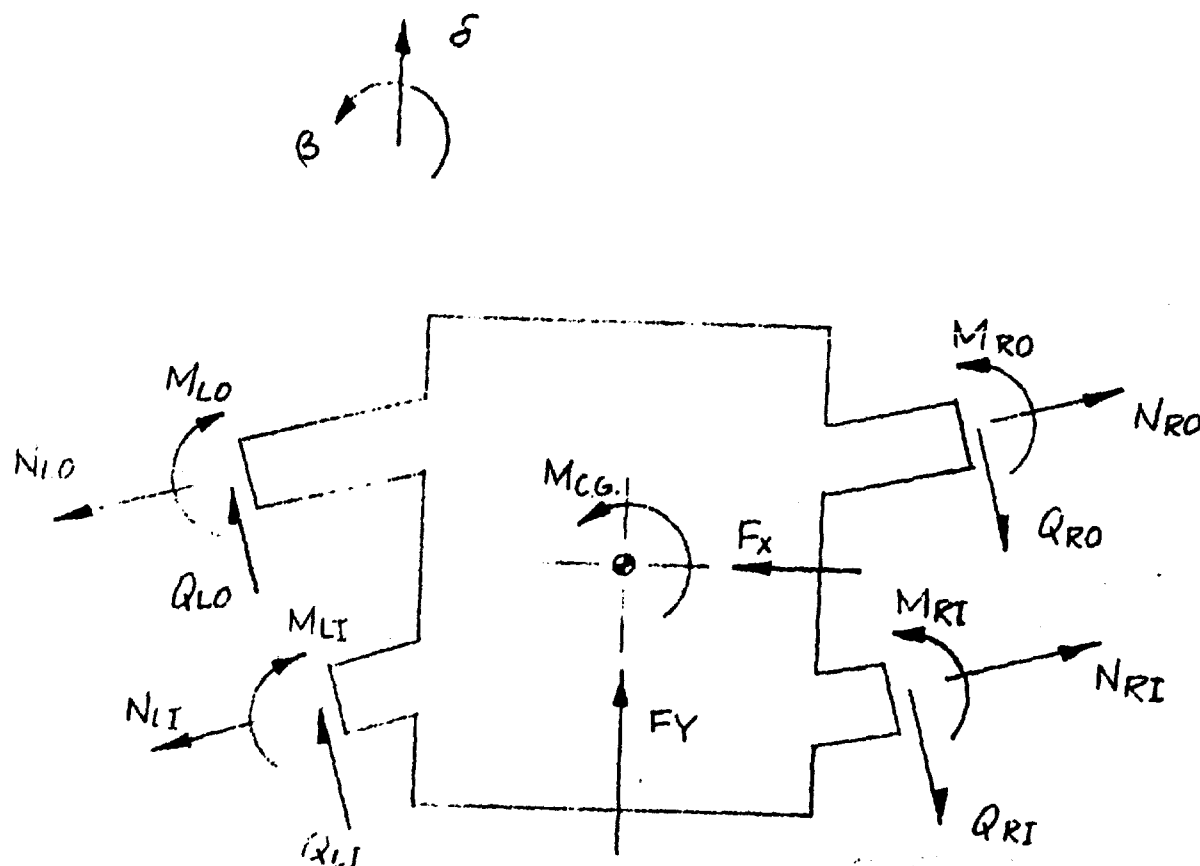
RING GEOMETRY

NOTE: ALL DIMENSIONS IN INCHES,
 ANGLES IN DEGREES

A = RING AREA, IN²

I_{YY} = RING MOMENT OF INERTIA ABOUT Y-Y AXIS, IN⁴

E = RING MODULUS OF ELASTICITY, PSI

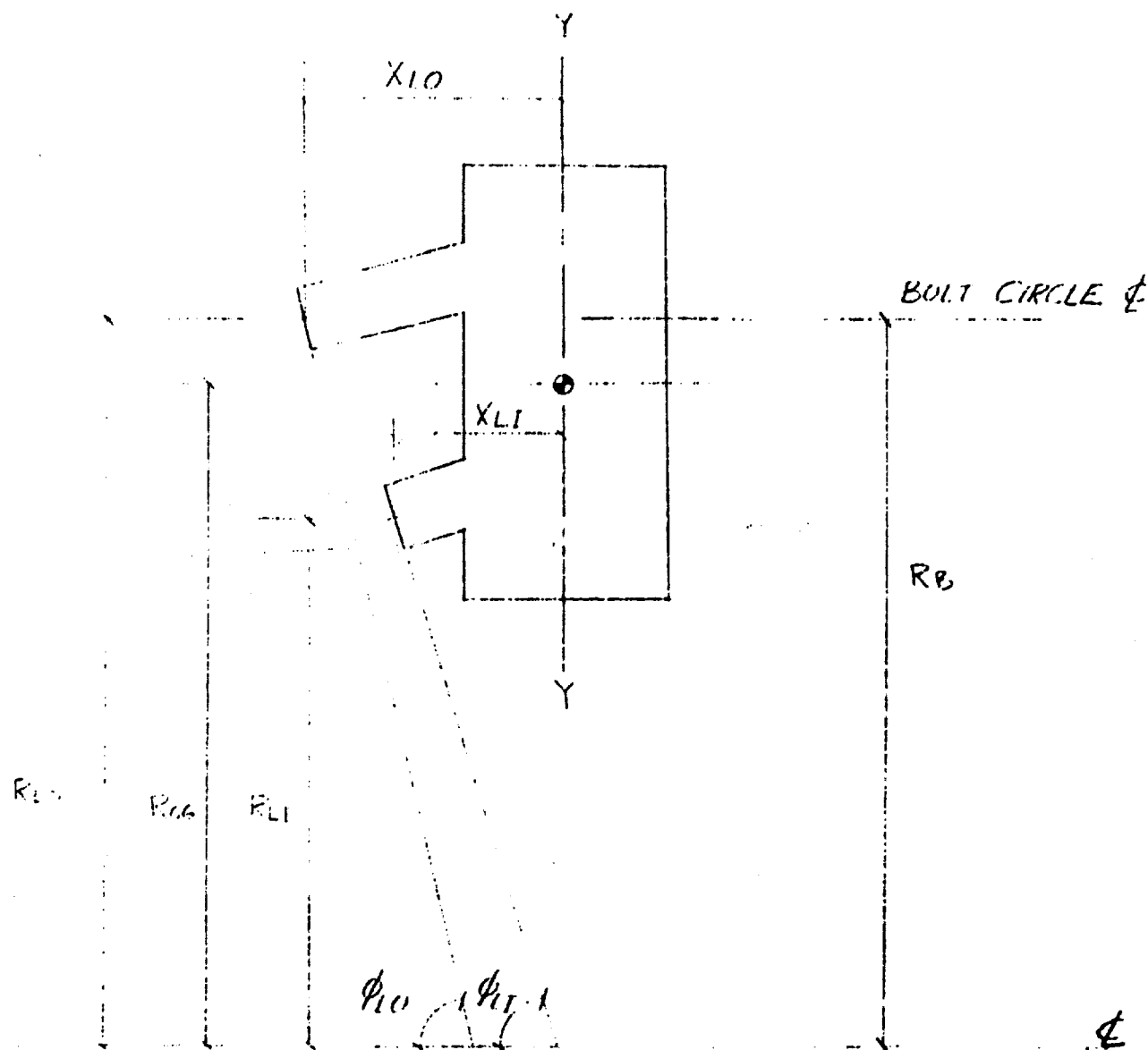


CL RING

RING FORCES

NOTE: N, Q, F_x, F_y IN LB/IN
 M IN IN-LB/IN
 δ IN INCHES
 β IN RADIANS

F_x, F_y & M_{CG} ARE RESULTANT FORCES REFERENCED TO RING C.G. (DUE TO PRESSURE AND EXTERNAL LOADS).



BOLTED FLANGE GEOMETRY

R_{B1} = ALL DIMENSIONS IN INCHES,

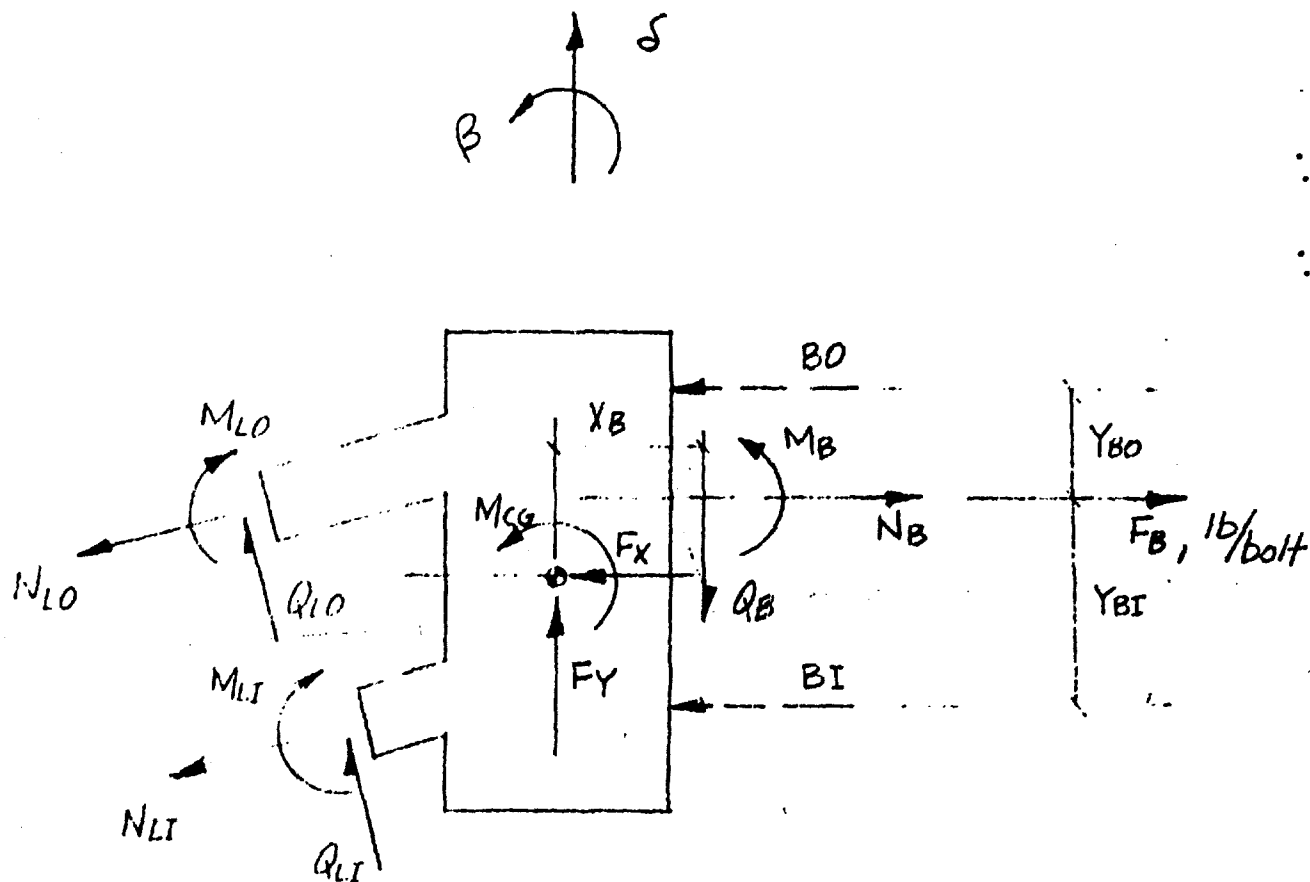
ANGLES IN DEGREES

A = CROSS AREA, IN^2

I_y = CROSS MOMENT OF INERTIA ABOUT Y-AXIS, IN^4

E = RING MODULUS OF ELASTICITY, PSI

N = NUMBER OF BOLTS



ϕ

BOLTED FLANGE FORCES

NOTE: N, Q, B, F_x, F_y IN lb/in

M IN in-lb/in

F_B IN lb/bolt

δ IN INCHES

β IN RADIANS

F_x, F_y & M_{CG} ARE RESULTANT FORCES REFERENCED TO RING C.G. (DUE TO THERMAL AND EXTERNAL LOADS)

UNCLASSIFIED

APPENDIX II
DETAILED TEST RESULTS

UNCLASSIFIED

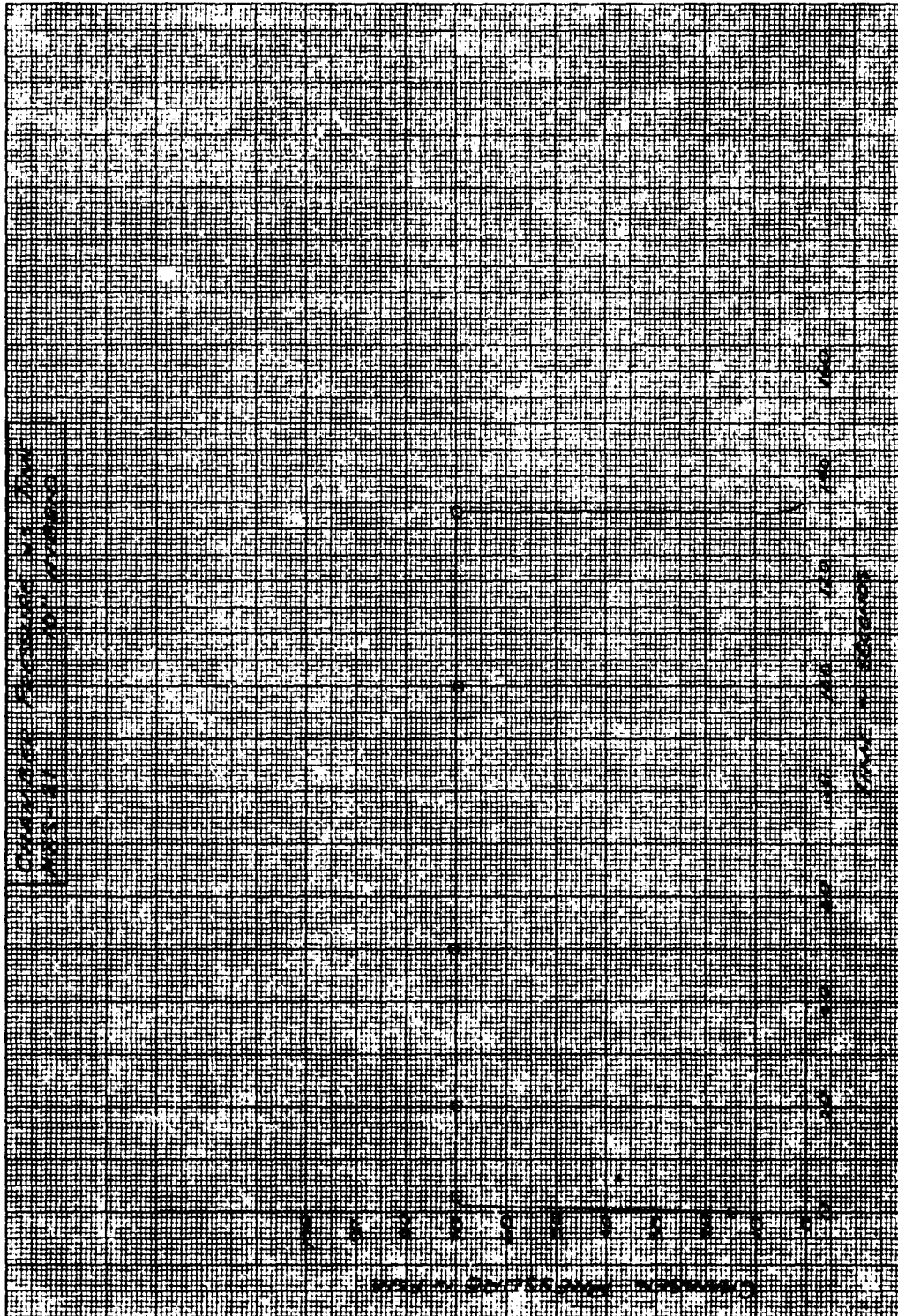
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TABLE II-1
(U) FUEL CONSUMPTION SUMMARY

<u>Test No.</u>	<u>Weight of Fuel Expended, lb</u>
H3S-10	66.97
H3S-13	27.00
H3S-14	56.20
H3S-15	38.50
H3S-16	71.68
H3S-18	24.22
H3S-19	58.30
H3S-20	40.9
H3S-21	40.9
H3S-22	57.3
H3S-24	2.671
H3S-25	62.6
H3S-27	39.6
H3S-31	57.53
H3S-32	93.0
H3S-33	89.0
H3S-34	8.3
H3S-35	64.4
H3S-37	87.0
H3S-38	95.5
H3S-39	1.603

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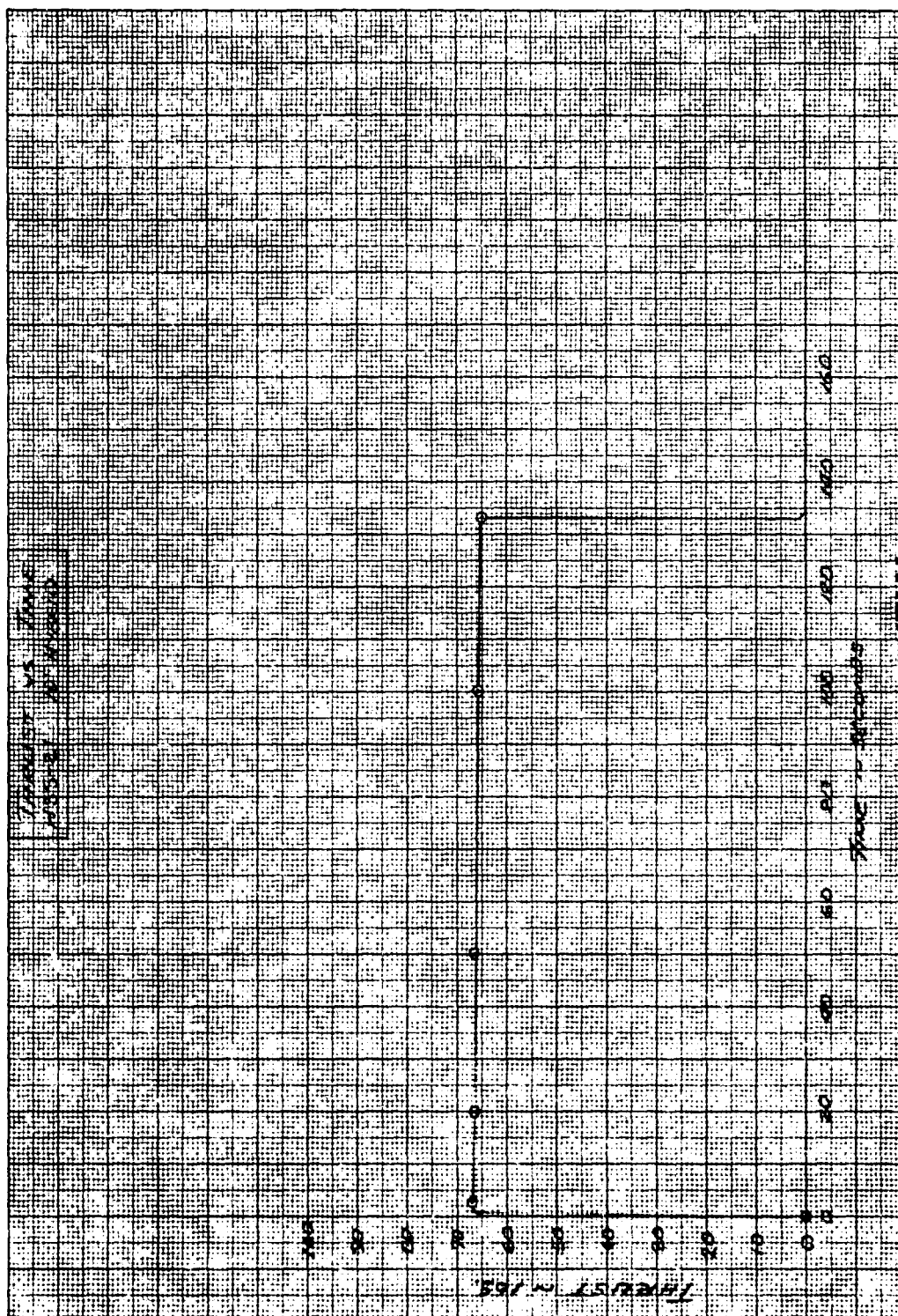
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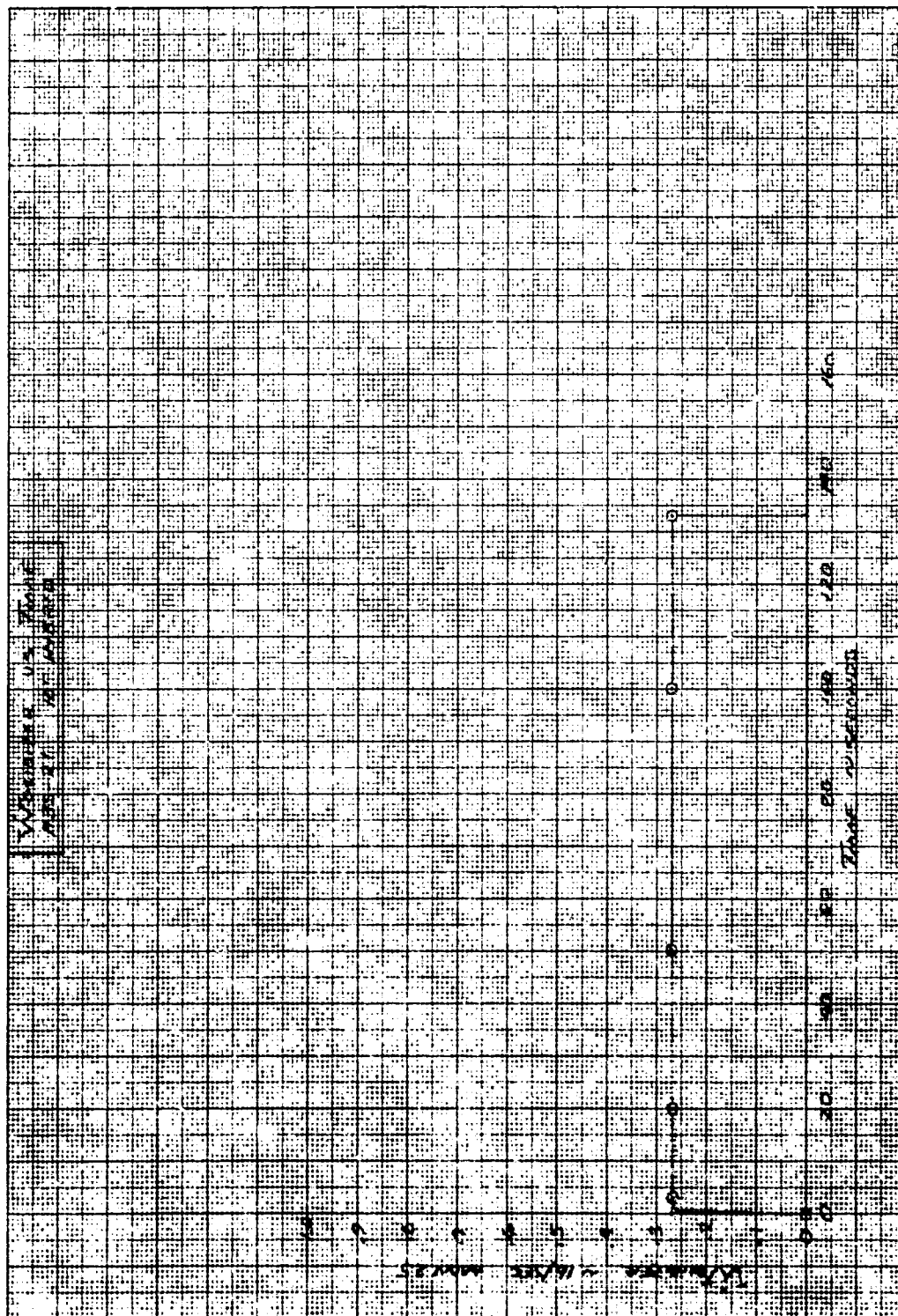
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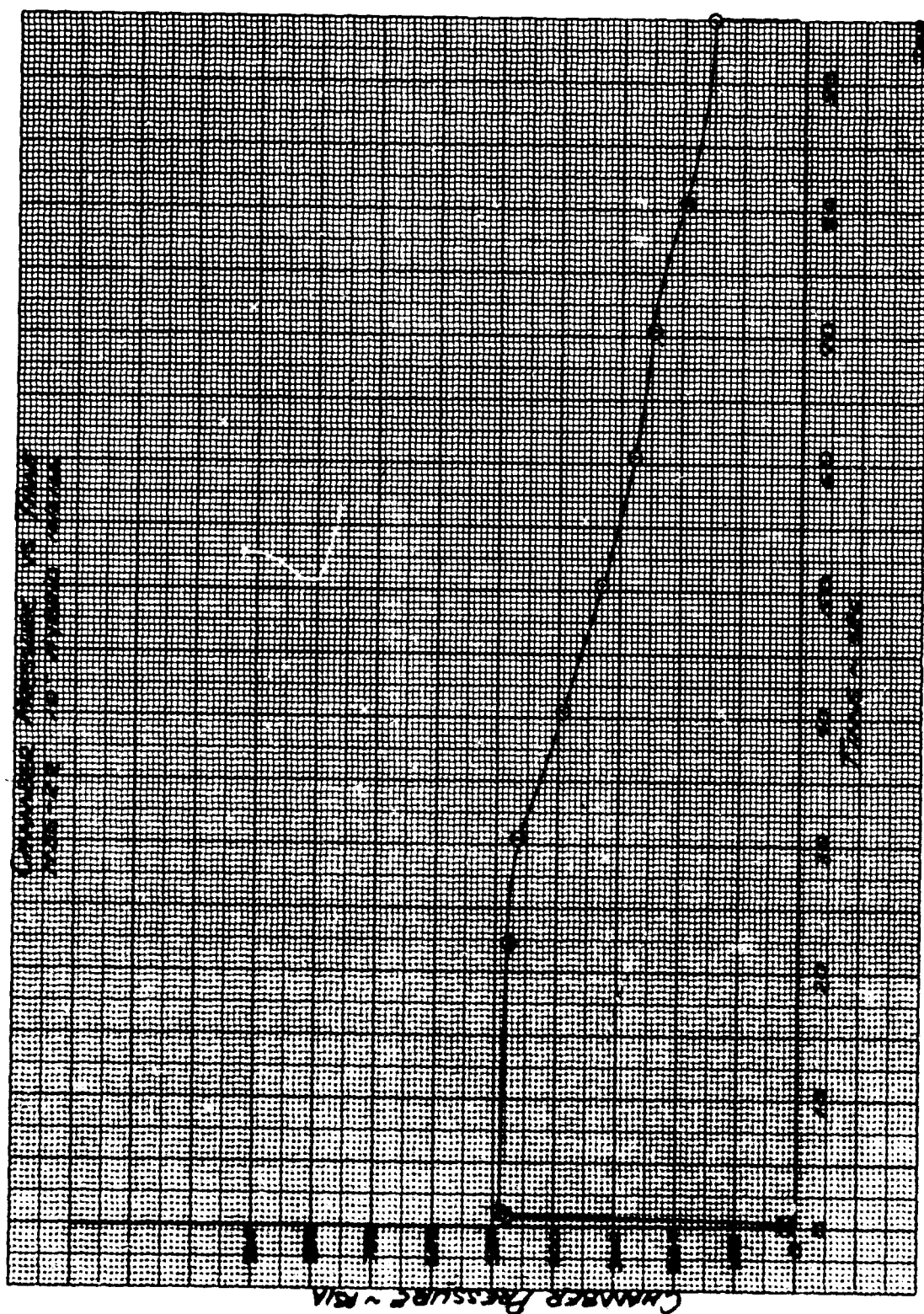
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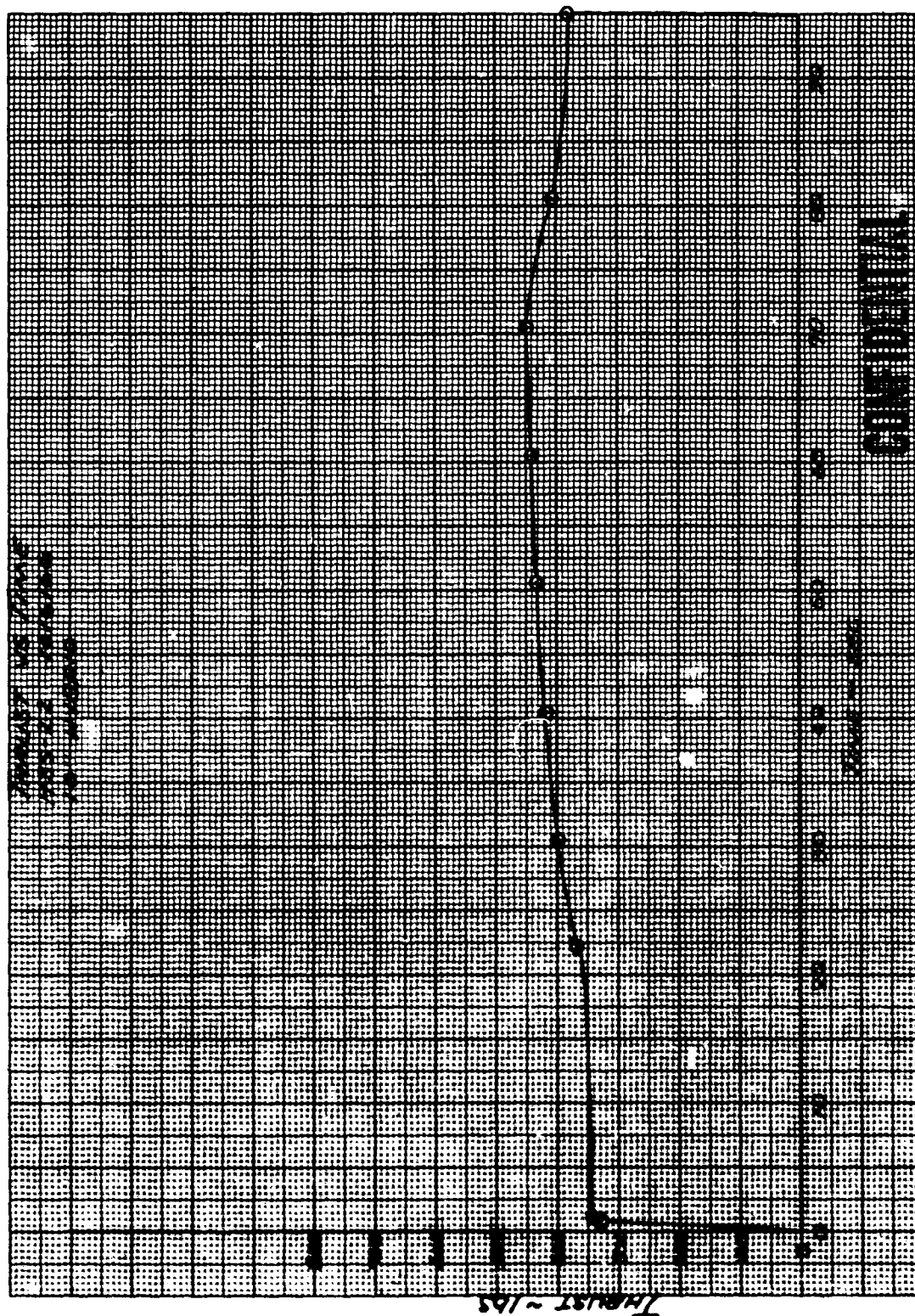
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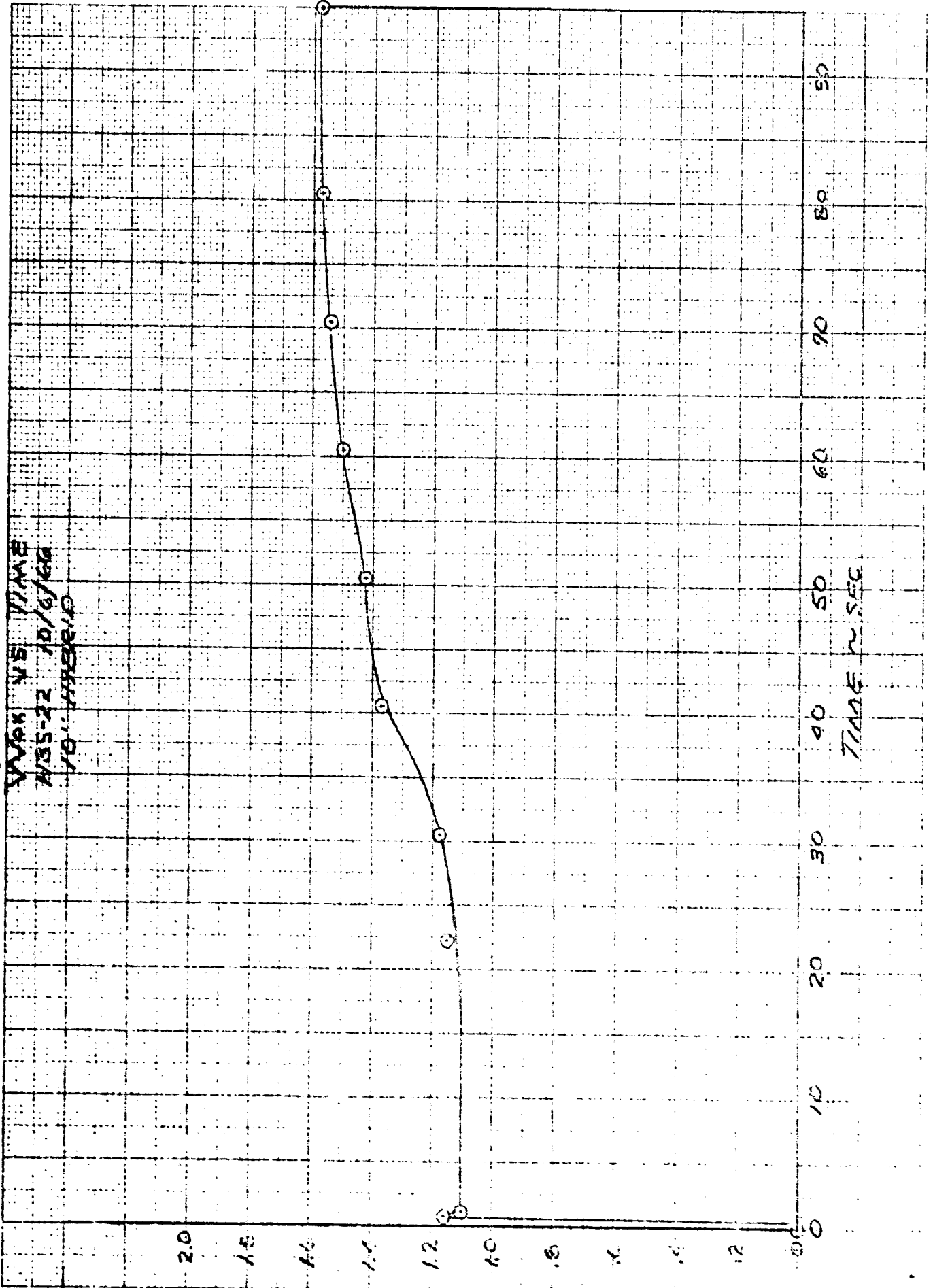
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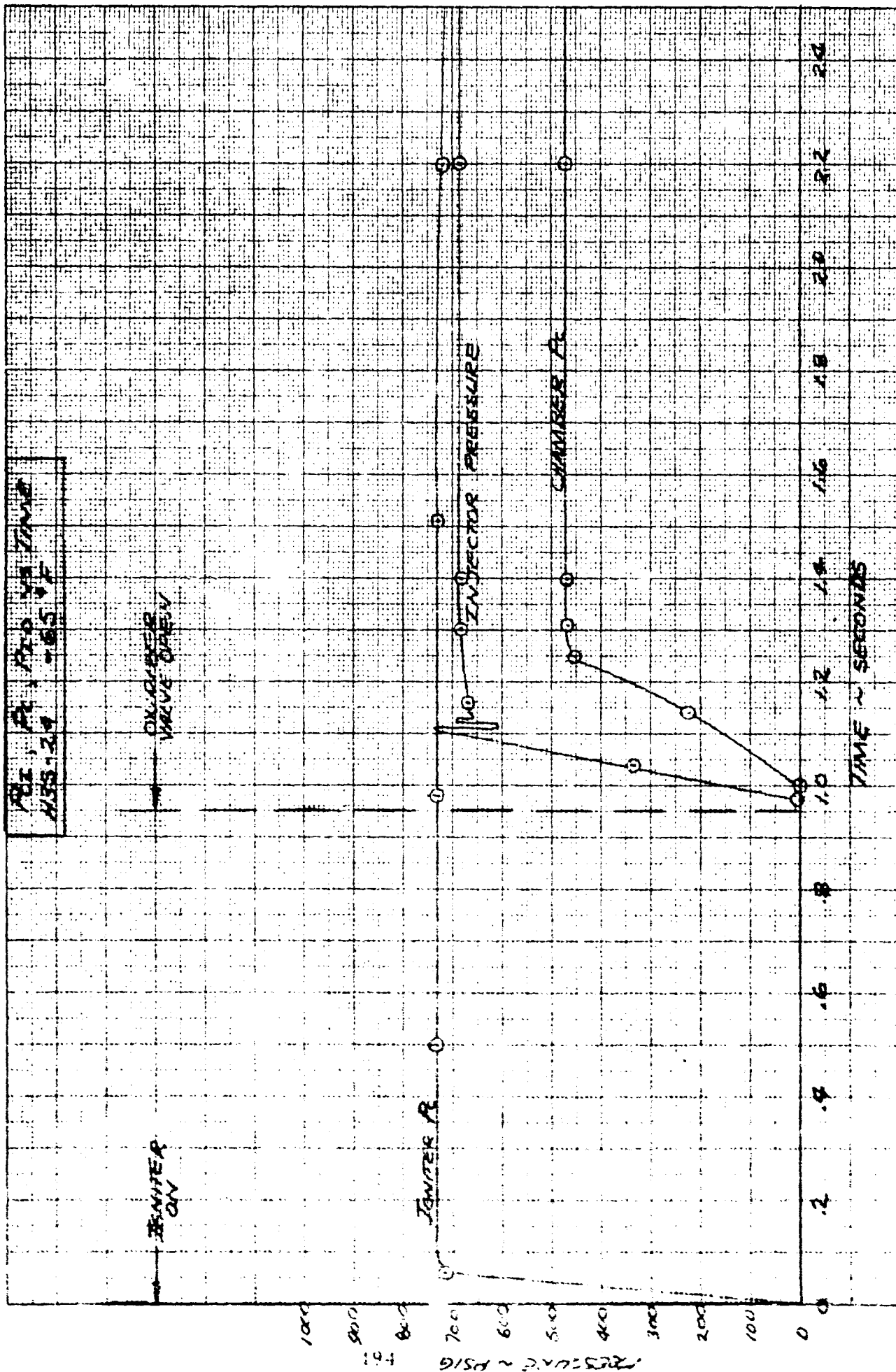
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CLEARPRINT CHART

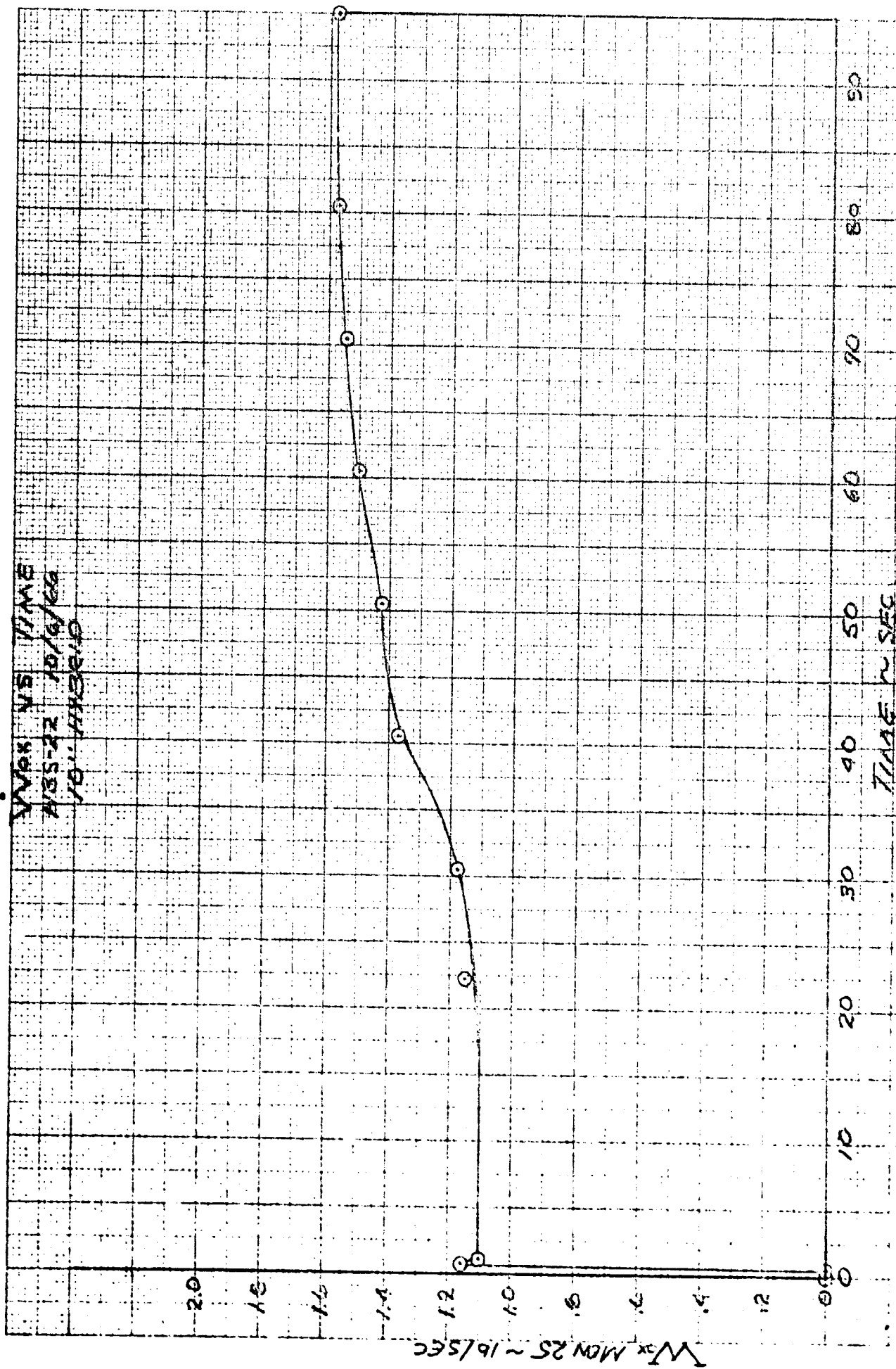
CLEARPRINT PAPER NO. C15 20 x 20 DIVISIONS PER INCH 184 x 200 DIVISIONS



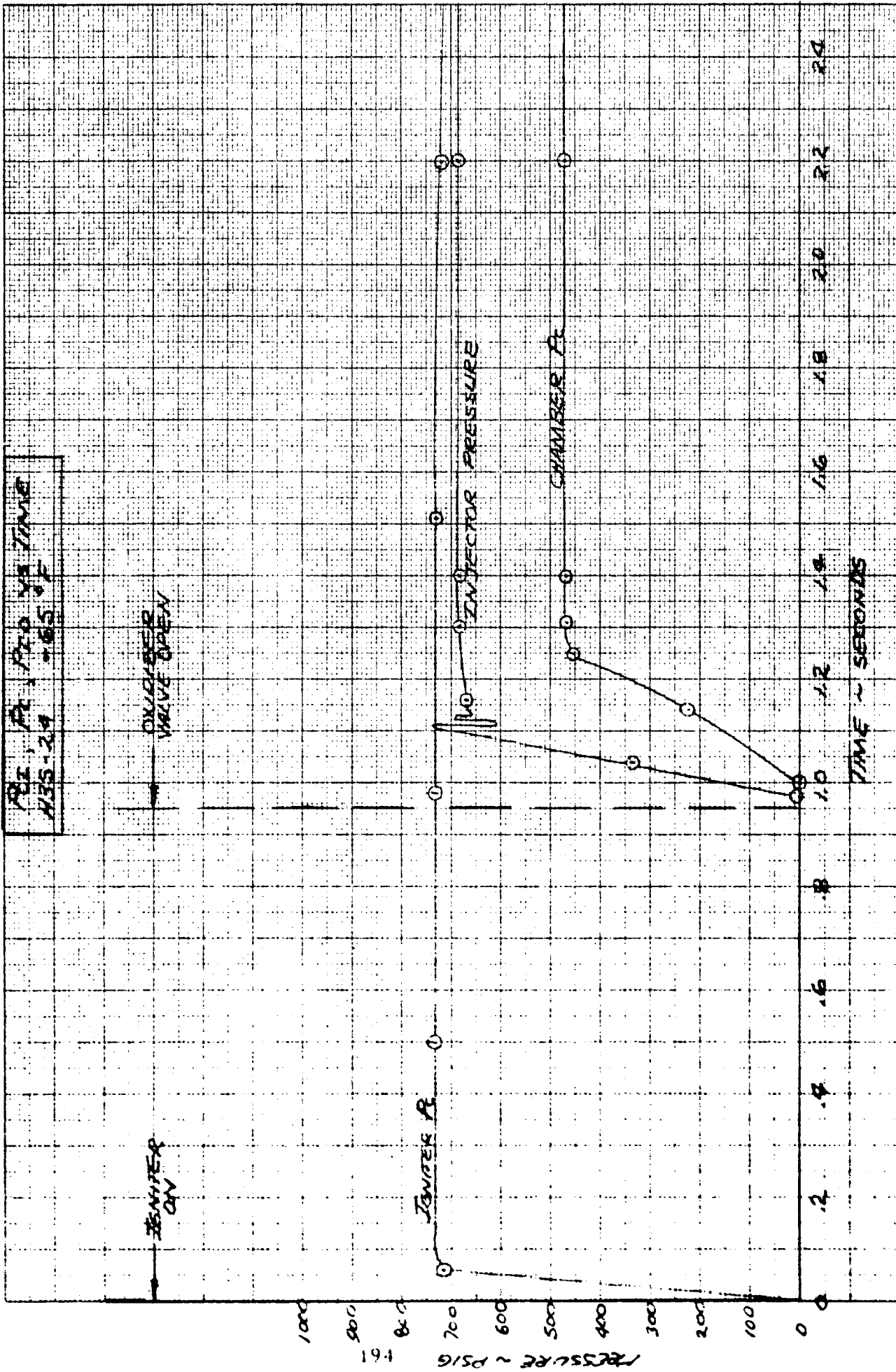
V_{max} MAY 25 ~ 16/5EC



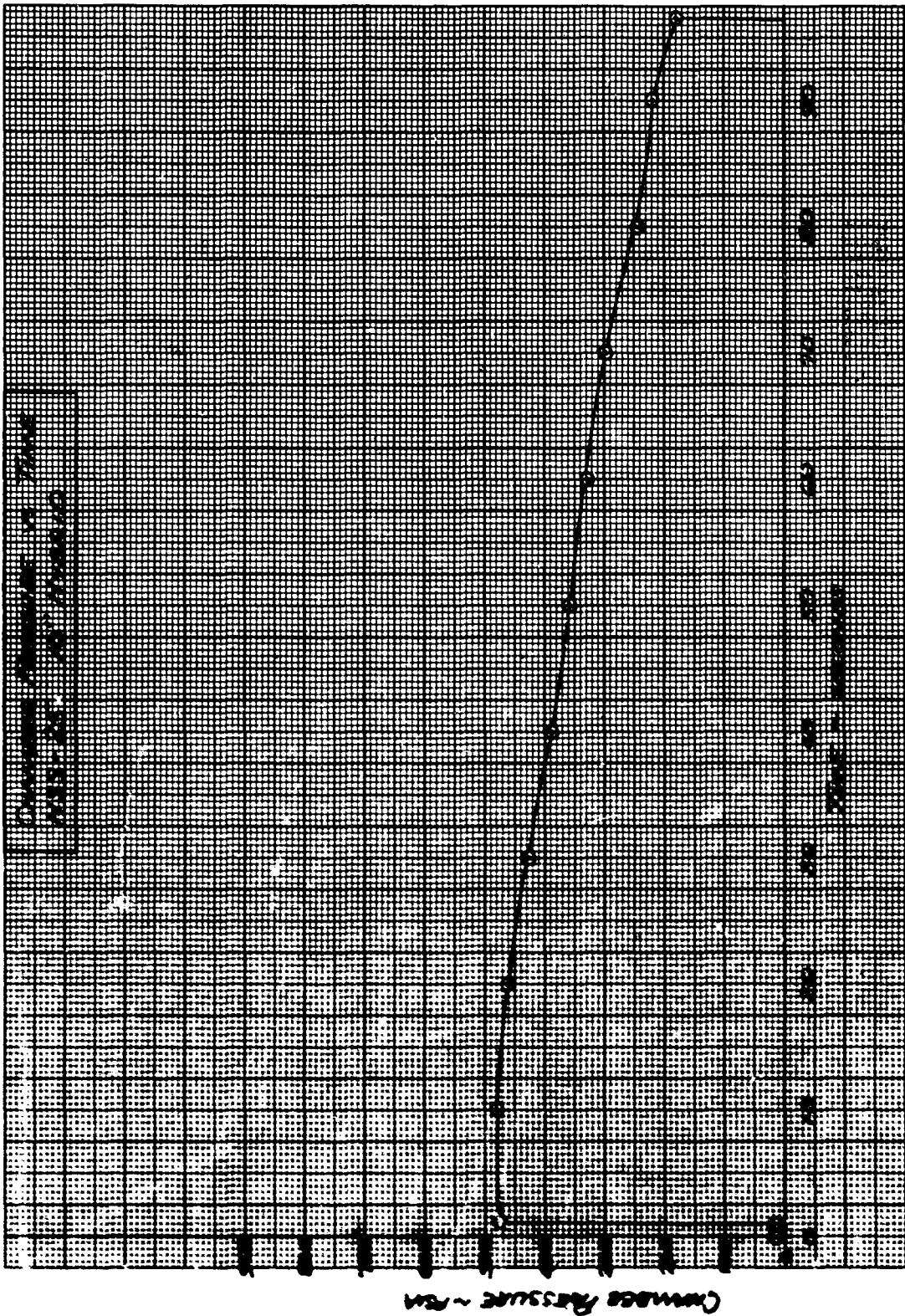
CLEARPRINT QUALITY



W_{max} MON 25 ~ 16 L/SEC



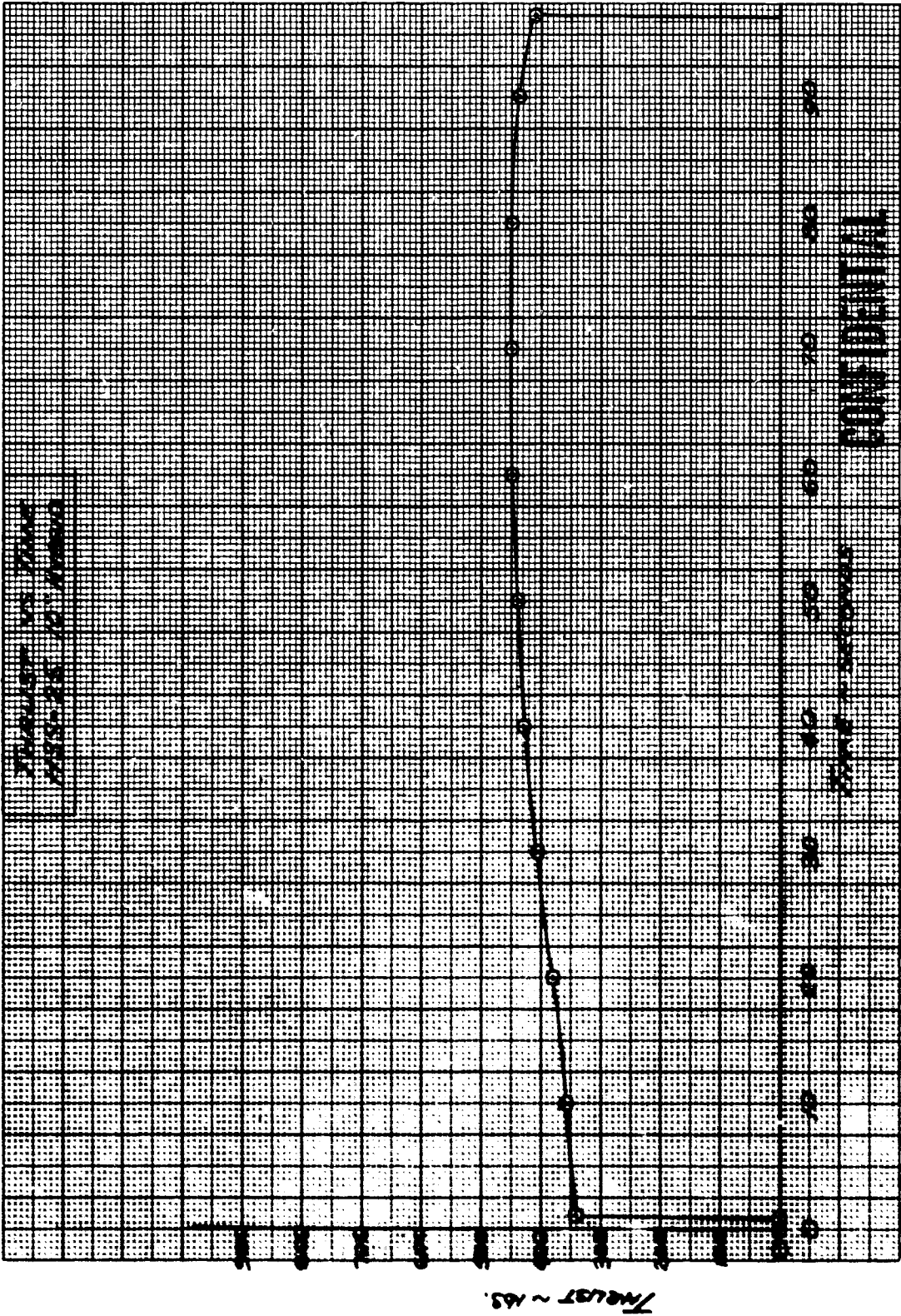
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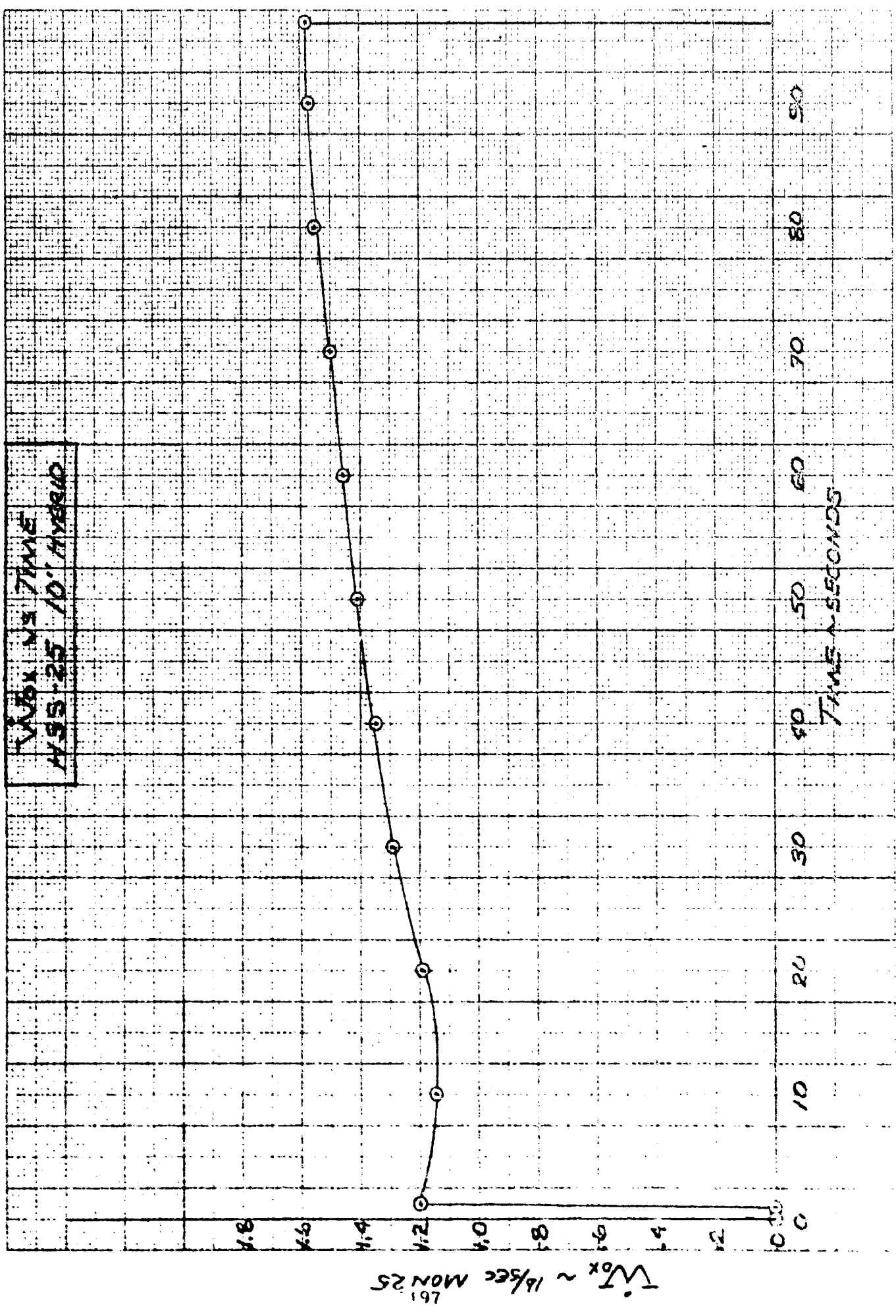
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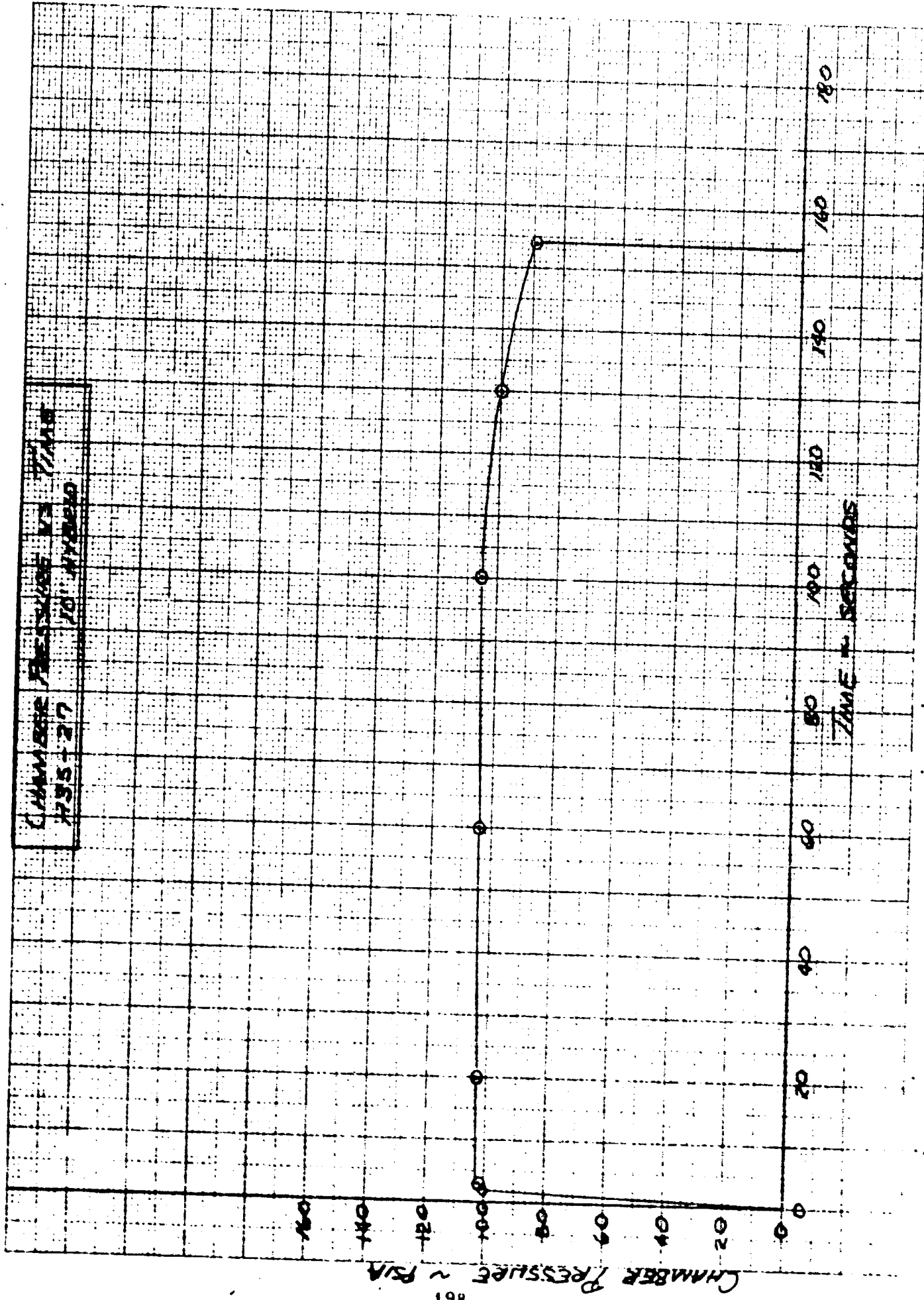
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CLEARPRINT COPY

W_{ox} VS TIME
HSS-25 10' HYBRID

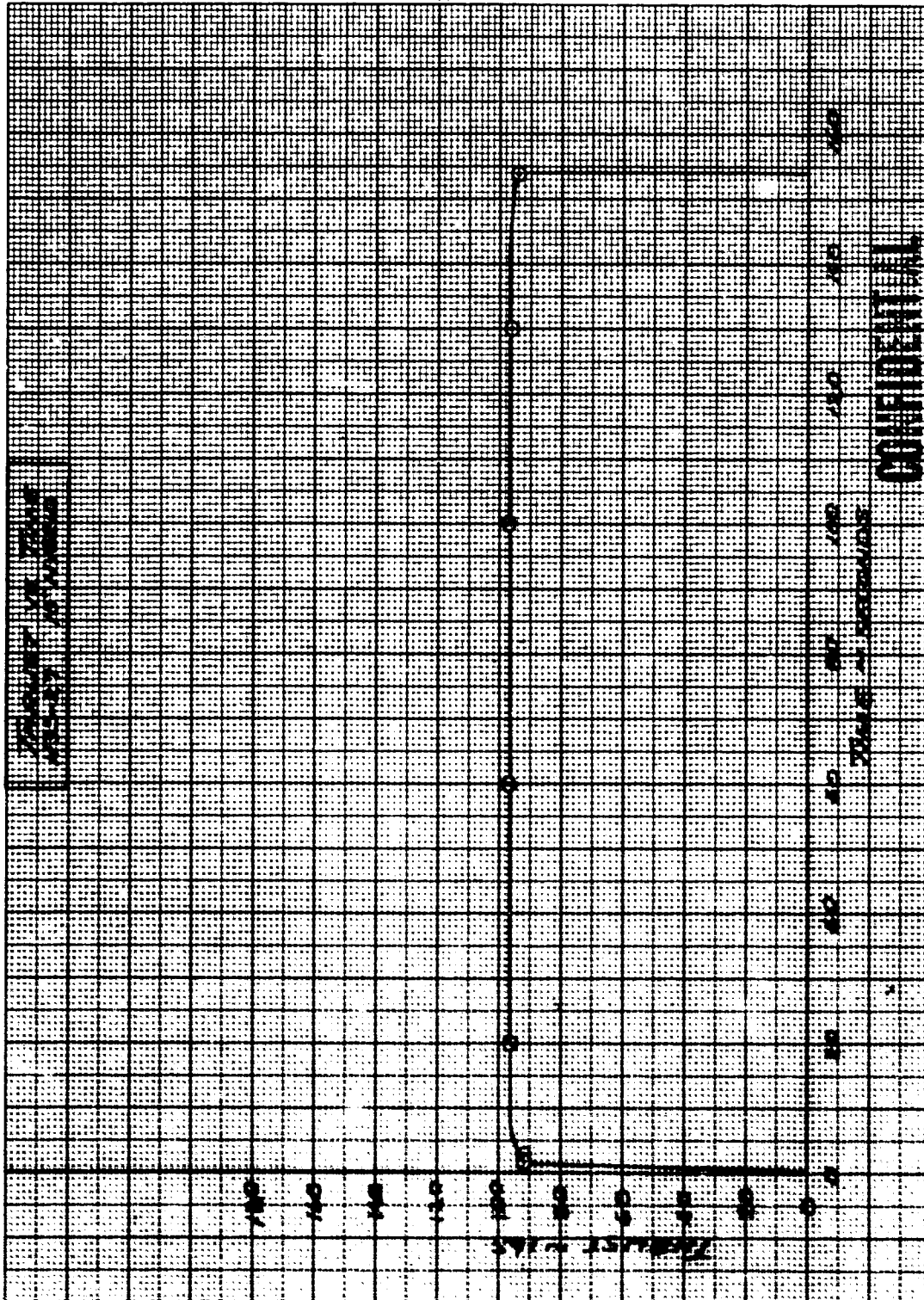


CHAMBER



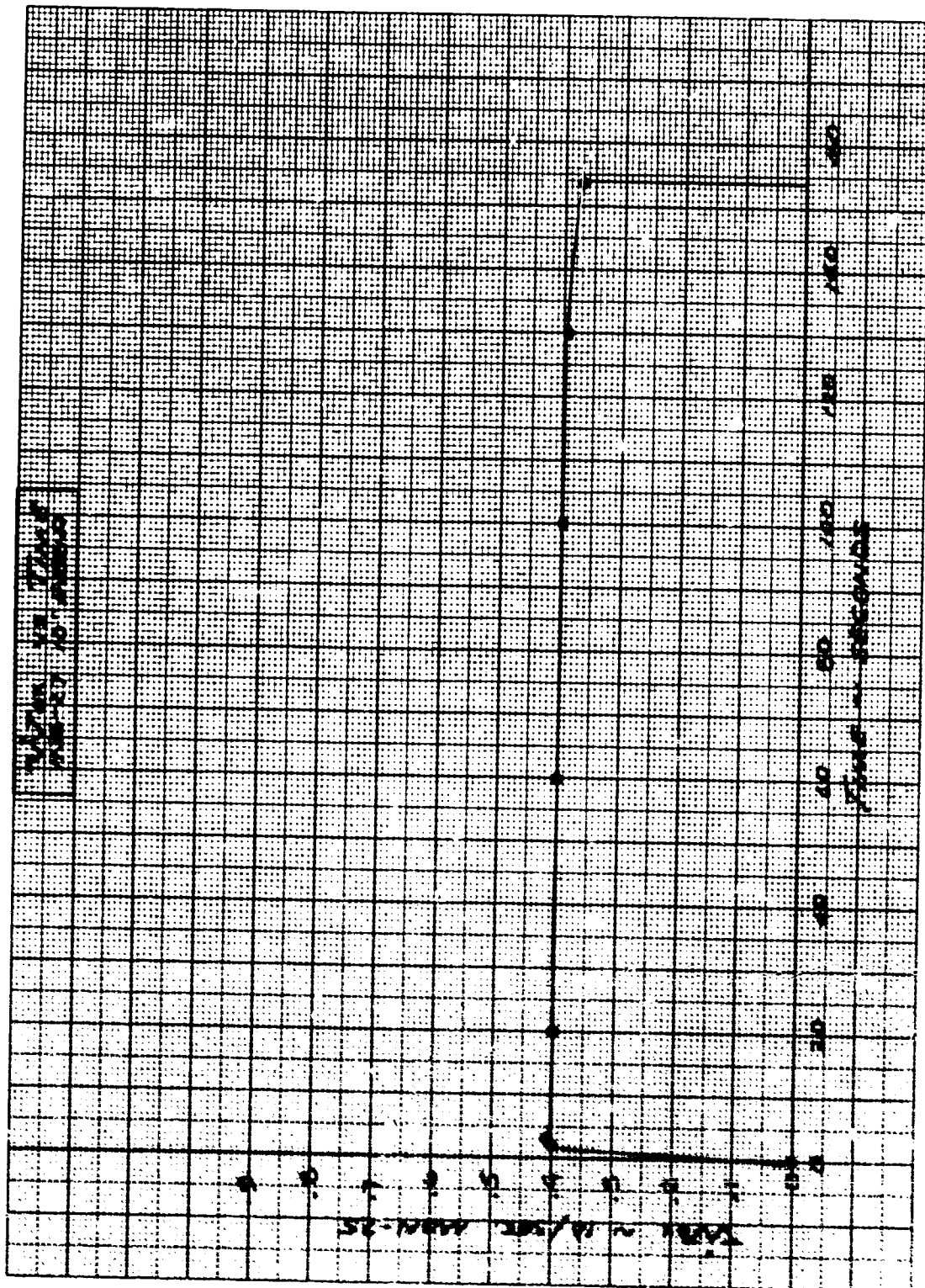
CHAMBER PRESSURE ~ PSIA
TIME ~ SECONDS

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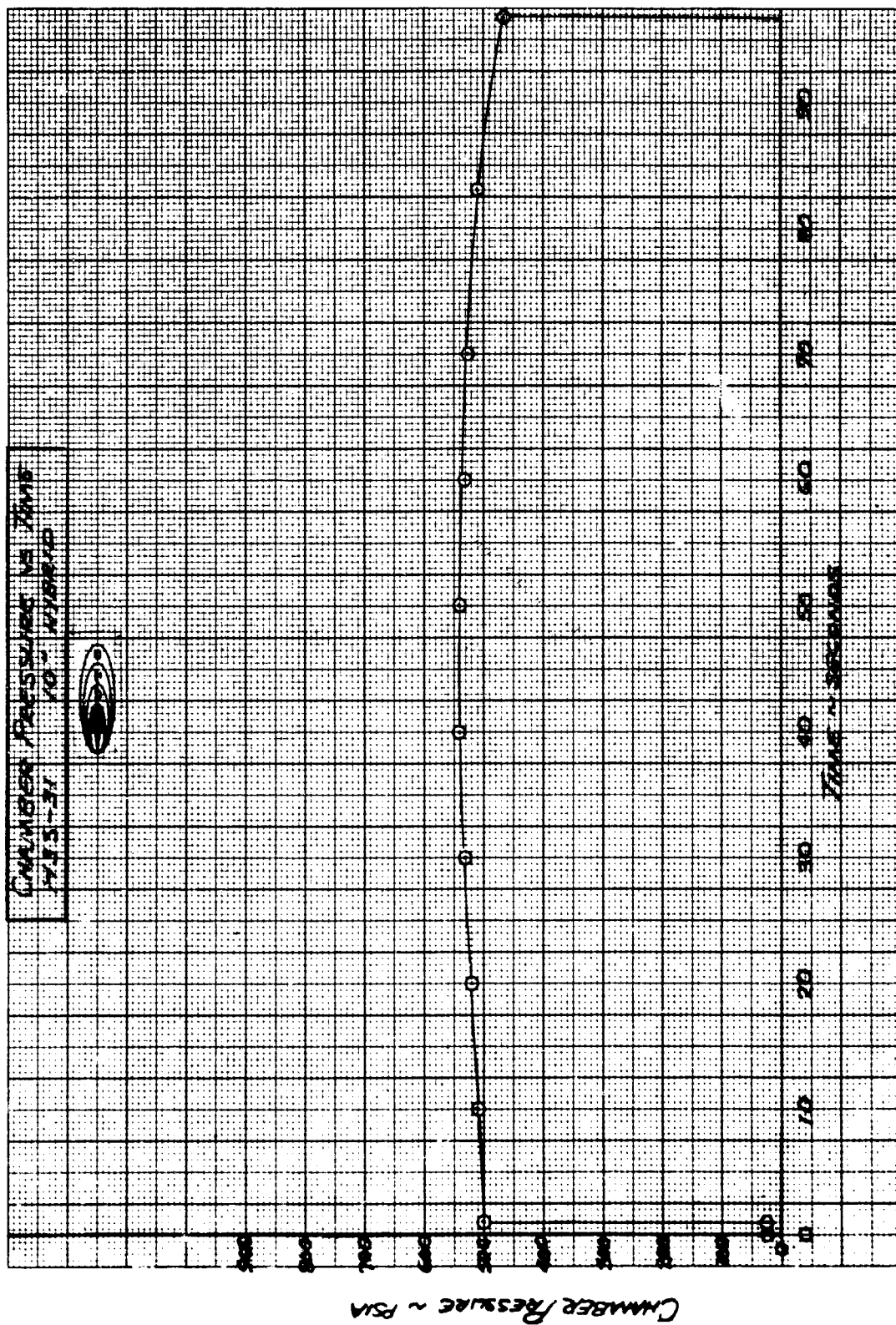


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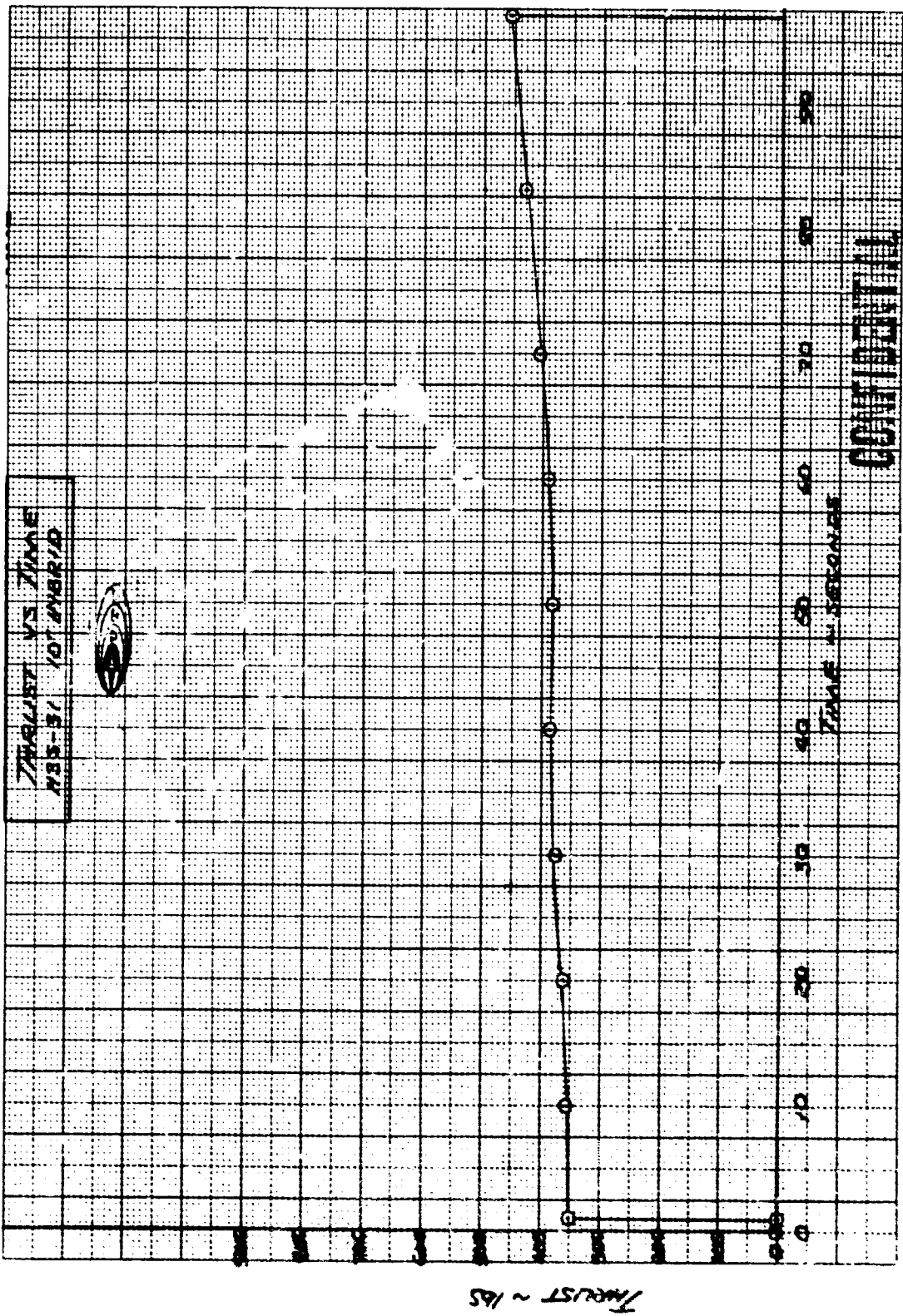
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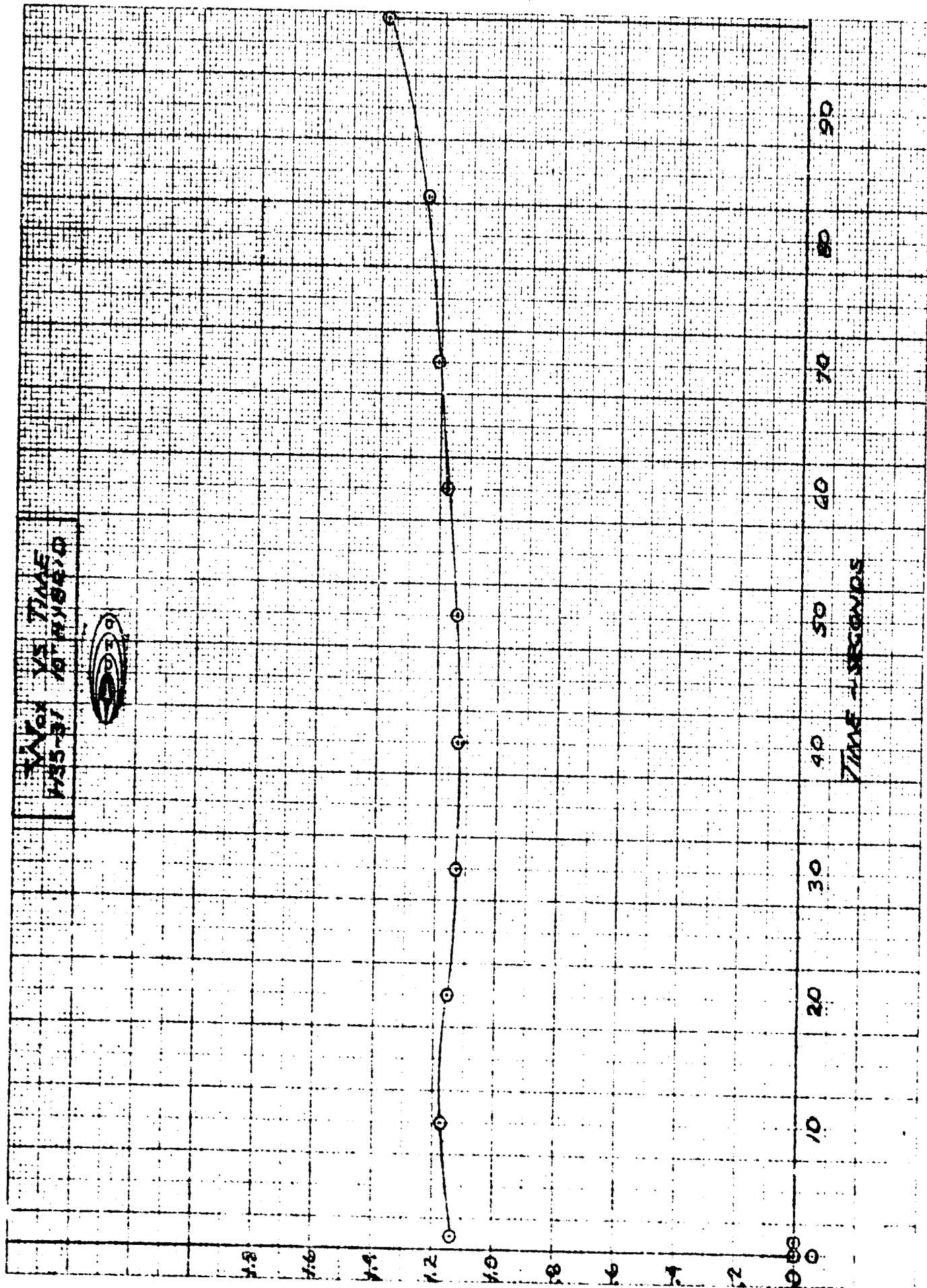
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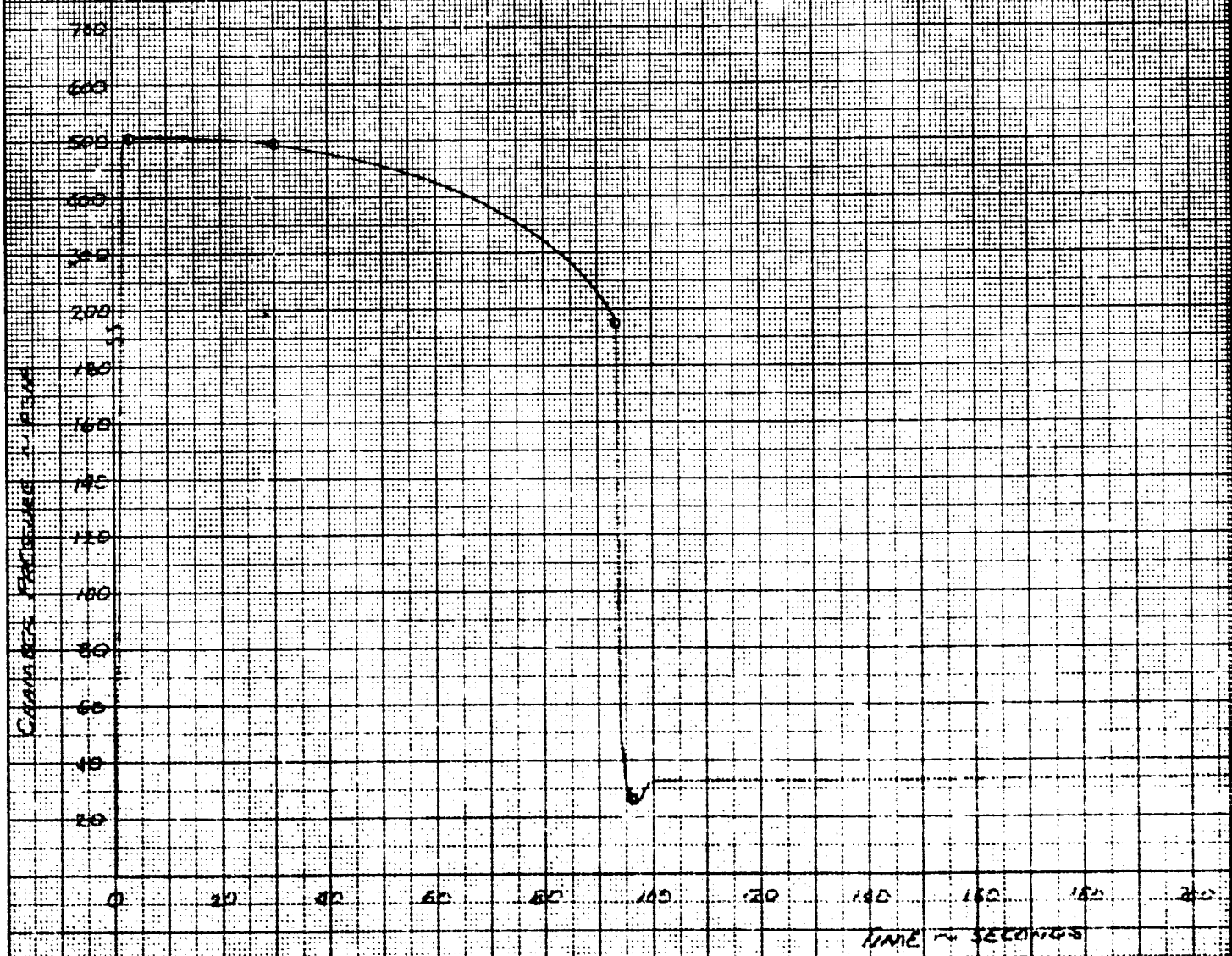


WOM VS TIME
435-37 10-11-84

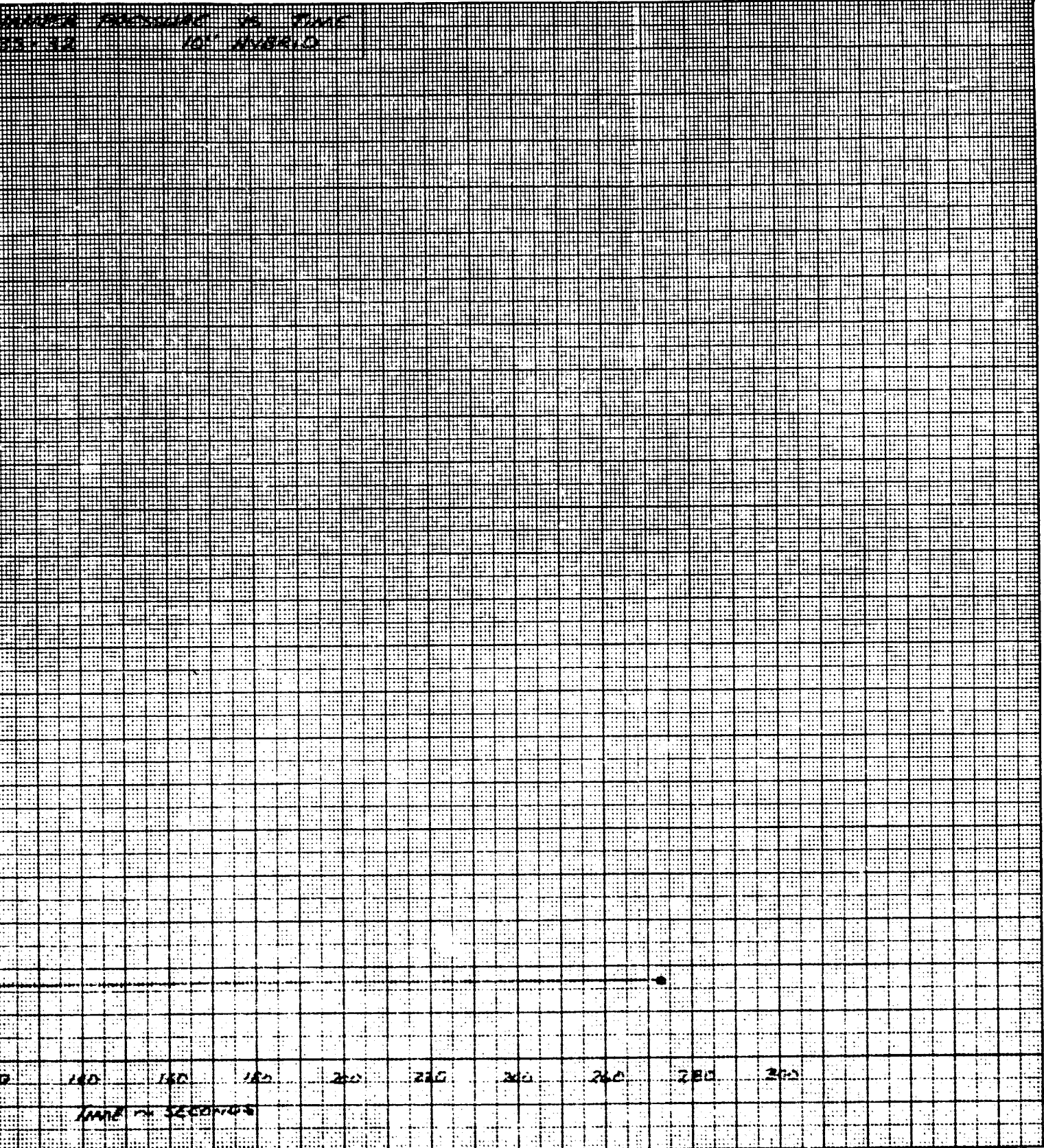


203 NOV-25 1972

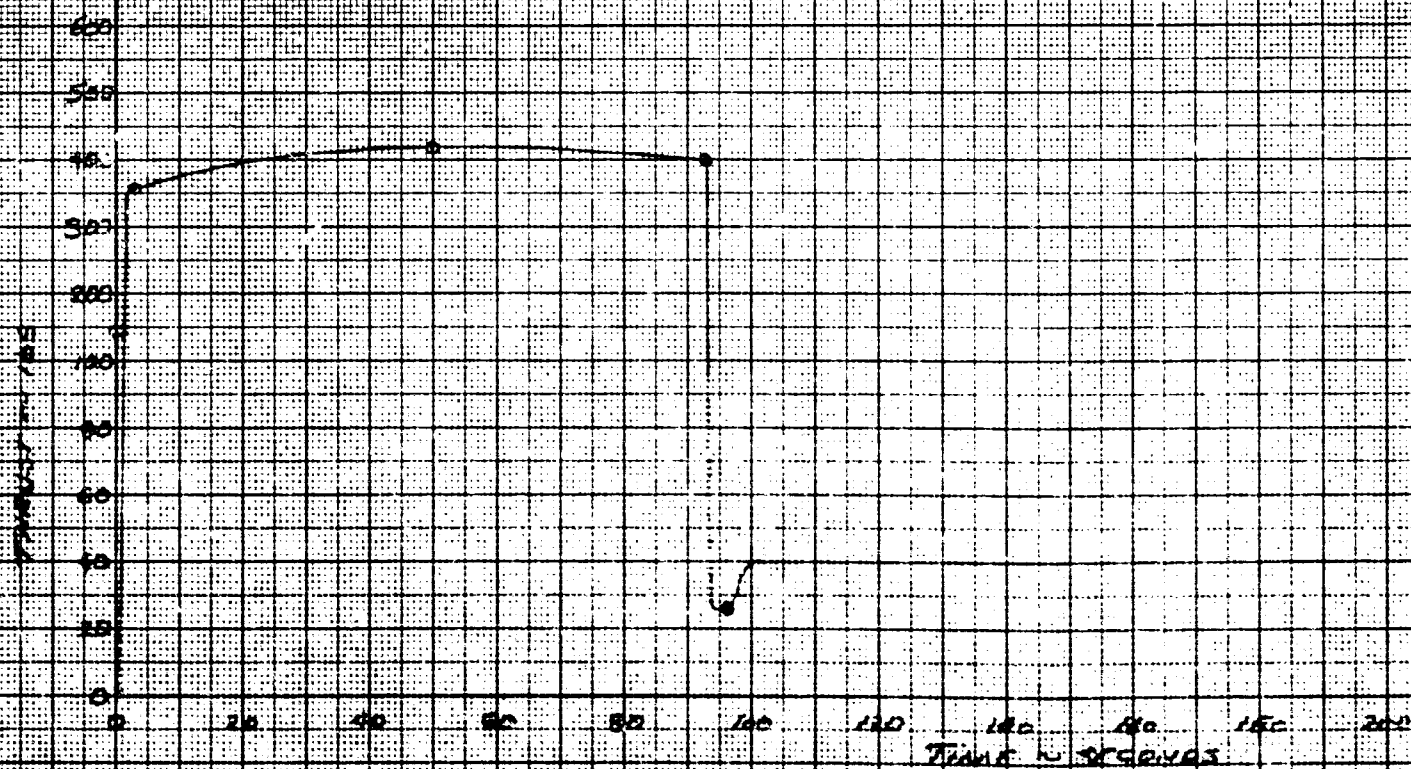
CHAMBER PRESSURE vs TIME
A35-32 10" HYBRID



WATER PRESSURE IN TIME
53'32" 10" ANGRIO

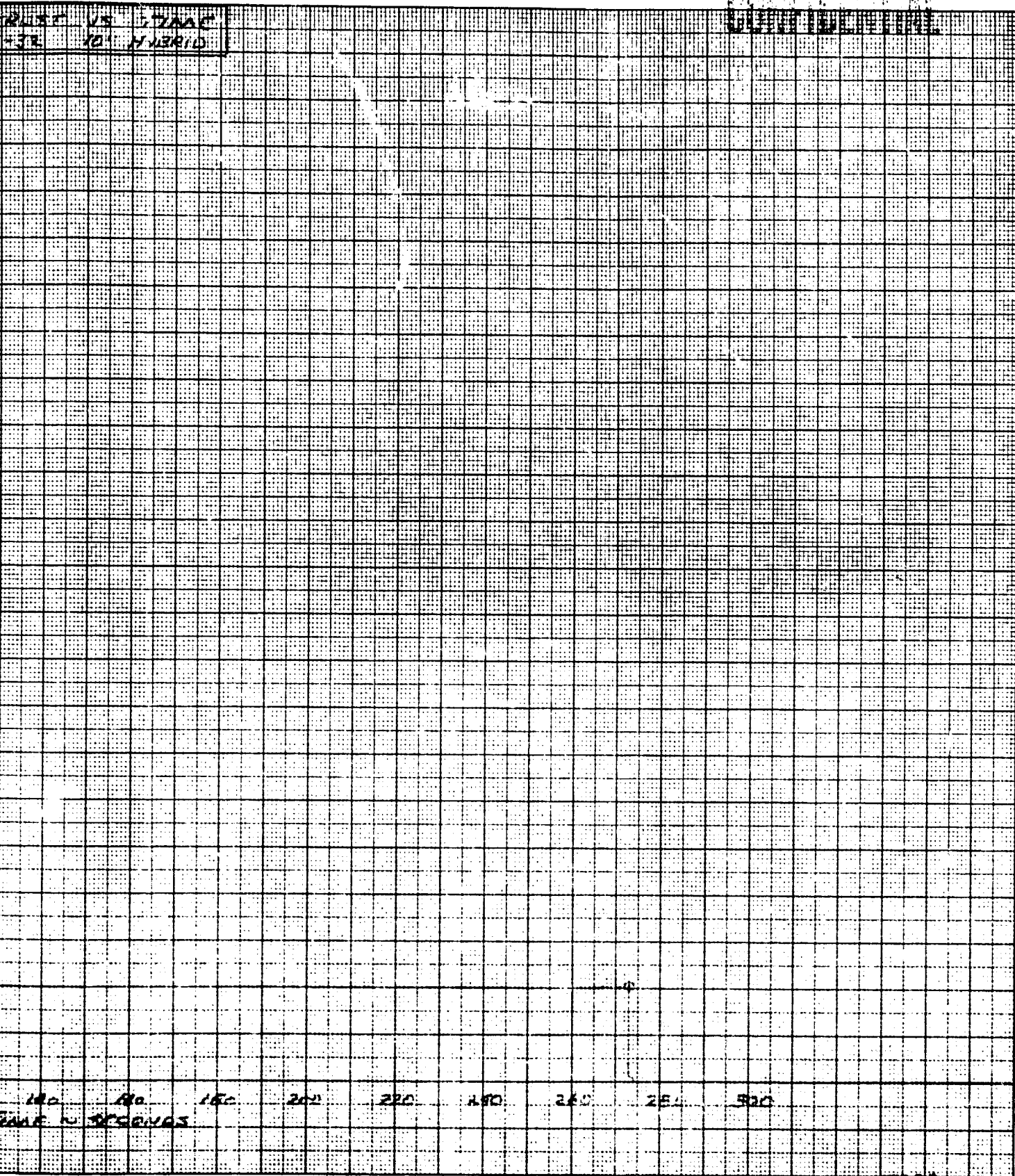


THRUST VS TIME
H35-3E 10' HYBRID



RUST VS. TAAAC
-3L 101 HYBRID

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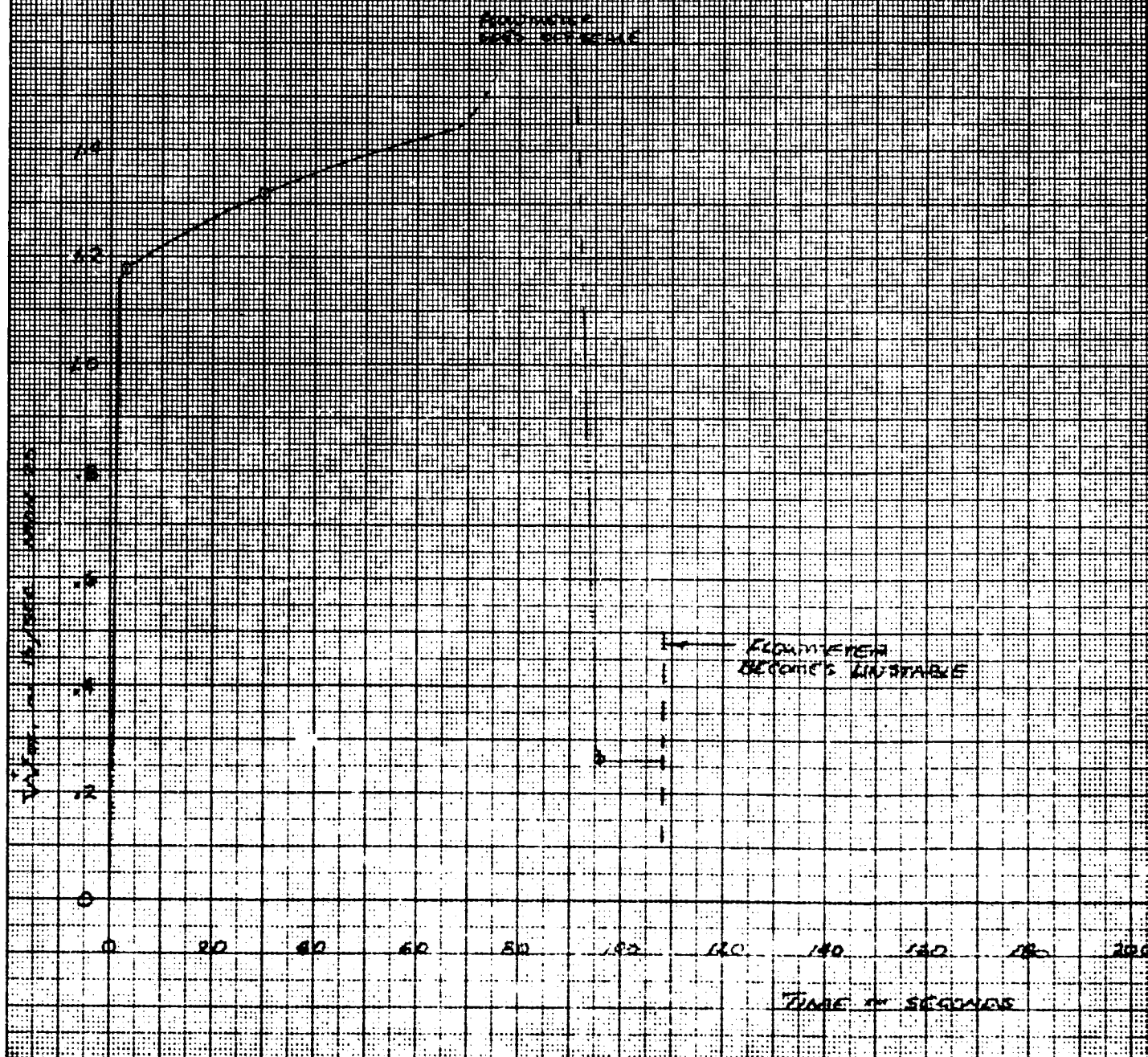


100 150 200 250 300 350 400 450 500 550
TIME IN SECONDS

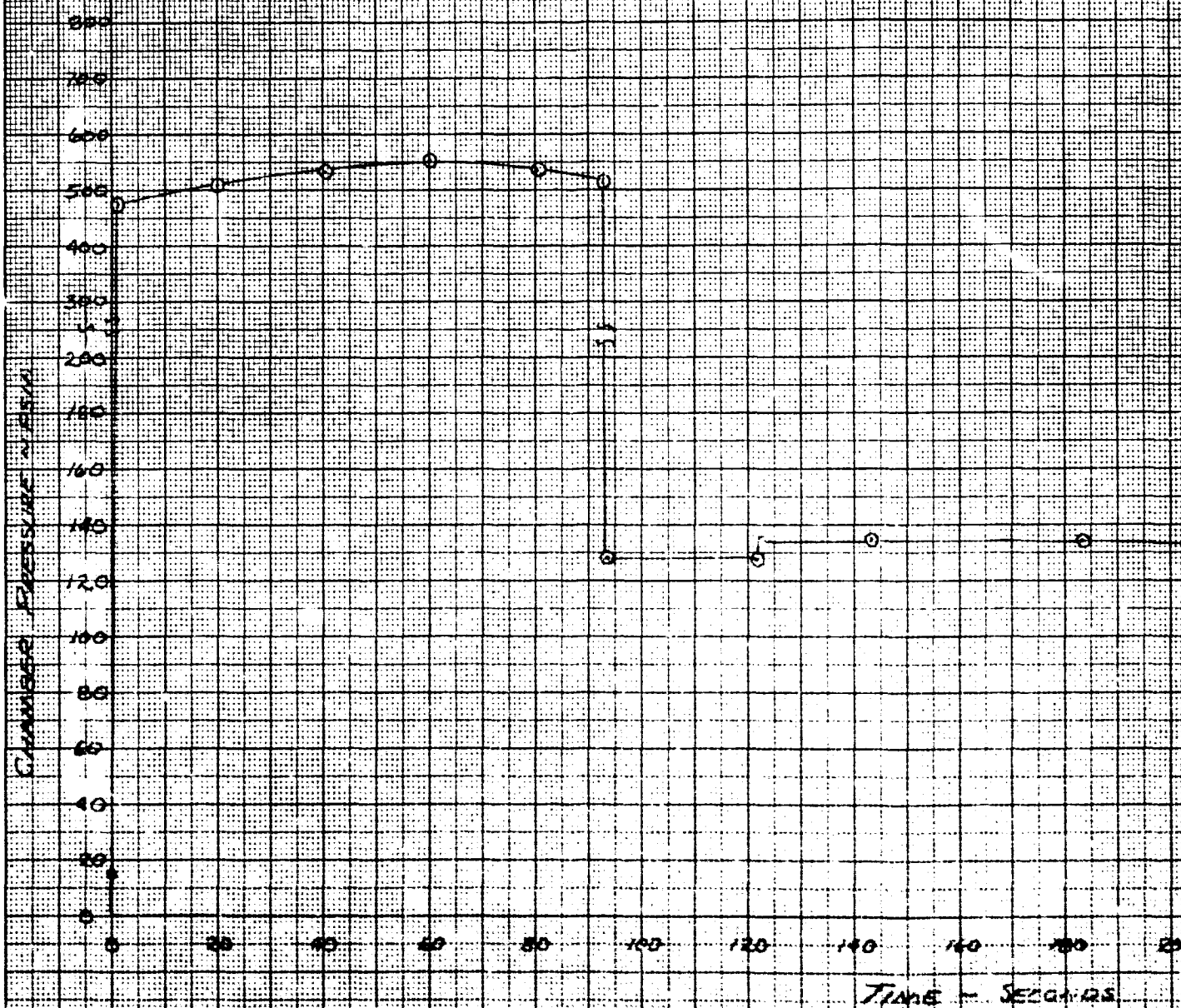
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FLIGHTER VS TIME
195-32 10' HOURS



CHAMBER PRESSURE VS TIME
H35-83 10" HYBRID



1000 PRESSURE VS TIME
10" HYBRID

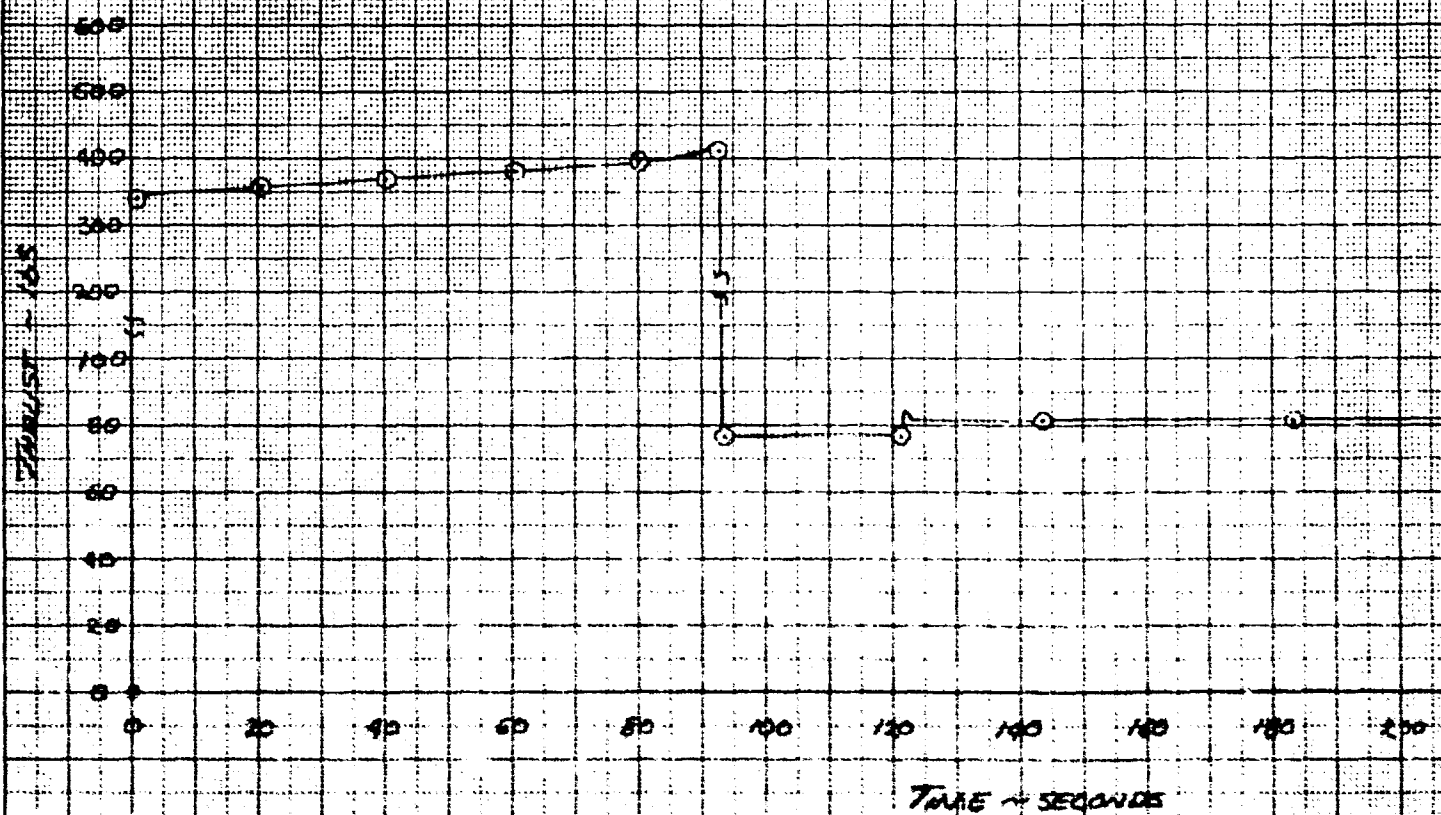


140 160 180 200 220 240 260

TIME - SECONDS

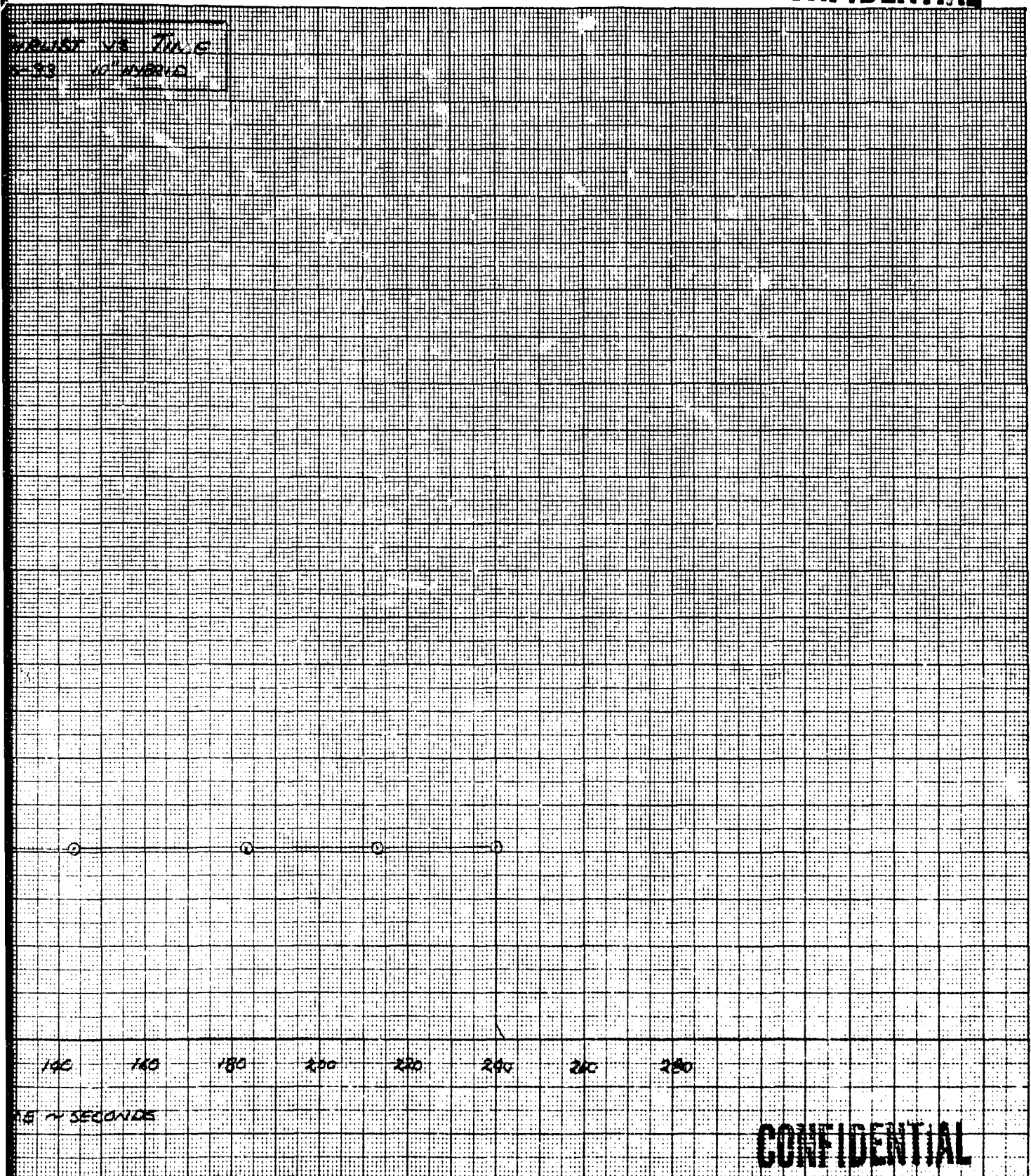
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THRUST vs TIME
MAY-83 M. WARD



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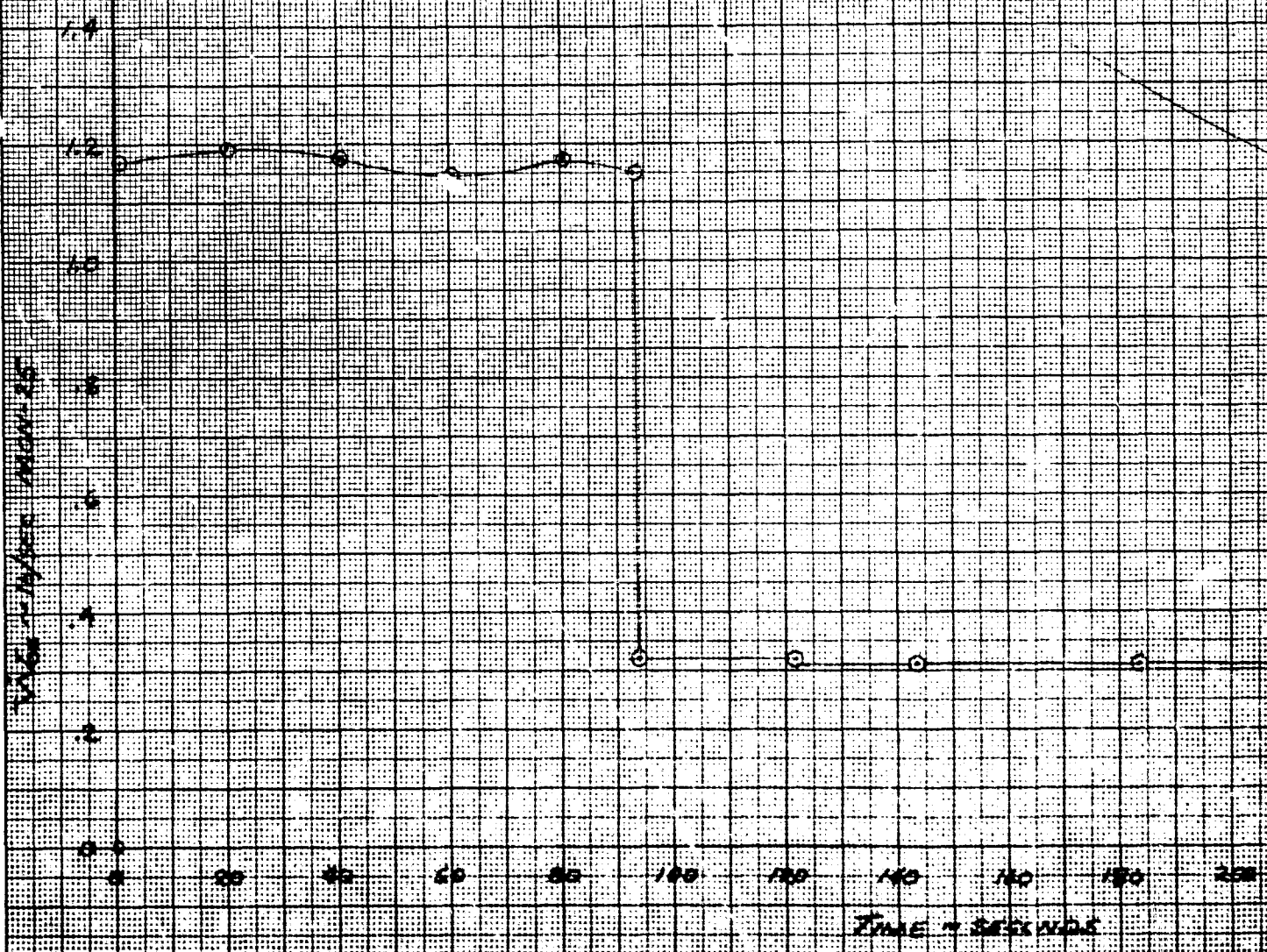
WINDST vs Time
S-93 10' WIND



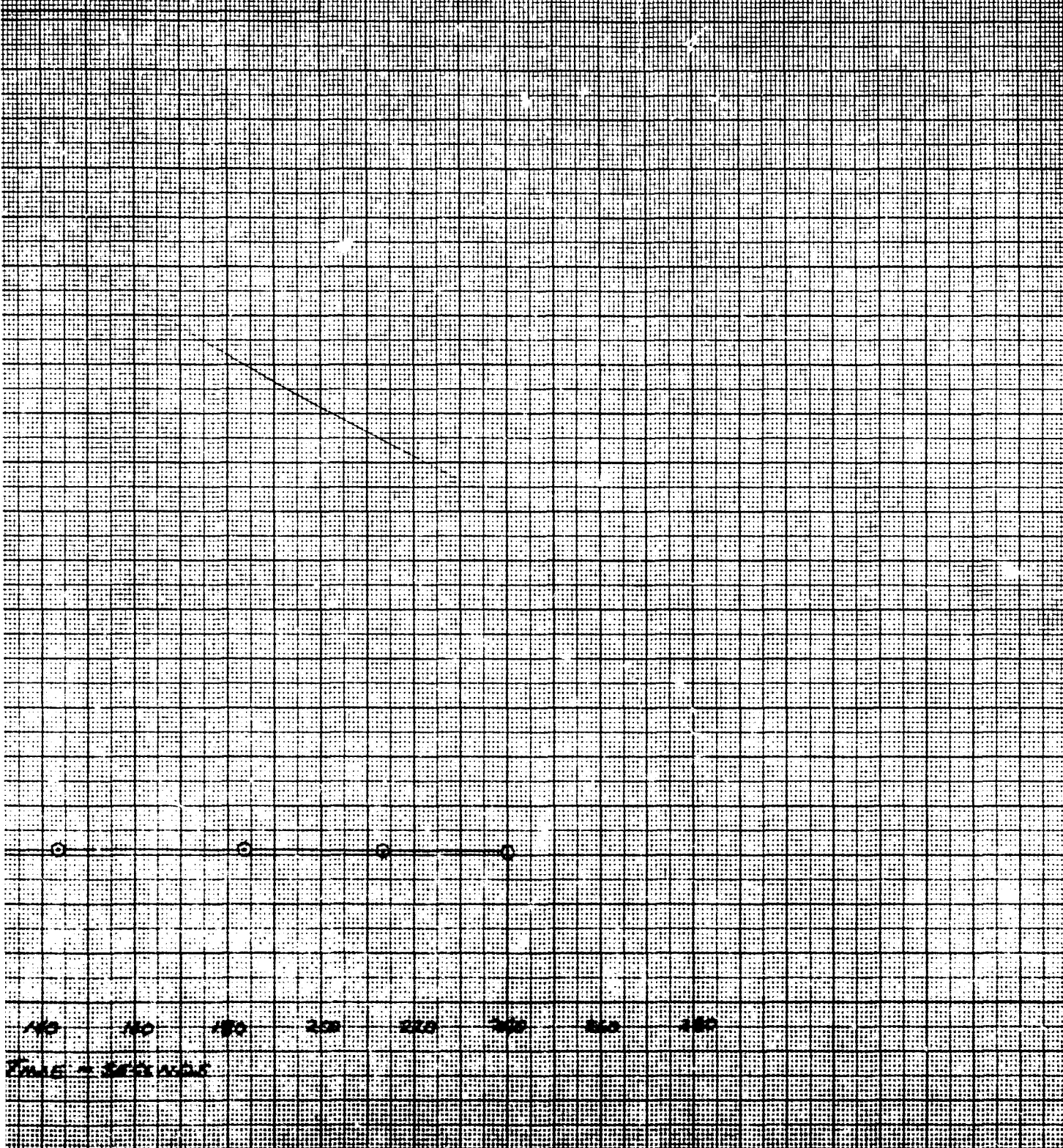
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SATURATED VS. TIME
 WBS-23 10' HYBRID

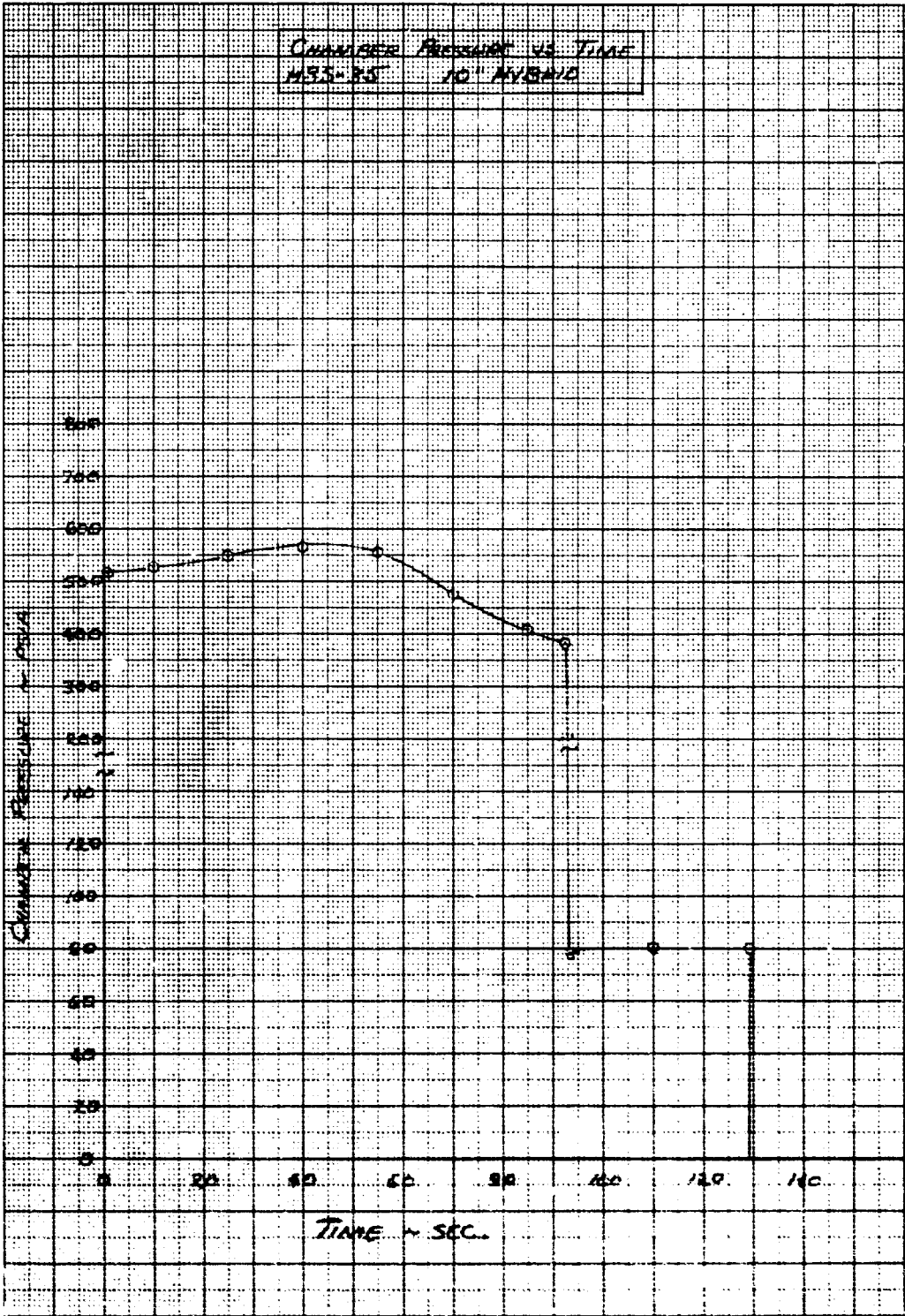


17 AUG 1968 VS TIME
05-38 01 HRS 10

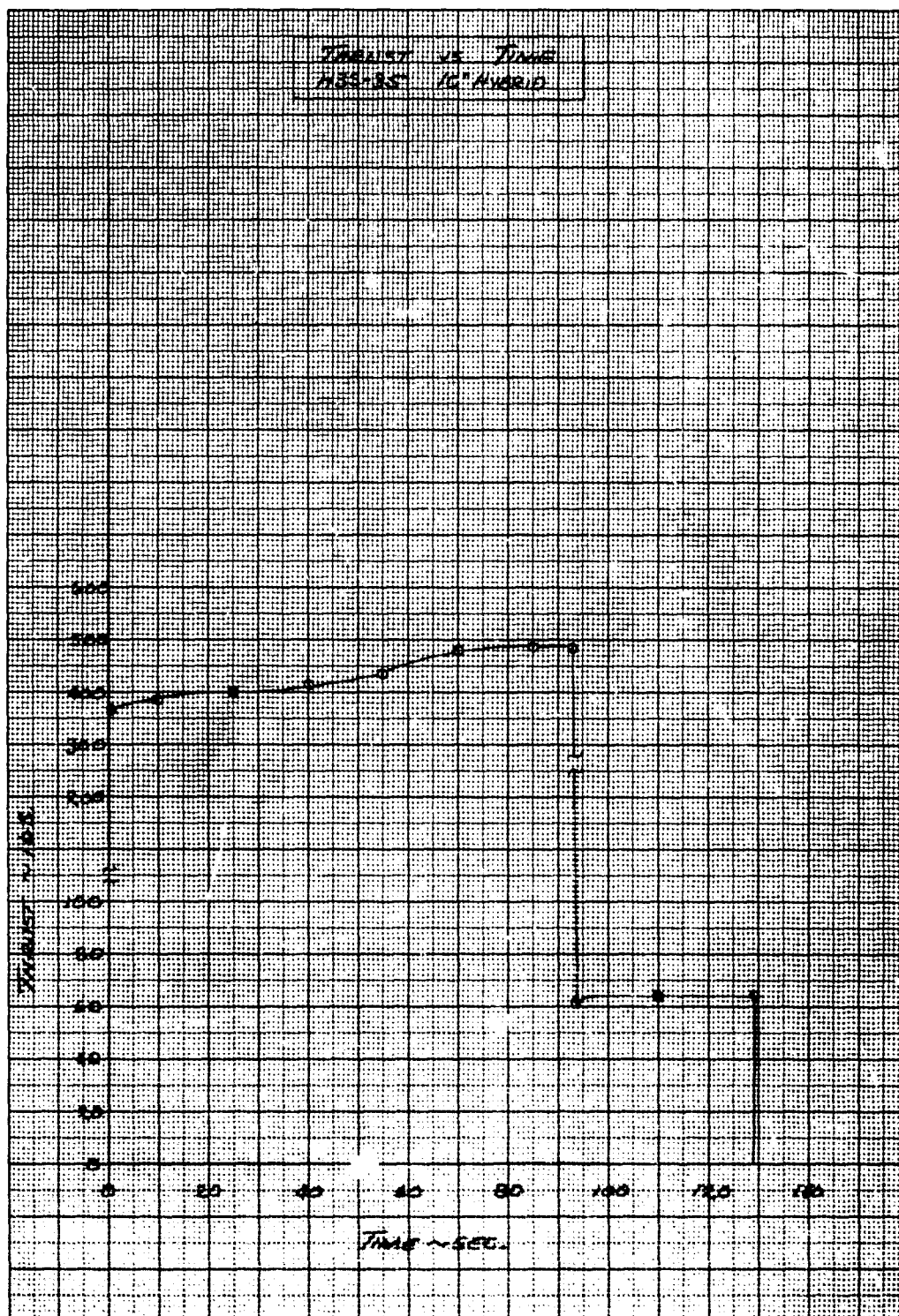


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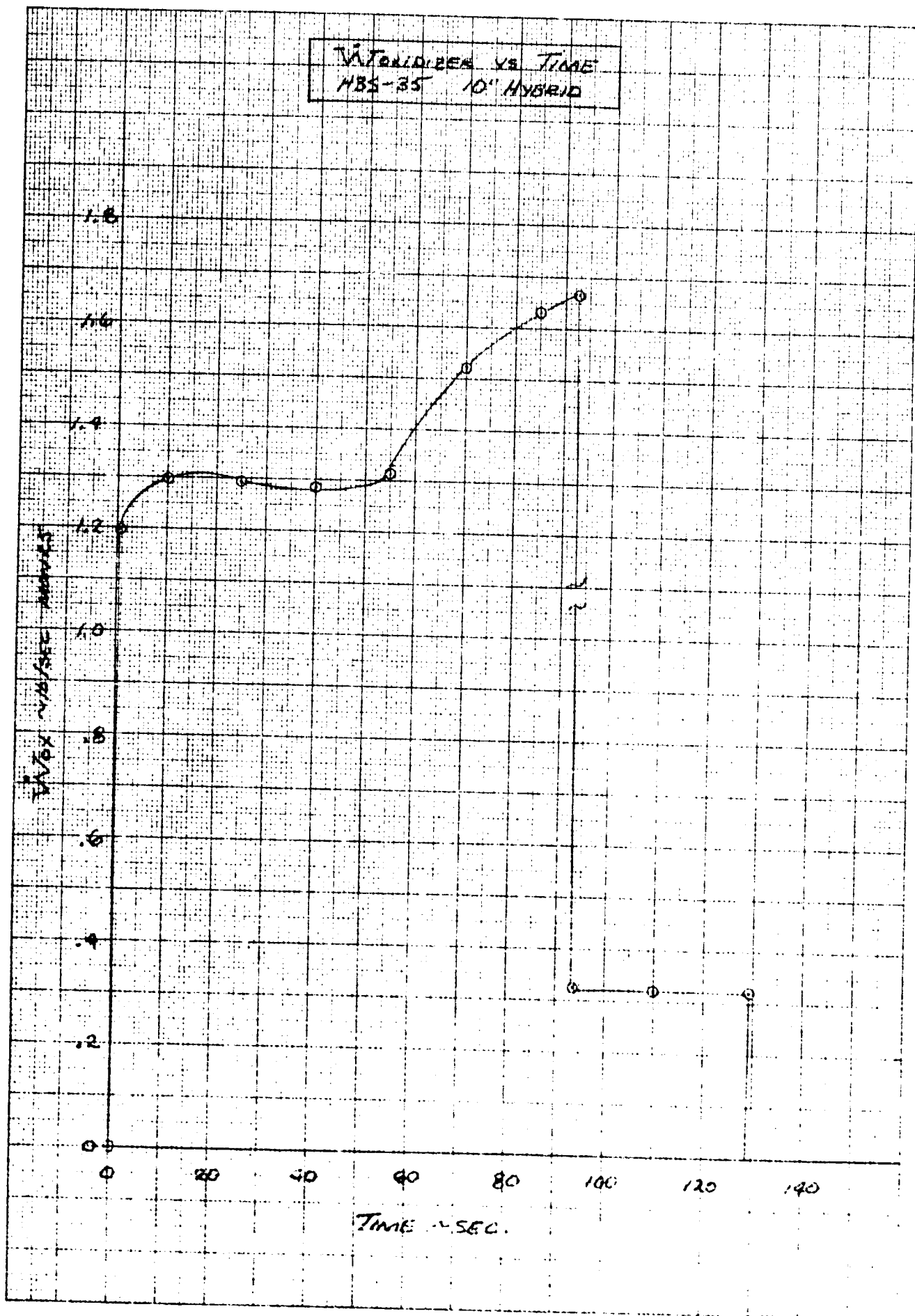
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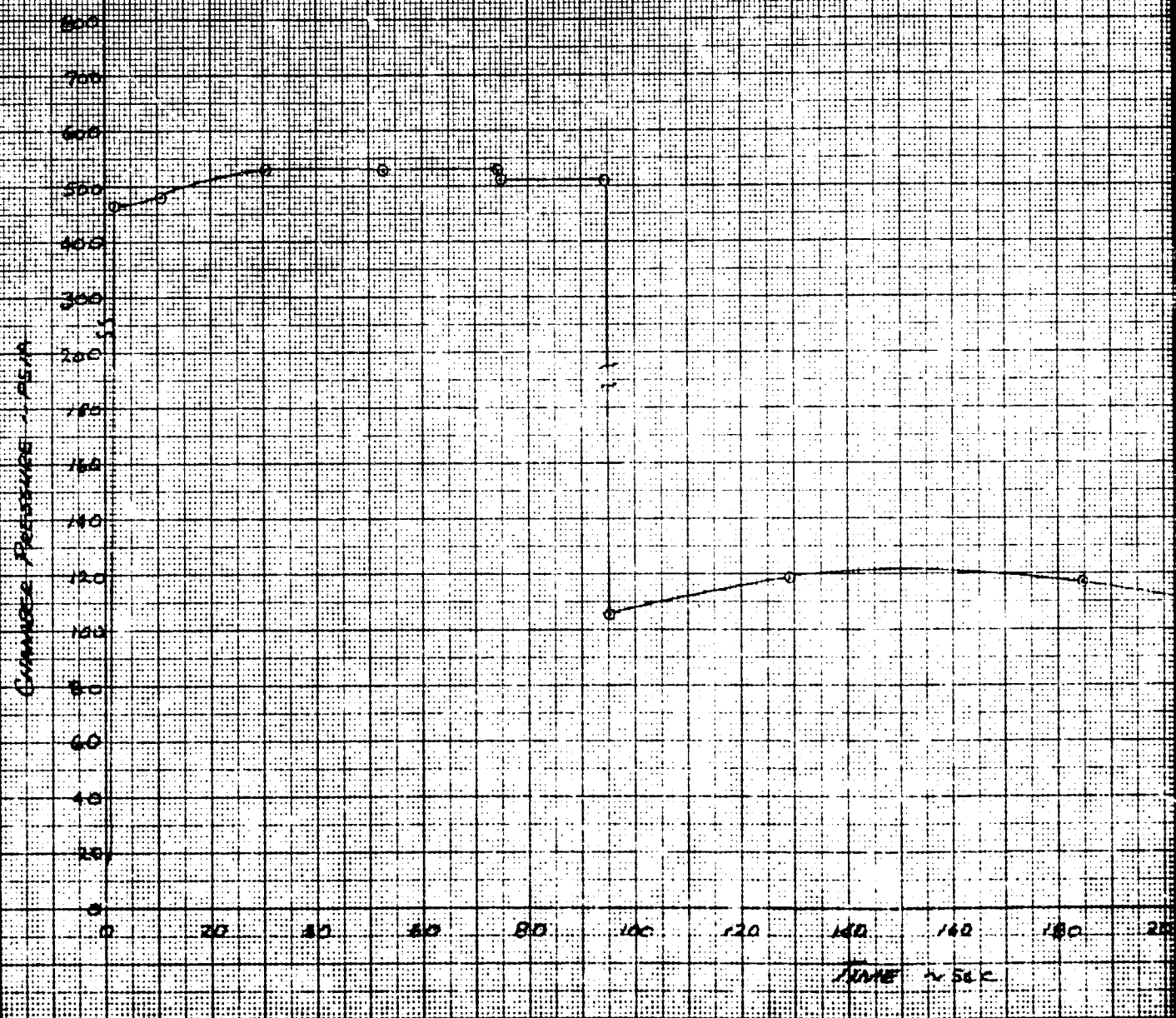
CONFIDENTIAL



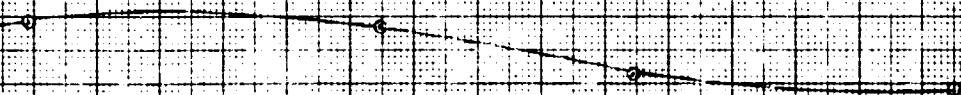
CONFIDENTIAL



Compressive Pressure vs. Time
H35-37 10° H₂O



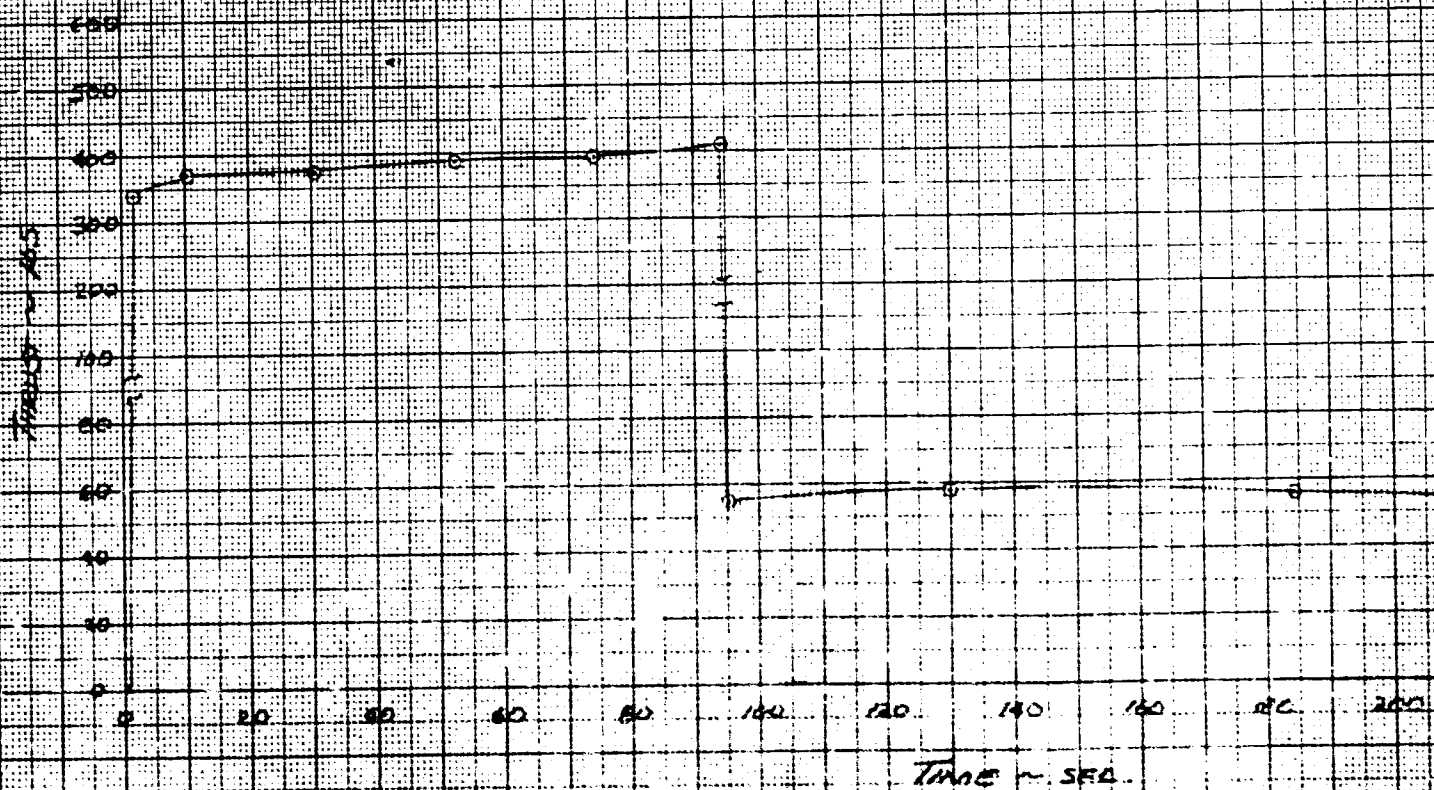
Pressure vs Time
10" HYDRO



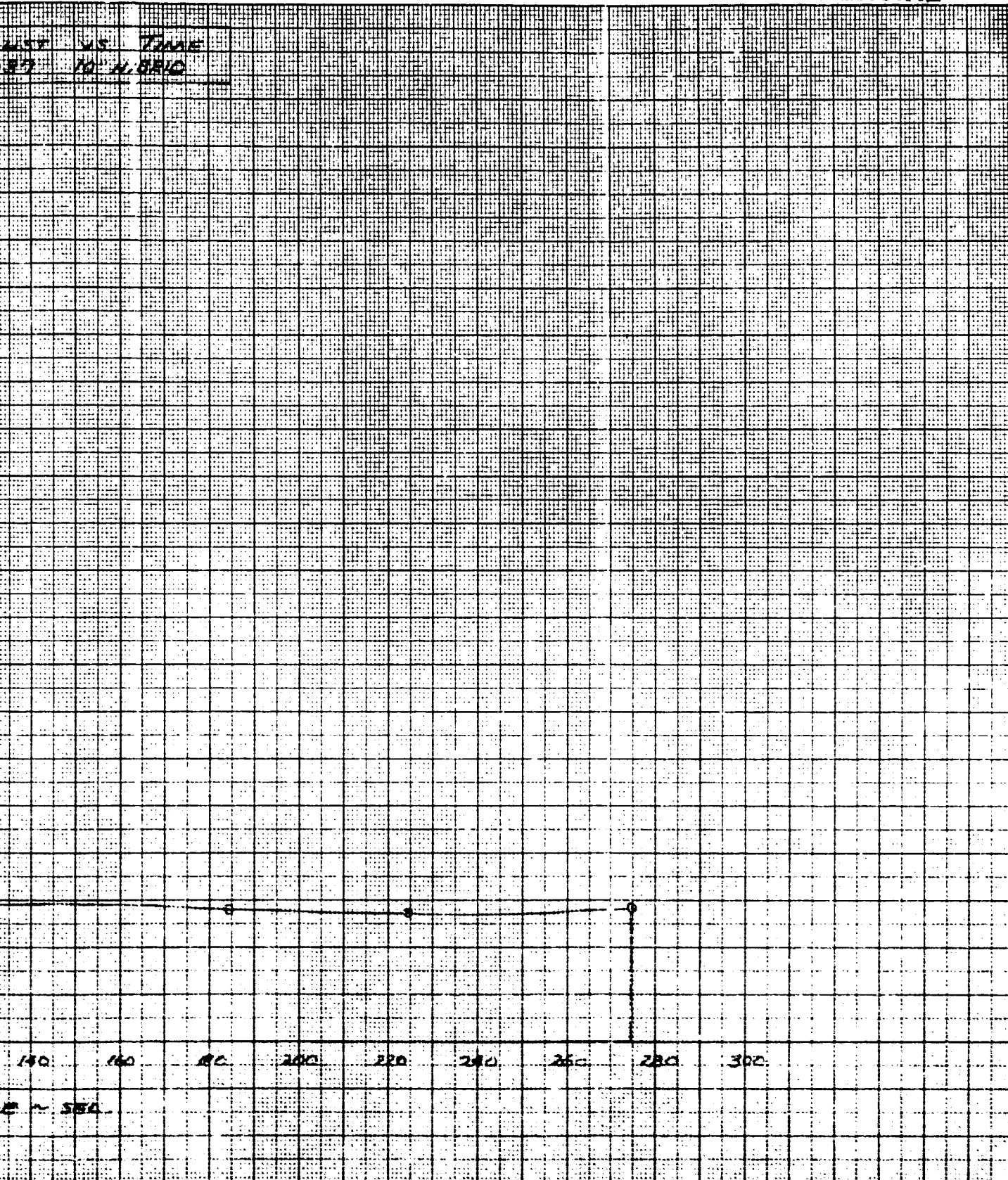
140 160 180 200 220 240 260 280 300 320
TIME IN SEC

2

THRUST VS TIME
HRS-57 10 H. BRIG



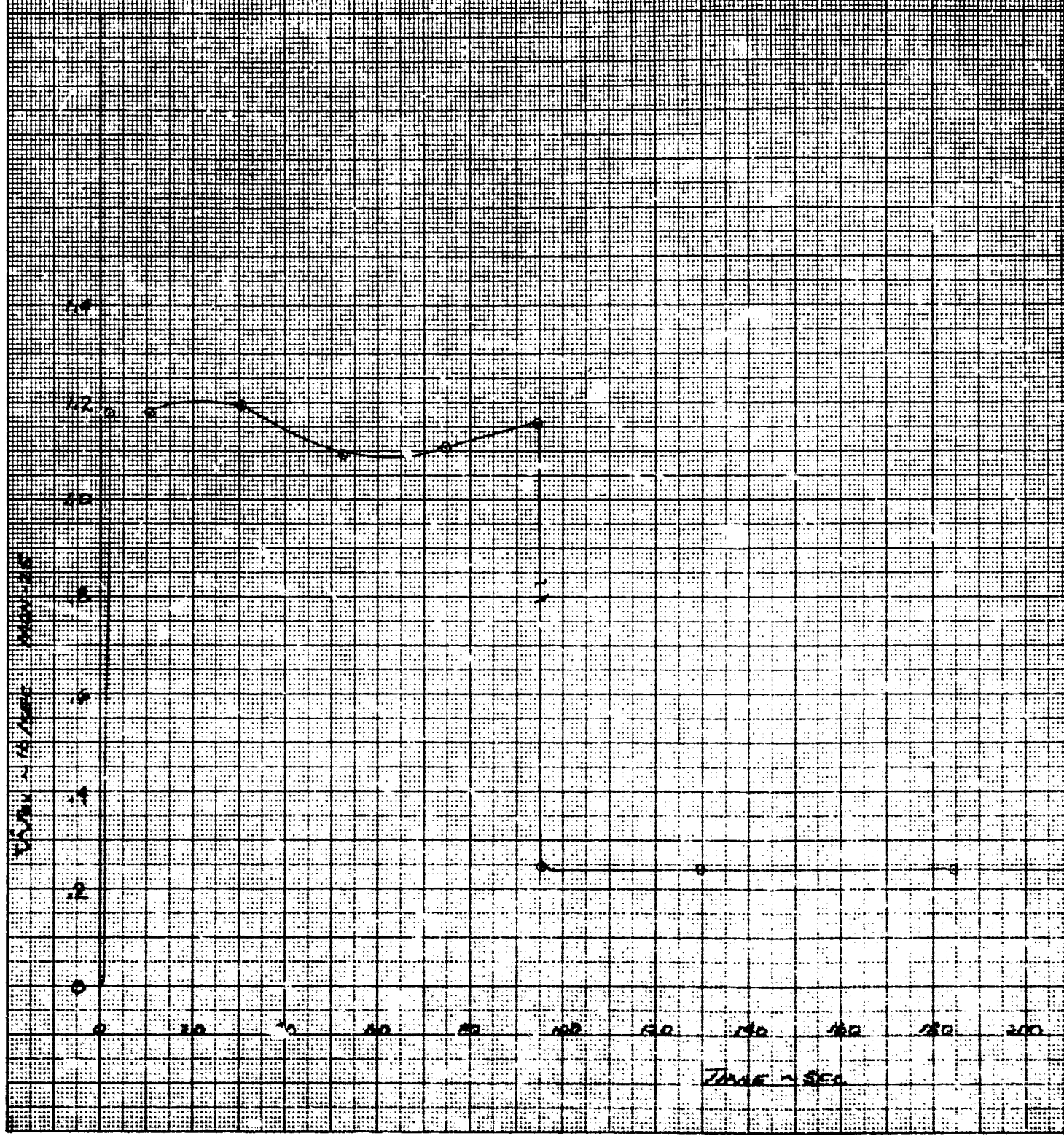
CONFIDENTIAL

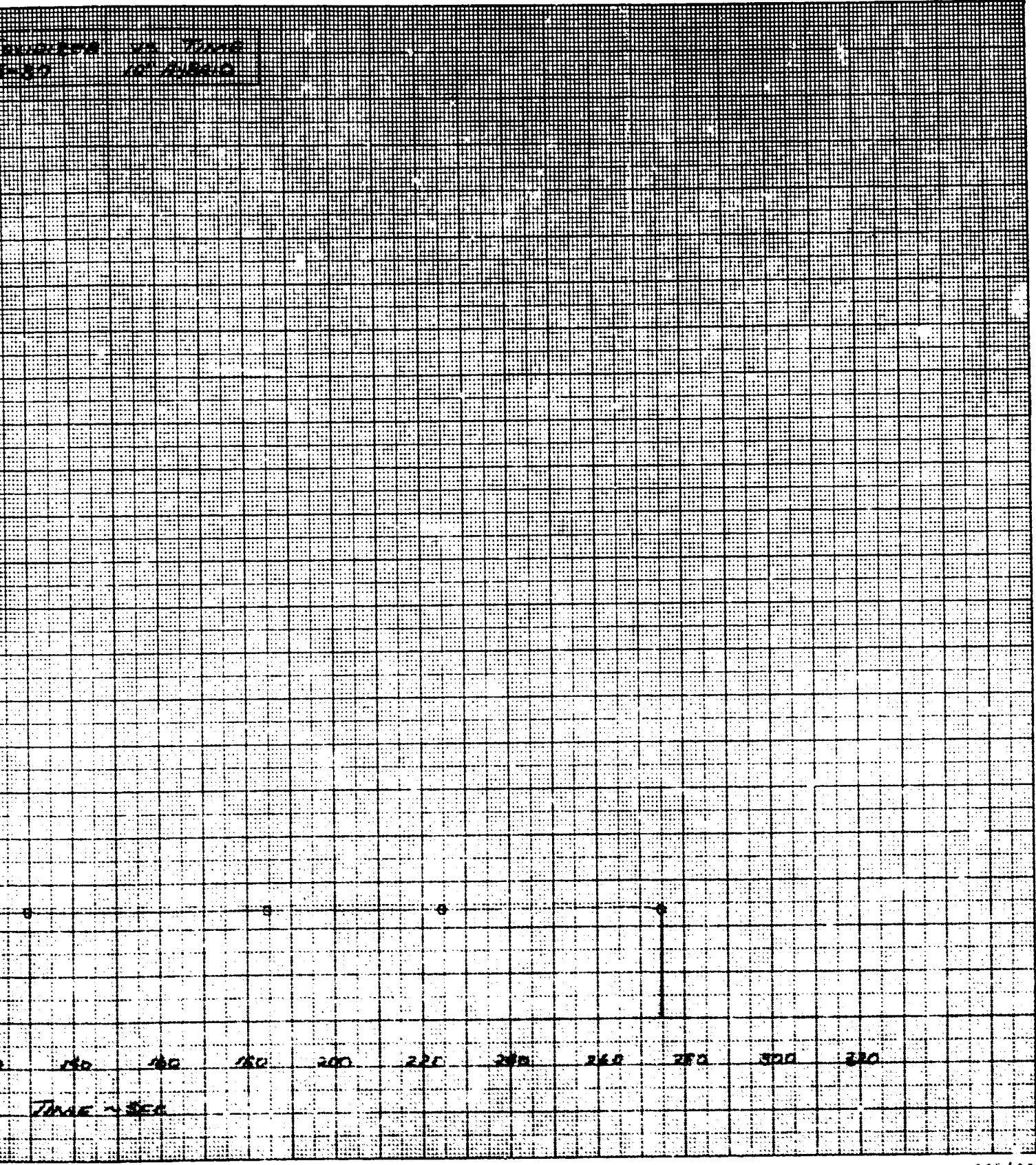


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2

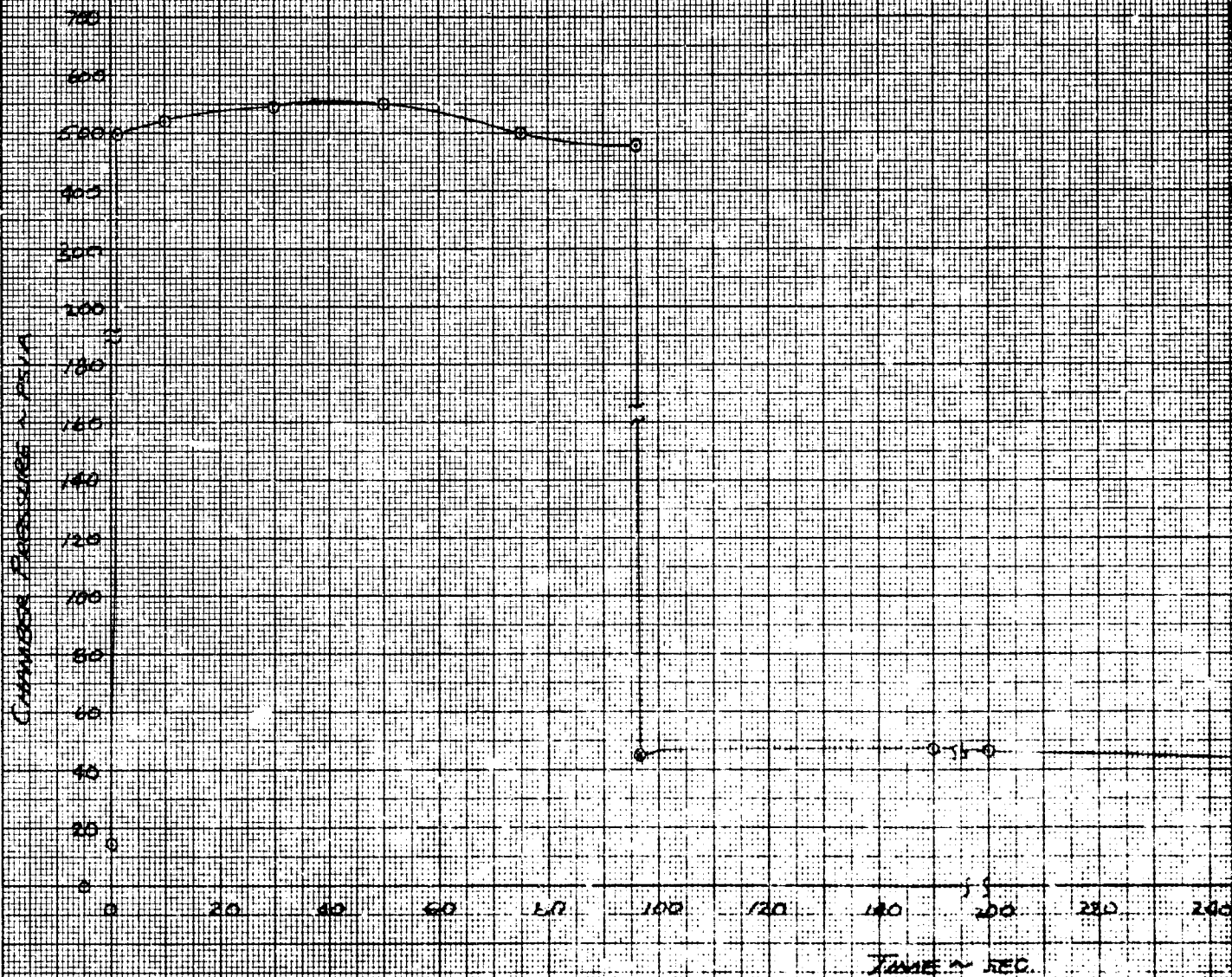
Velocity vs Time
 132-87 10 Mph



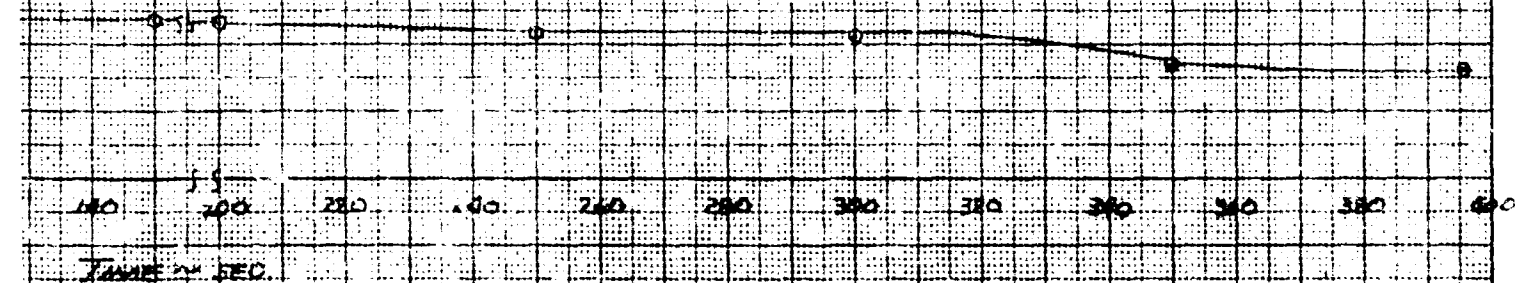


2

CHAMBER PRESSURE VS TIME
H35-38 10" HYBRID



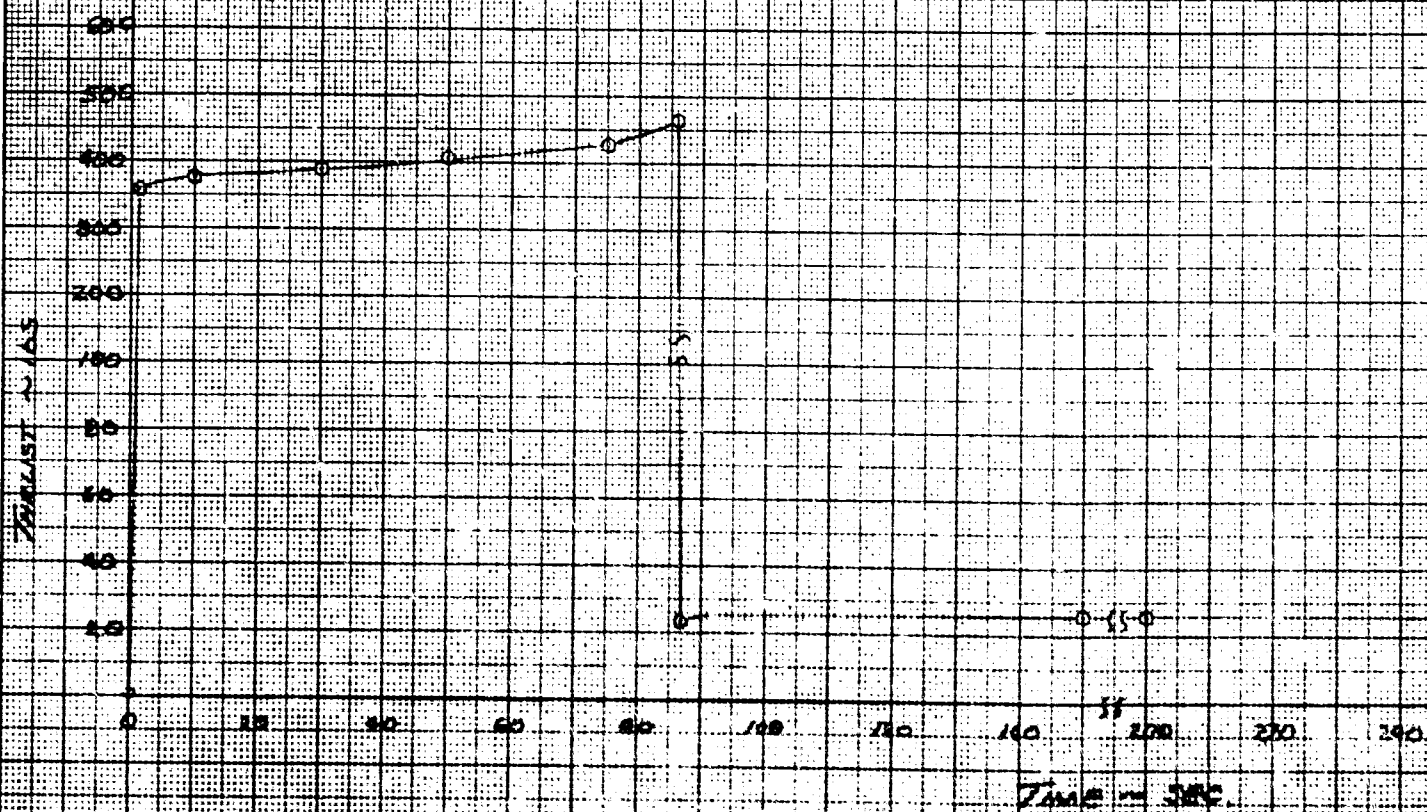
CHAMBER PRESSURE VS TIME
435-38 10" HYBRID



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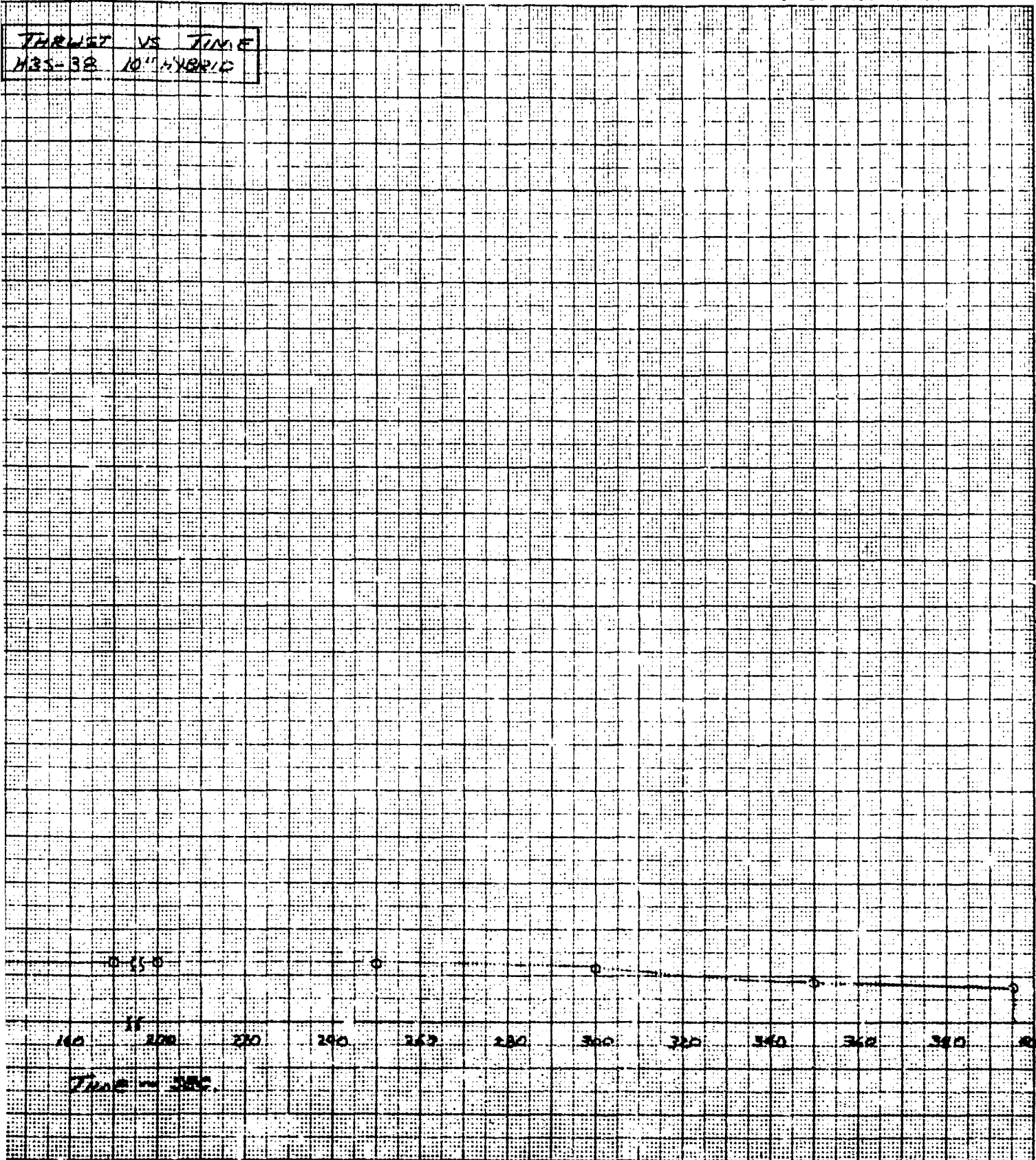
2

THRUST VS TIME
H35-32 10" HYBRID



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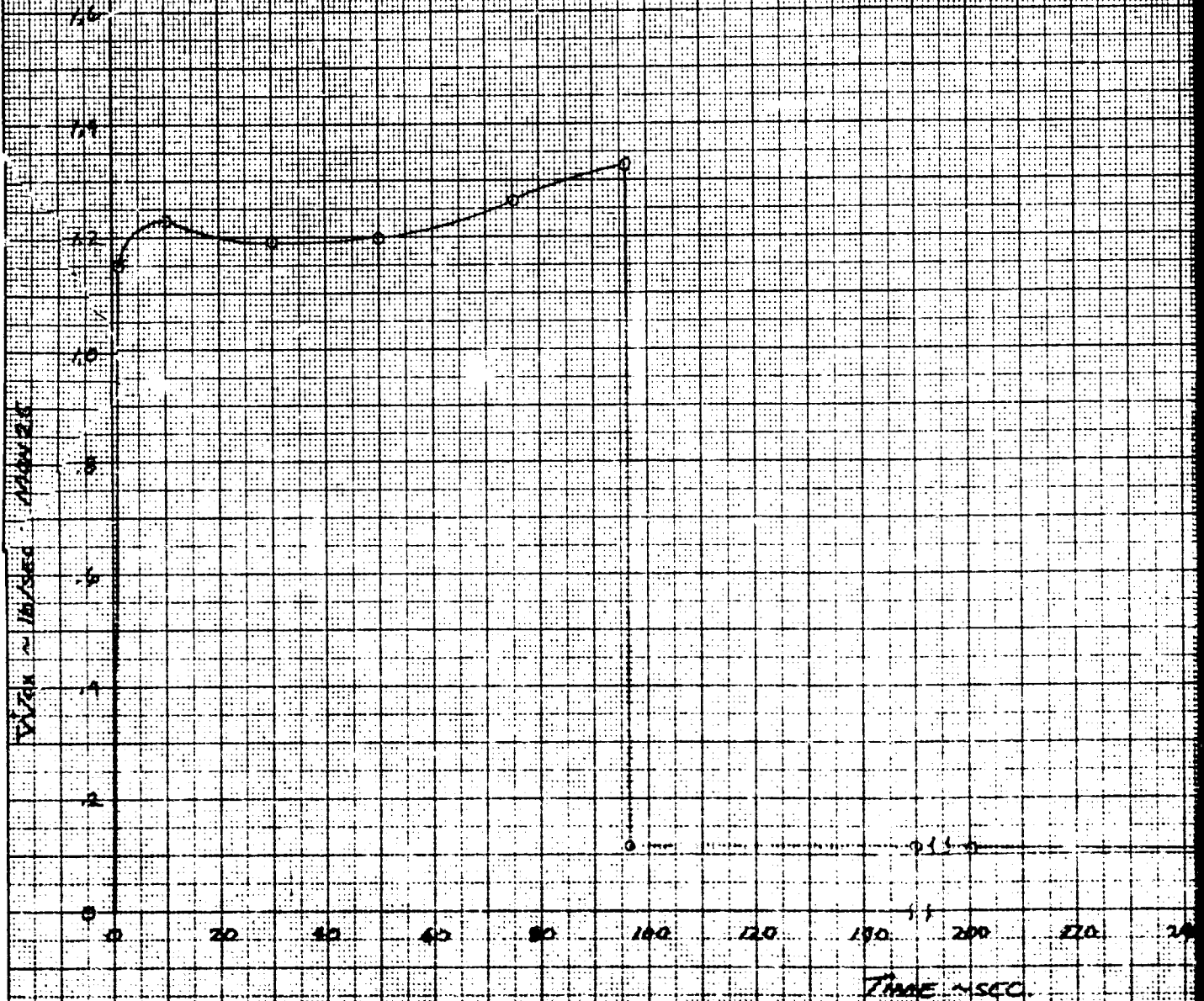
THRUST VS TIME
M35-38 10" HYBRID



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2

VARIABLE VS TIME
H35-3R 10" HYDRO



VARIABLE VS. TIME
H35-35 10" HYBRID

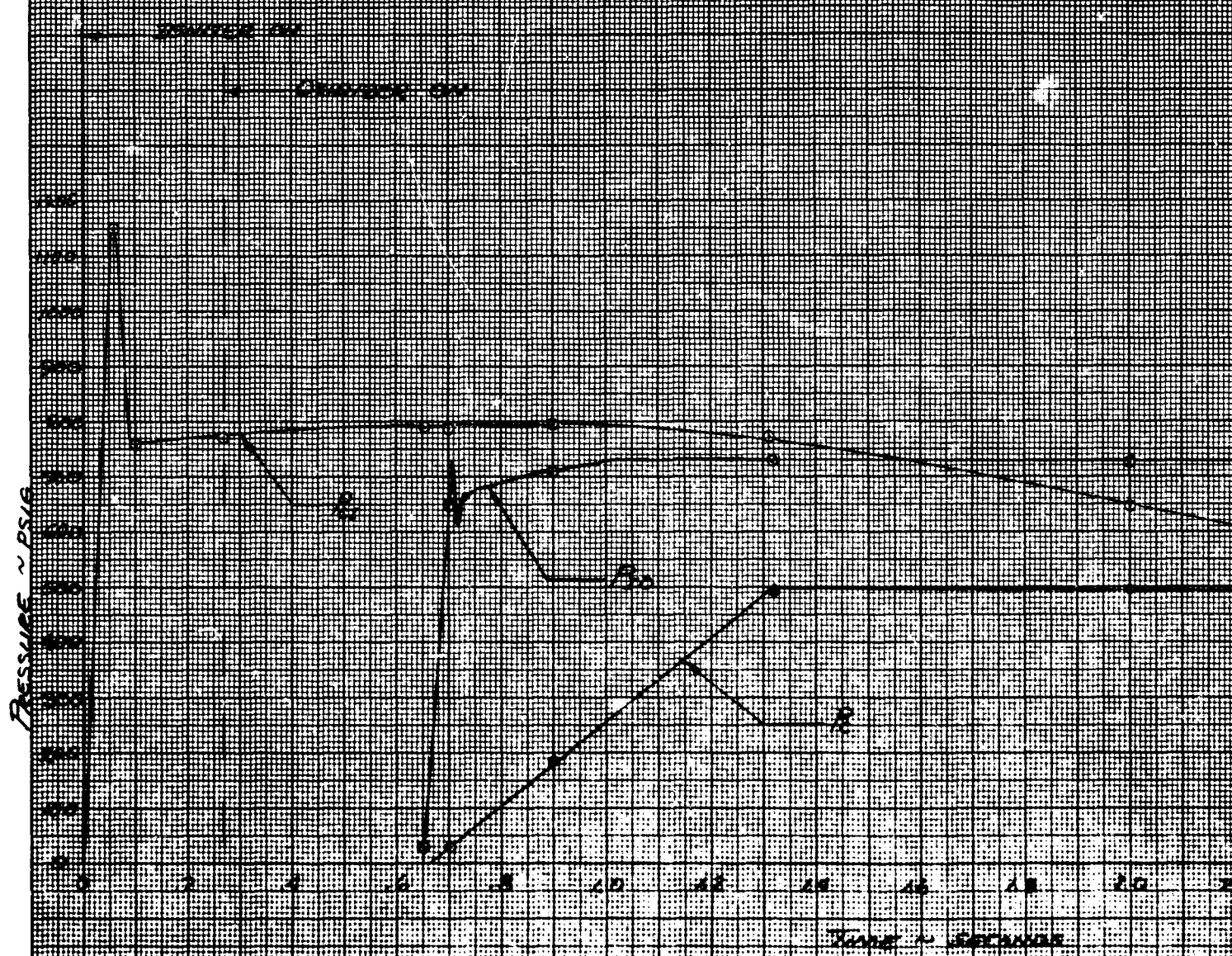
BAROMETER BECOMES UNSTABLE
NOT SUITABLE FOR DATA REDUCTION

190 200 210 220 230 240 250 260 270 280 290 300 310 320 330 340 350

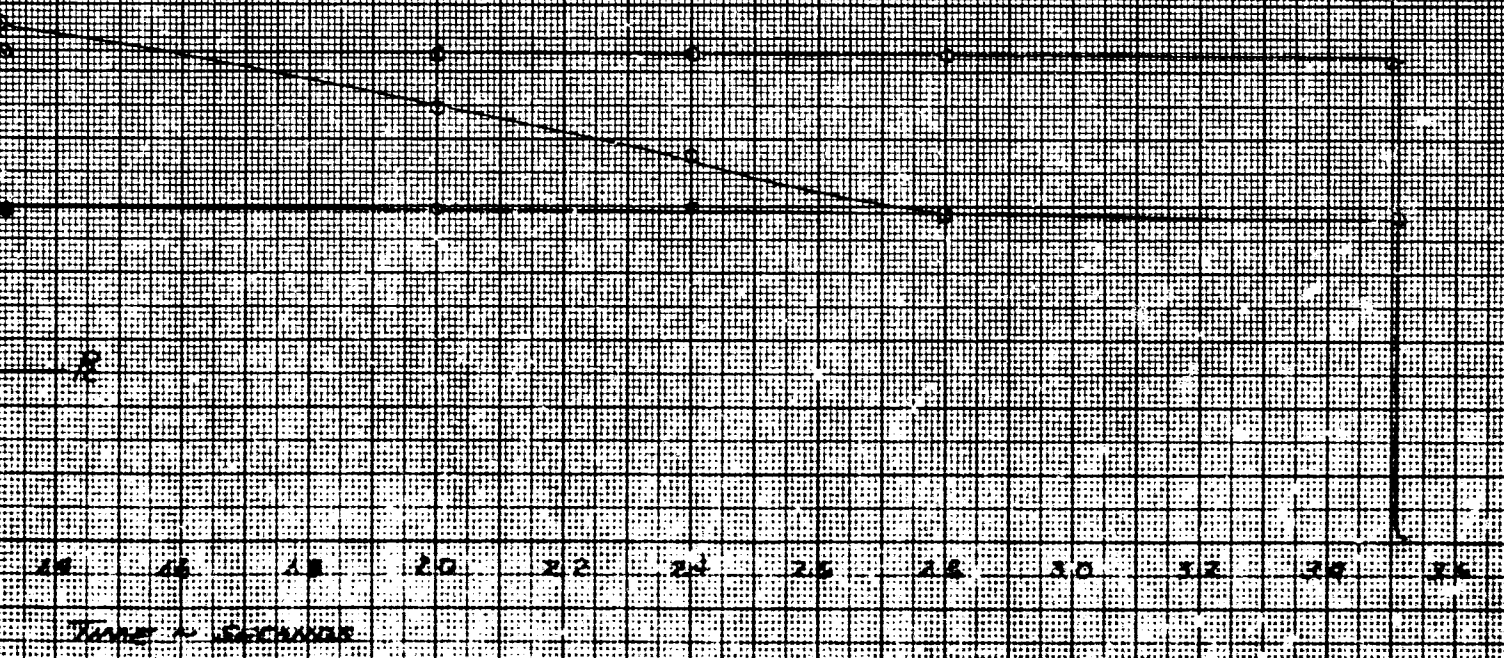
TIME - SEC

2

P₀ = 100
 P₁ = 100
 P₂ = 100
 P₃ = 100
 P₄ = 100
 P₅ = 100
 P₆ = 100
 P₇ = 100
 P₈ = 100
 P₉ = 100
 P₁₀ = 100
 P₁₁ = 100
 P₁₂ = 100
 P₁₃ = 100
 P₁₄ = 100
 P₁₅ = 100
 P₁₆ = 100
 P₁₇ = 100
 P₁₈ = 100
 P₁₉ = 100
 P₂₀ = 100
 P₂₁ = 100
 P₂₂ = 100
 P₂₃ = 100
 P₂₄ = 100
 P₂₅ = 100
 P₂₆ = 100
 P₂₇ = 100
 P₂₈ = 100
 P₂₉ = 100
 P₃₀ = 100
 P₃₁ = 100
 P₃₂ = 100
 P₃₃ = 100
 P₃₄ = 100
 P₃₅ = 100
 P₃₆ = 100
 P₃₇ = 100
 P₃₈ = 100
 P₃₉ = 100
 P₄₀ = 100
 P₄₁ = 100
 P₄₂ = 100
 P₄₃ = 100
 P₄₄ = 100
 P₄₅ = 100
 P₄₆ = 100
 P₄₇ = 100
 P₄₈ = 100
 P₄₉ = 100
 P₅₀ = 100
 P₅₁ = 100
 P₅₂ = 100
 P₅₃ = 100
 P₅₄ = 100
 P₅₅ = 100
 P₅₆ = 100
 P₅₇ = 100
 P₅₈ = 100
 P₅₉ = 100
 P₆₀ = 100
 P₆₁ = 100
 P₆₂ = 100
 P₆₃ = 100
 P₆₄ = 100
 P₆₅ = 100
 P₆₆ = 100
 P₆₇ = 100
 P₆₈ = 100
 P₆₉ = 100
 P₇₀ = 100
 P₇₁ = 100
 P₇₂ = 100
 P₇₃ = 100
 P₇₄ = 100
 P₇₅ = 100
 P₇₆ = 100
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 P₇₉ = 100
 P₈₀ = 100
 P₈₁ = 100
 P₈₂ = 100
 P₈₃ = 100
 P₈₄ = 100
 P₈₅ = 100
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 P₈₈ = 100
 P₈₉ = 100
 P₉₀ = 100
 P₉₁ = 100
 P₉₂ = 100
 P₉₃ = 100
 P₉₄ = 100
 P₉₅ = 100
 P₉₆ = 100
 P₉₇ = 100
 P₉₈ = 100
 P₉₉ = 100
 P₁₀₀ = 100



No. 14 Time
 10:00 AM
 10:00 AM
 10:00 AM



2

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APPENDIX III

DESCRIPTION OF COMPUTER PROGRAM
AND FREE-FIELD NUMBERS
(LF14ZAZ Hybrid Motor Performance Analyzer)

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SECTION I

COMPUTER PROGRAM DESCRIPTION

1. IDENTIFICATION

Program Title: Hybrid Motor Performance Analyzer
Library Number: LF14ZAZ
Computer: B 5500
System: Data Com Version 1 Patches 1-82
Compiler: Data Com Burroughs Extended ALGOL (60)
Version 1 Patches 1-5
Programmer/Analyst: Ken Guy, Ext. 2030
Customer: R. A. Jones
Date: 25 December 1966

2. PURPOSE

- A. To calculate the overall efficiency (N_C^*) of a motor test, such that the computed weight (output) of propellant expended is equal to the measured weight (input) of propellant provided.
- B. Having satisfied the equality of 2A, to calculate and print 15 time-varying parameters characterizing the motor firing.

3. INPUT

All input data are on cards. Multiple cases are allowed, with sequence specifications as required by the INPUT routine (see section II of this appendix).

Card

- C1. (<restricted Hollerith card>):* Any string of characters needed to form a title card
- C2. (<restricted ffcard>): The following values as <ffnumber>s:
- A. Start Time of Test (sec)

* Refer to section II of this appendix for free-field metalinguistics.

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B. Time Step (sec) - Time step must evenly divide boost time.

Note: Time step $\leq \Delta T_{MAX}$, where ΔT_{MAX} is the time step such that for any time T , start time $\leq T \leq$ end time, $O/F(T) \leq O/F(T - \Delta T_{MAX}) \times 1.15$ and $O/F(T) \geq O/F(T - \Delta T_{MAX}) \times 0.85$, except near the boost-sustain interface.

C. End Time of Test (sec)

Note: In this paper, "boost time" refers to the time of the boost-sustain interface and is used solely in describing boost-plus-sustain tests. "End time" or "final time" refers to the time of final motor cutoff (i.e., time of test completion); if the test is a boost, the "final time" is the time of the boost cutoff, and is not referred to as "boost time."

D. Printing Time Step (sec)

The 15 parameters mentioned in 2B are, assuming the equality of 2A, output at every time T such that:

1. $T = \text{start-time}$
2. $\text{Start-time} < T < \text{final-time}$ and $T \text{ MOD } \text{printing-time-step} = 0$
3. $T = \text{end-time}$.

E. Maximum number of motor tests to achieve the equality of 2A

F. Motor radius (in.)

G. Motor length (in.)

H. Fuel port radius at start time (in.)

I. Fuel density (lb/in.³)

J. Expended weight of propellant (lb)

K. Acceleration due to gravity (ft/sec²)

L. Error bound for equality in 2A (recommended: 0.05)

M. Nozzle thrust coefficient efficiency.

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- C3. (<restricted ffcard>): $\dot{W}_{ox}$ FGEN* (lb/sec; sec)
- C4. (<restricted ffcard>): Exist area FGEN (in.²; sec)
- C5. (<restricted ffcard>): Pressure FGEN (lb/in.²; sec)
- C6. (<restricted ffcard>): Gamma FGEN (; sec)
- C7. (<restricted ffcard>): Chamber-pressure drop FGEN (; sec)
- C8. (<restricted ffcard>): Ambient pressure FGEN (lb/in.²; sec)
- C9. One of the following:
 - A. (<restricted ffcard>): Thrust FGEN (lb; sec)
 - B. (<restricted Hollerith card>): Boost time (sec)
 - C. (<restricted Hollerith card>): Blank card.

C9-A is used if the thrust curve is known either to boost or to end time (i.e., if the test is a boost and the thrust curve is known, or if the test is a boost plus sustain and the thrust curve is known only for the boost). In the latter case, the program will compute the rest of the FGEN. The first card of the <ffcard> set must contain at least two <ffnumber>s.

C9-B is used if the test is a boost-plus-sustain and the thrust FGEN is unknown.

C9-C is used if the test is only a boost, and the thrust FGEN is unknown.

- C10. One of the following:
 - A. (<restricted ffcard>): Throat area FGEN (lb; sec)
 - B. (<restricted Hollerith card>): Throat area at start time, throat area at end of time (in.²)
 - C. (<restricted Hollerith card>): Throat area at start time, throat area at boost time, throat area at end time (in.²), boost time (sec).

* FGEN refers to the set of values needed to characterize a piecewise linear approximation to a curve. The first value is the integer <ffnumber> (=K) of points (abscissa-ordinate pairs) describing the piecewise linear line. The remaining values are the <ffnumber>s: Abscissa₁, Ordinate₁, Abscissa₂, Ordinate₂, ..., Abscissa_k, Ordinate_k. The entire set contains 2k+1 values. In our case, all FGEN are time functions. Abscissas must be increasing.

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C10-A is used whenever the throat area is completely known. The first card of the <ffcard> set must contain at least four <ffnumber>s.

C10-B is used if the test is a boost and the throat area FGEN is unknown. Both values are <ffnumber>s, and they both are confined to the same card.

C10-C is used if the test is a boost plus sustain and the throat area FGEN is unknown. All four values are <ffnumber>s, and all four are confined to the same card. If the test is a boost-plus-sustain, and if an FGEN curve exhibits step function characteristics at this interface, the following procedure should be used to represent the step:

1. For a boost time T_B , let the value of the FGEN curve (F) from the left be $F(T_B)^-$, and from the right be the value $F(T_B)^+$. Choose some small value ϵ ($\leq 10^{-3}$), and assign a new point $F(T_B + \epsilon) = F(T_B)^+$, while retaining the old point $F(T_B)^-$. Thus, the step is now a slope with base $= \epsilon$.
2. Every FGEN curve with step-function characteristics at boost time must be described as in 1, with the same ϵ . This latter requirement is very important.

C11. C_{th}^* FMAP data. All of the following:

- 11A (<restricted ffcard>): Integer number ($=K$) of oxyfuel-ratio ($=O/F_1$) values, $O/F_1, O/F_2, \dots, O/F_K$
- 11B (<restricted ffcard>): Integer number ($=N$) of level pressure curve ($=PC_i$) values, $PC_1, PC_2, \dots, PC_N$
- 11C (<restricted ffcard>): $C_{th}^*(1, 1), C_{th}^*(1, 2), \dots, C_{th}^*(1, N),$
 $C_{th}^*(2, 1), C_{th}^*(2, 2), \dots, C_{th}^*(2, N),$
 $\dots, \dots, C_{th}^*(K, 1), C_{th}^*(K, 2), \dots,$
 $C_{th}^*(K, N).$

All values of the Card-11 group are <ffnumber>s.

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4. OUTPUT

The following describes output for normal operations and may be altered by diagnostics output. The output information under discussion starts on the page indicated, but may be continued on as many pages as needed to complete the output.

A. Page 1

Listing of data deck, with current date.

B. Page 2

The title (see Card 1), the current date, and an edited representation of Cards 3, 4, 5, 6, 7, 8, 9A (if used) and 10A (if used).

C. Page 3 (Under Confidential Status)

An edited representation of Card 11 and Cards 2, 9B (if used), and either 10B or 10C (if either is used).

D. Page 4 (Under Confidential Status)

1. A columnar tabulation from start-time to end-time of the following 16 time-varying parameters:
 - a. Time
 - b. $\dot{W}_{OX}$ (input)
 - c. Expansion ratio ϵ (calculated)
 - d. Thrust (input, completed, or wholly calculated)
 - e. Chamber pressure (input)
 - f. Throat area (input or calculated)
 - g. Thrust coefficient $C_F \cdot N_{CF}$ (calculated)
 - h. I_{sp} (calculated)
 - i. C^*_{DEL} (calculated)
 - j. $\dot{W}_F$ (calculated)
 - k. Radius (calculated)
 - l. W_O (calculated)
 - m. Oxyfuel-ratio (calculated)

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- n. $\dot{R}$ (calculated)
 - o. G_0 (calculated)
 - p. Weight propellant expended (calculated).
2. The N_C^* yielding the equality of $2A$ (such a yield is hereafter termed a "successful test").
 3. The error function involved in computing the throat area (if the throat area was not input).

This error-function, $F(\text{time})$, is linear and passes through the point (start time, initial error function {output value}) and the point (end or boost time {whichever is less}, final error function {output value}). The ordinate of each point is, respectively,

$$\left. \frac{\text{THRUST}}{\text{PC} \cdot C_F \cdot A_T} \right|_{\text{start-time}}, \quad \left. \frac{\text{THRUST}}{\text{PC} \cdot C_F \cdot A_T} \right|_{\text{end time}}$$

Zero error is the line: error-function = 1.

5. RESTRICTIONS

A. Restrictions Imposed on Value

1. The values of Card 2 have the following bounds, in the form (lower bound, higher bound):
 - a. (0.0, 0.0) f. (0.0, 60.) j. (0.0, 2 at 5)
 - b. (0.05, 5.) g. (0.0, 400) k. (0.0, at 02)
 - c. (0.0, at 03) h. (0.0, 60.) l. (0.01, 1.)
 - d. (0.1, 10.) i. (0.0, 0.1) m. (0.89, 1.)
 - e. (15., at 02)
2. The number of input points in an FGEN curve must be >1 , <102 . If the thrust FGEN is to be completed to final time in a boost-plus-sustain, it is recommended that the number of input points for the thrust FGEN be <71 .
3. The value of ϵ must not change (see note with Card 10C).

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4. The following values have the bounds:

- a. Boost time: $(0, 10^3)$
- b. Initial throat area: $(0, 10^3)$
- c. Final throat area: $(0, 10^3)$
- d. Boost throat area: $(0, 10^3)$.

B. Restrictions Imposed on Options

- 1. Either Card 9A and any card of Card 10, or Card 10A and any card of Card 9, must be used. Card 9A with thrust only to boost time for a boost-plus-sustain test may not be used with Card 10A.
- 2. The input boost time must be different from the input final (end) time.

C. Miscellaneous Restrictions

- 1. Restrictions imposed by the INPUT routine (see section II of this appendix).
- 2. The input FMAP C_{th}^* must be composed of not more than 50 pressure curves, with each curve containing not more than 50 oxyfuel-ratio points.

The restrictions A-1, A-2, A-4, B-1, B-2, and C-1 are program monitored and, when violated, produce an error message. A-1, A-2, A-4, B-1, and B-2 cause the current motor test to be flushed.

6. DIAGNOSTICS

- A. Diagnostics as provided by INPUT routine (see section II of this appendix).
- B. Diagnostics as provided by restrictions A-1, A-2, A-4, B-1, and B-2.
- C. If the thrust coefficient is unobtainable after 20 iterations, a message is printed.

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- D. If the input data does not produce a $\text{Max } N_C^*$ and $\text{Min } N_C^*$ enclosing that N_C^* yielding the equality of $2A$, the current motor test is flushed outputting:
1. The restricting N_C^* bound
 2. The main function $F(O/F, \text{time}, N_C^*)$ which, for all time T , $\text{start-time} \leq T \leq \text{end-time}$, must have a zero for some O/F , $\{\text{Min } O/F \text{ of Card 11A}\} < O/F < \{\text{Max } O/F \text{ of Card 11A}\}$.
 3. The final results of a firing at this N_C^* .

7. GENERAL INFORMATION

- A. Average time for one test ~60 sec
- B. Storage requirements ~13,000 words.

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SECTION II

DESCRIPTION OF FREE-FIELD NUMBERS

1. DEFINITION AND SYNTAX OF FREE-FIELD NUMBER

A. Definition

$\langle \text{ffnumber} \rangle ::= \langle \text{unsigned number} \rangle \langle \text{comma} \rangle /$
 $\langle \text{unsigned number} \rangle \langle \text{ffstring} \rangle$
 $\langle \text{comma} \rangle / + \langle \text{unsigned number} \rangle$
 $\langle \text{comma} \rangle / + \langle \text{unsigned number} \rangle$
 $\langle \text{ffstring} \rangle \langle \text{comma} \rangle / - \langle \text{unsigned number} \rangle \langle \text{comma} \rangle / - \langle \text{unsigned number} \rangle \langle \text{ffstring} \rangle \langle \text{comma} \rangle$

$\langle \text{unsigned number} \rangle ::= \langle \text{decimal number} \rangle / \langle \text{exponent part} \rangle /$
 $\langle \text{decimal number} \rangle \langle \text{exponent part} \rangle$

$\langle \text{decimal number} \rangle ::= \langle \text{unsigned integer} \rangle / \langle \text{decimal fraction} \rangle / \langle \text{unsigned integer} \rangle$
 $\langle \text{decimal fraction} \rangle$

$\langle \text{exponent part} \rangle ::= @ \langle \text{integer} \rangle$

$\langle \text{decimal fraction} \rangle ::= \cdot \langle \text{unsigned integer} \rangle$

$\langle \text{integer} \rangle ::= \langle \text{unsigned integer} \rangle / + \langle \text{unsigned integer} \rangle / - \langle \text{unsigned integer} \rangle$

$\langle \text{comma} \rangle ::= ,$

$\langle \text{unsigned integer} \rangle ::= \langle \text{ffdigit} \rangle / \langle \text{unsigned integer} \rangle \langle \text{ffdigit} \rangle$

$\langle \text{ffstring} \rangle ::= \langle \text{ffletter} \rangle / \langle \text{ffstring} \rangle \langle \text{ffletter} \rangle /$
 $\langle \text{ffstring} \rangle \langle \text{ffdigit} \rangle$

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<ffdigit> ::= 0/1/2/3/4/5/6/7/8/9/<blank space>

<ffletter> ::= A/B/C/D/E/F/G/H/I/J/K/L/M/N/
O/P/Q/R/S/T/U/V/W/X/Y/Z/+/-/x/
=/#/>=</>/</(<)/[<]/<*/<-/<.<./<:/<:
<blank space>

<blank space> ::= {a single unit of horizontal spacing
which is blank; an unpunched or
skipped column on a card}

B. Syntax

1. A <ffnumber> must always end in a <comma>, and must contain only one <comma>. The <ffstring> must never start with a <ffdigit>, but must start with a <ffletter>; thereafter, up to the <comma>, any combination or "string" of <ffletter>s or <ffdigit>s is allowed. The <comma>, the @, and the / are not a part of the <ffletter> definition.
2. Examples of <ffnumber>s:
 - a. The value of each <ffnumber> is 123.456
123.456,
123.4 5 6,
1 2 3 . 45 6,
123.456 = THE % FOR NO. 1 (I. E. 2#),
1. 23 4 56 @ +0 2,
+1. 23456@+2,
1. 23456@2,
123.456@0,
123456@-3,
123.456 ,

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b. The value of each <ffnumber> is 2.0

2.0,

2,

002,

2@0,

2.0 00 0,

2. ,

2 OUNCES OF #4 THREAD(*),

c. The value of each <ffnumber> is 7 (integer)

7.0,

7,

7.4,

7.4999,

.7@1,

7 POINTS FOR F(x) = "TIME",

07POUNDS ,

Note: If the value of an ff<number> is intended to be integer, the value taken will be largest integer [<ffnumber> + 0.50000...]; hence 7.4999 is 7.

d. The value of each <ffnumber> is 4.0×10^{23}

4@23,

40@22,

+4 0 00. 00 @ 2 0 ISHA RDTOREA D ,

3. Examples of confusing <ffnumber>s:

The values of each line is not (i) 70492 or (ii) only 70492.

70,492

[value of 70; and Incomplete Value - see below]

70492

[Incomplete Value]

X = 70492,

[Ignored Value - see below]

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70491,

[value of 7049; "I" is
mispunched "2"]

70492 SETS(I.E., 2 GROUPS) [Value of 70492; and Incom-
plete Value]

4. Punching <ffnumber>s on an <ffcard>; Incomplete Values; and Ignored Values

a. Definition of <ffcard>

<ffcard> ::= <restricted ffcard> /
<unrestricted ffcard>

<unrestricted ffcard> ::= <unrestricted Hollerith
card> / <unrestricted
ffcard> <unrestricted
Hollerith card>

<restricted ffcard> ::= <restricted Hollerith
card> / <restricted ffcard>
<restricted Hollerith card>

<unrestricted
Hollerith card> ::= {ordinary 80 column "IBM"
card with full 80 columns
available}

<restricted
Hollerith card> ::= {ordinary 80 column "IBM"
card with full 71 columns
available (Cols. 1-71) and
a "/" punched in Col. 72;
Cols. 73-80 are reserved
for sequencing}

b. Syntax

The <ffcard> is a set of Hollerith cards. The <ffcard>
set contains either <unrestricted Hollerith card>s or
<restricted Hollerith card>s, but not both. The only
characteristic not indicated in the definition (to do so
would unduly complicate matters) is, if the next card
is not an <ffcard>, then the last <restricted Hollerith
card> or <unrestricted Hollerith card> of the current

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<ffcard> set must contain at least one <comma> needed to end a used <ffnumber>, (i.e., an <ffnumber> required as input by the program).

The <ffcard> definition includes the <restricted ffcard> refinement because many programs employ one of the several card-input routines (e.g., INPUT) which require certain card and case sequencing in Columns 73 - 80. For such programs, refer to the appropriate input-routine writeup.

In the following example, the letters LC indicate the last Hollerith card, the letters UR indicate "unrestricted," the letter R indicates "restricted," and the left bracket ({) indicates an <ffcard>.

Example of the value 123.456 and the value 74 as punched on an <ffcard>:

	COL 1			COL 72	COL 80
{UR,LC:	123.456,	74,			
{UR,LC:	123.456 POUNDS,		74 FEET,		
{R,LC:	123.456,	74,	/		
{R,LC:	123.456 POUNDS,		74 FEET,	/	
{UR:	1	2			
{UR:	3	.			
{UR:	4		5		6
{UR:	P	U	N		
{UR:	D	S,	7		
{UR:					
{UR,LC:	4			FE	E T,
{R:	1	2	/		
{R:	3	.	/		
{R:	4		5	6/	
{R:	P	U	N	/	
{R:	D	S,	7	/	
{R:				/	
{R,LC:	4		FE	ET,	/
{UR:					
{UR,LC:	123456@-	3POUNDS,	7.	4@+	1FEET,

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c. Incomplete Values

An incomplete value is encountered whenever the intended <ffnumber> does not have its ending <comma>; the result is the continual reading of the Hollerith card(s) until a <comma> is encountered or an END OF FILE situation occurs. In either case, the program receives data both incorrect and out of sequence.

Example: The values 74, 123.456, 27 are intended to be represented as <ffnumber>s on an <ffcard>; but 123.456 is actually an incomplete value

	COL		COL	COL
	1		72	80
{UR:	74,	123.456		
UR:				
UR,LC:	27,			

The second <ffnumber> has the value 123.45627, and the further reading of any <ffnumber>s would be out of sequence by one <ffnumber>.

d. Ignored Values

An ignored value is encountered whenever the intended <ffnumber> begins with an <ffstring> instead of an <ffdigit>. The result is that the variable into which the <ffnumber> was to be stored is unchanged; the reading process ignores this <ffnumber> and proceeds to the next <ffnumber>. The proper sequence of <ffnumber>s is, however, unaltered.

Example: The values 72 and 123.456 are to be read; but the value 74 is ignored and the value 123.456 is properly read.

	COL		COL	COL
	1		72	80
{UR,LC:	N = 74,	123.456 = N,		

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(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) United Technology Center Division of United Aircraft Corporation Sunnyvale, California		2a. REPORT SECURITY CLASSIFICATION CONFIDENTIAL	
3. REPORT TITLE Hybrid Propulsion System for an Advanced Rocket-Powered Target Missile (U)		2b. GROUP 4	
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Quarterly Technical Report covering period from 1 October 1966 through 31 December 1966			
5. AUTHOR(S) (Last name, first name, initial) Jones, Richard A.			
6. REPORT DATE February 1967		7a. TOTAL NO. OF PAGES 259	7b. NO. OF REFS None
9a. CONTRACT OR GRANT NO. AF 04(611) - 11632 b. PROJECT NO. c. d.		9b. ORIGINATOR'S REPORT NUMBER(S) UTC 2220-QTR2 9d. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFRPL-TR-67-54	
10. AVAILABILITY/LIMITATION NOTICES In addition to security requirements which must be met, this document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of AFRPL (RPPR/STINFO), Edwards, California 93523			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY Air Force Rocket Propulsion Laboratory Research and Technology Division Air Force Systems Command United States Air Force	
13. ABSTRACT The development of a hybrid propulsion system for an advanced rocket-powered target missile has advanced through the seventh program month. During the past 3 months, the heavyweight motor test series was completed successfully, and designs have been finalized for the flightweight thrust chamber assembly components. The results of the final nozzle evaluation tests have shown that the nozzle configuration selected has a nozzle material erosion rate of 0.45 mils/sec. Motor ignition has been demonstrated at -65° F at sea-level conditions and at a simulated altitude of 50,000 ft. The required thrust ratings have been demonstrated at boost and sustain thrust levels for the durations specified, and step thrust operation has been verified over an 8 to 1 range. The flightweight feed system component buildup has been initiated and cold-flow checkout tests will be conducted during the next reporting period. The current status of the program indicates that the hybrid propulsion units to be used in the flight demonstration program will be delivered in accordance with the original schedule.			

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT

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