NASA CR-144971
JAN 9, 1976

YF-12 LOCKALLOY VENTRAL FIN PROGRAM FINAL REPORT

VOLUME 1

By R. J. Duba, A. C. Haramis, R. F. Marks,
L. Payne and R. C. Sessing

Prepared for the joint NASA/USAF YF-12 Project by

LOCKHEED-CALIFORNIA COMPANY

A division of Lockheed Aircraft Corporation

ADVANCED DEVELOPMENT PROJECTS

Burbank, Calif.

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

(NASA-CR-144971) YF-12 LOCKALLOY VENTRAL FIN PROGRAM, VOLUME 1 Final Report (Lockheed-California Co.) 453 p HC $12.00 CSCL 01C
N76-23252
Unclas
G3/05 28212

NASA CR-144971
JAN 9, 1976

YF-12 LOCKALLOY VENTRAL FIN PROGRAM FINAL REPORT

VOLUME 1

By R. J. Duba, A. C. Haramis, R. F. Marks,
L. Payne and R. C. Sessing

Prepared for the joint NASA/USAF YF-12 Project by

LOCKHEED-CALIFORNIA COMPANY

A division of Lockheed Aircraft Corporation

ADVANCED DEVELOPMENT PROJECTS

Burbank, Calif.

for

**NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION**

FOREWORD

This final report documents the results of a program undertaken by the Lockheed Aircraft Corporation, Advanced Development Projects, for the joint NASA/USAF YF-12 Project. The report is prepared in two volumes. Volume 1 contains two parts. Part I provides an overview of the entire program, while Part II provides a detailed account of the program. Supporting test data and special reports prepared during the course of the program are presented as appendixes in Volume 2 of the report.

ABSTRACT

This report presents the results of the YF-12 Lockalloy Ventral Fin Program which was carried out by Lockheed Aircraft Corporation - Advanced Development Projects for the joint NASA/USAF YF-12 Project. The primary purpose of the program was to redesign and fabricate the ventral fin of the YF-12 research airplane, using Lockalloy, an alloy of beryllium and aluminum, as a major structural material. A secondary purpose, was to make a material characterization study of Lockalloy to validate the design of the ventral fin and expand the existing data base on this material. The report, therefore, covers all significant information pertinent to the design and fabrication of the ventral fin and presents the material characterization test results. Emphasis throughout is given to Lockalloy fabrication techniques and attendant personnel safety precautions.

ACKNOWLEDGMENT

Appreciation is expressed to ADP personnel, in both shop and engineering, whose support was essential in preparation of this report. Thanks is also given to the personnel of the Lockheed Rye Canyon facility, Structures and Materials Laboratory, especially W. Krupp and D.E. Pettit for their fracture toughness and crack growth analysis and E. Walden for his metallographic analysis of the Lockalloy material.

SUMMARY

Lockheed Aircraft Corporation - Advanced Development Projects (ADP) has recently completed a program to redesign and fabricate the ventral fin assembly of a National Aeronautics and Space Administration (NASA) YF-12 research airplane. This program, which was carried out under the joint NASA/USAF YF-12 Project, entailed the first major application of Lockalloy, an alloy of beryllium and aluminum, for a major structural component of an airplane. The program also called for a Lockalloy material characterization study to be carried out concurrently with the ventral fin design and fabrication effort.

Since the YF-12 is a high-performance airplane, its ventral fin is often subjected to loadings at temperatures approaching 600°F. Under these conditions, aeroelastic effects and flutter are a principal concern. Experience has shown that these phenomena are a function of structural rigidity and can be minimized by simply designing a stiffer fin. The necessary stiffness could have been achieved with an all-titanium structure; however, the penalty of added weight and possibly more parts appeared to be unacceptable. Consequently, a new design based upon the use of Lockalloy was proposed.

Lockalloy combines the ductile properties of aluminum with the high strength, low density, and stiffness of beryllium. It has excellent thermal characteristics and also exhibits good formability and machining characteristics. The new design, using Lockalloy as the major structural material for the ventral fin, called for a semimonocoque structure in which a relatively thick skin of Lockalloy panels serve to absorb the primary internal loads. A light titanium rib and beam skeleton supports and stabilizes the panels. For simplicity, a symmetrical hexagon airfoil was chosen since this section comprises all flat surfaces, and panel bends are needed only to form the leading and trailing edge wedges.

The Lockalloy material needed for the program was ordered from Kawecki Berylco Industries, Inc. immediately following contract award. Each piece of incoming Lockalloy material was qualification tested before use to ensure that its mechanical properties were consistent with the manufacturer's certification. This provided added assurance to the designer that the material would be compatible with its intended use.

The easy formability and machinability of Lockalloy were confirmed during fabrication of the ventral fin. Significantly, not one of the panels had to be scrapped during ~~the~~ ventral fabrication. Standard cutting tools used for structural aluminum alloys were used for the Lockalloy and no postmachining etching was required to eliminate microcracking. Lockalloy parts were hot-formed with relative ease on open-face ceramic dies. Forming was accomplished in the furnace without the use of a hot press. Formed parts did not require cleaning to remove oxidation.

Due to the toxicity associated with inhalation of beryllium particles, most machining of Lockalloy parts was accomplished by outside vendors who were specially equipped for this. However, safety tests performed during the program disclosed that relatively simple machining operations, such as reaming, countersinking, etc., can be done safely in-plant using only portable vacuum equipment to collect the beryllium particles. The safety tests ~~were~~ carried out under the supervision of Lockheed's Industrial Safety Department. These tests revealed that Lockalloy can be handled with relative safety by fabrication personnel despite its beryllium content. Special precautions need only be taken during machining to prevent dispersal of the beryllium particles; none are needed in connection with hot-forming operations.

Since this was one of the first major uses of Lockalloy, the material characterization study was carried out to validate the design concept and also provide additional data relative to the mechanical properties of this material.

The results of the tests indicate that Lockalloy is ideally suited to this and similar applications where light weight and stiffness in the face of compression-type loading are requisites.

TABLE OF CONTENTS

VOLUME 1

PRECEDING PAGE BLANK N

PAGE

PART I PROGRAM OVERVIEW (Continued)

PAGE

PART II PROGRAM DETAILS

SECTION

SECTION PAGE

SECTION PAGE

VOLUME 2

LIST OF ILLUSTRATIONS

PART I - PROGRAM OVERVIEW

PRECEDING PAGE BLANK NOT FILMED

PART II - PROGRAM DETAILS

LIST OF TABLES

PART I

PROGRAM OVERVIEW

SUMMARY

Part I contains and explains the viewgraphs prepared as a summary for the final contractor report on the YF-12 Lockalloy Ventral Fin Program, prepared for the joint NASA/USAF YF-12 Project.

The results of this program have demonstrated that Lockalloy is a suitable structural material for aerospace application. In view of the present lack of adequate statistical data on Lockalloy, any critical application will require continuous monitoring of the properties for the received material before it is applied. This is the same procedure which Lockheed used to design and build the YF-12 Mach 3 vehicle some fourteen years ago when the titanium alloys were also lacking an adequate statistical data background.

The data obtained during this program agreed reasonably well with the expectations as based on earlier information, except that the forming bend radii were not quite as good as expected.

Enough data has been developed to validate the YF-12 Ventral Fin Design and to justify committing Lockalloy to aerospace structural applications. However, there are areas where Lockheed believes additional testing would be useful, either before or during the next major application of Lockalloy. They include:

1. Establish a satisfactory means, by test and analysis, of determining the Modulus of Elasticity from coupon data, such that it will be consistent with measured stability allowable on plate or column specimens at both room temperature and 600°F.

2. Develop more test data and analysis on the effects of forming at 1050°F and the optimum practical stress relief cycle. The stress relief used on this program was to soak one hour at 1050°F. There are indications that there may be a more optimum heat treat cycle.

3. Establish (by tests) full S-n fatigue curves for $K_t = 1$ and $K_t = 3$, at room temperature and at 600°F.

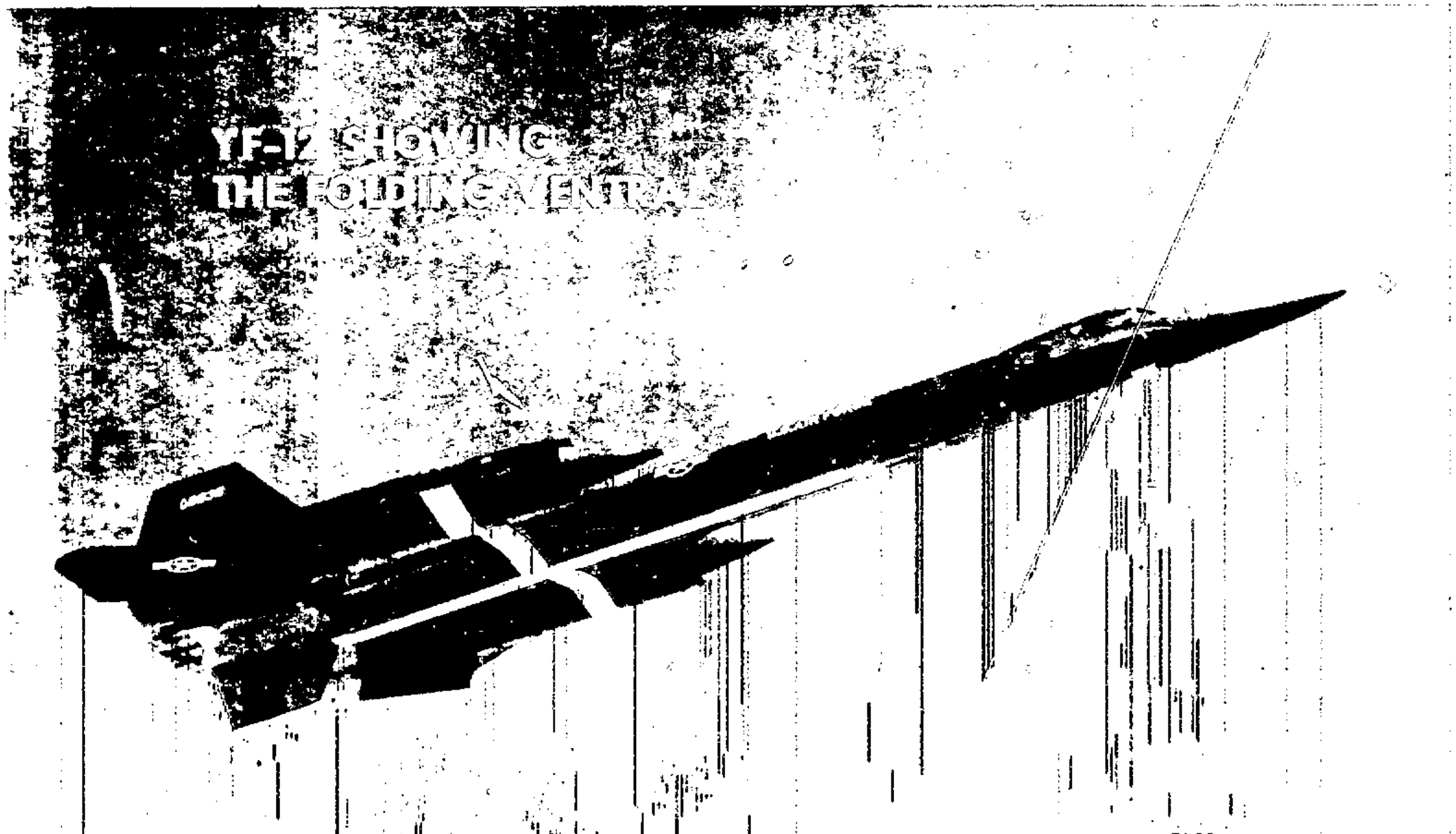
4. Run Creep Data Tests for additional stress levels at 600°F.

ORIGIN OF THE YF-12 LOCKALLOY VENTRAL PROGRAM

IN FEBRUARY OF 1975 THE TITANIUM CENTERLINE VENTRAL FIN ON THE NASA YF-12 MACH 3 AIRPLANE WAS LOST IN FLIGHT WHILE DOING DIRECTIONAL STABILITY TESTS AT MACH .95.

IT WAS DECIDED THAT THE AEROELASTIC DEFLECTIONS OF THE TITANIUM VENTRAL CONTRIBUTE SIGNIFICANTLY TO THE AERODYNAMIC LOADING ON THE VENTRAL. THE REPLACEMENT VENTRAL WOULD HAVE TO BE REDESIGNED WITH INCREASED STIFFNESS.

NO SPARE TITANIUM VENTRALS WERE AVAILABLE FOR REDESIGN AND/OR BEEFUP. IN VIEW OF THE STIFFNESS REQUIREMENTS IT WAS DECIDED TO USE THE BERYLLIUM-ALUMINUM COMPOSITE MATERIAL, KNOWN AS LOCKALLOY, AS THE PRIMARY STRUCTURAL MATERIAL FOR A REPLACEMENT VENTRAL FOR THIS AIRPLANE.



Lockheed "Skunk Works"
January 1976

C159-4

LOCKALLOY VENTRAL FIN PROGRAM

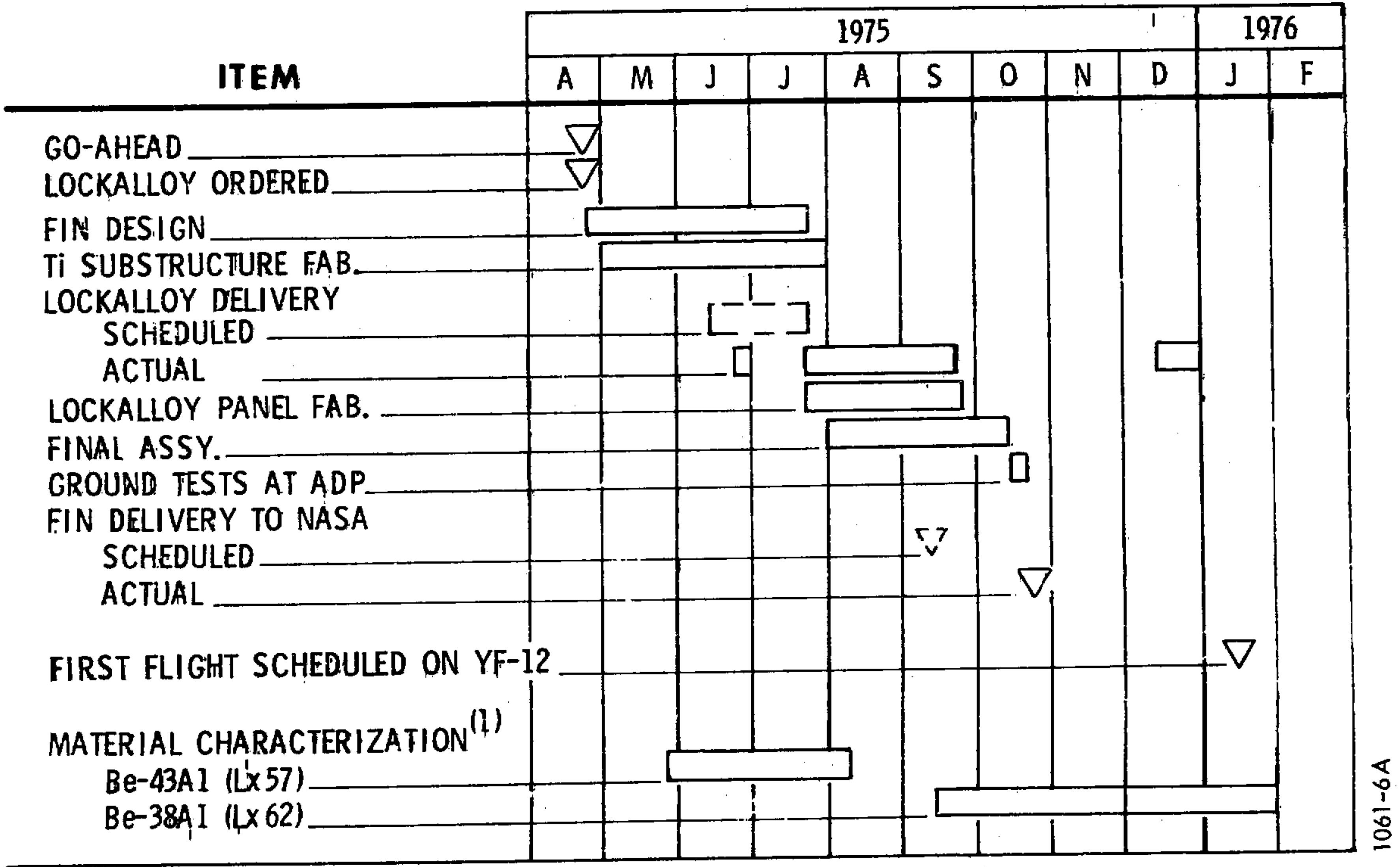
THE GO-AHEAD FOR DESIGNING AND BUILDING THE LOCKALLOY VENTRAL WAS RECEIVED THE LAST WEEK OF APRIL 1975. DELIVERY OF THE VENTRAL FIN TO NASA WAS SCHEDULED FOR MID SEPTEMBER 1975. IN ORDER TO MEET THIS VERY TIGHT SCHEDULE, ALL TASKS WERE CARRIED ON IN PARALLEL. THE DESIGN OF THE VENTRAL FIN ITSELF WAS STARTED IMMEDIATELY BASED ON THE MEAGER AMOUNT OF PUBLISHED DATA FOR LOCKALLOY AVAILABLE AT THE START OF THE PROGRAM. THE PLAN CALLED FOR SUFFICIENT CHARACTERIZATION WORK TO BE DONE, BEFORE DELIVERY OF THE VENTRAL FIN, TO VALIDATE THE DESIGN ASSUMPTIONS MADE AT THE BEGINNING.

THE LOCKALLOY DELIVERY WAS SCHEDULED BY KBI ON A "BEST EFFORT" BASIS AND WAS DUE TO BE DELIVERED BY THE END OF JULY. PROBLEMS AT KBI, ASSOCIATED WITH THE PLATE ROLLING TO THE SHEET SIZE REQUIRED, CAUSED THE LOCKALLOY MATERIAL DELIVERY FOR THE VENTRAL TO BE DELAYED APPROXIMATELY TWO MONTHS. THIS DELAYED THE DELIVERY OF THE VENTRAL, TO NASA, APPROXIMATELY FIVE WEEKS.

THE LOCKHEED LOCKALLOY VENTRAL PROGRAM VALUE WAS $635,000.00. THE WORK IS BEING COMPLETED WITHIN THE CONTRACT BUDGET, WHICH WAS ESTABLISHED PRIOR TO THE START OF WORK, IN SPITE OF THE PROBLEMS ENCOUNTERED.

NASA FLIGHT RESEARCH CENTER HAS INCORPORATED A VERY COMPLETE INSTRUMENTATION PROGRAM ON THIS VENTRAL FIN FOR FURTHER EVALUATION OF AERODYNAMIC LOADS DURING FLIGHT, AS WELL AS INTERNAL LOAD DISTRIBUTION WITHIN THE VENTRAL. THE FIRST FLIGHT IS PRESENTLY SCHEDULED FOR JANUARY 15, 1976.

YF-12 LOCKALLOY VENTRAL FIN PROGRAM

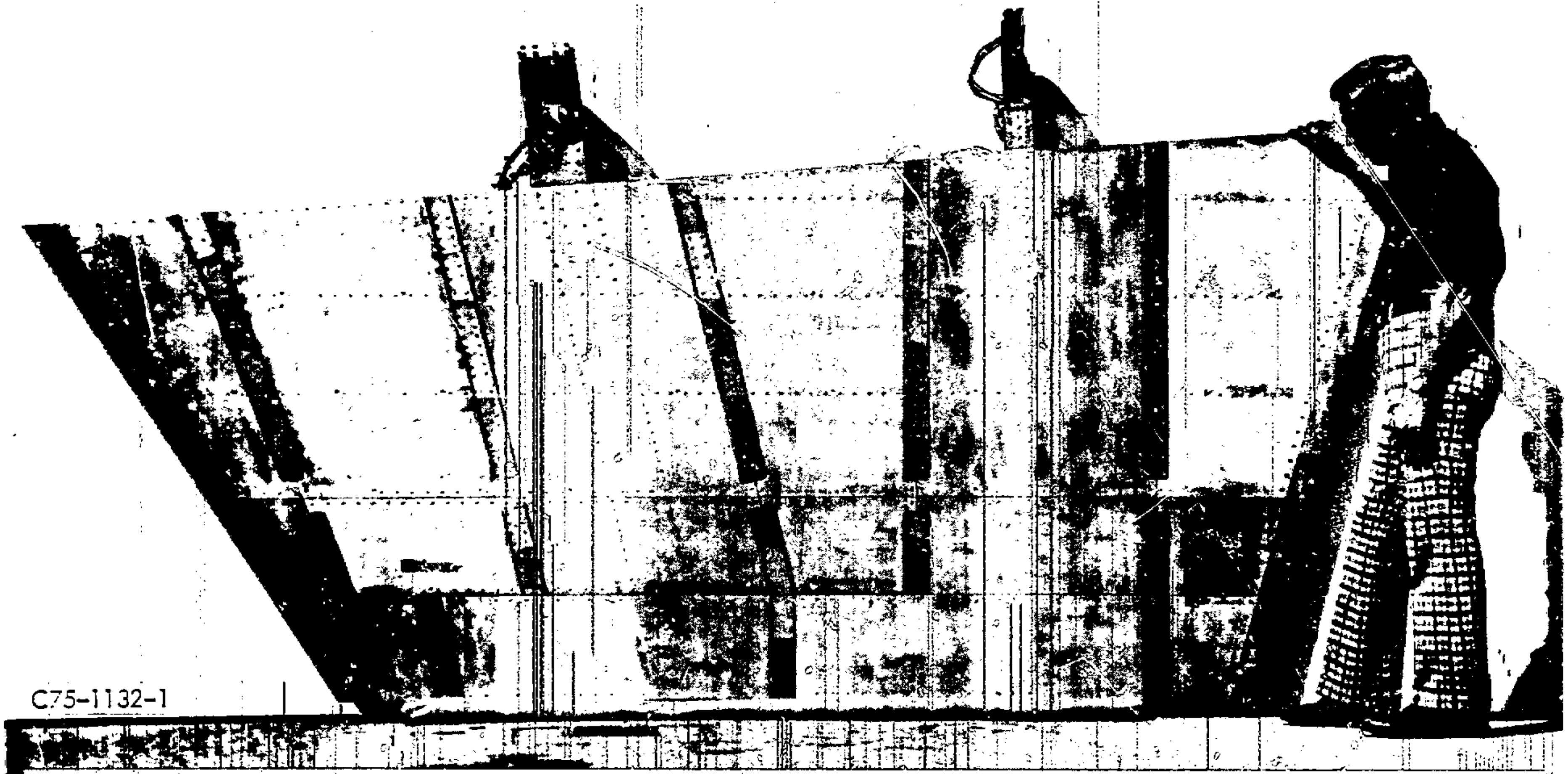


(1) APPROX. 400 SPECIMENS FROM 10 DIFFERENT HEATS

COMPLETED LOCKALLOY VENTRAL FOR YF-12

THE LOCKALLOY VENTRAL WAS CONSERVATIVELY DESIGNED TO BE APPROXIMATELY THE SAME WEIGHT AS A PROPOSED RE-DESIGNED, ALL-TITANIUM VENTRAL WOULD HAVE BEEN (250 POUNDS). THE STIFFNESS CHARACTERISTICS OF THE LOCKALLOY INCREASED THE OVER-ALL STIFFNESS OF THE VENTRAL BY SEVERAL HUNDRED PERCENT. THIS INCREASED STIFFNESS REQUIREMENT MAKES LOCKALLOY A LOGICAL SELECTION.

COMPLETED LOCKALLOY VENTRAL FOR YF-12

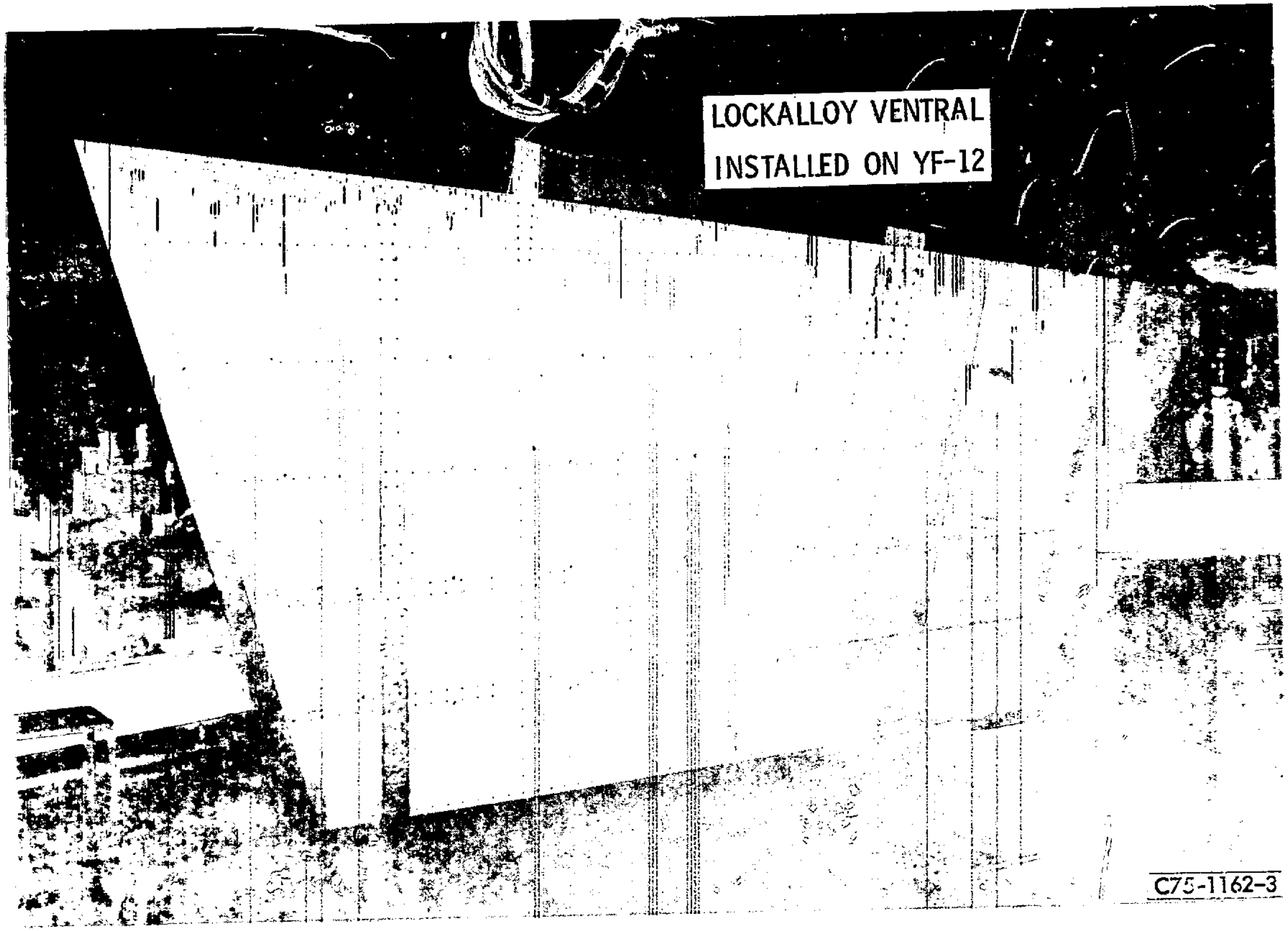


C75-1132-1

REPLACES THE RE-DESIGNED ALL-TITANIUM VENTRAL, AND FOR APPROXIMATELY THE SAME WEIGHT (250 LB), INCREASES THE CHORDWISE STIFFNESS BY 800% AND THE TORSIONAL STIFFNESS BY 500%.

LOCKALLOY VENTRAL INSTALLED ON YF-12

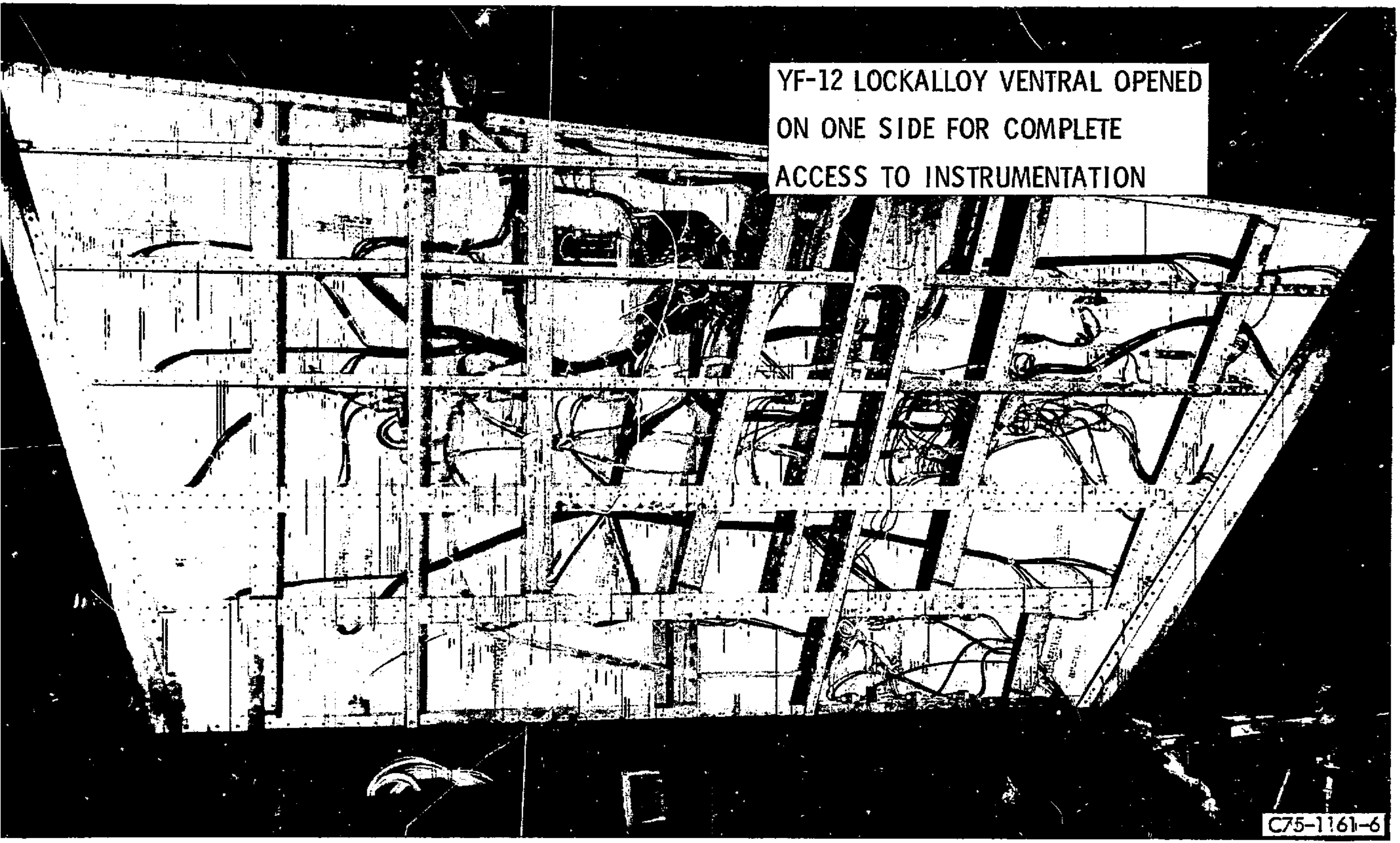
THE LOCKALLOY VENTRAL IS INSTALLED ON THE YF-12 AIRPLANE BY MEANS OF HINGE FITTINGS IN SUCH A WAY AS TO ALLOW FOR THE DIFFERENCE IN STIFFNESS OF LOCKALLOY, AS USED FOR THE VENTRAL, AND THE TITANIUM AIRPLANE TO WHICH THE VENTRAL IS ATTACHED. INSTRUMENTATION WAS CARRIED THROUGH TO THE AIRPLANE AT THE REAR HINGE STATION.



C75-1162-3

LOCKALLOY VENTRAL OPENED ON ONE SIDE FOR COMPLETE ACCESS TO INSTRUMENTATION

THE USE OF LOCKALLOY PLATES ATTACHED BY MEANS OF SCREWS PROVIDED COMPLETE ACCESSIBILITY TO THE INTERIOR OF THE VENTRAL FIN. THIS ACCESSIBILITY IS EXCEEDINGLY USEFUL FOR INSTALLING INSTRUMENTATION FOR PRESSURE PICKUPS, THERMOCOUPLES, AND STRAIN GAGES.



YF-12 LOCKALLOY VENTRAL OPENED
ON ONE SIDE FOR COMPLETE
ACCESS TO INSTRUMENTATION

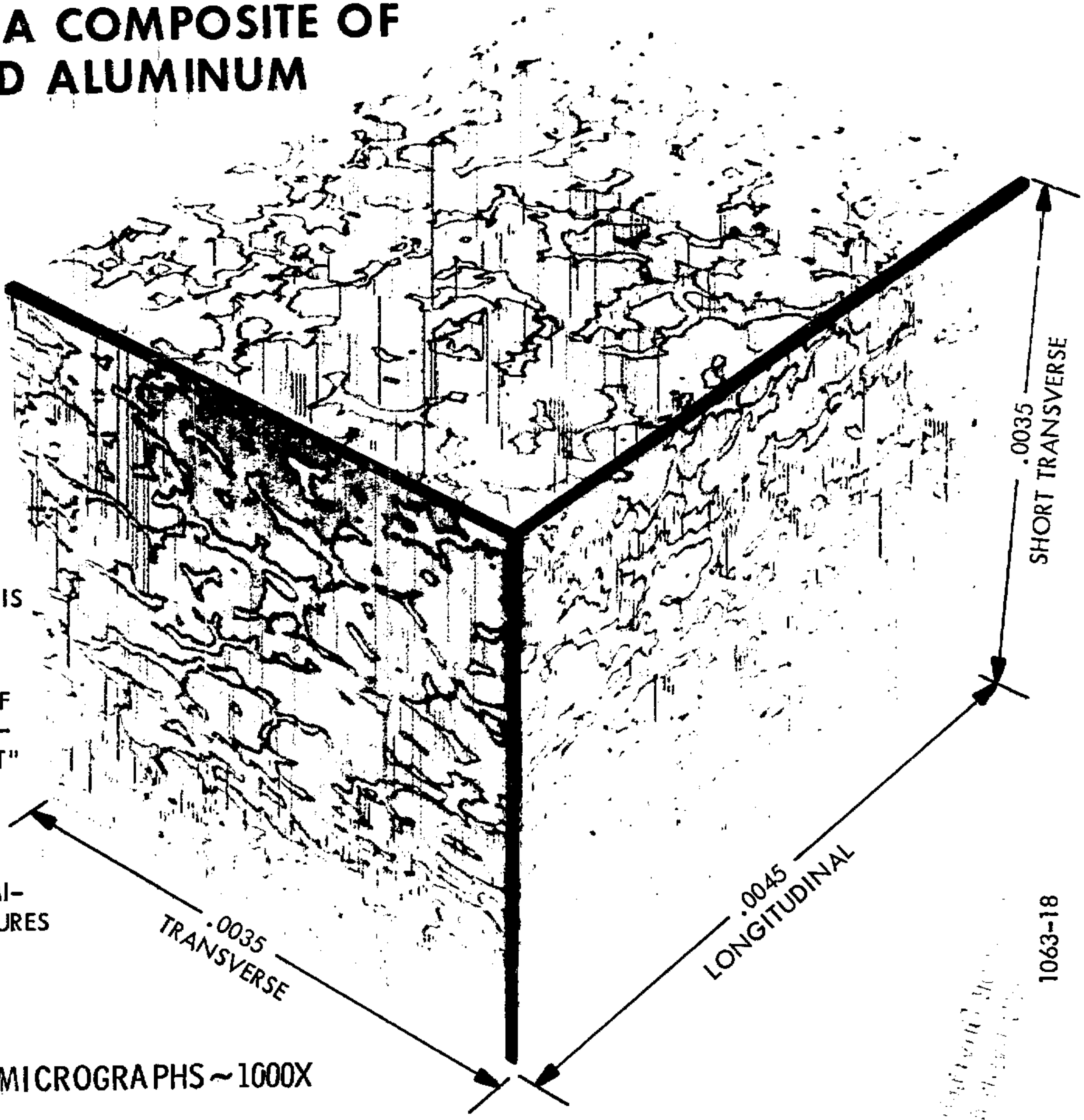
LOCKALLOY IS A COMPOSITE OF BERYLLIUM AND ALUMINUM

THE ADVANTAGES OF BERYLLIUM ARE PRIMARILY ITS VERY LOW DENSITY, ITS VERY HIGH STIFFNESS, AND ITS VERY HIGH HEAT CAPACITY.

MANY OF THE PROBLEM AREAS ASSOCIATED WITH USING BERYLLIUM CAN BE IMPROVED SIGNIFICANTLY BY MAKING A COMPOSITE OF BERYLLIUM WITH ALUMINUM. THIS COMPOSITE DISPLAYS BETTER FORMING, FRACTURE BEHAVIOR, AND MACHINING CHARACTERISTICS THAN PURE BERYLLIUM. THE APPLICATION OF BERYLLIUM AS A COMPOSITE WITH ALUMINUM IS MORE PRACTICAL FOR MANY PURPOSES THAN BERYLLIUM IN THE PURE STATE.

LOCKALLOY IS A COMPOSITE OF BERYLLIUM AND ALUMINUM

- ALL THREE FACE SPECIMENS WERE TAKEN WITHIN A 1/4" X 3/4" AREA IN THE SAME PIECE OF LX-62
- DARK AREAS ARE BERYLLIUM AND LIGHT AREAS ARE ALUMINUM
- THE ALUMINUM IS PRESENT AS SMALL RELATIVELY SOFT INCLUSIONS WITHIN THE BERYLLIUM
- THE MELTING TEMPERATURE IS
  - ▲2350°F FOR BERYLLIUM
  - ▲1220°F FOR ALUMINUM
- WHEN HEATED ABOVE 1190°F (EUTECTIC TEMP) THE ALUMINUM WILL TEND TO "SWEAT" OUT AS DROPLETS ON THE SURFACE
- AS TEMPERATURE REACHES 1500°F TO 1750°F THE ALUMINUM VAPOR PRESSURE RUPTURES THE BERYLLIUM WITHOUT MELTING IT



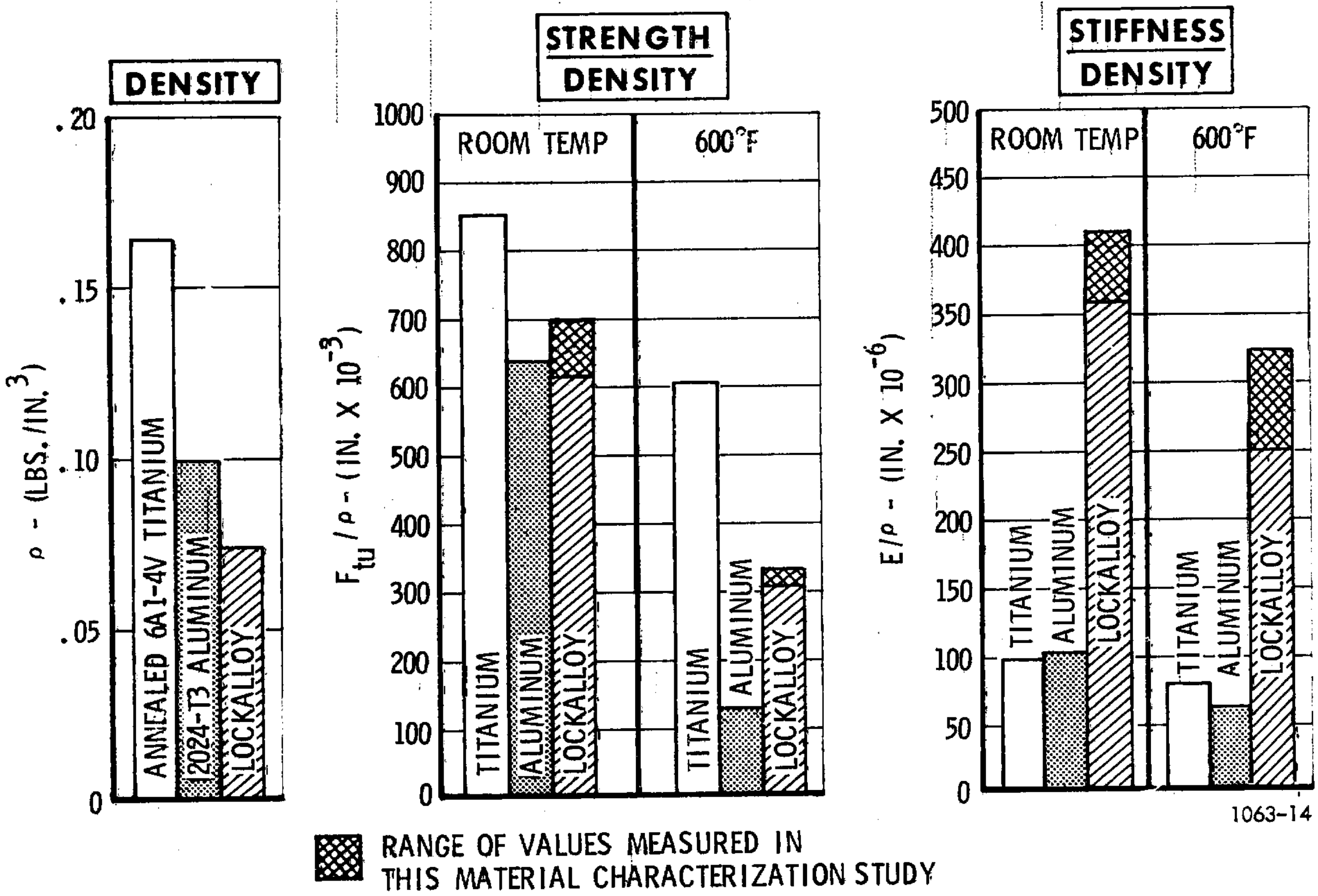
3 DIMENSIONAL PHOTO MICROGRAPHS ~ 1000X

LOCKALLOY (Be-38Al) AS A STRUCTURAL MATERIAL

LOCKALLOY IS USEFUL AT 600°F. IT IS COMPETITIVE WITH 2024 ALUMINUM AT ROOM TEMPERATURE ON A STRENGTH-TO-WEIGHT RATIO BASIS. ON A STIFFNESS-TO-WEIGHT RATIO BASIS LOCKALLOY EXCELS BOTH TITANIUM AND ALUMINUM AT BOTH ROOM TEMPERATURE AND AT 600°F.

THE SUPERIORITY OF LOCKALLOY ON A STIFFNESS BASIS SUGGESTS THAT LOCKALLOY CAN BE USED, TO CONSIDERABLE ADVANTAGE, FOR STABILITY CRITICAL STRUCTURE. ITS LOW DENSITY SUGGESTS SEMI-MONOCOQUE CONSTRUCTION.

LOCKALLOY (Be-38Al) AS A STRUCTURAL MATERIAL



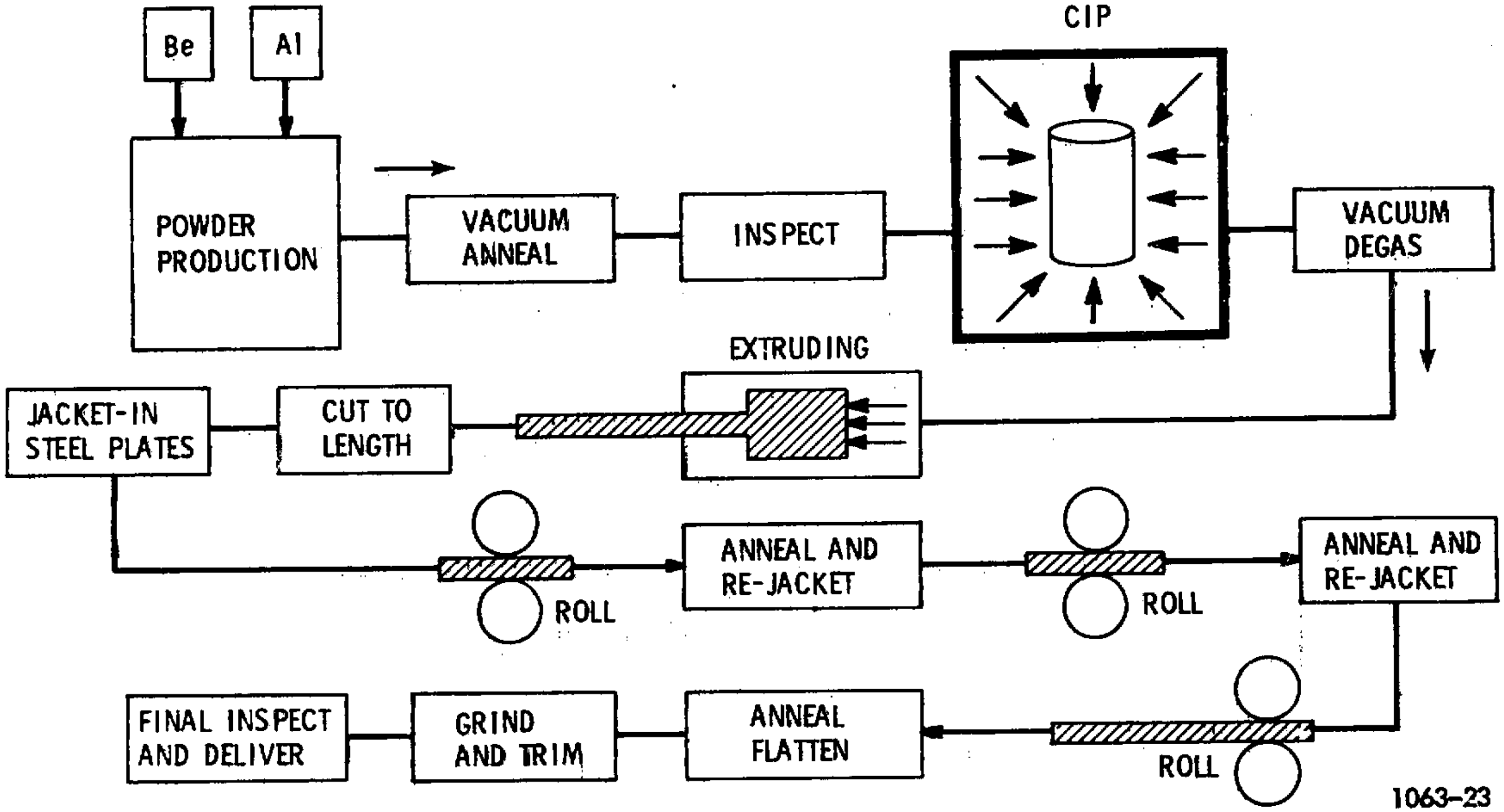
LOCKALLOY SHEET AND PLATE MANUFACTURING

BERYLLIUM AND ALUMINUM ARE HEATED TOGETHER, PAST THE MELTING TEMPERATURE OF BERYLLIUM, TO 2475°F. THE SOLUTION OF BERYLLIUM IN ALUMINUM IS THEN ATOMIZED AND COOLED TO FORM POWDER PARTICLES. EACH PARTICLE OF LOCKALLOY POWDER CONTAINS A COMPLETE MIX OF MUCH SMALLER BERYLLIUM PARTICLES "FLOATING" IN NEARLY PURE ALUMINUM. THE BERYLLIUM IS NOT ATTACHED TO THE BERYLLIUM AT THIS STAGE.

AFTER VACUUM ANNEALING AND INSPECTION THE POWDER IS MADE INTO A BILLET FOR EXTRUSION BY COLD ISOSTATIC PRESSING (CIP). THIS OPERATION PRODUCES NEAR FULL DENSITY, BUT STILL HAS NOT CAUSED THE BERYLLIUM TO HAVE STRUCTURAL CONTINUITY.

THE EXTRUSION PROCESS AT 970°F ESTABLISHES LOCKALLOY MECHANICAL PROPERTIES BY ESSENTIALLY "FORGE WELDING" THE BERYLLIUM PARTICLES TOGETHER AND FORCING THE ALUMINUM INTO A MYRIAD OF SMALL ALUMINUM POOLS OR INCLUSIONS. THE EXTRUSION IS CUT TO THE LENGTH OF THE DESIRED SHEET AND THEN IS ROLLED PROGRESSIVELY TO OBTAIN THE WIDTH OF THE DESIRED SHEET. TRANSVERSE ROLLING SIGNIFICANTLY IMPROVES THE TRANSVERSE ELONGATION PROPERTIES.

LOCKALLOY SHEET AND PLATE MANUFACTURE



1063-23

LOCKALLOY SHEET AND PLATE SIZE LIMITING FACTORS

THE SIZE OF THE SHEETS OBTAINED FOR THE VENTRAL PROGRAM WERE LIMITED TO 35 INCHES BY 40 INCHES FOR THE [illegible]-INCH THICK SHEETS.

THE EXTRUSION PRESS AT REACTIVE METALS, INC., WHICH HAS BEEN QUALIFIED TO HANDLE LOCKALLOY, IS LIMITED TO PRODUCING AN EXTRUSION CROSS SECTION MEASURING 8-1/8 INCH BY 1-1/8 INCH. WITH THIS CROSS SECTION THE FINAL SHEET WIDTH IS LIMITED, BASED ON CROSS ROLLING TO A DESIRED THICKNESS.

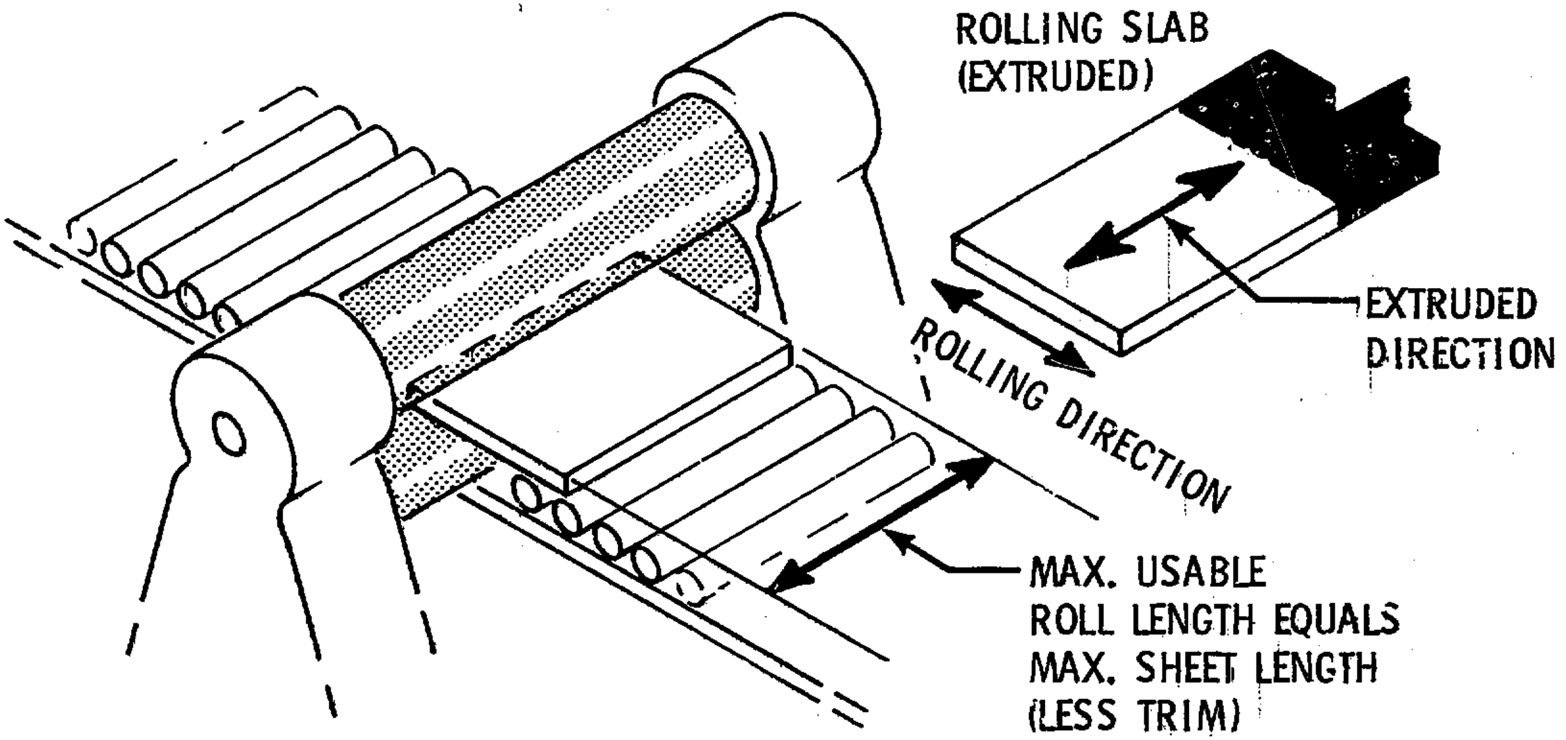
THE LENGTH OF THE FINAL SHEET DEPENDS ON THE WIDTH OF THE ROLLING MILL AVAILABLE. THE MILL BEING USED BY RMI AT READING, PENNSYLVANIA, WILL PRODUCE A 40-INCH SHEET LENGTH.

THE LIMITATION ON SHEET AND PLATE SIZES IS SIMPLY A MATTER OF FACILITIES. NOTHING ABOUT THE LOCKALLOY ITSELF CAUSES ANY LIMITATION.

HOWEVER, THE COST OF USING LARGER EQUIPMENT TO PRODUCE RELATIVELY SMALL AMOUNTS OF LOCKALLOY SHEET AND PLATE IN LARGE SIZES IS LIKELY TO BE QUITE HIGH. FOR PRESENT PLANNING PURPOSES IT IS DESIRABLE TO USE MATERIAL IN THE SIZE RANGE ALREADY PRODUCED FOR LOCKALLOY VENTRAL PROGRAM. THIS CONDITION WILL EXIST UNTIL SIGNIFICANTLY MORE DEMAND FOR LOCKALLOY IS DEVELOPED.

LOCKALLOY SHEET AND PLATE SIZES LIMITING FACTORS

- LENGTH DEPENDS ON ROLLING MILL WIDTH



- WIDER ROLLING MILL WILL INCREASE SHEET OR PLATE LENGTH
- WIDER AND/OR THINNER ROLLING SLAB CROSS-SECTIONS WILL RESULT IN WIDER SHEETS OR PLATES WITH A REDUCED NUMBER OF ROLLINGS.

1063-30

KBI 1975 PRODUCTION CAPABILITY

THE 1975 LOCKALLOY PRODUCTION CAPABILITY WAS SET BY THE POWDER PRODUCTION CAPACITY OF 1000 POUND/MONTH.

THE NET PRODUCTION OF LOCKALLOY END PRODUCT IS LESS THAN 1000 POUND/MONTH BASED ON LOSSES BY TRIMMING AND OR SCRAPPING.

BECAUSE OF THE SPECIAL HANDLING REQUIREMENTS FOR BERYLLIUM THIS POWDER PRODUCTION WORK CAN ONLY BE DONE IN A QUALIFIED BERYLLIUM FACILITY.

KBI 1975 PRODUCTION CAPABILITY

- LOCKALLOY POWDER PRODUCTION — 1000 LBS/MO.
  POWDER HEAT TREATING — 24 HR CYCLE-LIMITED TO ONE VACUUM FURNACE

- COLD ISOSTATIC PRESSING (CIP) OF POWDER TO A 200 LB BILLET — RELATIVE SHORT CYCLE
  - AMPLE CAPACITY
- PRODUCTION OF ROLLING SLAB BY EXTRUDING BILLET — RMI PRESS QUALIFIED TO PRODUCE SLABS UP TO 8 1/8 X 1 1/8 IN. CROSS SECTION
  - ADEQUATE CAPACITY

- ROLLING — KBI ROLLING MILL WILL HANDLE PLATES UP TO 41 INCHES LONG. PRODUCTION IS PACED BY THE ANNEALING AND STEEL JACKETING BETWEEN SUCCESSIVE ROLLING OPERATIONS

- FLATTENING — CAPACITY LIMITED TO ONE FLATTENING PRESS
  - CAN ACCOMMODATE SEVERAL SHEETS SIMULTANEOUSLY.

1063-24

LOCKALLOY PLATE PRODUCTION DIFFICULTIES

THE DELAY OF APPROXIMATELY TWO MONTHS IN OBTAINING LOCKALLOY FOR THE YF-12 VENTRAL FIN WAS PRIMARILY A RESULT OF HAVING BEEN TOO OPTIMISTIC IN TRYING TO PRODUCE 50-INCH LONG PANELS THAT REQUIRED LENGTHWISE ROLLING.

IT IS APPARENT THAT THE NUMBER OF SUCCESSIVE ROLLING OPERATIONS SHOULD BE KEPT TO A MINIMUM. THIS WILL GREATLY REDUCE COST, BECAUSE IT NOT ONLY SAVES WORK BUT ALSO DECREASES THE RISK OF SCRAPPING PANELS DURING SUBSEQUENT ROLLINGS.

LOCKALLOY PLATE PRODUCTION DIFFICULTIES

- SHEET SIZES FOR THE VENTRAL FIN WERE ESTABLISHED AT 25 x 50 IN.
- THESE 25 x 50 IN. PANELS WERE LARGER THAN HAD BEEN ROLLED AT START OF VENTRAL PROGRAM.
- IT REQUIRED 3 ROLLINGS, WIDTHWISE AND A FOURTH ROLLING, LENGTHWISE TO PRODUCE THE 25 x 50 IN. PANELS.
- LENGTHWISE ROLLING RESULTED IN CRACKING OF SHEETS.
- DELETION OF THIS ROLLING LIMITED MAX. SHEET LENGTH TO 41 IN. WHICH IS THE USEABLE WIDTH OF THE ROLLING MILL LESS JACKETING AND TRIMMING.
- THE FINISHED THICKNESS REQUIRED DETERMINES THE CROSS-SECTION OF THE STARTING EXTRUSION SLAB AND THE NUMBER OF PROGRESSIVE CROSS ROLLINGS THAT ARE NEEDED.
- ELIMINATION OF LENGTHWISE ROLLING REDUCES COST, AND DOES NOT ADVERSELY AFFECT THE MECHANICAL PROPERTIES.

1063-31

LOCKALLOY COST PICTURE

THE COST OF LOCKALLOY WILL ALWAYS BE EXPENSIVE BASED ON BERYLLIUM CONTENT. SINCE PRODUCTION OF LOCKALLOY IS RELATIVELY NEW, IT IS REASONABLE TO ASSUME THAT THE COST WILL DECREASE ALONG A "LEARNING CURVE". IN 1975-DOLLARS THE COST FOR LOCKALLOY PLATE, .60 INCHES THICK, IS $200.00 PER POUND.

THE USE OF LOCKALLOY WILL NO DOUBT BE LIMITED BY ITS COST TO THOSE APPLICATIONS WHERE ITS LOW WEIGHT, HIGH STIFFNESS, AND HIGH SPECIFIC HEAT CHARACTERISTICS MAKE IT ECONOMICALLY FEASIBLE.

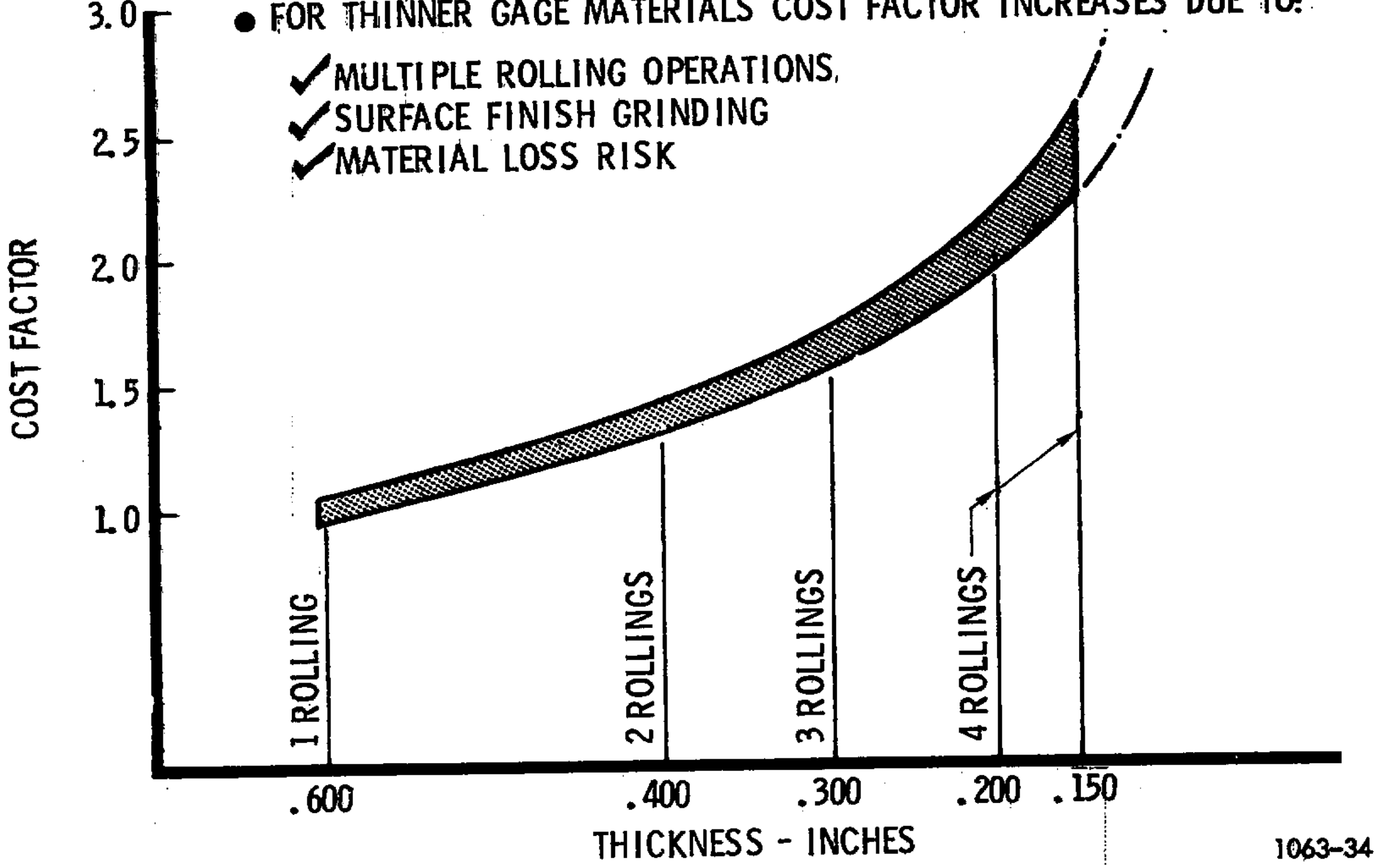
THE COST OF LOCKALLOY SHEET OR PLATE IS VERY DEPENDENT UPON THE REQUIRED FINAL THICKNESS. IN ORDER TO REDUCE THE THICKNESS MORE EXPENSIVE ROLLING IS REQUIRED. FOR THE THINNER GAGES SURFACE GRINDING ALSO BECOMES A SIGNIFICANT COST FACTOR, BECAUSE IT REPRESENTS A GREATER FRACTION OF MATERIAL LOST IN GRINDING.

LOCKALLOY IS USEFUL MATERIAL IN THE EXTRUDED STATE AT MINIMUM EXPENSE. WHEN SUBSEQUENTLY ROLLED TO REDUCE THICKNESS, THE COST PER POUND GOES UP VERY RAPIDLY.

THE MORE ECONOMICAL USES FOR LOCKALLOY SHEET AND PLATE WILL BE THOSE APPLICATIONS WHERE IT CAN BE USED IN RELATIVELY THICK SECTIONS .15-INCHES THICK OR GREATER.

LOCKALLOY COST PICTURE

- BASED ON KBI PRICE OFFER TO LOCKHEED (1-6-76) FOR X-24C BILL OF MATERIALS
- FOR THINNER GAGE MATERIALS COST FACTOR INCREASES DUE TO:
  - ✓ MULTIPLE ROLLING OPERATIONS,
  - ✓ SURFACE FINISH GRINDING
  - ✓ MATERIAL LOSS RISK



1063-34

LOCKALLOY MATERIAL CHARACTERIZATION - OVERVIEW

THE YF-12 LOCKALLOY VENTRAL FIN WAS DESIGNED ON THE BASIS OF DATA AVAILABLE BEFORE THE START OF THIS PROGRAM. THIS DESIGN DATA WAS VALIDATED USING MATERIAL PROPERTY DATA OBTAINED FROM REMNANTS AND SAMPLES TAKEN FROM THE ACTUAL MATERIAL USED TO BUILD THE VENTRAL FIN. IN THIS WAY THE FLIGHT SAFETY OF THAT VENTRAL FIN IS NOT DEPENDENT UPON HAVING AVAILABLE PROBABILITY PROPERTY VALUES OBTAINED ON A STATISTICAL BASIS.

THE CHARACTERIZATION WORK WAS CARRIED OUT IN SUFFICIENT DETAIL TO ASSURE SATISFACTORY VENTRAL PERFORMANCE FROM A MATERIAL STANDPOINT.

LOCKALLOY MATERIAL CHARACTERIZATION-OVERVIEW

PURPOSE

- VALIDATE YF-12 VENTRAL FIN DESIGN
- EXPAND MATERIAL AND MANUFACTURING DATA BASE

SCOPE

- COMPILE AND REVIEW EXISTING DATA (LITERATURE SURVEY)
- INVESTIGATE SAFETY AND HANDLING REQUIREMENTS
- DETERMINE MECHANICAL PROPERTIES AT ROOM TEMPERATURE AND 600°F
  - Be-38AI (2 THICKNESSES)
- DETERMINE FORMING LIMITATIONS AT ROOM AND ELEVATED TEMPERATURES
  - Be-43AI (1 THICKNESS)
  - Be-38AI (2 THICKNESSES)

OVER 400 SPECIMENS FROM 10 DIFFERENT HEATS OF MATERIAL

- CONDUCT TEST OF MAJOR STRUCTURAL COMPONENT
  - 20 INCH SQUARE Be-38AI PANEL
  - DETERMINE SHEAR BUCKLING AND ULTIMATE SHEAR STRENGTH
- INVESTIGATE EFFECTS OF THERMAL SHOCK
  - 20 INCH SQUARE Be-38AI PANEL
  - SIMULATE LOCAL INTERFERENCE HEATING TO APPROXIMATELY 1000°F
  - DETERMINE RESIDUAL SHEAR STRENGTH AFTER THERMAL SHOCK

1063-12

SAFETY REQUIREMENTS - LOCKALLOY

LOCKALLOY IS CONSIDERED TO BE SIMILAR TO BERYLLIUM AS FAR AS SAFETY REQUIREMENTS ARE INVOLVED. THEREFORE ANY FACILITY QUALIFIED TO HANDLE BERYLLIUM IS AUTOMATICALLY QUALIFIED TO HANDLE LOCKALLOY.

THE LOCKHEED "SKUNK WORKS" IS NOT CURRENTLY AN APPROVED BERYLLIUM FACILITY. IN ORDER TO OVERCOME THIS SITUATION WHILE BUILDING THE LOCKALLOY VENTRAL AND PERFORMING THE MATERIAL CHARACTERIZATION TESTS. ALL MACHINING, DRILLING, GRINDING, ETC. WAS SUBCONTRACTED TO APPROVED BERYLLIUM FACILITY HOUSES. LOCKHEED MONITORED THE AIR FOR BERYLLIUM CONTENT DURING ANY EVEN REMOTELY POSSIBLE HAZARDOUS OPERATIONS PERFORMED IN PLANT.

SAFETY REQUIREMENTS - LOCKALLOY

BECAUSE OF Be CONTENT, LOCKALLOY DUST, FINE CHIPS AND FUMES MAY BE TOXIC IF INHALED.

PRECAUTIONS

- ✓ COLLECT DUST AND CHIPS PRODUCED DURING MACHINING AND EXHAUST THROUGH COLLECTORS AND FILTERS.
- ✓ MONITOR AIR FOR Be CONTENT DURING ANY MACHINING OPERATIONS.
- ✓ CLEAN AND WIPE THOROUGHLY AFTER MACHINING - SEGREGATE RAGS IN CONTROLLED CONTAINERS.
- ✓ WASH HANDS BEFORE SMOKING AND EATING.

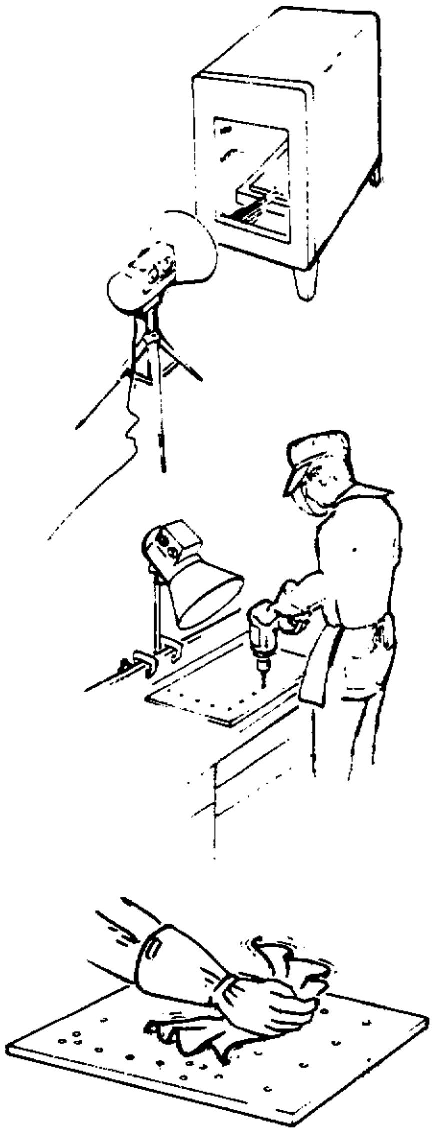
SAFETY TESTING - LOCKALLOY

AS A PART OF THE MATERIAL CHARACTERIZATION PROGRAMS IT WAS CONSIDERED ESPECIALLY IMPORTANT TO MAKE TESTS FOR POSSIBLE BERYLLIUM CONTAMINATION OF THE ENVIRONMENT.

THIS WAS DONE BY USING AN APPROVED ENVIRONMENTAL TESTING DEVICE THAT USED HIGH VOLUMES OF AIR PULLED THROUGH ABSOLUTE FILTERS WHICH ARE SUBSEQUENTLY ANALYZED FOR BERYLLIUM.

THE WIPING TESTS INVOLVED USING FILTERS FROM THE TEST DEVICE FOR HAND WIPE PRIOR TO ANALYSIS.

SAFETY TESTING - LOCKALLOY



- MONITORED FURNACE DURING HEATING - TO 1100°F
  - NO DETECTABLE Be LEVELS

- MONITORED AIR DURING REAMING AND COUNTERSINKING OPERATIONS
  - LOW LEVELS: .09 ug OF Be PER CU. METER

- WIPE TESTS WERE PERFORMED. PANEL SURFACES CHECKED IN THE "AS RECEIVED" AND "AFTER MACHINING" CONDITIONS.
  - DETECTABLE Be LEVELS BUT WITHIN ESTABLISHED LIMITS.

- WIPE TESTS OF SPECIMENS EXPOSED TO CORROSIVE ENVIRONMENT.
  - INDICATE ADVISABILITY OF SURFACE COATINGS FOR PROTECTION AGAINST POSSIBLE CONTAMINATION FROM PRODUCTS OF CORROSION.

- EMPLOYEES INVOLVED WITH HANDLING OF LOCKALLOY UNDERWENT MEDICAL EXAMINATIONS AT THE START OF THE PROGRAM AND WILL UNDERGO A RE-EXAMINATION AT CONCLUSION OF PROGRAM.

HANDLING OF LOCKALLOY SAFELY

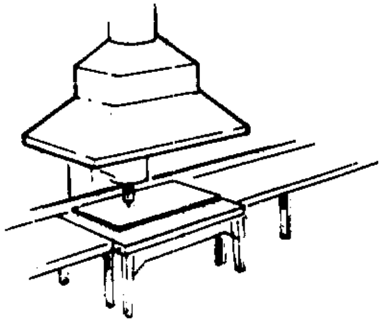
RECOMMENDATIONS FOR SAFE HANDLING OF LOCKALLOY ARE BASED ON:

(A) THE POTENTIAL HAZARD OF BERYLLIUM PARTICLES BEING INHALED; AND

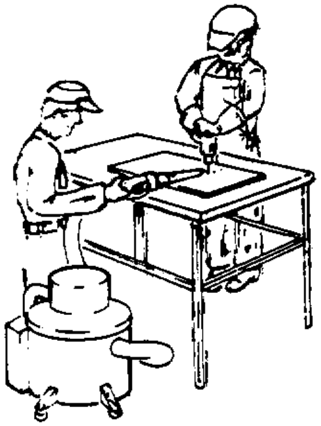
(B) THE SAFETY TESTS PERFORMED AS A PART OF THIS PROGRAM.

THE CONCERN FOR HAZARD SHOULD BE TAKEN SERIOUSLY. HOWEVER, THE REQUIRED PRECAUTIONS ARE PRACTICAL AND CAN BE HANDLED ECONOMICALLY.

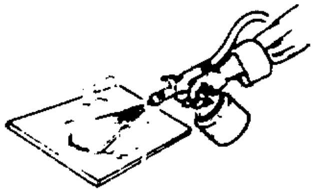
HANDLING OF LOCKALLOY SAFELY



- EXPOSURES TO 1100°F FOR THERMAL PROCESSING DO NOT PRODUCE TOXIC EFFECTS
- EXTENSIVE METAL REMOVAL OPERATIONS SHOULD BE PERFORMED IN CONTROLLED AREAS EQUIPPED WITH EXHAUST SYSTEMS FOR ATMOSPHERIC CONTROL. ADEQUATE VENDOR MACHINING CAPACITY EXISTS.



- FOR ANY "ON ASSEMBLY" PROVIDE LOCALIZED CHIP PICK-UP DRILLING
- PAINT OR SPRAY PARTS WITH PEELABLE COATINGS FOR HANDLING THROUGH FIT-UP AND ASSEMBLY OPERATIONS
- PAINT OR SURFACE TREAT PARTS IN DETAIL PRIOR TO FINAL ASSEMBLY



- MONITOR AIR PERIODICALLY

MECHANICAL AND DESIGN PROPERTIES TESTS (Be-38Al)

THE TESTS PERFORMED IN THIS PROGRAM WERE PREDICATED ON USING LOCKALLOY SHEET IN THICKNESSES OF .125 INCH, .150 INCH, AND .250 INCH.

THE TESTS WERE SELECTED IN ORDER TO SUBSTANTIATE THE VENTRAL FIN DESIGN AND TO DETERMINE MATERIAL CHARACTERISTICS FOR FABRICATION PROCEDURES.

MECHANICAL AND DESIGN PROPERTIES TESTS (Be-38Al)

MOST SPECIMENS TESTED AT BOTH ROOM TEMPERATURE AND AT 600°F
- AS RECEIVED (NO EXPOSURE)
- AFTER 100 HOURS EXPOSURE AT 600°F

- TENSION - LONGITUDINAL, LONG TRANSVERSE, AND SHORT TRANSVERSE
- COMPRESSION - LONGITUDINAL AND LONG TRANSVERSE
- SHEAR
- POISSON'S RATIO - LONGITUDINAL
- BEARING - LONGITUDINAL AND LONG TRANSVERSE
  - $e/D = 1.5$
  - $e/D = 2.0$
- NOTCHED TENSION - LONGITUDINAL AND LONG TRANSVERSE
- CREEP - LONGITUDINAL AND LONG TRANSVERSE
- FATIGUE ENDURANCE LIMIT - LONGITUDINAL AND LONG TRANSVERSE
  - $K_t = 1$
  - $K_t = 3$
- JOINT STRENGTH - LONG TRANSVERSE
- FRACTURE TOUGHNESS - LONGITUDINAL AND LONG TRANSVERSE
- RATE OF CRACK GROWTH - LONGITUDINAL AND LONG TRANSVERSE
- STRESS CORROSION RESISTANCE - LONG TRANSVERSE

1063-11

RESULTS OF MECHANICAL AND DESIGN PROPERTIES TESTS (Be-38A1)

THE RESULTS OF THESE TESTS ARE IN SATISFACTORY AGREEMENT WITH OTHER DATA PUBLISHED FOR LOCKALLOY WITH ONE EXCEPTION. THE MODULUS OF ELASTICITY, AS OBTAINED FROM COUPON DATA, SHOWS CONSIDERABLE SCATTER WITH OCCASIONAL VERY LOW VALUES. IN ORDER TO EVALUATE THE VALUE OF E FOR THE PANELS USED IN THE VENTRAL FIN, THEY WERE TEST MEASURED FOR STIFFNESS IN BENDING. THIS STIFFNESS WAS USED TO CALCULATE E. VALUES OBTAINED IN THIS MANNER WERE ALL IN A RANGE FROM $24 X 10^{-6}$ TO $29 X 10^{-6}$. IT APPEARS THAT THE METHODS USED TO DERIVE E FROM COUPON DATA NEED TO BE REFINED SO AS TO GIVE VALUES FOR E RELATING TO MEASURED STIFFNESSES ON LARGER COMPONENTS.

THE TESTS PERFORMED, AFTER 5% STRETCH FOLLOWED BY ONE HOUR OF STRESS RELIEF AT 1050°F, SHOWED SOME LOSS IN STRENGTH AND ELONGATION. THESE RESULTS SUGGEST THAT THE STRESS RELIEVING CYCLE USED (DURATION AND OR TEMPERATURE) MAY NOT REPRESENT THE OPTIMUM HEAT TREATMENT CYCLE.

RESULTS OF MECHANICAL AND DESIGN PROPERTIES TESTS (Be-38Al) (1 OF 2)

VALUES SHOWN ARE APPLICABLE AFTER 100 HOURS EXPOSURE AT 600°F

		ROOM TEMP	600°F
● TENSION			
F_{tu} (KSI)	L	47.1 - 52.6	23.9 - 25.0
	LT	49.6 - 51.8	23.2 - 24.5
	ST	13.7 - 17.2	
F_{ty} (KSI)	L	36.2 - 37.8	21.8 - 23.5
	LT	34.8 - 36.2	21.2 - 23.5
E* (MSI)		27.0 - 31.0	19.0 - 24.5
e (%)	L	5 - 12	7 - 12
	LT	8 - 13	9 - 11
● COMPRESSION			
F_{cy} (KSI)	L	31.9 - 34.8	21.9 - 23.6
	LT	31.6 - 32.6	22.4 - 23.3
E_c (MSI)			17.2 - 21.8
● SHEAR			
F_{su} (KSI)		29.5 - 40.2	16.3 - 21.0
G (MSI)		11.6 - 13.6	7.9 - 10.8
● POISSON'S RATIO		.142 - .163	.140 - .198
● BEARING			
F_{bru} (KSI)	e/D = 1.5	69.8 - 85.0	34.2 - 43.6
	e/D = 2.0	89.7 - 104.3	44.0 - 53.3
F_{bry} (KSI)	e/D = 1.5	58.0 - 74.3	31.9 - 42.3
	e/D = 2.0	61.9 - 80.0	40.5 - 46.6

*BASED ON STRAIN GAGE DATA

1063-9

RESULTS OF MECHANICAL AND DESIGN PROPERTIES TESTS (Be-38Al) (2 OF 2)

		ROOM TEMP	600°F
● (NOTCHED (Kt = 3) STRENGTH) / (UN-NOTCHED STRENGTH)			
LONGITUDINAL	(L)	0.934 - 1.016	1.336 - 1.376
LONG TRANSVERSE	(LT)	0.990 - 1.020	1.249 - 1.340
● CREEP STRESS (KSI) TO PRODUCE 0.5% DEFORMATION IN 100 HOURS AT 600°F			
LONGITUDINAL	(L)	—	7.5 - 10.5
LONG TRANSVERSE	(LT)	—	9.0 - 10.0
● ULTIMATE JOINT STRENGTH (LBS./FASTENER)			
.125 THICKNESS			
3/16 INCH FLUSH TITANIUM SCREWS		1812 - 2065	1235 - 1468
.150 THICKNESS			
3/16 INCH FLUSH TITANIUM SCREWS		2212 - 2412	1455 - 1525
1/4 INCH FLUSH TITANIUM SCREWS		3225 - 3275	2105 - 2300

1063-10

FRACTURE TOUGNESS COMPARISON

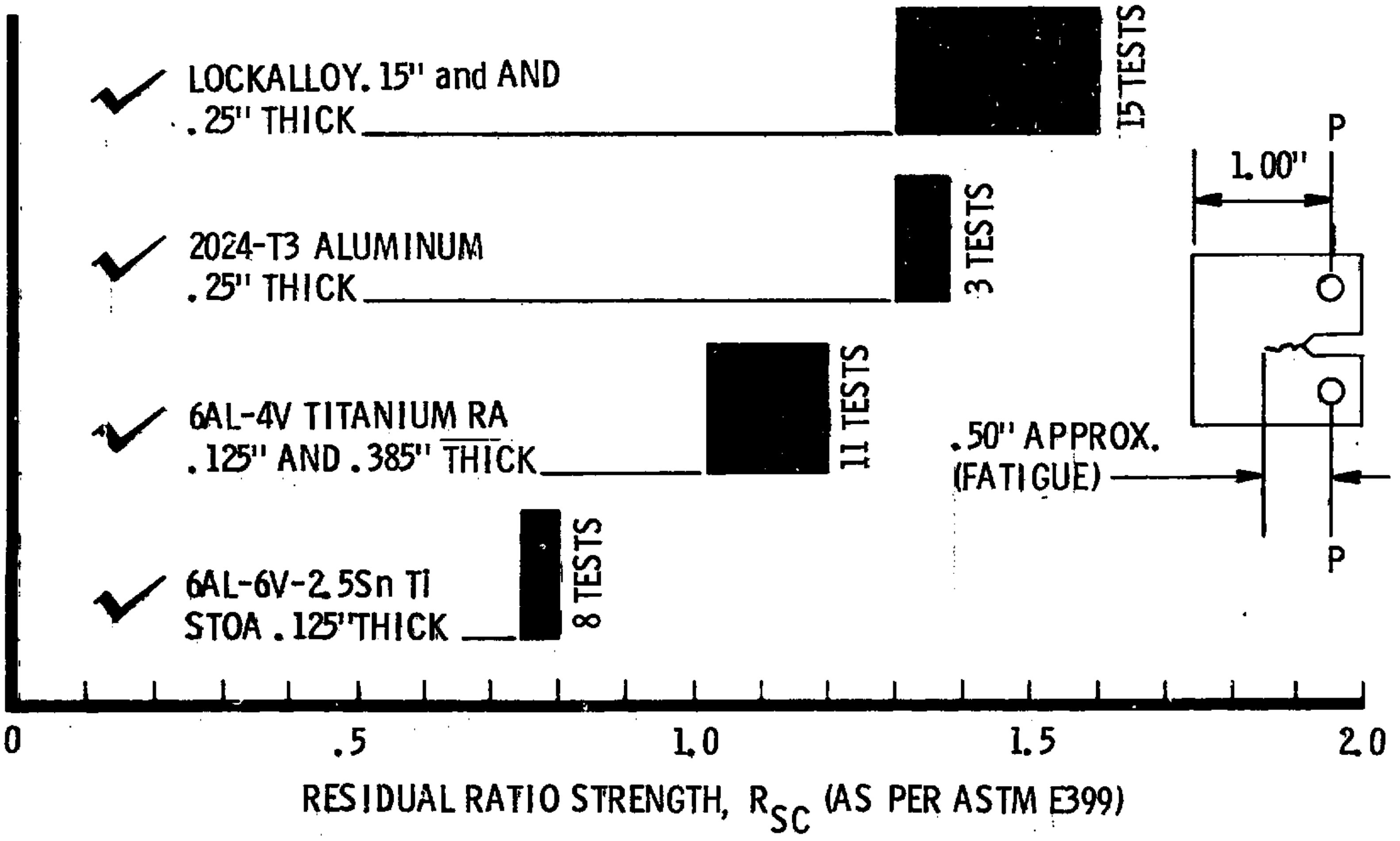
THE FRACTURE TOUGHNESS OF LOCKALLOY IS RELATIVELY QUITE GOOD. THE RESIDUAL STRENGTH RATIO, R_{SC}, IS EQUAL TO OR BETTER THAN FOR 2024-T3 ALUMINUM AND IS CONSIDERABLY BETTER THAN FOR 6AL-4V (RECRYSTALIZATION ANNEALED) TITANIUM.

K_{IC} VALUES WERE NOT OBTAINED, SINCE A SPECIMEN MINIMUM THICKNESS OF MORE THAN ONE INCH WOULD BE REQUIRED IN ORDER TO SHOW VALID K_{IC} VALUES.

ORIGINAL PAGE IS
OF POOR QUALITY

FRACTURE TOUGHNESS COMPARISON

- ALL TESTS DONE BY LOCKHEED RYE CANYON LABORATORY
- THE TITANIUM TESTS ARE REPORTED IN AFML-TR-74-183
- THE LOCKALLOY AND ALUMINUM TESTS ARE REPORTED WITH THE LOCKALLOY VENTRAL PROGRAM IN REPORT SP-4451.



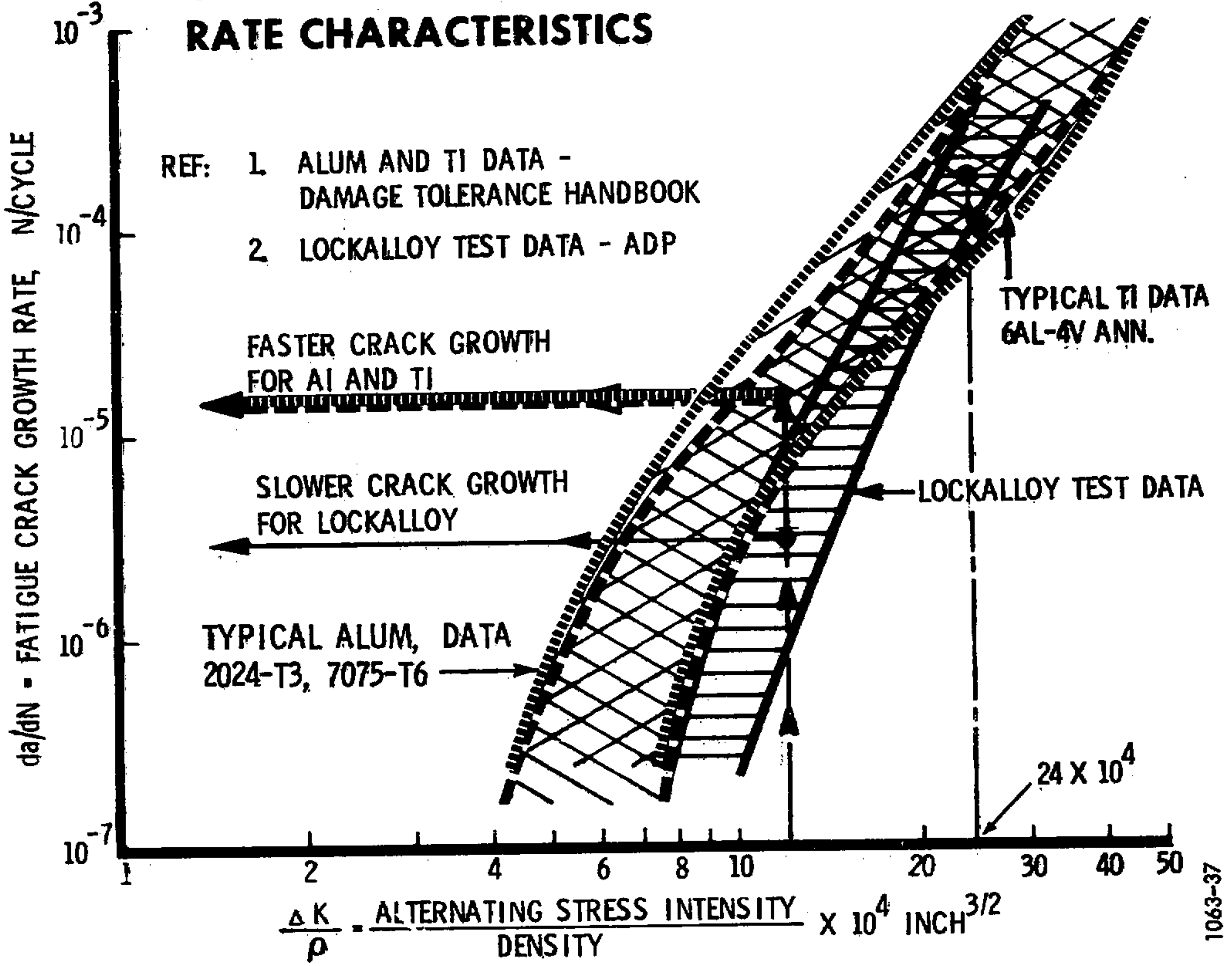
1063-35

CRACK GROWTH RATE CHARACTERISTICS

CRACK GROWTH RATES FOR LOCKALLOY ARE QUITE FAVORABLE AS COMPARED TO TYPICAL ALUMINUM AND TITANIUM ALLOYS UP TO AN OPERATING STRESS LEVEL OF 20,000 psi FOR THE LOCKALLOY WITH A CRACK .50-INCHES LONG IN A WIDE PANEL.

IT IS SUGGESTED THAT THE SOFT ALUMINUM INCLUSIONS, SCATTERED PROFUSELY THROUGH THE BERYLLIUM, ACT AS "CRACK STOPPERS" AND SIGNIFICANTLY RESTRAIN CRACK GROWTH.

CRACK GROWTH RATE CHARACTERISTICS

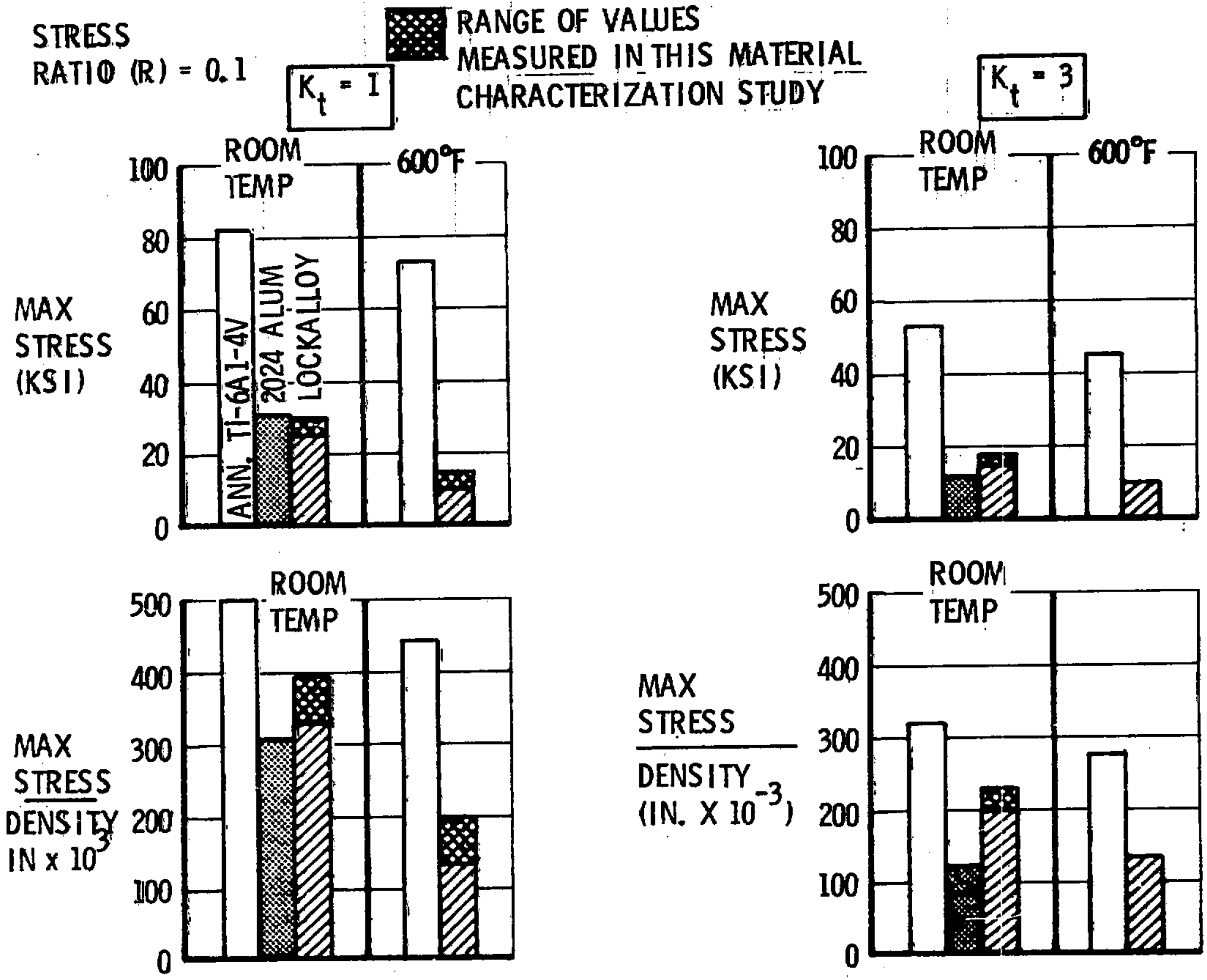


FATIGUE ENDURANCE LIMIT (Be-38Al)

THE FATIGUE ENDURANCE LIMIT FOR LOCKALLOY, BASED ON STRESS/DENSITY, IS SIGNIFICANTLY BETTER THAN FOR 2024-T3 ALUMINUM FOR A K_t OF 3 AT ROOM TEMPERATURE AND IS APPROXIMATELY TWO-THIRDS AS GOOD AS 6Al-4V TITANIUM ON THIS SAME BASIS. AT 600°F THE LOCKALLOY ENDURANCE LIMIT FOR $K_t = 3$ IS AS GOOD AS FOR 2024-T3 ALUMINUM AT ROOM TEMPERATURE FOR THE SAME K_t.

THE FATIGUE DATA FOR TITANIUM AND ALUMINUM ALLOYS ARE HANDBOOK VALUES. THE LOCKALLOY VALUES ARE BASED ON THE TESTS PERFORMED IN THIS PROGRAM. THE LOCKALLOY VALUES ARE CONSISTENT WITH DATA DEVELOPED PRIOR TO THIS PROGRAM.

FATIGUE ENDURANCE LIMIT AT 10^7 CYCLES (Be-38Al)



1063-15

GALVANIC AND GENERAL CORROSION - LOCKALLOY

LOCKALLOY IS SUBJECT TO GALVANIC AND GENERAL CORROSION ATTACK COMPARABLE TO CONVENTIONAL STRUCTURAL ALUMINUM ALLOYS. WHEN COATED WITH ADP HIGH TEMPERATURE ALUMINIZED PAINT, ALL SPECIMENS SHOWED EXCELLENT RESISTANCE TO SALT SPRAY TESTS.

GALVANIC AND GENERAL CORROSION RESISTANCE - LOCKALLOY

TEST CONDITIONS

- 2 LOCKALLOY-TITANIUM JOINT SPECIMENS WITH TITANIUM SCREWS IMMERSED IN 3 1/2% SALT SOLUTION FOR 1800 HOURS

  1 SPECIMEN BARE (UNPROTECTED)
  1 SPECIMEN PROTECTED WITH ADP HIGH TEMP. ALUMINIZED PAINT

- 4 SPECIMENS SUBJECTED TO STANDARD 3 1/2% SALT SPRAY TEST FOR 168 HOURS

  2 SPECIMENS BARE (UNPROTECTED)
  2 SPECIMENS PROTECTED WITH ADP HIGH TEMP. ALUMINIZED PAINT AND SCRATCHED THROUGH PAINT TO BARE LOCKALLOY

- 1 SPECIMEN SUBJECTED TO 3 1/2% SALT SPRAY TEST FOR 4600 HOURS

  1/3 OF SPECIMEN BARE (UNPROTECTED)
  2/3 OF SPECIMEN PROTECTED WITH ADP HIGH TEMP. ALUMINIZED PAINT

RESULTS

- LOCKALLOY SUBJECT TO GALVANIC AND GENERAL CORROSION ATTACK IF NOT PROTECTED - SIMILAR TO ALUMINUM ALLOYS
- ADP HIGH TEMP. ALUMINIZED PAINT PROVIDES EXCELLENT PROTECTION AGAINST GALVANIC AND GENERAL CORROSION
- SPECIMEN SUBJECTED TO 4600 HOUR SALT SPRAY SHOWED MODERATE CORROSION ON BARE END AND NO CORROSION ON PAINTED END

1063-36

STRESS CORROSION RESISTANCE (Be-38Al)

THE STRESS CORROSION TESTS SHOWED NO EVIDENCE OF STRESS CORROSION CRACKING FOR EXPOSURES UP TO 100 HOURS. 100 HOURS WAS THE MAXIMUM TIME EXPOSURE USED IN THIS PROGRAM.

STRESS CORROSION RESISTANCE (Be-38Al)

TEST CONDITIONS

- 3 TYPES OF SPECIMENS TESTED AT ROOM TEMPERATURE AND 600°F
  - BARE (UNPROTECTED)
  - PROTECTED WITH CHEMICAL CONVERSION COATING (ALODINE 1200)
  - PROTECTED WITH ADP HIGH TEMPERATURE ALUMINIZED PAINT
- SPECIMENS COATED WITH 3 1/2% SALT SOLUTION
- SPECIMENS LOADED IN TENSION
  - 35 KSI AT ROOM TEMPERATURE
  - 10 KSI AT 600°F
- SPECIMENS INSPECTED FOR STRESS CORROSION CRACKING AFTER 10, 50, AND 100 HOURS

RESULTS

- NO EVIDENCE OF STRESS CORROSION CRACKING ON ANY SPECIMENS

1063-13

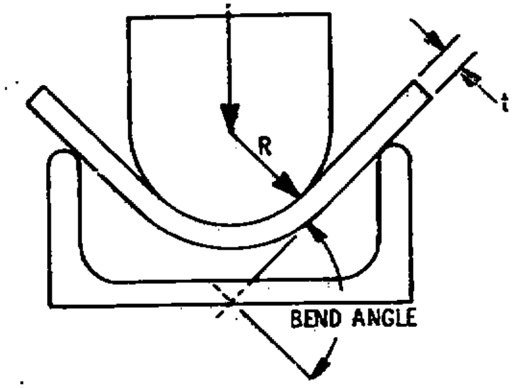
BEND TESTS - Be-38Al LOCKALLOY

LOCKALLOY CAN BE FORMED AT ROOM TEMPERATURE TO A MINIMUM $R/_t$ OF 15.

HOT BENDS AT $1050^{\circ}F$ CAN BE PERFORMED DOWN TO AN $R/_t$ OF 7. SOME BENDING WAS ATTEMPTED AT A $600^{\circ}F$ FORMING TEMPERATURE, BUT WAS NOT CONSIDERED SATISFACTORY.

LOCKALLOY HAS MUCH LESS SPRING-BACK THAN TITANIUM OR ALUMINUM BECAUSE OF THE COMBINATION OF HIGH STIFFNESS AND LOW ULTIMATE ALLOWABLE OF THE MATERIAL.

BEND TESTS-LOCKALLOY



		Be-43Al		Be-38Al		Be-38Al	
THICKNESS		.250 IN.		.250 IN.		.150 IN.	
GRAIN		L	T	L	T	L	T
BEND COLD (R.T.)		$R/_t$ = 15 MIN 3° BEND	$R/_t$ = 15 MIN 3° BEND	$R/_t$ = 15 MIN 3° BEND	$R/_t$ = 15 MIN 3° BEND	$R/_t$ = 15 MIN 105° BEND	$R/_t$ = 15 MIN 105° BEND
BEND HOT	1050°F	$R/_t$ = 7 MIN 105° BEND	$R/_t$ = 7 MIN 105° BEND	$R/_t$ = 7 MIN 105° BEND	$R/_t$ = 7 MIN 105° BEND	$R/_t$ = 6 MIN 105° BEND	$R/_t$ = 7 MIN 105° BEND
	600°F	N.A.	$R/_t$ = 7 FAILED AT 14° BEND	$R/_t$ = 8 FAILED AT 29° BEND	$R/_t$ = 8 FAILED AT 16° BEND	N.A.	N.A.

1063-19

LOCKALLOY SHEAR PANEL TEST SETUP

IN ORDER TO EVALUATE THE BEHAVIOR OF LOCKALLOY FOR A SIGNIFICANT STRUCTURAL COMPONENT TEST, A 20 X 20 INCH PLATE WAS SHEAR TESTED.

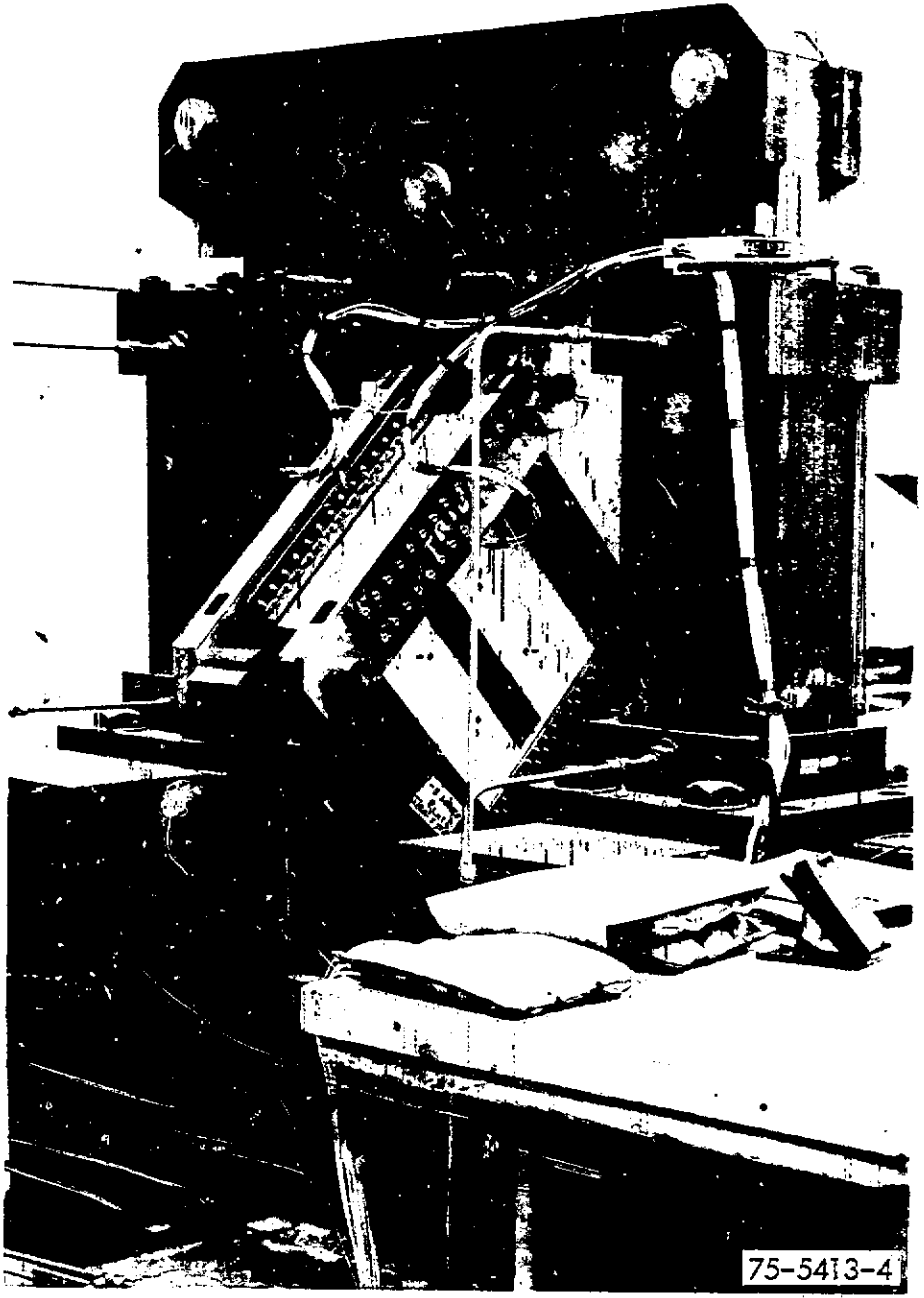
THE PLATE WAS SELECTED SO THAT IT WOULD BE WELL BUCKLED BEFORE FAILURE IN ORDER TO COMPARE PREDICTED "INITIAL BUCKLING" STRESS LEVEL WITH MEASURED "INITIAL BUCKLING" STRESS LEVEL.

LOCKALLOY
SHEAR PANEL TEST -SET UP

A .15 X 20 IN. X 20 IN. PLATE
WAS TESTED TO ULTIMATE IN A
'PICTURE FRAME' JIG

TEST PURPOSES

- TO TEST A PANEL THAT MIGHT REPRESENT AN ACTUAL AIRPLANE APPLICATION OF A HEAT-SINK, LOCKALLOY STRUCTURE.
- TO COMPARE MEASURED VERSUS PREDICTED INITIAL BUCKLING IN SHEAR.
- TO DETERMINE FAILURE STRESS.



1063-29

LOCKALLOY SHEAR PANEL TEST RESULTS

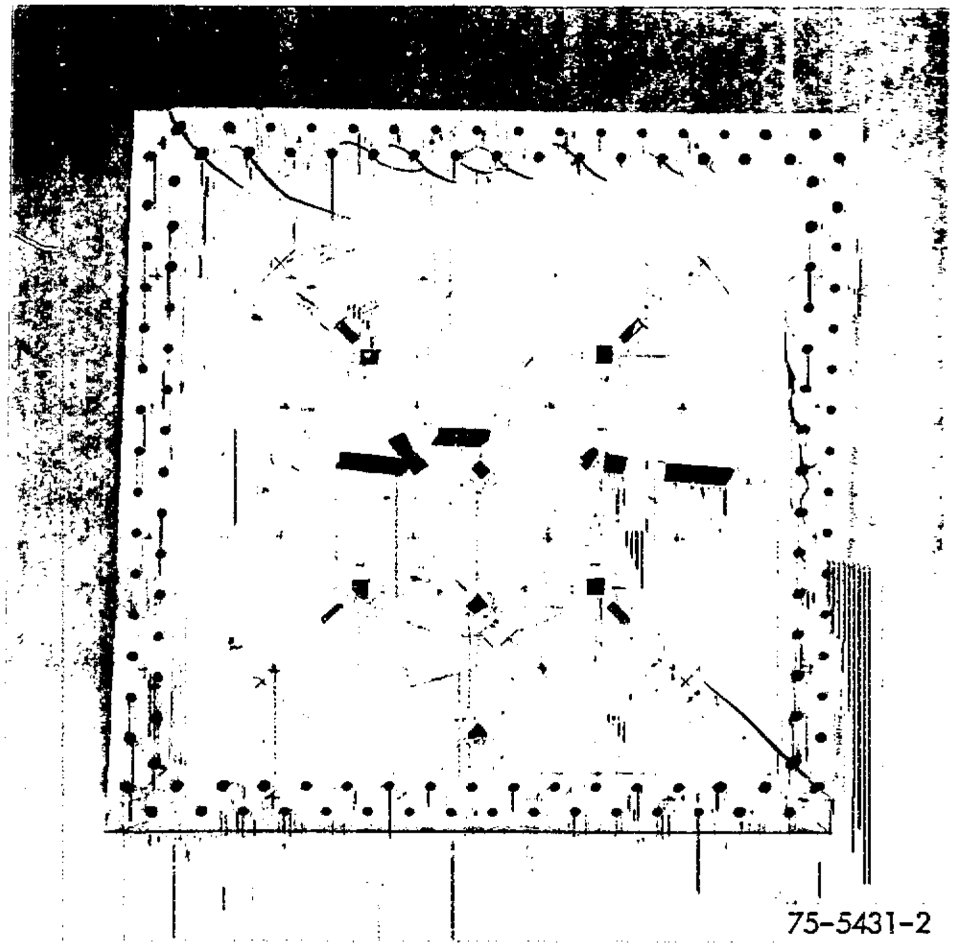
THE BEHAVIOR OF THE PANEL UNDER LOAD EQUALED OR EXCEEDED PREDICTED EXPECTATIONS. THE INITIAL BUCKLING, AS DETERMINED BY INSTRUMENTATION, MATCHED PREDICTIONS. THE PANEL WAS LOADED FIRST IN ONE DIRECTION UNTIL PERMANENT BUCKLING WAS ENCOUNTERED. THEN THE PANEL WAS REVERSED AND LOADED IN THE OPPOSITE DIRECTION TO INITIAL BUCKLING AND ON UNTIL A FAILURE WAS OBTAINED. THE ULTIMATE LOAD HUNG ON FOR 10 MINUTES BEFORE PRODUCING THE FINAL FAILURE. DURING THIS TIME DEFLECTION WAS INCREASING SOMEWHAT AND SNAPPING NOISES WERE OCCURRING.

THE STRESS LEVEL MEASURED AT THE CENTER OF THE PANEL WAS LOWER THAN NEAR THE EDGE OF THE PANEL DUE TO THE DETAILS OF THE EDGE ATTACHMENT FRAMES.

EXAMINATION OF THE FAILED STRUCTURE SHOWS THAT THE MATERIAL BEHAVED IN A VERY DUCTILE MANNER.

LOCKALLOY SHEAR PANEL TEST RESULTS

- $P_{FAILURE}$ = 120,000 LB
- $F_{FAILURE}$ = 28,280 PSI, GROSS SECTION SHEAR STRESS
- FAILURE OCCURED AT THE NET SECTION THROUGH THE EDGE ATTACHMENT HOLES
- HOLES SHOWED 10% ELONGATION AFTER FAILURE
- NOTE PERMANENT PANEL BUCKLE
- PERMANENT SHEAR STRAIN = 1.75° (.03 $IN/_{IN}$)
- LOAD/DEFLECTION DATA SHOWS LARGE PLASTIC DEFORMATION BEFORE FAILURE



75-5431-2

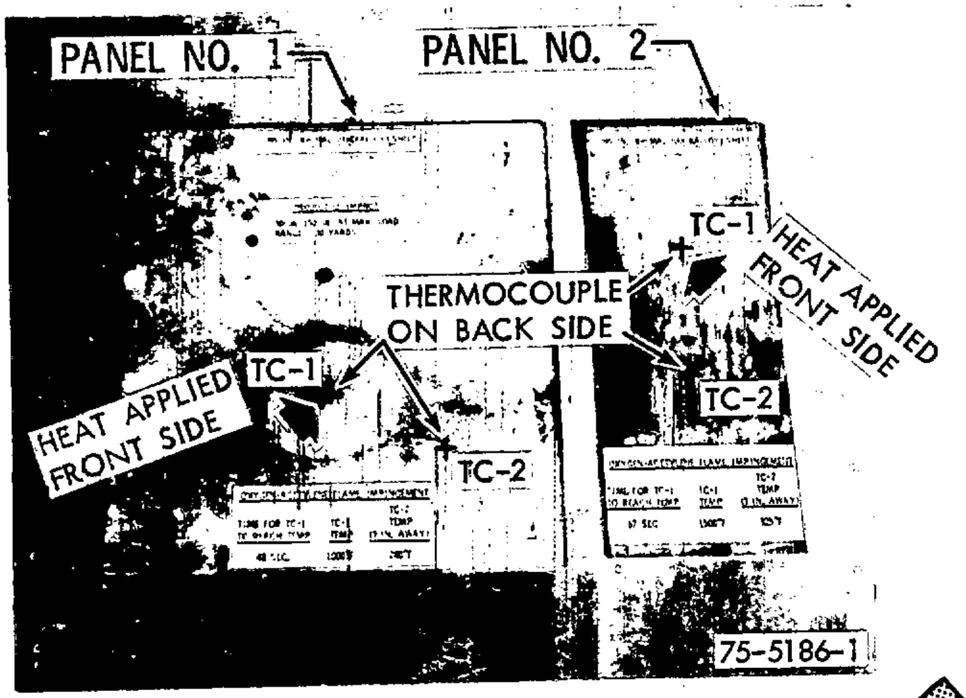
1063-28

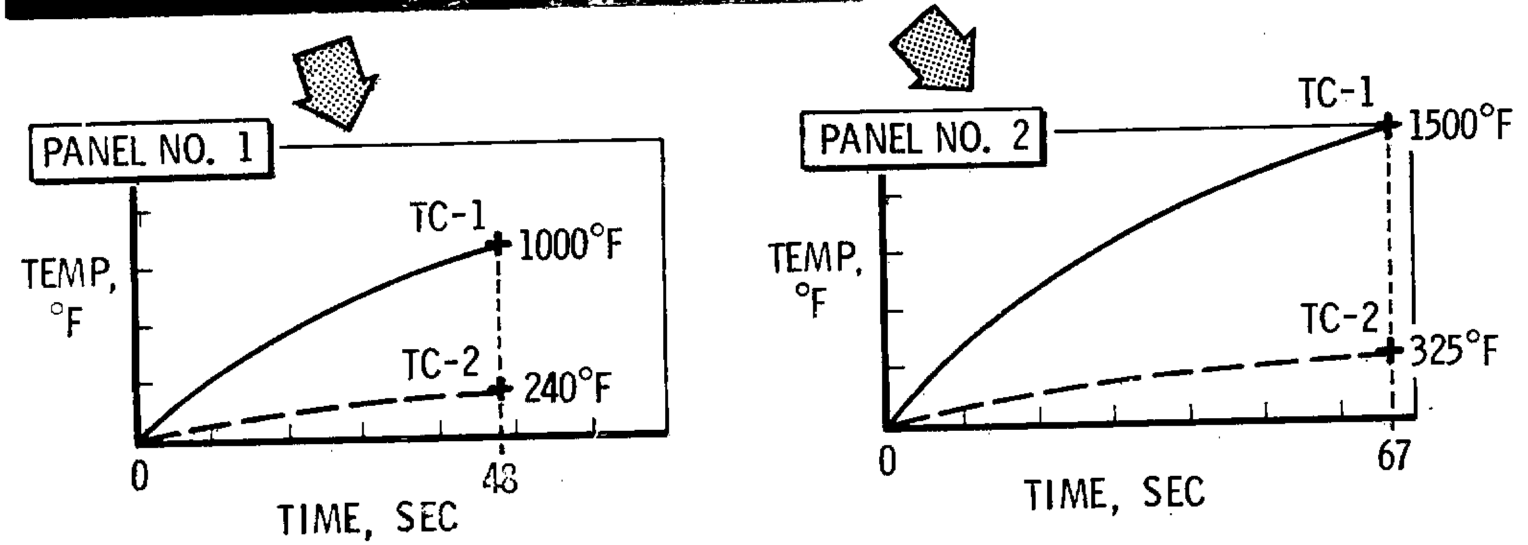
LOCKALLOY THERMAL SHOCK TESTS

EXPERIMENTAL RESULTS INDICATE THAT EXTREMELY SEVERE THERMAL SHOCK MAY BE APPLIED TO THE LOCKALLOY WITHOUT PRODUCING STRAIN CRACKING OR SHRINKAGE CRACKING. AS THE LOCAL TEMPERATURE EXCEEDS APPROXIMATELY 1100°F. SOME DROPLETS OF ALUMINUM WILL PERSPIRE FROM THE SURFACE OF THE PANEL.

LOCKALLOY THERMAL SHOCK TESTS

- THERMOCOUPLES WERE INSTALLED ON THE BACK FACE.
- AN OXY-ACETYLENE FLAME WAS DIRECTED AT THE FRONT FACE.
- TIME AND TEMPERATURE WERE MEASURED.
- PERMANENT DEFLECTIONS WERE .05 IN. AND .01 IN. RESPECTIVELY.
- ZYGLO INSPECTION SHOWED NO CRACKS.
- SOME ALUMINUM PERSPIRED FROM SURFACE AT 1500°F





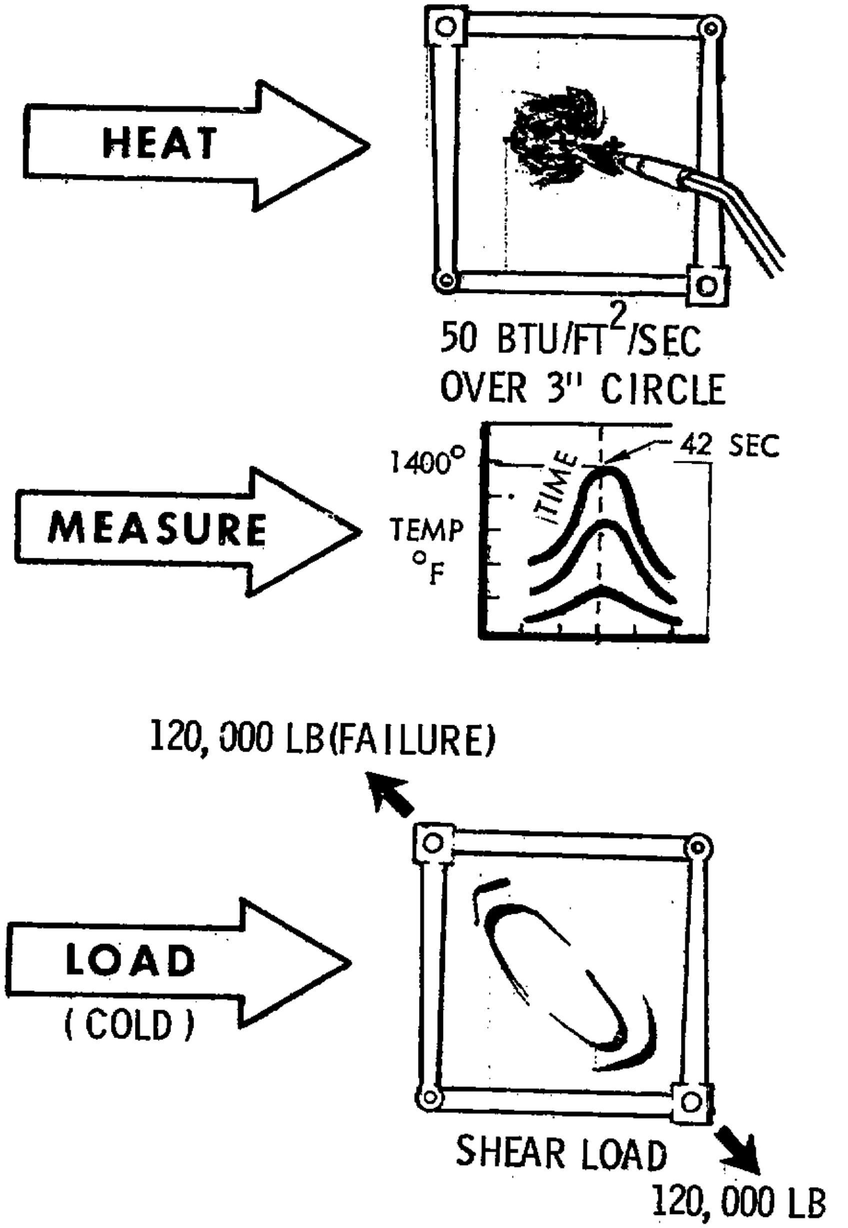
LOCKALLOY SHEAR PANEL THERMAL SHOCK TESTS

IT IS DESIRABLE TO EVALUATE THE EFFECT OF A THERMAL SHOCK ON A LOCKALLOY COMPONENT WHICH MIGHT BE ABLE TO CARRY LOAD AFTER EXPERIENCING THE HEAT SHOCK. IN ORDER TO DO THIS A SHEAR PANEL, SIMILAR TO THE ONE PREVIOUSLY SHEAR TESTED, WAS SUBJECTED TO THERMAL SHOCK TEST WITH TIME/TEMPERATURE MEASUREMENTS ACROSS THE PANEL. THESE MEASUREMENTS INDICATED MAXIMUM THERMAL GRADIENTS OF APPROXIMATELY [illegible] PER INCH. AFTER THE THERMAL SHOCK TEST INSPECTION BY DYE CHECKING REVEALED NO CRACKS, ALTHOUGH A SLIGHT BULGE AND SMALL FLAW WERE NOTED WHERE A DROP OF ALUMINUM HAD PERSPIRED FROM THE SURFACE DIRECTLY UNDER THE HEAT APPLICATION. THE PANEL WAS THEN SHEAR LOADED, AND IT CARRIED THE SAME LOAD THAT WAS CARRIED BY THE PANEL WHICH HAD NOT EXPERIENCED THE THERMAL SHOCK TEST. THE PANEL FAILED IN NET SECTION THE SAME WAY THAT THE COMPARISON SHEAR PANEL FAILED. NEITHER PANEL FAILED IN THE AREA WHERE THE HEAT SHOCK WAS APPLIED.

LOCKALLOY SHEAR PANEL THERMAL SHOCK TESTS

- AN OXY-ACETYLENE FLAME WAS DIRECTED AT A SHEAR PANEL
- TEMPERATURE MEASURED VS TIME
- THE PANEL WAS TESTED TO FAILURE AFTER THE HEAT SHOCK

PANEL SUBJECTED TO HEAT SHOCK WAS 100% AS GOOD AS SIMILAR PANEL WITHOUT HEAT SHOCK



HEAT

50 BTU/FT^2/SEC
OVER 3" CIRCLE

MEASURE

120, 000 LB(FAILURE)

LOAD
(COLD)

SHEAR LOAD
120, 000 LB

1063-17

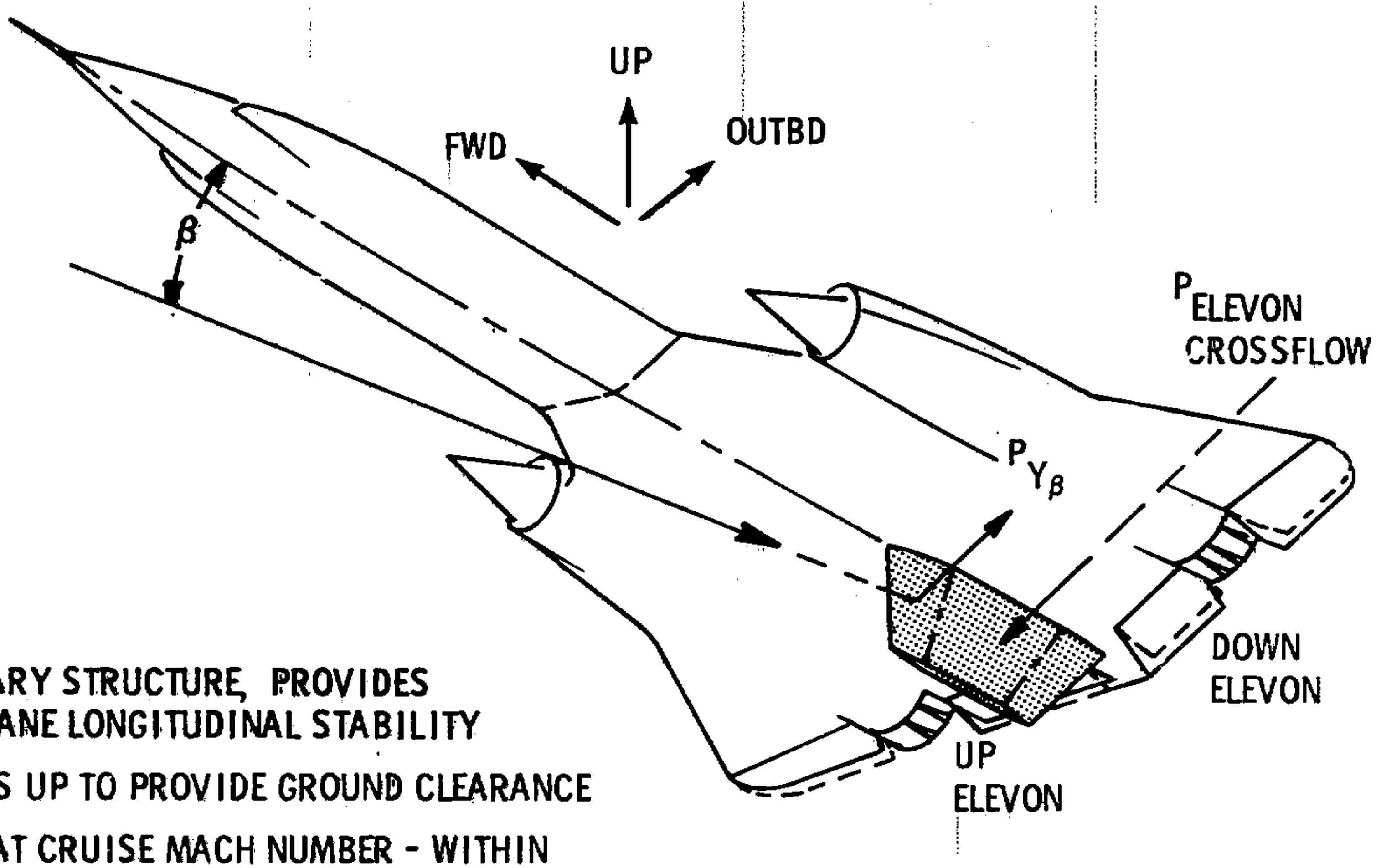
VENTRAL FIN STRUCTURAL REQUIREMENTS

THE FOLDING VENTRAL ON THE BOTTOM OF THE YF-12 IS REQUIRED FOR LONGITUDINAL STABILITY AT HIGH SPEED. IN ORDER TO PROVIDE GROUND CLEARANCE FOR LANDING AND TAKE-OFF ATTITUDES THE VENTRAL MUST FOLD TO A HORIZONTAL POSITION.

AERODYNAMIC LOADINGS ON THE VENTRAL ARE A RESULT OF AIRCRAFT YAW OR SIDESLIP COMBINED WITH THE CROSS FLOW ASSOCIATED WITH DIFFERENTIAL ELEVON POSITION BETWEEN THE LEFT AND RIGHT SIDES OF THE AIRPLANE.

AEROELASTIC DEFLECTION OF THE VENTRAL CAUSES AEROELASTIC LOAD INCREMENTS WHICH ADD SIGNIFICANTLY TO THE OVER-ALL VENTRAL AIRLOADING.

VENTRAL FIN STRUCTURAL REQUIREMENTS



- PRIMARY STRUCTURE, PROVIDES AIRPLANE LONGITUDINAL STABILITY
- HINGES UP TO PROVIDE GROUND CLEARANCE
- 550°F AT CRUISE MACH NUMBER - WITHIN LOCKALLOY TEMPERATURE CAPABILITY
- LOCKALLOY VENTRAL HAS LOWER AEROELASTIC EFFECTS THAN TITANIUM VENTRAL DUE TO HIGHER STIFFNESS

1063-7

LOCKALLOY VENTRAL STRUCTURAL DESIGN CONCEPT

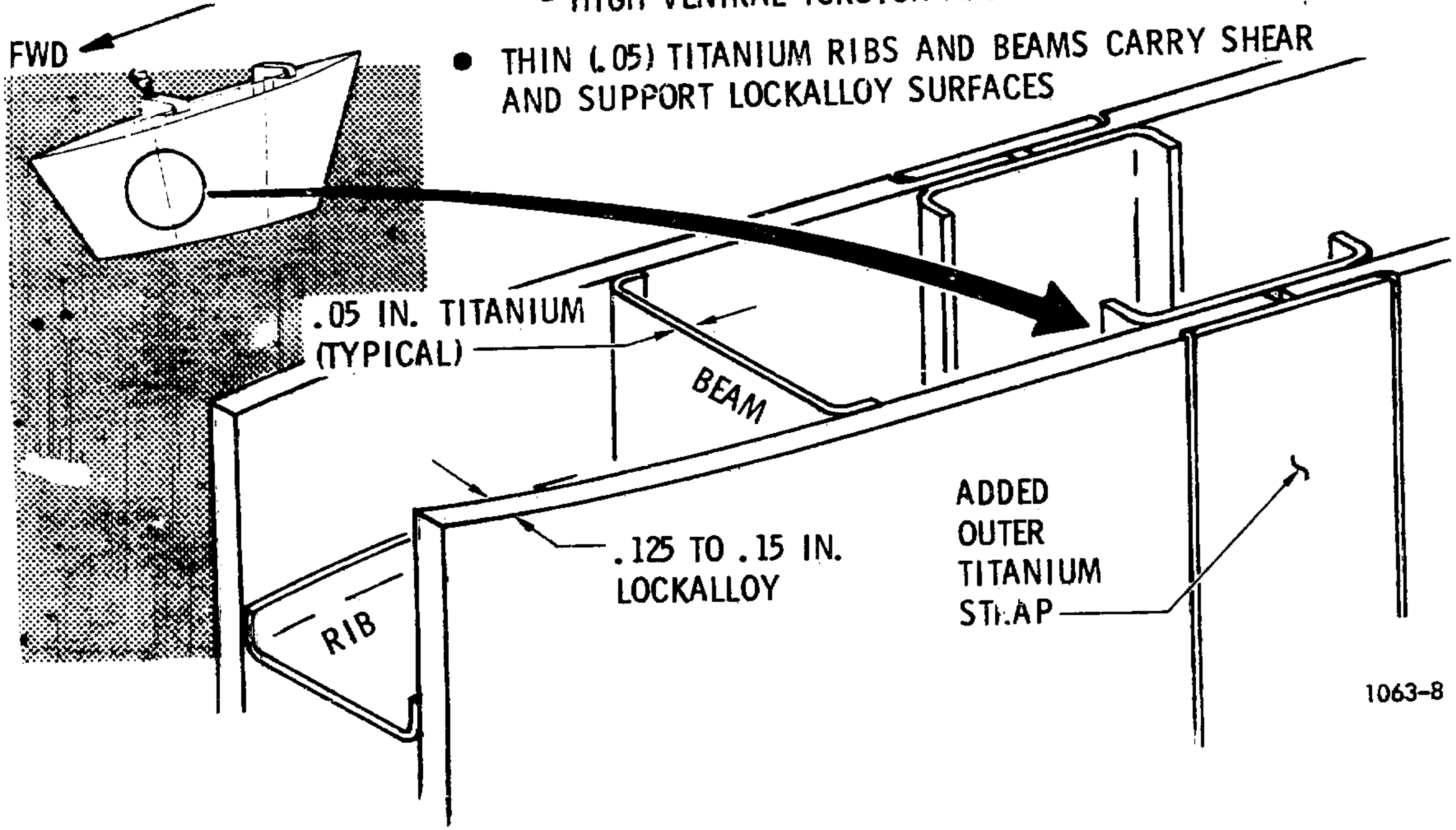
THE LOCKALLOY VENTRAL WAS DESIGNED TO CARRY ALL PRIMARY LOADS IN THE LOCKALLOY SURFACE PLATES. THE TITANIUM SUBSTRUCTURE WAS KEPT TO THE MINIMUM REQUIRED TO STABILIZE THE LOAD-CARRYING LOCKALLOY SURFACE PANELS.

THE LOCKALLOY SURFACE PANELS ARE ATTACHED USING TITANIUM SCREWS IN ORDER TO PROVIDE COMPLETE ACCESS TO ANY PART OF THE VENTRAL INTERIOR.

THE STRESS LEVELS IN THE TITANIUM, WORKING IN PARALLEL WITH LOCKALLOY, ARE QUITE LOW BECAUSE THE MODULUS OF ELASTICITY FOR TITANIUM IS APPROXIMATELY ONE-HALF THAT FOR LOCKALLOY.

LOCKALLOY VENTRAL STRUCTURAL DESIGN CONCEPT

- VERIFY, BY SAMPLE TESTING, THAT EACH PIECE OF MATERIAL WILL SATISFY THE REQUIREMENTS FOR THAT PARTICULAR PART
- SEMI-MONOCOQUE: FLAT-PLATE SURFACES CARRY ALL SPANWISE AND CHORDWISE BENDING LOADS
- HIGH LOCKALLOY STIFFNESS PROVIDES
  - ADEQUATE FLATPLATE BUCKLING ALLOWABLES
  - HIGH VENTRAL TORSION AND BENDING STIFFNESS
- THIN (.05) TITANIUM RIBS AND BEAMS CARRY SHEAR AND SUPPORT LOCKALLOY SURFACES



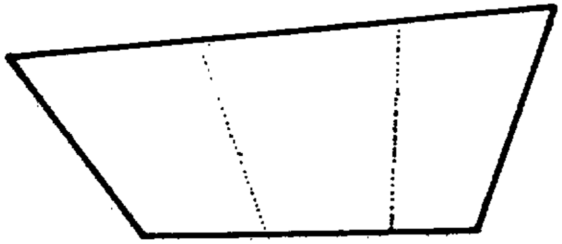
TOOLING REQUIREMENTS

THE TOOLING APPROACH FOR THE VENTRAL WAS BASED ON THE CONCEPT THAT ALL MACHINING AND DRILLING OF THE LOCKALLOY COVER PLATES WOULD BE DONE AT AN OUTSIDE APPROVED BERYLLIUM HANDLING FACILITY. LOCKHEED FURNISHED INDIVIDUAL TEMPLATES FOR MACHINING EACH PANEL.

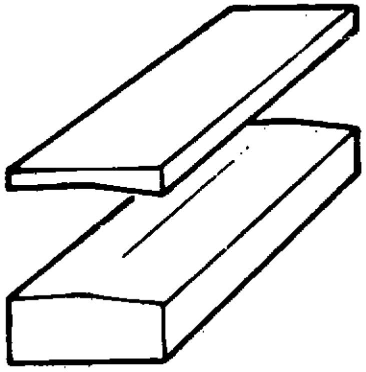
THE MALE CERAMIC DIE USED FOR FORMING THE CONTOUR BREAK AT THE FRONT AND REAR BEAMS WAS CAST ON THE PLASTER SPLASH WHICH IN TURN WAS TAKEN FROM THE WOODEN MOCKUP.

TOOLING REQUIREMENTS

BASIC DIMENSIONS DRAWING

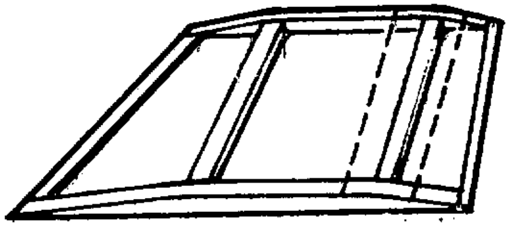


MASTER TOOL
SINGLE PLANE
TEMPLATE

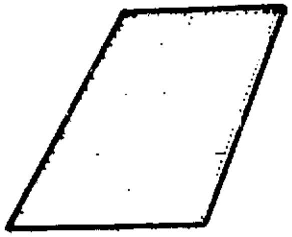


PLASTER SPLASH
(2 REQ'D)

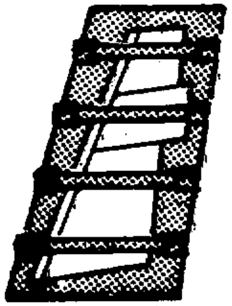
CERAMIC FORMING
DIE (2 REQ'D)
(CAST ON PLASTER
SPLASH)



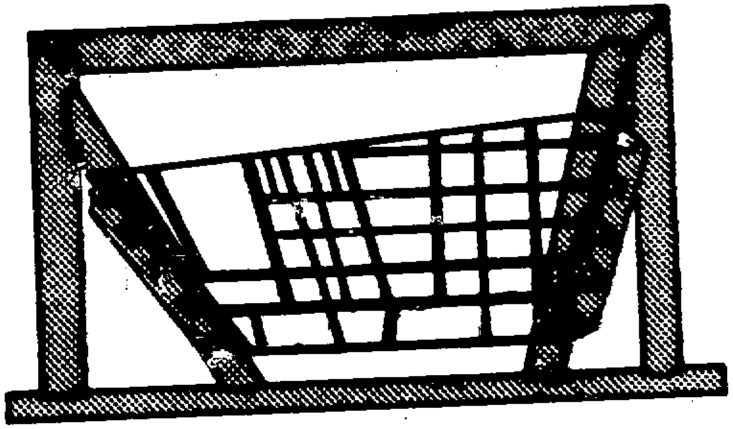
1/2 WOODEN SKELETON MOCK-UP



INDIVIDUAL TEMPLATES
FOR MACHINING PANELS



HOLDING/DRILL FIXTURE
LEADING AND TRAILING
EDGE SUB ASSY



ASSEMBLY FIXTURE

1063-21

MACHINABILITY - LOCKALLOY

LOCKALLOY MACHINES AND DRILLS QUITE READILY. FOR EXAMPLE, THE LOCKALLOY LEADING AND TRAILING EDGE WEDGES ARE PORTED FOR PRESSURE PICKUP USING AN .090 DIAMETER HOLE DRILLED 2.5 INCHES INTO THE WEDGE PIECE AT 8 PLACES.

THE MAIN PROBLEM IN MACHINING LOCKALLOY IS THE "FRIGHT FACTOR" WHICH A MACHINIST UNDERGOES WHEN HE THINKS ABOUT THE COST, SHOULD HE RUIN A PART.

ON THE VENTRAL FIN PROGRAM 32 PANELS, ONE LEADING EDGE WEDGE, AND ONE TRAILING EDGE WEDGE WERE MACHINED WITHOUT SCRAPPING A SINGLE PART.

C-2

MACHINABILITY - LOCKALLOY

- MACHINING OF LOCKALLOY DOES NOT PRESENT THE PROBLEMS ASSOCIATED WITH THE MACHINING OF Be.
  NO POST-MACHINING ETCHING OF LOCKALLOY IS NECESSARY
- LOCKALLOY MACHINES WITH RELATIVE EASE USING HIGH SPEED STEEL OR CARBIDE CUTTERS
- DRILLS EASILY WITH COBALT DRILLS
- LOCKALLOY MACHINING COSTS APPROXIMATELY TWICE AS MUCH AS MACHINING 7075-T6 ALUMINUM

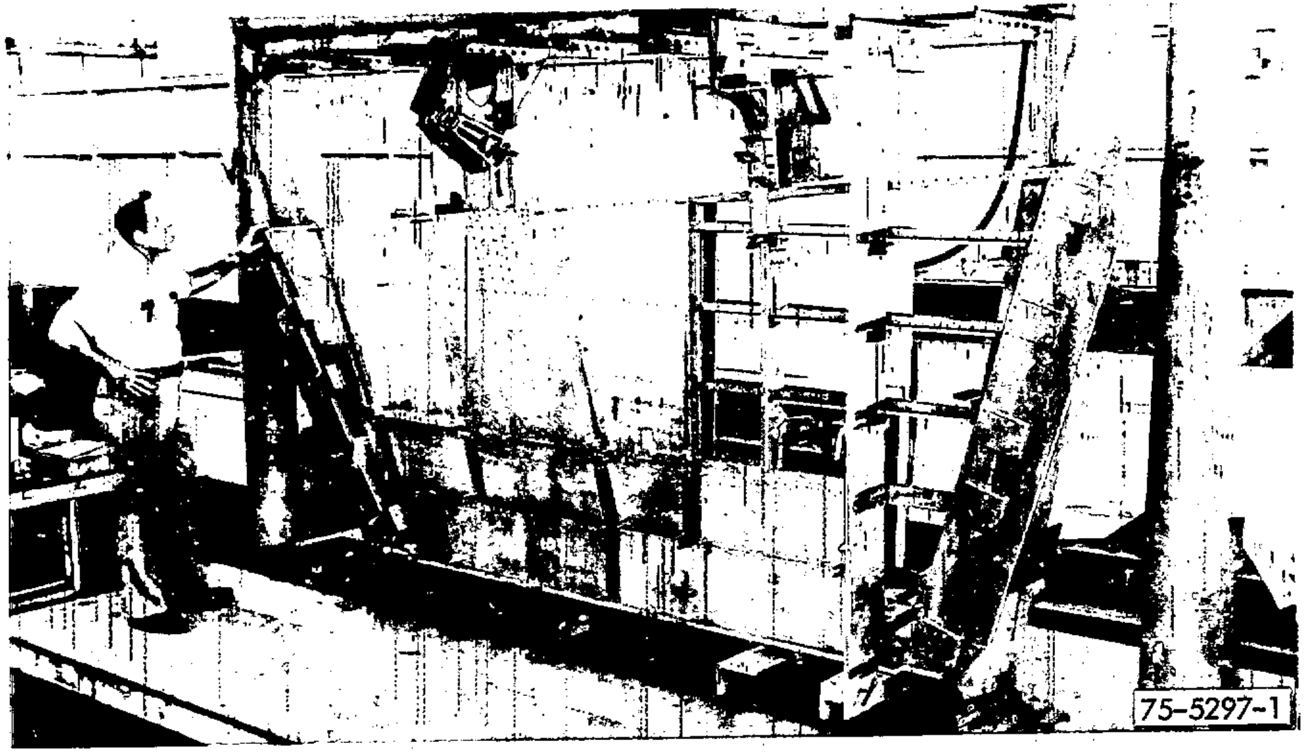
1063-33

ASSEMBLY SEQUENCE

THE ASSEMBLY SEQUENCE WAS ESTABLISHED PRIMARILY BY THE REQUIREMENT TO DO ALL FINISH MACHINING AND DRILLING ON THE LOCKALLOY PARTS BEFORE ASSEMBLY.

THE FINISHED LOCKALLOY PLATES WERE THEN USED AS TOOLS TO DRILL THE SUBSTRUCTURE FOR FINAL PANEL INSTALLATION.

ASSEMBLY SEQUENCE



- ASSEMBLE SUBSTRUCTURE
- LOCATE FINISHED MACHINED PANELS
- PILOT DRILL SUBSTRUCTURE THROUGH BUSHED PANEL HOLES
- WITH LOCKALLOY PANEL REMOVED, DRILL SUBSTRUCTURE HOLES TO REQUIRED SIZE
- FINAL ASSEMBLY

1063-20

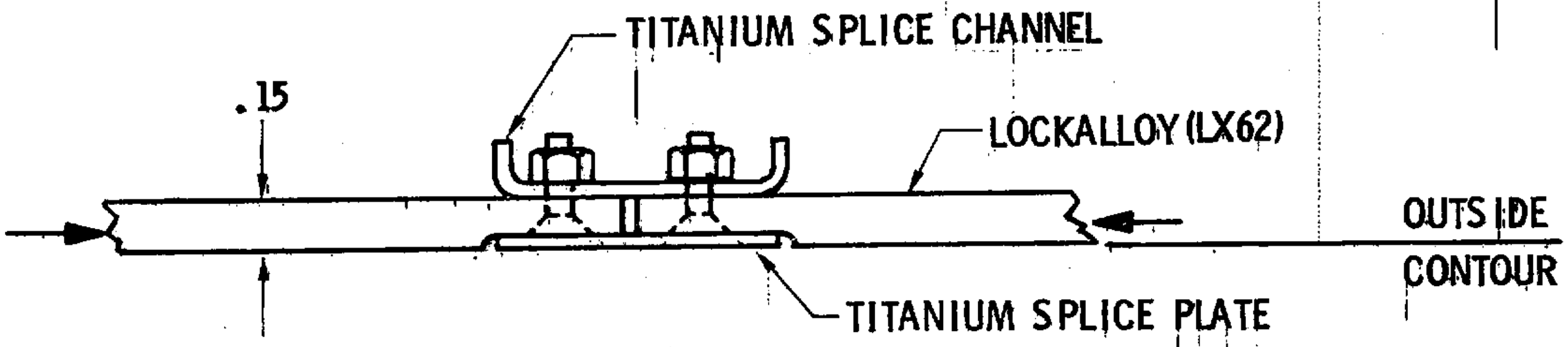
VENTRAL SURFACE COMPRESSIVE JOINT SPECIMEN

THIS COMPRESSIVE JOINT SPECIMEN IS TYPICAL OF THE SPANWISE SPLICES IN THE VENTRAL SURFACES WHICH CARRY THE CHORDWISE BENDING LOADS APPLIED TO THE VENTRAL.

THE OUTER TITANIUM SPLICE PLATE WAS ADDED DURING TEST DEVELOPMENT AND USED TO ELIMINATE JOINT ECCENTRICITY AND IMPROVE THE JOINT EFFICIENCY.

VENTRAL SURFACE COMPRESSIVE JOINT SPECIMEN

SURFACE AXIAL JOINT SPECIMEN



- THIS JOINT WAS TESTED TO VERIFY PREDICTED AXIAL LOAD CAPABILITY IN COMPRESSION
- OUTER SPLICE PLATE REQUIRED TO REDUCE JOINT ECCENTRICITY WHERE NO LATERAL SUPPORT IS PROVIDED AT SPLICE
- SPLICE MEMBERS ARE IN SHORT SECTIONS TO REDUCE THERMAL LOADS

1063-22

VENTRAL SPANWISE BENDING SPECIMEN

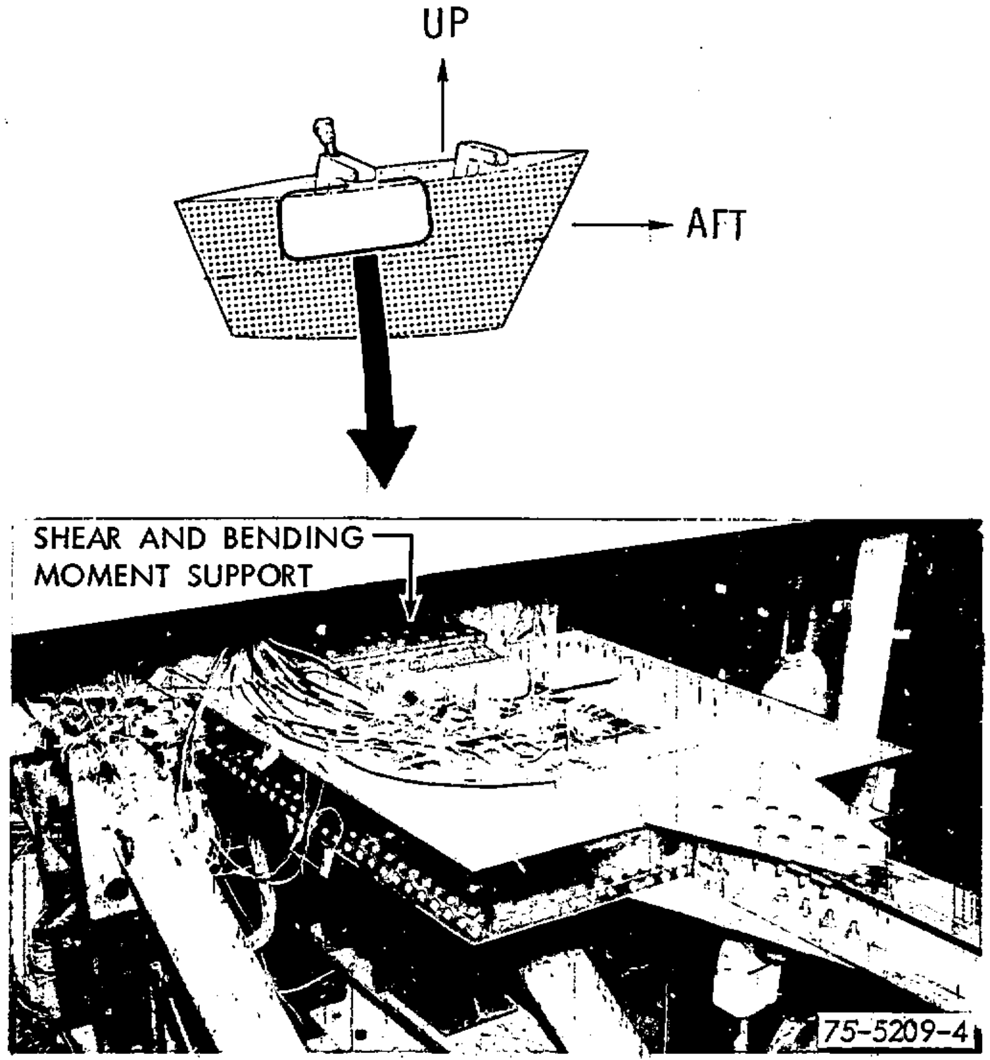
THIS VENTRAL FIN IS SOMEWHAT UNIQUE AS STRUCTURE. THE LOCKALLOY LOAD-CARRYING SURFACES ARE .12 TO .15 INCHES THICK AND ARE EQUIVALENT TO STEEL IN STIFFNESS. THE TITANIUM SUBSTRUCTURE IS LESS THAN ONE-HALF THE GAGE OF THE SURFACE PANELS AS WELL AS HAVING ONE-HALF THE STIFFNESS.

A SPANWISE BENDING TEST WAS CARRIED OUT, IN ORDER TO VERIFY THAT SUCH LIGHT SUBSTRUCTURE COULD STABILIZE THE LOCKALLOY SURFACE STRUCTURE. THE TEST SIMULATES SPANWISE BENDING AT THE CRITICAL ROOT STATION AND WAS CARRIED TO FAILURE IN ORDER TO SUBSTANTIATE ULTIMATE STRENGTH OF THE VENTRAL.

THE LOCKALLOY SURFACE PANELS FOR THIS TEST WERE SIMULATED BY USING 321 ANNEALED STAINLESS STEEL WHICH HAD VERY NEARLY THE CORRECT STIFFNESS AND YIELD STRESS.

VENTRAL SPANWISE BENDING TEST

- TEST SPECIMEN DUPLICATES FRONT BEAM AND ROOT JOINT OF THE VENTRAL
- SIMULATED SURFACE STRESSES ARE MAXIMUM AT THIS LOCATION
- FAILURE STRESS VERIFIED PREDICTED STRESS
- FAILURE OCCURRED BY COLLAPSE OF THE TITANIUM SUPPORT CHANNELS, ALLOWING SIMULATED LOCKALLOY PANELS TO BUCKLE IN COMPRESSION.



1063-4

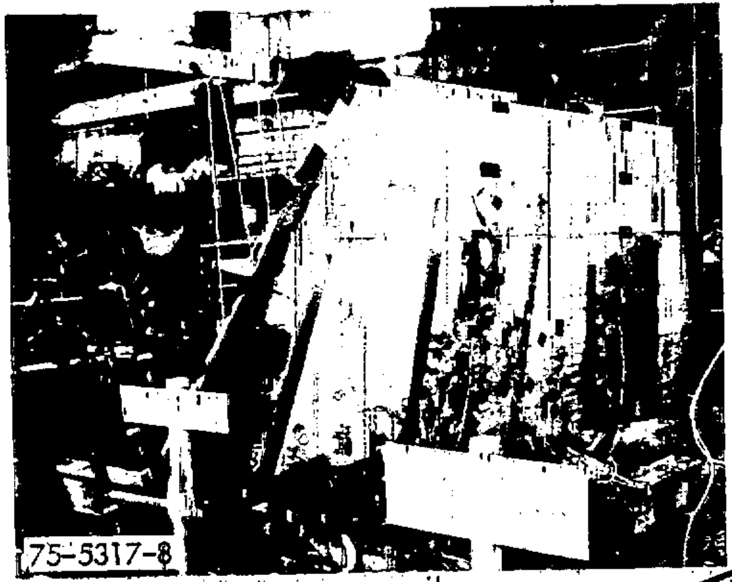
LOCKALLOY VENTRAL PROOF TESTS

THE COMPLETED VENTRAL FIN WAS SUBJECTED TO A PROOF TEST PROGRAM WHICH APPLIED THE MAXIMUM LOADS EXPECTED IN FLIGHT. STATIC TEST INSTRUMENTATION, AS WELL AS FLIGHT TEST INSTRUMENTATION, WAS MONITORED DURING THESE TESTS.

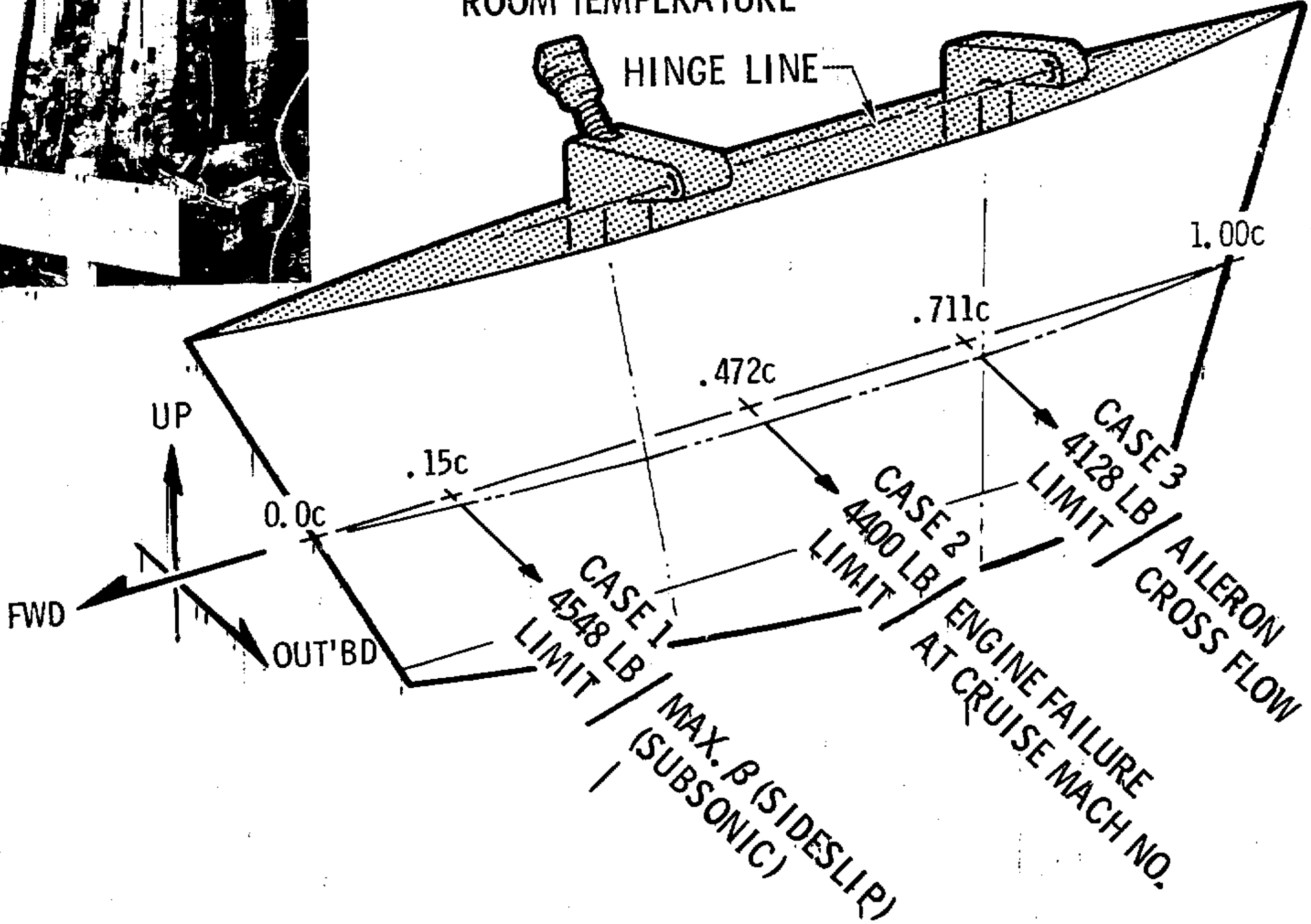
THE CASE A CONDITION LOADS, WHICH OCCUR AT ELEVATED TEMPERATURE, WERE NOT CRITICAL AND THE CONDITION WAS TESTED IN ORDER TO VERIFY STRESS DISTRIBUTION.

THIS CORRELATION WAS ESTABLISHED WITH THE PREDICTED INTERNAL LOADS AS WELL AS WITH THE INSTRUMENTATION WHICH WILL BE READ DURING ACTUAL FLIGHT.

LOCKALLOY VENTRAL PROOF TESTS



- VENTRAL LOADED TO LIMIT LOAD
- THREE CASES ARE SHOWN
- ALL TESTS WERE CONDUCTED AT ROOM TEMPERATURE



SECTION 1

INTRODUCTION

1.1 PURPOSE OF REPORT

This report documents and summarizes the results of a program undertaken by Lockheed-Advanced Development Projects (ADP) for the NASA Flight Research Center to design, fabricate, and ground test a Lockalloy ventral fin assembly for the YF-12 research airplane. It also presents the results of an accompanying material characterization study for Lockalloy, which was used in the construction of the ventral fin assembly.

1.2 PROGRAM OBJECTIVES AND ACCOMPLISHMENTS

On 21 April 1975, Lockheed-ADP was awarded a contract under the joint NASA/USAF YF-12 Project to develop a ventral fin assembly for the YF-12, using Lockalloy as the major structural material. The contract also specified that a material characterization study of Lockalloy be conducted concurrently to support the ventral design. The ventral fin was to be designed to exceed previously established physical and mechanical requirements that were used for the design of an all-titanium ventral fin. One of the principal design objectives was increased stiffness.

Lockalloy has sufficient strength at 600°F to be considered as an alternate material for titanium on a vehicle operating at Mach 3. The modulus of elasticity is almost twice that of the commonly used titanium alloys, and the density is about one-half that of these titanium alloys. This makes Lockalloy very attractive for use in relatively thick surface panels with a minimum of supporting substructure. The new design emphasizes simplicity of construction and entails the use of both Lockalloy and titanium. The substructural elements and fittings are made of titanium, while the surface elements (panels) are made of Be-38Al Lockalloy (62 percent beryllium, 38 percent aluminum).

Lockalloy combines the most desirable characteristics of both beryllium and aluminum. The ductile properties of pure aluminum are combined with the higher strength and stiffness of beryllium. The physical properties of Lockalloy are equally as attractive as its mechanical properties, since it has high specific heat and thermal conductivity and has low density. In addition, Lockalloy exhibits good formability and machining characteristics and useful structural properties from -320° to 800°F.

This program represents the first significant application of Lockalloy as a structural material for a major aircraft component. The published properties of Lockalloy made it the best material to use on the ventral fin. The program offered an opportunity to explore Lockalloy and more fully characterize it as a structural material. The ventral fin fabrication operations provided firsthand experience in machining and forming Lockalloy, while the material characterization study did much to expand the material data base and validate the ventral fin design.

When the YF-12 aircraft were built some 14 years ago, titanium alloys were almost as new and untried as Lockalloy is today. Accordingly, the YF-12 philosophy of qualification testing and recording of each piece of incoming material was also used on the YF-12 Lockalloy Ventral Fin Program. These qualification testing results are of much greater value to the designer than any data obtained by statistical means. Even the well=known aircraft materials of today could be more safely utilized using qualification testing data on the specific piece of material to be used, rather than relying on standard statistical results which constitute "probability values."

To ensure that the design objectives of the program had been met, the completed ventral fin assembly was instrumented, installed in a loading fixture, and subjected to a series of proof and calibration tests. Proof-loading was employed to subject the fin to the maximum loads anticipated in flight. The calibration tests were performed to calibrate flight test instrumentation. These tests were completed without incident and the ventral fin assembly was subsequently delivered to the NASA Flight Research Center.

1.3 SCOPE OF REPORT

This report contains a detailed account of the ventral fin design and fabrication effort and the accompanying material characterization study. A narrative discussion of all program activities and significant events in chronological sequence is presented in Section 2. The results of the Lockalloy material characterization study are summarized and analyzed in Section 3, while supporting data may be found in Appendixes A thru E. Section 4 discusses the design criteria for the ventral fin, including design support testing. Tooling requirements for the ventral fin fabrication are discussed in Section 5. Section 6 covers fabrication of the fin, including in-plant operations and vendor operations, and also includes a summary of Lockalloy fabrication experience. The ventral fin ground tests are described in Section 7.

SECTION 2

CHRONOLOGICAL EVENTS AND PROGRAM ACTIVITIES

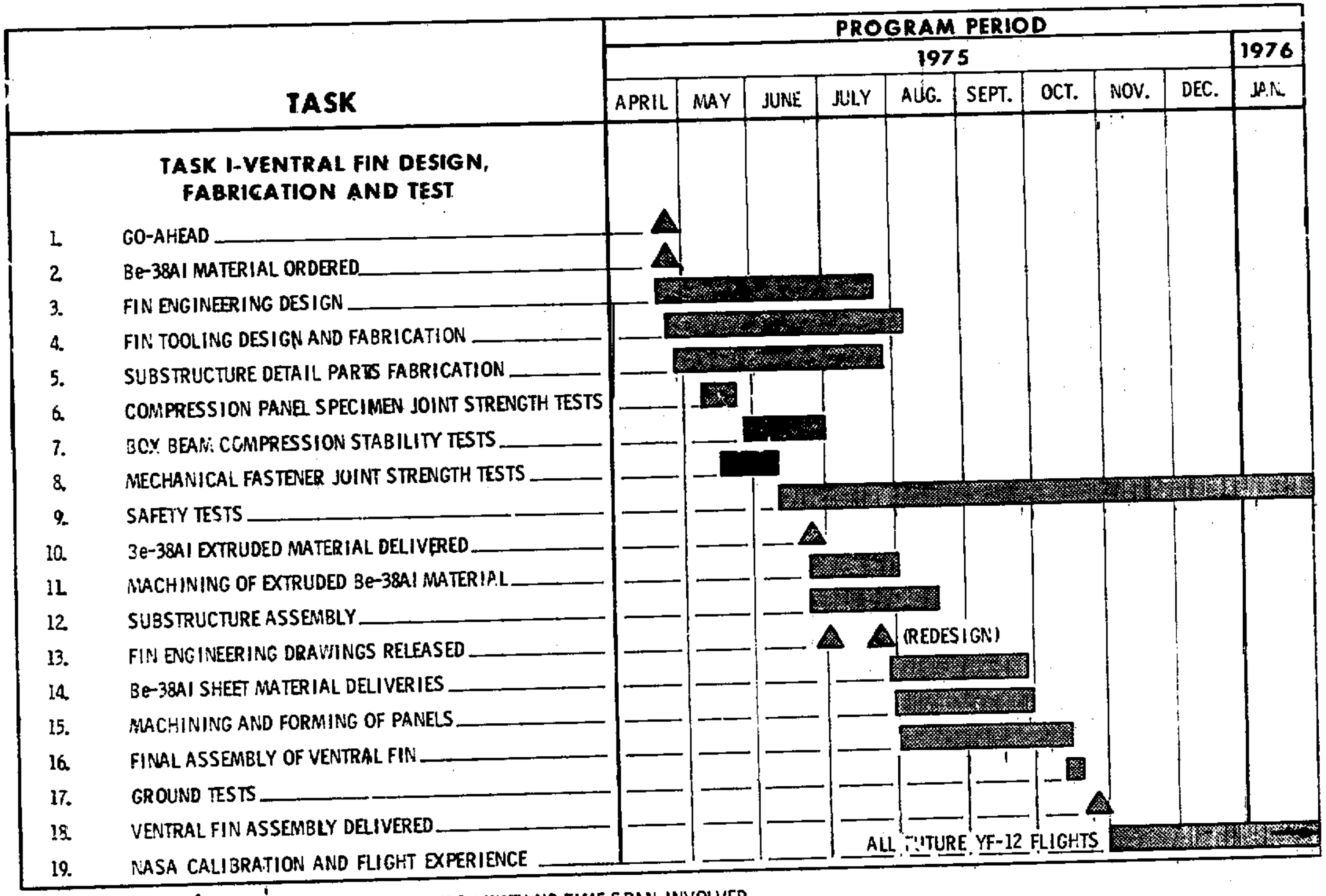
This section provides an overview of the YF-12 Lockalloy Ventral Fin Program from the standpoint of program activities and significant events.

2.1 PROGRAM SCHEDULE

The major events associated with the program and the time frame in which they occurred are listed in the Program Schedules, Figures 2.1-1, 2.1-2, and 2.1-3.

2.2 ACTIVITIES AND SIGNIFICANT EVENTS

2.2.1 Task I - Ventral Fin Design, Fabrication, and Test - The Be-38Al Lockalloy material needed to fabricate the ventral fin, provide the contingencies, and carry out the material characterization study of this alloy was ordered from Kawecki Berylco Industries, Inc. (KBI) on 22 April 1975 (see Figure 2.1-1). This included both sheet material and extrusions. Delivery of this material was scheduled during the period 15 June to 18 July 1975. The material required for fin fabrication was to be delivered first, along with sheet material for that portion of the material characterization study required to validate the fin design. Contingency material was scheduled for delivery last. Actually, deliveries of the sheet material needed for the fin surface panels were made in the period 25 July through 22 September 1975. Production problems involving the larger Lockalloy sheet material were experienced at KBI. As a result of these problems, the sheet material accepted was 40 inches long rather than 50 inches as originally ordered and necessitated an added splice in the ventral fin.



NOTE: ▲ DENOTES COMPLETION OF TASK WITH NO TIME SPAN INVOLVED

Fig. 2.1-1 - Program Schedule, Task I

Engineering development tests were conducted in May and June 1975 to prove ultimate load capability of critical portions of the fin. These included: (1) compression panel tests to validate panel splicing design techniques, (2) mechanical fastener joint strength tests to validate mechanical fastener spacing, (3) box beam compression stability tests to verify that the titanium substructure would provide adequate support for the Lockalloy surface panels. In addition, safety tests were performed throughout the contract period to determine the possible existence of health hazards when working with Lockalloy at elevated temperatures or when performing relatively simple machining operations, using only portable vacuum equipment to collect toxic beryllium particles.

Fin tooling design and fabrication were completed on schedule in June and July of 1975, except for rework required by the aforementioned design changes to provide for the additional skin splice necessitated by the 40-inch length limitation on Lockalloy sheet material. This included tooling required to fabricate the titanium substructure details and the Lockalloy surface panels, as well as that required for final assembly of the fin.

Assembly of the fin substructure was initiated on 26 June 1975, approximately one week ahead of schedule. By mid-August, assembly had been completed except for drilling of holes needed to attach the Lockalloy surface panels. This final fabrication process could not be completed until all Lockalloy panels were available. The machined and drilled panels were needed to transfer attachment holes to the substructure.

Final machining and forming of the 32 Lockalloy surface panels and the extruded Lockalloy leading and trailing edge members were completed by 23 September 1975. Final assembly of the ventral fin was completed 14 October 1975. The completed fin assembly was instrumented, installed in a test fixture, and subjected to a series of proof-load tests beginning on 15 October 1975. These tests were completed on

20 October. Modification of the titanium substructure near the rear beam support was indicated in the course of the tests and was completed in the next few days. The ventral fin assembly was delivered to the NASA Flight Research Center on 28 October 1975.

2.2.2 Task II - Lockalloy Material Characterization Study - The Be-38Al Lockalloy material needed to carry out the material characterization studies was ordered 22 April 1975, along with that needed for fabrication of the ventral fin (see Figure 2.1-2). Machining of all tension, notched tension, and bend specimens from an existing plate of .250-inch thick Be-43Al Lockalloy (left over from a previously completed cost study of the X-24C airplane) was completed by the first week in June. Characterization tests of the Be-43Al material began in May and were completed the first week in August.

An extensive literature search to compile existing data on Lockalloy products was conducted by the Lockheed Information Services Department in May 1975. Review of this data by Lockheed-ADP Engineering was completed by mid-July.

To obtain preliminary thermal shock information on Lockalloy, two samples of .095-inch thick Be-38Al alloy sheet were tested in May 1975. This material was obtained from Lockheed Missiles and Space Company, Inc., without cost to NASA.

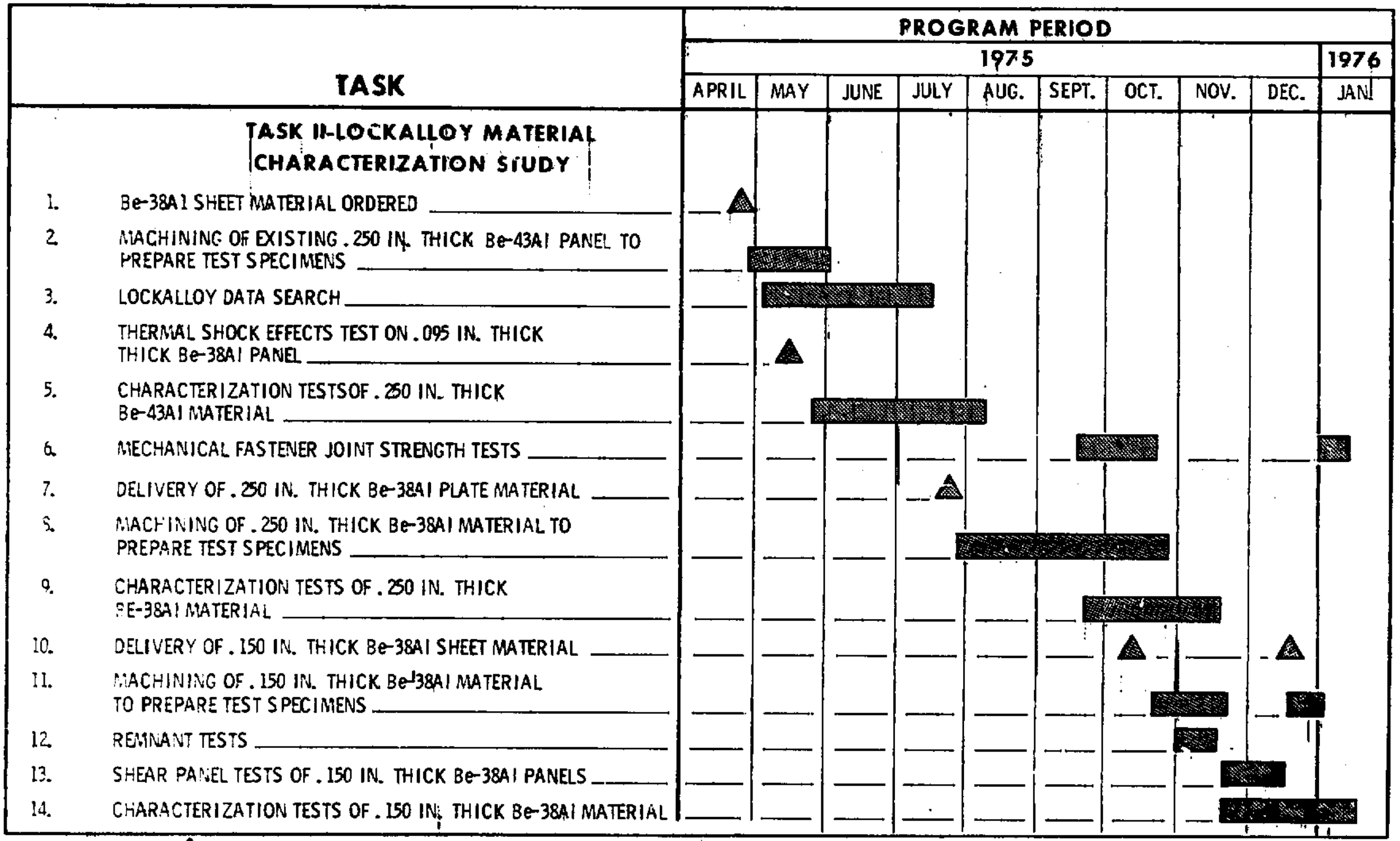
First delivery of the Be-38Al material required for the characterization study was received near the end of July 1975. This shipment consisted of the .250-inch thick plate material. Machining of test coupons from this material was accomplished by an outside vendor in accordance with Lockheed engineering drawings. Delivery of the test specimens from the vendor was made on 27 August. However, subsequent inspection of the 69 tension specimens just prior to testing revealed that they did not conform to dimensional tolerances; they were then returned to the vendor for rework. Meanwhile, testing of some of the acceptable specimens were completed in September. The reworked tensile specimens were received on 20 October, and by mid-November all tests had been concluded.

Two of the three sheets of the .150-inch Be-38Al material required for the characterization study of this material were received from KBI on 7 October 1975. The sheets were sent out for machining of test specimens about mid-October. The test specimens were delivered 15 November and characterization tests began immediately thereafter. The third sheet of this material was delivered after 17 December and test specimens were not available until January 1976. The characterization tests of this material (including shear panel tests) were completed in January.

Shear panel tests involving two 22-inch square, .150-inch thick Be-38Al panels were performed in two increments as shown in Figure 2.1-2. This was dictated by the fact that the panels were fabricated at different times. The first panel was fabricated from the scheduled 7 October shipment of Lockalloy, while the second panel was fabricated from a special piece of Lockalloy material supplied by KBI later, specifically for this test. The first panel was subjected to shear tests to provide data on shear buckling allowables and ultimate shear strength. The second panel was subjected to a localized 1000°F thermal shock test. After the thermal shock test the panel was tested in the shear jig to provide direct comparison of the capability of a severely heat-shocked specimen to carry shear as compared to a virgin panel representing a significant airplane part.

Remnant tests were performed the first part of November 1975. Remnants from each sheet of Lockalloy used for fin surface panels were tested to evaluate KBI certification data and thereby provide added assurance that each panel had acceptable mechanical properties.

2.2.3 <u>Task III - Reporting and Documenting</u> - Appropriate emphasis was given to providing adequate documentation for the YF-12 Lockalloy Ventral Fin Program. Numerous reports were prepared during the contract period, a documentary film was produced, and a final program review was held to provide a forum in which the results



NOTE: △ DENOTES COMPLETION OF TASK WITH NO TIME SPAN INVOLVED

Fig. 2.1-2 - Program Schedule, Task II

of the program could be reported and discussed. These items are listed in the program schedule for this task, Figure 2.1-3, and discussed further in the following paragraphs.

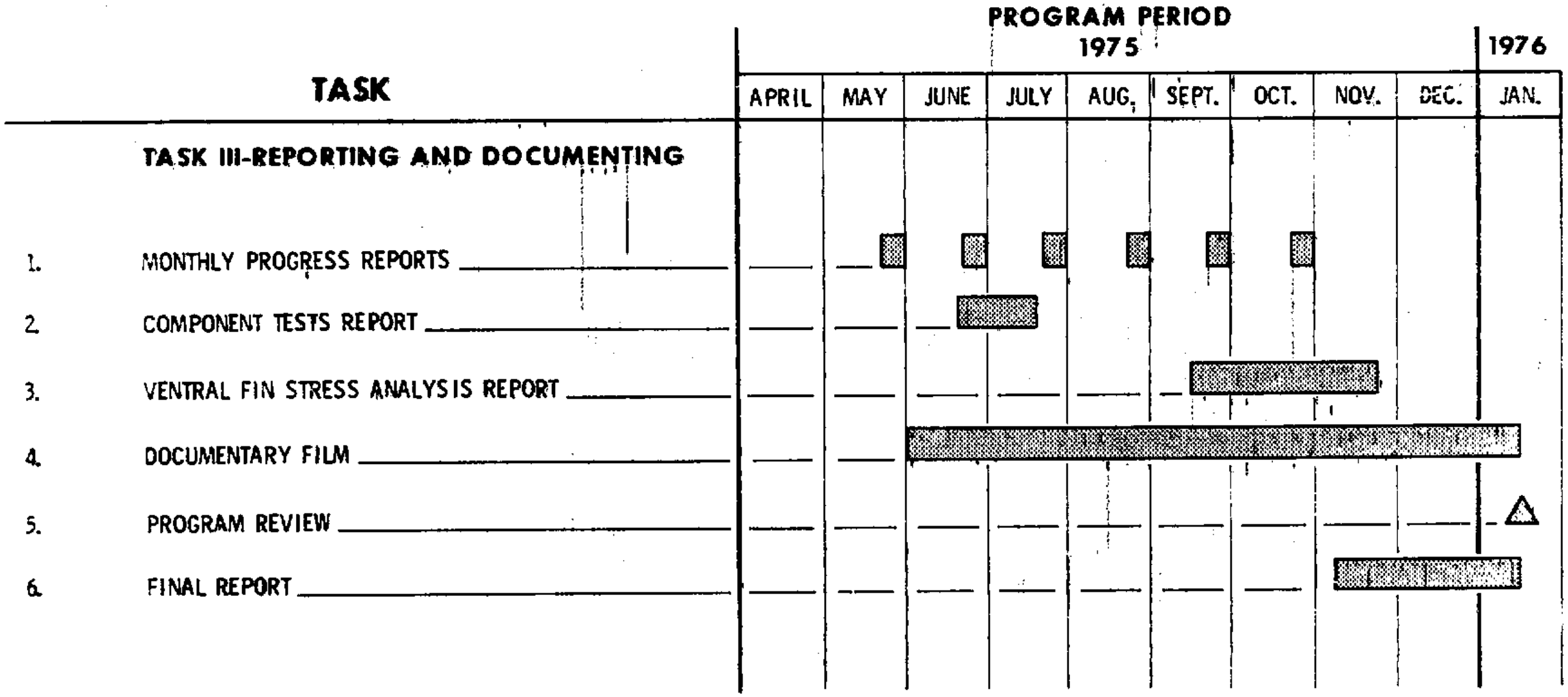
2.2.3.1 <u>Monthly Progress Reports</u> - Six monthly progress reports providing a technical commentary on the preceding month's effort were prepared during the program. These reports were submitted during the period 1 June to 1 November 1975.

2.2.3.2 <u>Special Reports</u> - In addition to the monthly progress reports, special technical reports (Items 2 thru 5, Figure 2.1-3) were generated during the course of the program. These reports provided advance information concerning certain tests or analyses performed in connection with Task I. The following special reports were published:

Report Title	Date
Component Tests for Lockalloy Ventral	24 June 1975
Stress Analysis - Lockalloy Ventral Fin	17 July 1975

The above reports are provided in Volume II, Appendixes D and E, of this final report.

2.2.3.3 <u>Program Review</u> - On 12, 13 and 14 January 1976 a program review was held at Langley Research Center. This consisted of graphically illustrated oral presentations and included a showing of the documentary film prepared as a contractural requirement. The presentation included a review of the program highlights as well as significant developments resulting from the first use of Lockalloy for a primary structural element of an airplane.



NOTE: △ DENOTES COMPLETION OF TASK WITH NO TIME SPAN INVOLVED

Fig, 2.1-3 - Program Schedule, Task III

2.2.3.4 Documentary Film - A sound motion picture in full color was prepared to codument program highlights. The film runs approximately 18 minutes and includes Lockalloy production at KBI, material testing, handling safety, ventral fin fabrication, ground testing, installation on the aircraft, and recalibration and vibration tests. The film was presented in conjunction with the program review in January 1976.

2.2.3.5 Final Report - This final report in two volumes, "YF-12 Lockalloy Ventral Fin Program, Final Report", (Volume I - CR-144971 and Volume II - CR-144972, dated 9 January 1976) was prepared to provide detailed documentation of the program. The report covers every significant aspect of the design and fabrication of the ventral fin; it also summarizes the results of the Lockalloy material characterization study and contains the substantiating data.

2.3 LOCKALLOY MATERIAL PROCUREMENT

2.3.1 Initial Order - The initial order for Be-38Al Lockalloy that was placed with KBI on 22 April 1975 provided sufficient material for ventral fin fabrication, material characterization studies, and for unforeseen contingencies. This order consisted of the following material:

Fin Fabrication

6 sheets .150 x 25 x 50 inches
4 sheets .125 x 25 x 50 inches
2 sheets .125 x 28 x 50 inches
1 extruded bar .6 x 4.25 x 67 inches
1 extruded bar .606 x 3.75 x 67 inches

Material Characterization Study

2 sheets .150 x 25 x 50 inches

1 plate .250 x 21 x 36 inches

1 plate .250 x 21 x 24 inches

Contingency Material

2 sheets .150 x 25 x 50 inches

2 sheets .125 x 25 x 50 inches

1 extruded bar .6 x 4.25 x 67 inches

2.3.2 Lockalloy Production Problems - KBI agreed on a "best effort" basis to deliver the Lockalloy material during the period 15 June to 18 July 1975. This was based upon the fact that KBI had sufficient -38 mesh Be-38Al powder on hand to complete the order; it also assumed that final production of the deliverable material would be accomplished without incident or interruption. Consequently, Lockheed-ADP based its 15 September 1975 scheduled delivery of the ventral fin assembly upon this qualified commitment. By the end of June 1975, it became apparent that KBI could not meet its scheduled deliveries and that non-availability of the Lockalloy sheet material would impact the delivery of the ventral fin to the NASA Flight Research Center. As a result, Lockheed-ADP developed a closer working relationship with KBI.

KBI produces Lockalloy sheet or plate material by encasing an extruded preform in a steel envelope and hot-rolling it several times to obtain the required thickness. For this order, KBI elected to use an existing die to produce 1.125 x 8.125 inch rectangular extruded bars. To obtain maximum material utilization from this shape, the bars were cut into preforms 35 to 38 inches long (considerably less than the 50-inch length of the sheet material ordered). Rolling operations were employed to produce sheets of the required dimensions and also improve transverse ductility in the process. Following each rolling operation, the Lockalloy was encased in a new steel envelope. In an effort to expedite this order, KBI substituted a different type of steel for that normally used for these envelopes. The first Lockalloy plate produced, however, was found to be cracked following the second rolling, and KBI thus reverted to the type of steel used previously for the rolling envelopes.

The preforms were to be subjected to three rolling operations opposite the direction of extrusion (widthwise), followed by a fourth rolling in the direction of extrusion (lengthwise) to obtain the required .150-inch thickness and to bring the sheets out to the required 50-inch lengths. The Lockalloy plates were to be encased in a new steel envelope following the first and second rolling operations. The third and fourth rollings were to be accomplished successively, without replacing the envelope.

Having corrected the difficulties associated with the type of steel used for the rolling envelopes (as described previously), the first two rolling operations were successfully accomplished on several plates with no evidence of cracking. The combined third and fourth rolling operation, however, produced Lockalloy sheets with excessive edge cracking. To correct this problem, it was decided that the steel envelope should be replaced following the third rolling (opposite the direction of extrusion), before attempting the fourth, lengthwise rolling.

The third (widthwise) rolling was accomplished on 10 Lockalloy plates without cracking. The fourth (lengthwise) rolling using new envelopes was attempted for the first time on 11 July 1975. It proved to be unsuccessful. The first two plates that were rolled to the required length were found to be extensively cracked. The amount of rolling was then reduced for the remaining eight plates. This diminished but did not eliminate the cracking. Some material from these plates was salvageable.

KBI had already cut all existing extruded material into the shorter lengths and also had several plates in process which had been subjected to two rolling operations. To make use of this material and avoid further delays in production, the troublesome lengthwise rolling operation was eliminated. Thereafter, all replacement material was rolled only in the widthwise direction. This resulted in plates which were approximately 25 inches wide and which were thicker and shorter than originally required. Proper sheet thicknesses were then obtained by grinding at KBI. To accommodate the shorter length sheet material, Lockheed-ADP revised the original fin design by adding one additional chordwise splice near the outer tip of the ventral fin.

The revised design required a total of 32 individual surface panels, 12 more than on the original design. To facilitate Lockalloy production and make the requirements less stringent, Lockheed-ADP supplied KBI with surface panel templates. KBI in turn provided sheet material of sufficient size to allow panel fabrication. This eliminated the requirement for 50-inch sheet material. In addition, the following measures were adopted (with the concurrence of Lockheed-ADP and NASA) to further reduce risks:

a. Rolling temperatures were increased from approximately 1000°F to approximately 1100°F.

b. Steel envelopes that formerly had been cut open by shearing were now removed by cutting with an acetylene torch.

c. Additional clearances were provided between the Lockalloy and the steel envelope frame.

d. Trimming of Lockalloy edges between rolling operations were now accomplished by milling rather than sawing to minimize the possibility of cracks developing from the jagged edges produced by sawing.

c. Rolling speeds were decreased from 60 to 90 feet per minute to 30 feet per minute.

As a result of the above measures, the required Lockalloy sheet/plate material was produced without further incident. However, since practically all of the existing -38 mesh Be-38Al powder had been used up previously, the time-consuming process of making more powder and producing more extruded bars caused some delay in the final delivery of this material.

2.4 LIAISON RECORD

2.4.1 NASA Liaison - Liaison with NASA during the program primarily involved personnel from the NASA Flight Research Center, although program progress was monitored periodically by NASA Langley Research Center.

A meeting involving representatives from NASA Flight Research Center and Lockheed-ADP was held at Lockheed-ADP the first week of May 1975. The purpose of the meeting was to determine requirements for flight instrumentation of the ventral fin. This meeting was attended by R. Klein and G. Matranga of NASA, and Z. Armijo, L. Cass, J. Meyer, and R. Murphy of Lockheed-ADP.

A special design review meeting was held at the NASA Flight Research Center, Edwards Air Force Base, on 8 August 1975. This meeting was attended by the following personnel from NASA and Lockheed-ADP:

NASA Personnel

R. Banner

M. DeAngelis

V. Horton

R. Klein

E. Kordes

A. Kuhl

G. Matranga

R. Meyer

J. Neher

J. Phelps

M. Tang

M. Thompson

Lockheed-ADP Personnel

L. Cass

H. Combs

W. Fox

J. Mayesh

R. Murphy

R. Sessing

A. Weddell

On 6 November 1975, J. Watts and S. Kirkham from the NASA Langley Research Center visited the Lockheed-ADP facility. They reviewed the program results to date and were briefed on the current status/results of the material characterization study.

On 1 December 1975, following installation of the ventral fin on the YF-12 airplane, a meeting of key program representatives from both NASA and Lockheed-ADP was held at NASA Flight Research Center. The purpose of the meeting was to present analytical and test data to verify the structural integrity of the current ventral fin design. The topics discussed included predicted and measured stress patterns, predicted loads based on wind tunnel data, and results of flutter analyses and calibration tests.

In addition, a synopsis of Lockheed-ADP's experience and findings pursuant to the development of Lockalloy technology was presented.

Attendees included:

NASA Personnel

W. Albrecht
D. Berry
W. Cazier
M. DeAngelis
M. DeGeer
G. Gillyard
V. Horton
J. Jenkins
R. Klein
G. Matranga
R. Meyer
M. Peterson
M. Thompson

Lockheed-ADP Personnel

L. Cass
H. Combs
D. Ford
W. Fox
M. Mayesh
J. Meyer
R. Murphy
R. Sessing
C. Sumpter

The final program meetings were held at the NASA Langley Research Center on 12-14 January 1976 for purposes of conducting the program review (Paragraph 2.2.3.3).

2.4.2 Vendor Liaison - Vendors associated with this program included KBI and various local machine shops. The latter were used to machine the Lockalloy components of the ventral fin and prepare the Lockalloy test specimens needed for the material characterization study. They were selected on a competitive bid basis from a number of machine shops that have beryllium machining facilities. These facilities are characterized by having the special equipment needed to collect the dust and other particles produced during the machining process. Among the vendors used for Lockalloy machining were L.A. Gauge Company, Inc., Peterson-Jones Manufacturing Company, and Waltco Engineering Company.

Two formal meetings were held with KBI representatives during the program. The first was at Lockheed-ADP on 22 April 1975, the day following contract award. KBI personnel attending the meeting included: J. Abeles, Chairman of the Board; R. Strock, Manager Beryllium Metal Sales, Long Beach, Calif.; and P. Smith, Sales Engineer, Long Beach. The meeting was also attended by B. Rich, H. Combs, R. Passon, and T. Haramis of Lockheed-ADP. Price negotiations for the Lockalloy material needed for the program were concluded at the meeting. In addition, the Lockalloy delivery schedule was agreed upon and the KBI production facility was "turned on" by a phone call from Mr. Abeles. The need for film coverage of Lockalloy production (for inclusion in the ventral fin documentary film) was also discussed on a preliminary basis at this meeting, but no commitments were made. (KBI subsequently agreed to furnish the necessary film footage as part of their original quote.)

The second meetings with KBI were held at their facility on 10, 11, and 12 July 1975. These meetings were called to discuss Lockalloy production problems and to allow T. Haramis of Lockheed-ADP and R. Jackson of NASA Langley Research Center to personally witness the critical fourth rolling operations (see Paragraph 2.3.2). KBI personnel present included: J. Cinerazzo (Vice President and General Manager), W. Lidman (Program Manager), and D. Brillhard (Chief Metallurgist, R & D), and D. Schoenly (Manager KBI, Hazelton, Penn. facility). At the final meeting on 12 July, all present were briefed and were in accord with the previously outlined special measures that were to be adopted for the production of the remaining Lockalloy sheet material.

SECTION 3

MATERIAL CHARACTERIZATION STUDY

3.1 INTRODUCTION

This section contains the results of the Lockalloy material characterization study that was carried out concurrently with the design and fabrication of the ventral fin. This study was of special significance because it not only served to validate the design of the fin, but was needed to expand the existing data base for Lockally sheet and plate as currently produced at the mill. It also afforded the opportunity to gain additional Lockalloy fabrication experience as a result of performing the various bend tests and preparing the numerous test specimens that were needed in the course of this study. The need for Lockalloy characterization data applicable to the design of the ventral fin became apparent early in the program as a result of an extensive literature search (see Paragraph 3.2).

The material characterization study consisted mainly of standard tests to determine the formability and mechanical properties of Lockalloy alloys of varying composition and thickness. In addition, special tests were performed to:

a. Evaluate lap shear joint strength

b. Test the shear strength of a Lockalloy panel with and without localized thermal shock

c. Verify the Lockalloy manufacturer's certification data

d. Verify short transverse tensile strength data

e. Evaluate the effect of repeated cold-forming on the integrity of the material

A summary of the data obtained in the course of the material characterization study is presented at the end of this section.

3.2 ANALYSIS OF EXISTING LOCKALLOY DATA

As part of the material characterization study, an extensive literature search has been conducted by the Lockheed Information Services Department to compile existing data on Lockalloy products. Pertinent documents obtained as a result of this survey were reviewed by Lockheed - ADP Engineering. None of these documents provided data covering the thicknesses of Lockalloy material required for this program. The vast majority of the published data is for materials produced early in the development of this family of alloys and does not reflect current material manufacturing procedures. Most of the data applies to material produced before the current 1 percent maximum limitation on Be-Al oxides was imposed. Sheet products were usually tested in the as-rolled or a partially annealed condition, rather than the fully annealed condition specified for the material in this program. Formability studies have been concerned with establishing minimum forming temperature, rather than determining minimum bend radii at a higher temperature where forming and stress-relieving can be accomplished in one operation.

This analysis of existing Lockalloy data thus disclosed the lack of practical data and corroborated the need for the material characterization study. A complete bibliography listing the publications that were reviewed for applicable Lockalloy data is presented in Appendix A.

3.3 TESTING OF .250 INCH THICK Be-43Al

Characterization tests were performed on test specimens prepared from .250-inch thick Be-43Al plate. These tests were primarily intended to provide baseline data concerning the forming characteristics of this alloy. The resultant data is needed to provide a basis for comparison with comparable data obtained as a result of similar testing of .250-inch thick Be-38Al plate. The formability tests performed consisted of tension, bend, and notched tension tests. Tensile coupons were prepared to determine strain parameters and evaluate forming characteristics at both room and elevated temperatures. Requirements for and effectiveness of intermediate stress-relieving cycles during room and elevated temperature forming were evaluated in the course of these tests.

In addition to the above tests, lap shear joint strength tests were performed to evaluate joint strength at room and elevated temperatures for various fastener sizes. The specimens tested were machined to .150 and .125-inch thicknesses to facilitate comparison with similar data obtained from testing Be-38Al alloy of like thicknesses. A summary of all tests performed is presented in Table 3.3-1. These tests are described in succeeding paragraphs.

ITEM	TEST	SPECIMEN TYPE	GRAIN DIRECTION	MATERIAL CONDITION & TEST DESCRIPTION	TEST TEMP °F	NO. OF SPECIMENS	SPECIMEN IDENT.
1	TENSION	S-12	L	AS RECEIVED - TEST AT 3 DIFFERENT STRAIN RATES	R.T.	9	1-T2L ← -T9L, -T24L
2				STRESS RELIEVE - 1 HOUR AT 1050°F	R.T.	3	1-T10L, -T11L, -T12L
3				AS RECEIVED - TEST AT 3 DIFFERENT STRAIN RATES	1050	9	1-T14L ← -T21L, -T34L
4				STRETCH 5% (PERMANENT STRAIN) - RELAX	R.T.	3	1-T1L, -T22L, -T23L
5				STRETCH 5% - RELAX - STRESS RELIEVE	R.T.	3	1-T25L, -T26L, -T27L
6				STRETCH 5% - RELAX - STRESS RELIEVE - REPEAT CYCLE	R.T.	3	1-T28L, -T29L, -T30L
7				STRETCH 5% - RELAX - STRESS RELIEVE - REPEAT CYCLE TWICE	R.T.	3	1-T31L, -T32L, -T33L
7.1				STRETCH 5% AT 1050°F - RELAX	R.T.	3	1-T35L, -T36L, -T40L
8				STRETCH 5% AT 1050°F - STRESS RELIEVE	R.T.	3	1-T37L, -T38L, -T39L
9				STRETCH 5% AT 1050°F - STRESS RELIEVE - REPEAT CYCLE	R.T.	3	1-T13L, -T41L, -T42L
10			T	AS RECEIVED - TEST AT ONE STRAIN RATE	R.T.	3	1-T1T, -T2T, -T3T
11				SAME AS ITEM 2	R.T.	3	1-T4T, -T5T, -T6T
12				SAME AS ITEM 8	R.T.	3	1-T7T, -T8T, -T9T
13	BEND	S-50	L	AS RECEIVED - BEND AT R.T. TO ESTABLISH MIN. B.R.	R.T.	5	1BM-1L ← 1BM-5L
14		S-46		AS RECEIVED - BEND AT 1050°F TO ESTABLISH MIN. B.R.	1050	5	1UB-1L ← 1UB-5L
15		S-50	T	SAME AS ITEM 13	R.T.	5	1BM-1T ← 1BM-5T
16		S-46		SAME AS ITEM 14	1050	5	1UB-1T ← 1UB-5T
17	NOTCHED TENSION $K_t = 3$	S-49	L	AS RECEIVED	R.T.	3	1NT-1L, 2L, -3L
18			T	AS RECEIVED	R.T.	3	1NT-1T, -2T, -3T
19	LAP SHEAR JOINT	S-54-4	T	AS RECEIVED - NO SOAK (.150-IN. THICK MATERIAL) FLUSH SCREW - 3/16-IN. DIA.	R.T. 600	2 2	1J3.15-1, -2 1J3.15-3, -4
		S-54-5		AS RECEIVED - NO SOAK (.150-IN. THICK MATERIAL) FLUSH SCREW - 1/4-IN. DIA.	R.T. 600	2 2	1J4.15-1, -2 1J4.15-3, -4
		S-54-4		AS RECEIVED - NO SOAK (.125-IN. THICK MATERIAL) FLUSH SCREW - 3/16-IN. DIA.	R.T.	2	2J3.125-1, -2
		S-55-4		AS RECEIVED - NO SOAK (.125-IN. THICK MATERIAL) FLUSH NUT/FLUSH SCREW - 3/16-IN. DIA.	R.T.	2	2J3.125-3, -4

NOTE: JOINT SPECIMENS WERE MACHINED TO SPECIFIED THICKNESSES FROM .250 IN. THICK PLATE.

TABLE 3.3-1. TEST SUMMARY FOR .250 INCH THICK Be-43Al LOCKALLOY PLATE (SHEET NO. HA508-1)

3.3.1 Forming Characteristics - Be-43Al .250 Thickness - In order to establish forming characteristics, as well as effects of forming on Be-43Al Lockalloy plate properties, tensile tests were conducted as summarized in Table 3.3-1.

Table 3.3.1-1 shows the results of tensile coupons tested at various loading strain rates. Test strain rates were increased and decreased by an order of magnitude from the standard tensile strain rate of .005 in/in/min. The results indicate that decreasing the strain rate to .0005 in/in/min. did not have any effect on the elongation of the material and, therefore, using excessively low forming rates is not expected to improve formability characteristics. Conversely, increasing the rate to .050 in/in/min. (10 times the normal rate) decreased the elongation from 10% to 7%, which suggests that the material's tolerance to deformation is impaired at relatively high rates of forming.

Tensile tests conducted at temperatures of 1050°F show a decrease in tensile strength to approximately 2 to 5 ksi and a corresponding increase of the elongation to 20%. The data is shown in Table 3.3.1-2.

Test data of coupons tested after an initial R.T. stretching to 5% and stretching to 5% followed by stress relieving cycles are shown in Table 3.3.1-3.

The yield stress of coupons with stretching of 5% without stress relieving is increased from 40 to 46 ksi indicating the effects of work hardening. Coupons stress relieved for 1 hour at 1050°F after stretching to 5% show a decrease in ultimate and yield stress from the "as received" values. Repeating the stretching and stress relieving twice did not seem to have any further effects on the material strength. The total elongation does show some increase after repeated stretching and stress relieving, but falls short of that expected of a material that has had intermediate anneals. This does suggest that the stress relieving cycle used (duration and/or temperature) may not represent an adequate heat treatment.

Test data of coupons stretched 5% at 1050°F instead of room temperature with repeated annealing and stress relieving cycles is presented in Table 3.3.1-4. This data also shows a decrease in strength over the "as received" condition, and lower than expected elongation.

Test results of coupons stress relieved at 1050°F for one hour without prior straining are presented in Table 3.3.1-5, and it shows that exposure to this cycle has no effects on the material properties.

From the results of these tests it can be concluded that additional effort is required to better define formability and determine appropriate annealing and heat treating cycles for this material.

SPECIMEN IDENTIFICATION	STRAIN RATE IN/IN/MIN	DIRECTION	ULTIMATE KSI	YIELD KSI	% ELONG IN 1 INCH	E X 10^{-6} PSI
1-T24L	.005	LONG.	53.5	42.8	10	29.5
1-T2L			52.9	40.6	9	27.5
1-T3L			53.0	40.5	10	29.1
AVG.			53.1	41.3	10	28.7
1-T1T	.005	TRANS.	51.0	40.6	7	31.7
1-T2T			51.2	40.3	7	(1.)
1-T3T			50.3	40.5	6	(1.)
AVG.			50.8	40.5	7	
1-T4L	.0005	LONG.	53.1	40.2	10	30.7
1-T5L			52.0	40.6	10	31.0
1-T6L			51.9	40.4	10	29.2
AVG.			52.3	40.4	10	30.3
1-T7L	.050	LONG.	51.0	40.6	7	(1.)
1-T8L			51.2	40.3	7	(1.)
1-T9L			50.3	40.5	6	(1.)
AVG.			50.8	40.5	7	

(1.) NOT OBTAINABLE

REF. RN 550470

TABLE 3.3.1-1. TENSILE TEST RESULTS FOR .250 INCH THICK Be-43Al LOCKALLOY PLATE TESTED AT ROOM TEMP., AND THREE DIFFERENT STRAIN RATES IN THE AS RECEIVED CONDITION

SPECIMEN IDENTIFICATION	STRAIN RATE IN/IN/MIN	DIRECTION	TEST TEMP °	ULTIMATE KSI	YIELD KSI	% ELONG. IN 1 INCH	E X 10^{-6} PSI
1-T34L	.025	LONG.	1050	3.2	2.5	17	2.4
1-T14L	.005			2.3	2.1	20	1.8
1-T15L	.005			2.2	1.8	21	1.9
AVG.				2.2 (1)	2.0 (1)	20 (1)	1.8 (1)
1-T16L	.0005	LONG	1050	1.2	1.1	27	2.0
1-T17L	.0005 (2)			3.0	.93	15	2.1
1-T18L	.0005 (2)			3.1	.96	20	-
AVG.				2.7	.97	21	2.0
1-T19L	.050	LONG.	1050	5.4	4.8	15	2.1
1-T20L	.050			4.8	4.3	19	2.0
1-T21L	.050			4.8	4.3	19	2.0
AVG.				5.0	4.5	18	2.0

(1) AVERAGE OF LAST TWO SPECIMENS IN GROUP.

(2) STRAIN RATE WAS INCREASED AFTER YIELD WAS OBTAINED AFFECTING THE RECORD ULTIMATE AND ELONGATION VALUES.

REF. RN 550480

TABLE 3.3.1-2. TENSILE TEST RESULTS FOR .250 INCH THICK Be-43Al LOCKALLOY PLATE TESTED AT 1050°F AND DIFFERENT STRAIN RATES

SPECIMEN IDENTIFICATION	CONDITION	DIRECTION	TEST TEMP	ULTIMATE KSI	YIELD KSI	% ELONG IN 1 INCH	E X 10^{-6} PSI
1-T1L	STRETCH 5% @ RT., RELAX, TEST	LONG	ROOM TEMP	52.7	-	10	31.0
1-T22L				53.1	46.8	9	28.6
1-T23L				52.2	46.0	7	24.7
AVG				52.7	46.4	9	28.1
1-T25L	STRETCH 5% @ RT., RELAX, STRESS RELIEVE 1 HR @ 1050°F, TEST	LONG	ROOM TEMP	42.6	35.6	8	28.2
1-T26L				47.2	35.8	10	21.5
1-T27L				49.8	35.1	11	25.4
AVG				46.5	35.5	10	25.0
1-T28L	STRETCH 5% @ RT., RELAX, STRESS RELIEVE 1 HR @ 1050°F; REPEAT CYCLE TEST.	LONG	ROOM TEMP	45.5	35.1	14	22.1
1-T29L				47.9	39.7	4 (2)	27.7
1-T30L				47.3	34.8	16	21.7
AVG				46.4	35.0	15	21.9
1-T31L	STRETCH 5% @ RT., RELAX, STRESS RELIEVE 1 HR @ 1050°F; REPEAT CYCLE TWICE, TEST.	LONG	ROOM TEMP	43.1	34.0	18	19.6
1-T32L				47.2	34.2	9 (3)	22.9
1-T33L				45.9	33.8	15 (4)	20.1
AVG				45.4	34.0	18	20.9

(1) TOTAL ELONGATION, STRETCH + TEST
(2) FAILED DURING 1ST STRETCH
(3) FAILED DURING 2ND STRETCH
(4) FAILED DURING 3RD STRETCH

REF: RN PAGE 550476, 550477

TABLE 3.3.1-3. TENSILE TEST RESULTS OF .250 INCH THICK Be-43Al LOCKALLOY AFTER STRETCHING AT ROOM TEMPERATURE

SPECIMEN IDENTIFICATION	CONDITIONING	DIRECTION	TEST TEMP.	ULTIMATE KSI	YIELD KSI	% ELONG IN 1 INCH (1)	E X 10^{-6} PSI
1-T35L	STRETCH 5% @ 1050°F RELAX, TEST	LONG.	ROOM TEMP	45.5	38.7	9	30.6
1-T36L				41.2	39.1	7	28.8
1-T40L				44.3	38.8	8	30.5
AVG				43.7	38.9	8	30.0
1-T37L	STRETCH 5% @ 1050°F, RELAX, STRESS RELIEVE 1 HR @ 1050°F, TEST	LONG	ROOM TEMP	40.2	39.1	7	20.0
1-T38L				41.5	39.9	7	22.0
1-T39L				47.3	39.7	11	23.7
AVG				43.0	39.6	8	21.9
1-T7T	STRETCH 5% @ 1050°F, RELAX, STRESS RELIEVE 1 HR @ 1050°F, TEST	TRANS	ROOM TEMP	45.0	38.6	10	28.0
1-T8T				43.7	38.9	9	24.2
1-T9T				44.4	38.9	9	29.1
AVG				44.4	38.8	9	27.1
1-T13L	STRETCH 5% @ 1050°F, RELAX, STRESS RELIEVE 1 HR @ 1050°F, REPEAT CYCLE, TEST	LONG	ROOM TEMP	36.6	35.6	12	17.4
1-T41L				38.4	33.4	14	24.7
1-T42L				37.5	35.4	12	20.3
AVG				37.5	34.8	13	20.8

REF RN 550478
550479

TABLE 3.3.1-4. TENSILE TEST RESULTS OF .250 INCH THICK Be-43Al LOCKALLOY AFTER STRETCHING AT 1050°F

SPECIMEN IDENTIFICATION	DIRECTION	CONDITION	TEST TEMP.	ULTIMATE KSI	YIELD KSI	% ELONG IN 1 INCH	E X 10^{-6} PSI
1-T10L 1-T11L 1-T12L AVG.	LONG	STRESS RELIEVED 1 HR @ 1050°F	ROOM TEMP	53.3 53.8 52.6 53.2	41.2 41.5 41.7 41.5	8 10 8 9	31.2 30.9 31.2 31.1
1-T4T 1-T5T 1-T6T AVG	TRANS.	STRESS RELIEVED 1 HR @ 1050°F	ROOM TEMP	51.6 52.5 51.8 52.0	40.3 40.2 40.9 40.5	7 8 7 7	30.6 29.3 29.2 29.7

REF: RN PAGE
550475

TABLE 3.3.1-5. TENSILE TEST RESULTS FOR .250 INCH THICK Be-43Al LOCKALLOY STRESS RELIEVED FOR 1 HR @ 1050°F, TESTED AT ROOM TEMPERATURE.

3.3.1.1 Tensile Tests - Tensile tests were conducted according to standard ASTM E111-61 practices. Tensile specimens of a pin loaded, one-inch gage length configuration as shown on page B-3 of the Appendix were installed in a 30,000 lb. Baldwin Mark B Universal Testing Machine. A microformer type load-strain recorder utilizing a Baldwin Model B3M, one-inch gage length ASTM Class B extensometer was used to provide an automatic load-deflection curve for room temperature tensile tests. A typical set-up of the room temperature tensile test is shown in Fig. 3.3.1.1-1 and a close-up view of the extensometer attached to the specimen is shown in Figure 3.3.1.1-

For elevated temperature test a modified Baldwin Model PSH8 Extensometer, as shown in Fig. 3.3.1.1-3 was used for strain recordings. A 1500°F Marshall circulating air furnace, as shown in Fig. 3.3.1.1-1, equipped with a Marshall temperature controlle was used for all elevated tensile tests. A thermocouple attached to the specimen was used to monitor the actual temperature on the specimen as recorded on a Brown recorder

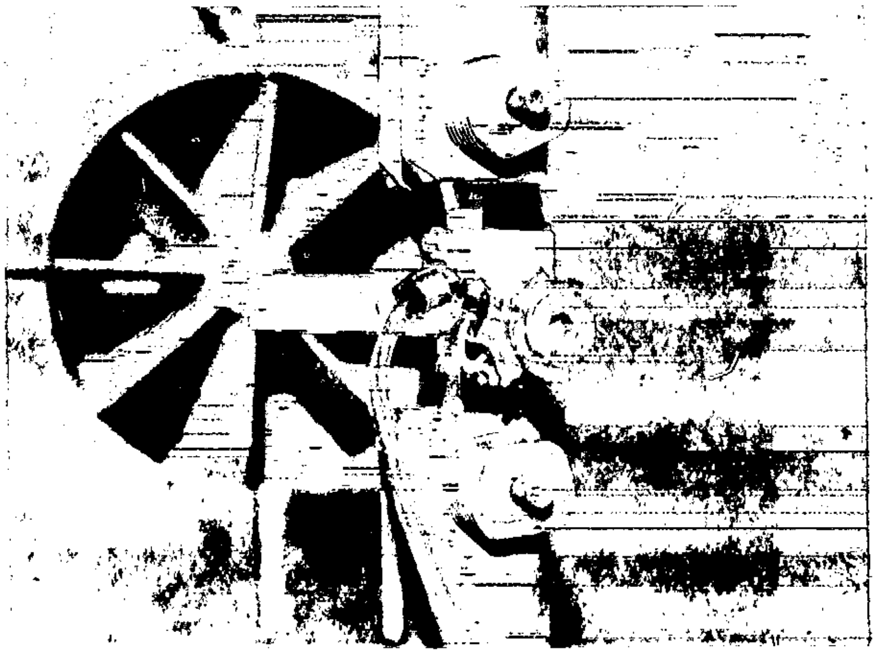
Unless otherwise noted, specimens were loaded at a constant head travel rate that produced a strain of .005 inches per inch per minute. The faster .05, or slower .005 inches per inch per minute rate tests were conducted at ten times or one-tenth of the standard rate, respectively. As noted, some of the very slow rate tests were speeded up after the yield point had been determined to save time. Yield and modulus values were determined graphically from the autographic load-strain curves. An expanded load-strain curve was used on many of the tests in an attempt to more adequately define the straight line portion of a predominately non-linear load-strain curve. The intent was to provide more consistent data reduction from one technician to another.

Pre-stretching of the tensile specimens was accomplished by loading the specimens in tension and measuring head travel with a Baldwin Model PD-1M Deflectometer. The deflection was predetermined so as to produce a permanent set of approximately 5 percent as noted on the autographic load-deflection curve. This procedure of pre-straini was used to preclude any possible premature failures at gage attachment points particularly during elevated temperature testing. The specimen was then unloaded and the actual permanent deformation was determined by measuring between very lightly scribed gage marks previously applied to a light coating of layout dye. These measurements were made to an accuracy of .0002 inch using a microscope with a traveling stage.

The results of the tensile testing for the .25 thick Be-43 Al alloy are presented in Tables 3.3.1-1 through 3.3.1-5.

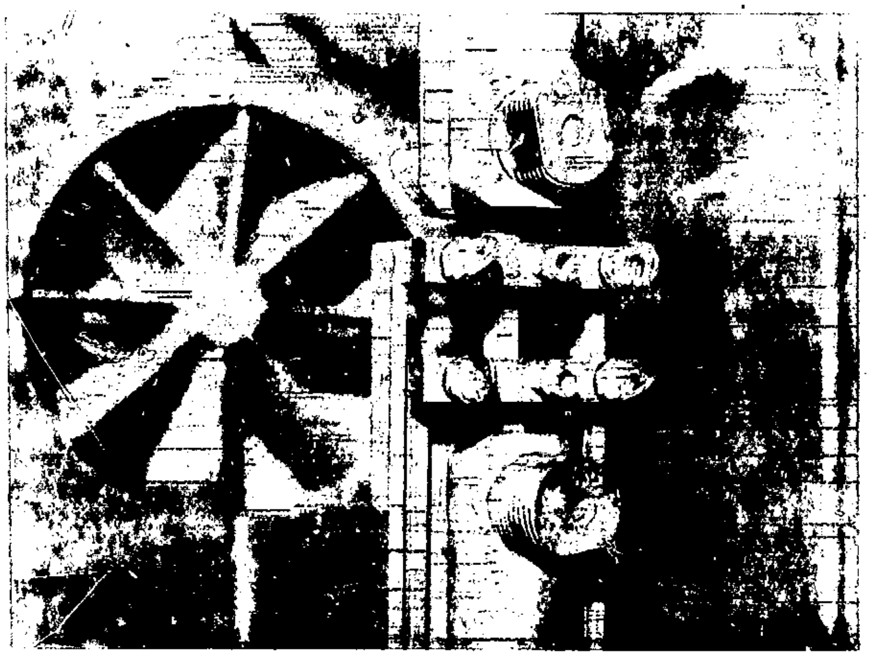
75-5354-6

Fig. 3.3.1.1-1 Overall view of a typical room temperature tensile test. All room temperature tests were conducted with the furnace in place but not operating.



75-5354-1

Fig. 3.3.1.1-2 Close-up view of the Model B3M tensile extensometer installed on a specimen before test.



75-5354-2

Fig. 3.3.1.1-3 View showing method of attachment of the Model PSH8 elevated temperature extensometer on a test specimen before test.

3.3.1.2 Bend Tests - Three Point - Bend tests were accomplished at room temperature and at 1050°F to verify the material manufacturer's recommendation of 10 t bend radius at room temperature and 6 t bend radius at elevated temperatures.

From an off-the-shelf Be-43Al alloy plate having the dimensions of 21.0 x 36.0 x .250 inches, a total of ten (10) bend specimens of each of the geometries shown on pages B-8 and B-12 of the Appendix were machined by an out-of-plant, approved beryllium machining facility. For both the room temperature and elevated temperature bend specimens, five (5) specimens were obtained in both the longitudinal direction, hereafter designated as "L" (parallel to extrusion direction) and in the transverse direction, hereafter designated as "T" (normal to extrusion direction).

Room Temperature Bends

The room temperature bend tests were accomplished in a power brake utilizing a female channel die 3.00 inches wide and 2.5 inches deep having 1.0 inch thick legs rounded at the ends with a .50 inch radius. Male dies having radii of 3.75 inch and 2.50 inch were used to produce bends at R/t's of 15 and 10, respectively. A typical set-up in the power brake before and after bending is shown in Figure 3.3.1.2-1 The maximum bend possible for this combination of male and female dies was approximately 35° at an R/t of 15. It was found necessary to use rubber back-up to hold the specimen firmly against the radius of the male die to prevent the specimen from diving ahead of the male die.

1050°F Bend Testing

Elevated temperature bend tests at 1050°F were accomplished by a bending fixture installed in a Marshall oven between the platens of a Baldwin Universal Testing Machine. A typical set-up is shown in Fig. 3.3.1.2-2. The bending fixture, shown in Fig. 3.3.1.2-3 consists of a female die, 2.12 inches wide having varying span capabilities to accommodate 2.00 inch thick male dies of various radii to cover a range of R/t's from 4 thru 10. A Marshall temperature controller maintained the furnace temperature at 1050°F ± 10°F, but during bend testing actual bend specimen temperature was monitored by a thermocouple placed on the bend specimen and read out on a temperature recorder.

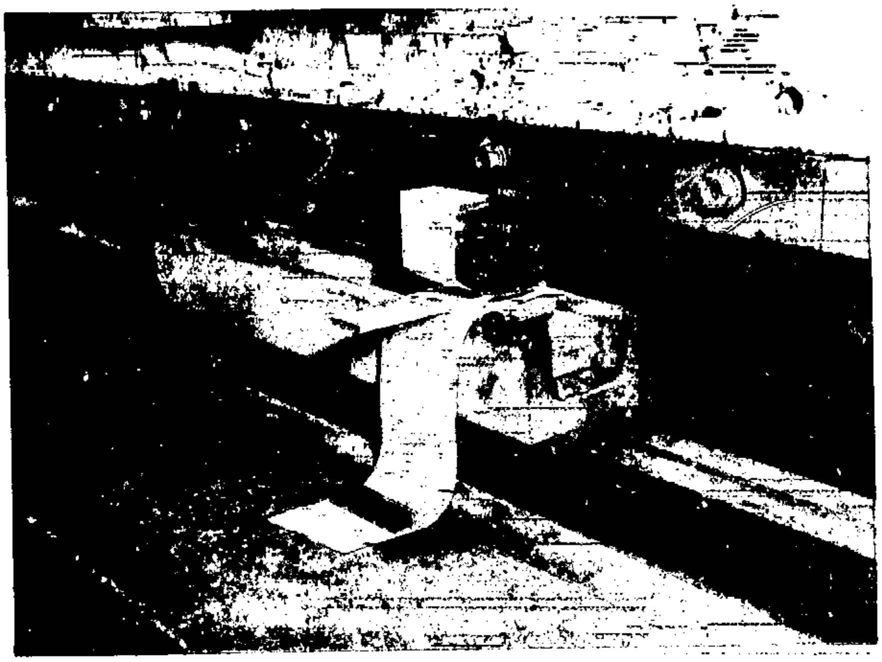
The first bend test at 1050°F was accomplished at an R/t = 6.0. For this R/t, a male die of 1.50 inch radius was used with the span of the female determined by the following expression:

$$\text{Span} = \text{Male Diameter} + \text{Twice Specimen Thickness} + .250 \text{ inches}$$

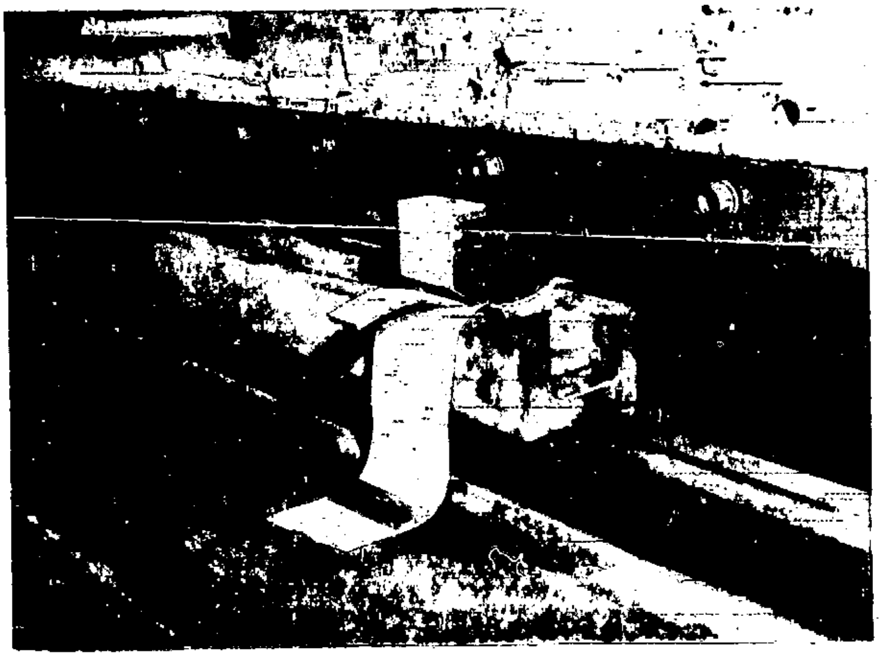
$$= 2 \times 1.50 + 2 \times .25 + .25 = 3.75 \text{ inches}$$

With the temperature stabilized at 1050°F, load was applied and the bend specimen was moved to a pre-determined deflection, as monitored by head travel, calculated to produce a permanent set bend of 105 degrees. At this point a visual check was made by removing a small cover in the oven door, and if necessary increasing deflection to obtain the desired bend. The cover was replaced and the temperature was stabilized at 1050°F for each added increment of deflection. The initial rate of head travel was .60 in./min. but bending at a slower rate of .06 in./min. produced acceptable bends whereas failures occurred at the higher rate for the same R/t. A bend is considered acceptable if when bent through a angle of 105 degrees (permanent set), no cracks or ruptures are evident on the surface at 10X magnification.

The results of the room temperature and 1050°F bend tests for the .25 thick Be-43Al alloy are shown in Table 3.3.1.2-1. Based on these tests, the approximate three degree bend required on the ventral fin outer skin panels at the front and rear beams could be safely made cold using an R/t = 15, not R/t = 10. At 1050°F, it appears that a minimum R/t = 7, not 6 should be used for good bends. The one specimen bent at an R/t = 7 at 600°F was accomplished to demonstrate that optimum bending characteristics are not obtained at this temperature as was indicated in some preliminary literature.

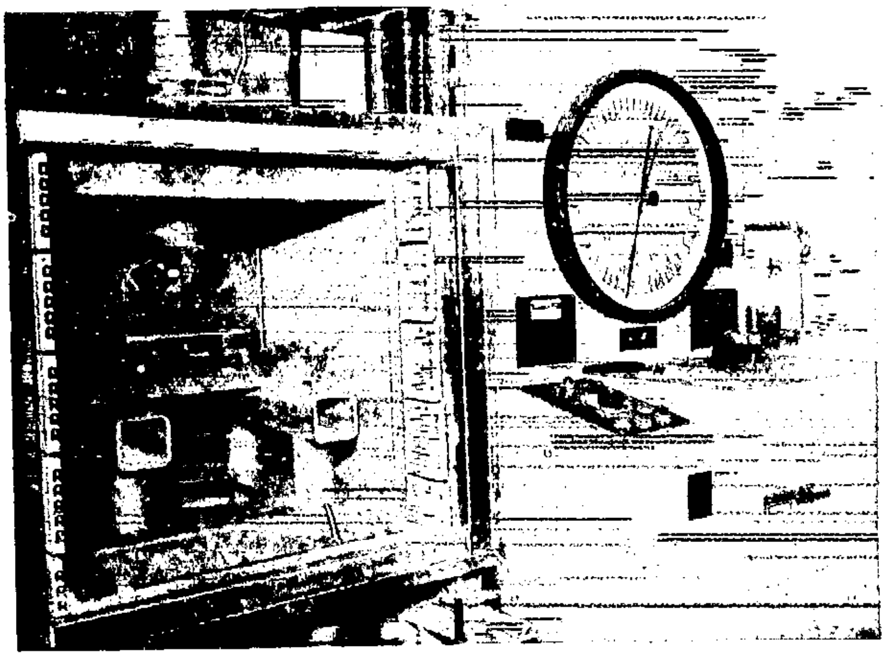


Before Bending



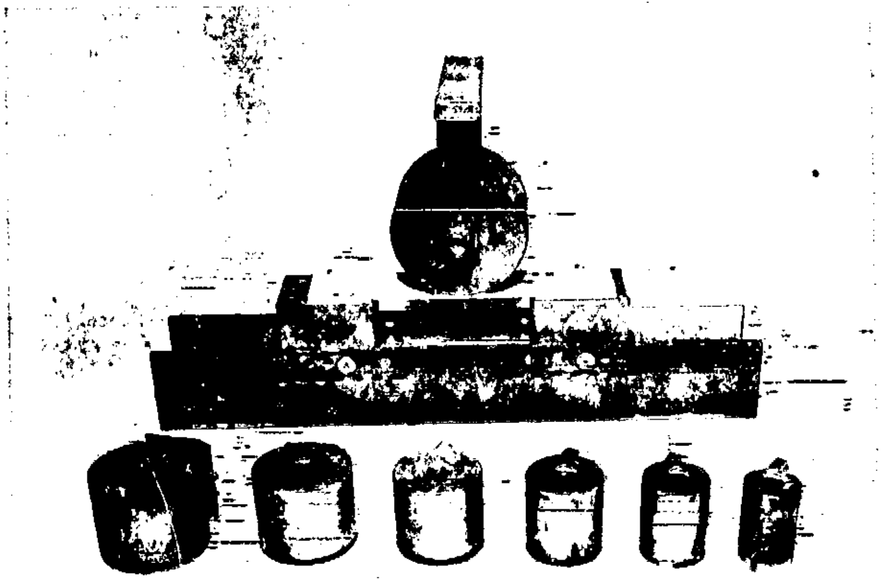
After Bending

Figure 3.3.1.2-1 Typical Set-Up of Room Temperature Bend Test At R/t of 15 in Power Brake.



75-5362-2

Figure 3.3.1.2-2. Typical Elevated Temperature Bend Test Set-Up.



75-5362-1

Figure 3.3.1.2-3 Elevated Temperature Bending Fixture Showing Female and Male Dies.

FORMING TEMP.	RADIUS THICKNESS	GRAIN DIRECTION	SPECIMEN NUMBER	RESULTS
ROOM TEMP.	15	LONG.	1BM-1L 1BM-2L	NO FAILURE AT 3° BEND - WITH OR WITHOUT RUBBER BACK-UP.
			1BM-3L	NO FAILURE WHEN BENT THROUGH 35° WITH RUBBER BACK-UP.
		TRANS.	1BM-1T 1BM-2T	NO FAILURE AT 3° BEND - WITH OR WITHOUT RUBBER BACK-UP.
			1BM-4T	FAILED AT 15° BEND - WITH RUBBER BACK-UP.
	10	LONG.	1BM-4L	FAILED AT 5° BEND - WITHOUT RUBBER BACK-UP.
				FAILED AT 14° BEND - WITH RUBBER BACK-UP.
		TRANS.	1BM-3T	FAILED AT 5° BEND - WITHOUT RUBBER BACK-UP.
				FAILED AT 8° BEND - WITH RUBBER BACK-UP.
1050°F	7	LONG.	1UB-1L	NO FAILURE AT 105° BEND AT .6 IN./MIN. BEND RATE.
		TRANS.	1UB-1T	HAIRLINE CRACK AT 105° BEND AT .6 IN./MIN. BEND RATE.
			1BM-5T	NO FAILURE AT 105° BEND AT .06 IN./MIN. BEND RATE.
	6	LONG.	1UB-3L	SURFACE CRACKS AT 120° BEND AT .6 IN./MIN. BEND RATE.
			1UB-4L	NO FAILURE AT 105° BEND AT .06 IN./MIN. BEND RATE.
		TRANS.	1UB-3T	SEVERE SURFACE CRACKS WHEN OVERFORMED 36° AT .6 IN./MIN. BEND RATE.
			1UB-4T	SURFACE CRACKS AT 96° BEND AT .6 IN./MIN. BEND RATE.
			1UB-5T	HAIRLINE CRACK AT 105° BEND AT .06 IN./MIN. BEND RATE.
	5	LONG.	1UB-2L	SURFACE CRACKS AT 94° BEND AT .6 IN./MIN. BEND RATE.
		TRANS.	1UB-2T	SURFACE CRACKS AT 70° BEND AT .6 IN./MIN. BEND RATE.
600°F	7	TRANS.	1BM-1T	FAILED AT 14° BEND AT .06 IN./MIN. BEND RATE.

TABLE 3.3.1.2-1. LOCKALLOY Be-43Al (LX-57) BEND TEST RESULTS ($t = .25$ in.)

3.3.1.3 Stress Relieving - The necessity of stress relieving parts formed at room temperature is illustrated by the sketches shown in Fig. 3.3.1.3-1 through 3.3.1.3-4.

The initial traces of specimens 5BM-2T and 5BM-2L formed at room temperature are shown in Figure 3.3.1.3-1. The specimens were then placed into an oven and soaked for one hour at 600°F, removed, and allowed to cool to room temperature. Superimposing the specimens on the initial trace shows a change in shape as indicated by the dashed line. The change in shape is due to the residual stresses induced during forming.

The trace of another specimen, identified 5BM-4L, also formed at room temperature is shown in Figure 3.3.1.3-2. This specimen was stress relieved for two hours at 1050°F while weighted down in matched Glasrock dies and allowed to cool, while weighted, to room temperature. Superimposing the specimen over the initial trace showed no change in shape. The specimen was then soaked for one hour at 600°F and allowed to air cool to room temperature. Again, superimposing the specimen on the initial trace showed no change in shape had taken place indicating the residual stresses induced during forming were effectively stress relieved.

The same procedure was followed for specimen number 5BM-5T, shown in Figure 3.3.1.3-3 as for specimen 5BM-4L with the exception that the specimen was unloaded immediately from the matched Glasrock dies after the 2 hour stress relief at 1050°F and allowed to cool to room temperature by hanging in still air. Superimposing the specimen on the initial trace after the one hour bake at 600°F showed no change in shape, again indicating the stress relief cycle to be effective. This procedure shows promise of increased productivity for parts requiring cold forming operations.

The traces for specimens 5UB-1L, 5UB-1T and 5UB-3L formed at 1050°F are shown in Figure 3.3.1.3-4. Soaking these specimens at 600°F for one hour, air cooling and then superimposing them over the initial trace shows no change in shape had taken place. Hot forming at 1050°F eliminates the necessity of any further stress relieving.

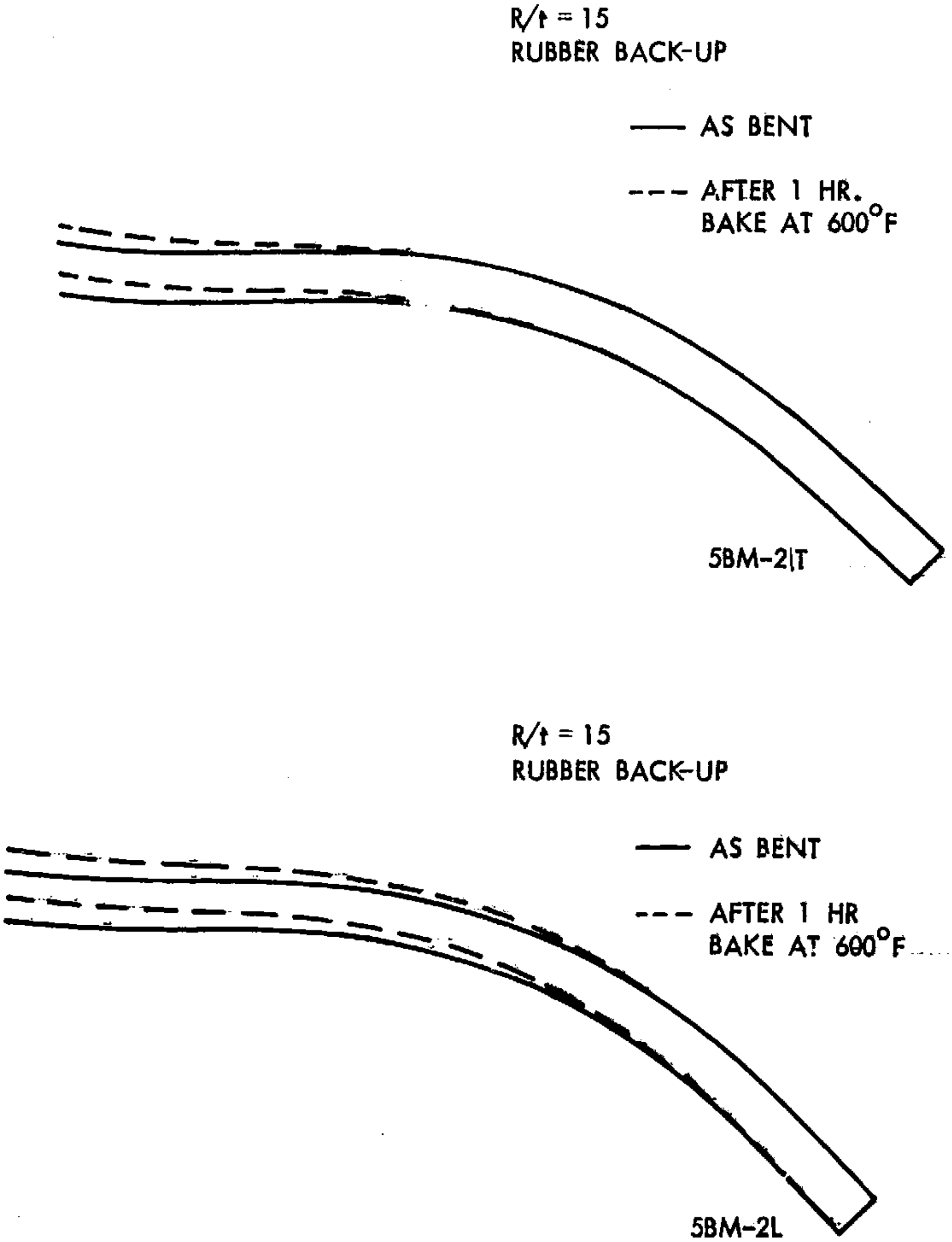
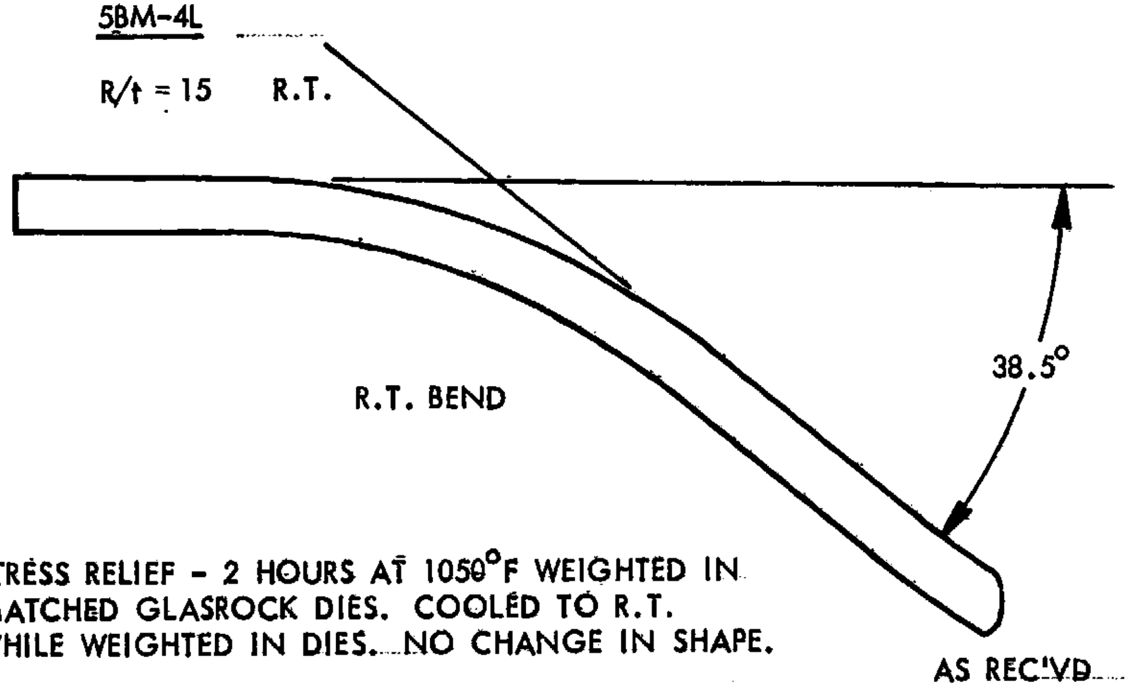
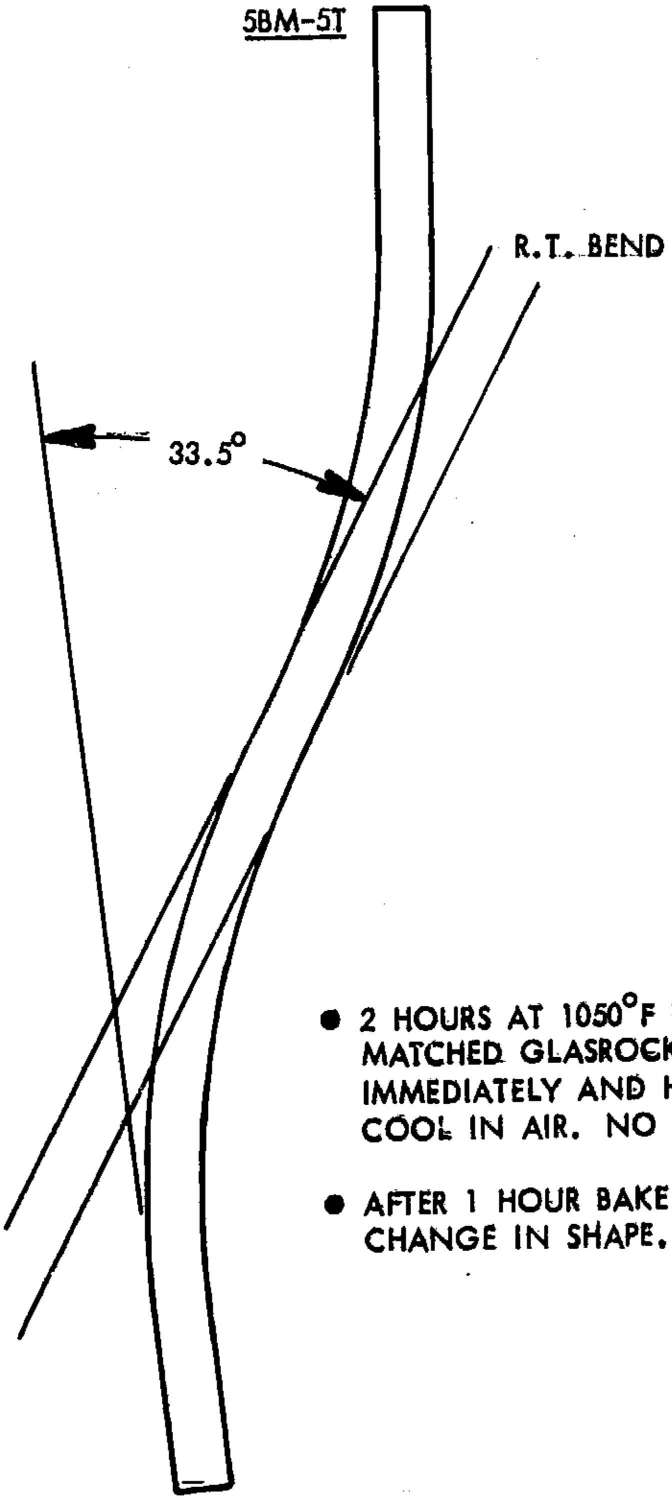


Figure 3.3.1.3-1 Bend Specimens



- STRESS RELIEF - 2 HOURS AT 1050°F WEIGHTED IN MATCHED GLASROCK DIES. COOLED TO R.T. WHILE WEIGHTED IN DIES. NO CHANGE IN SHAPE.
- 1 HR. AT 600°F. NO CHANGE IN SHAPE.

Figure 3.3.1.3-2 Bend Specimen



- 2 HOURS AT 1050°F IN WEIGHTED MATCHED GLASROCK DIES - UNLOADED IMMEDIATELY AND HUNG ON HOOK TO COOL IN AIR. NO CHANGE IN SHAPE.
- AFTER 1 HOUR BAKE AT 600°F. NO CHANGE IN SHAPE.

Figure 3.3.1.3-3 Bend Specimen

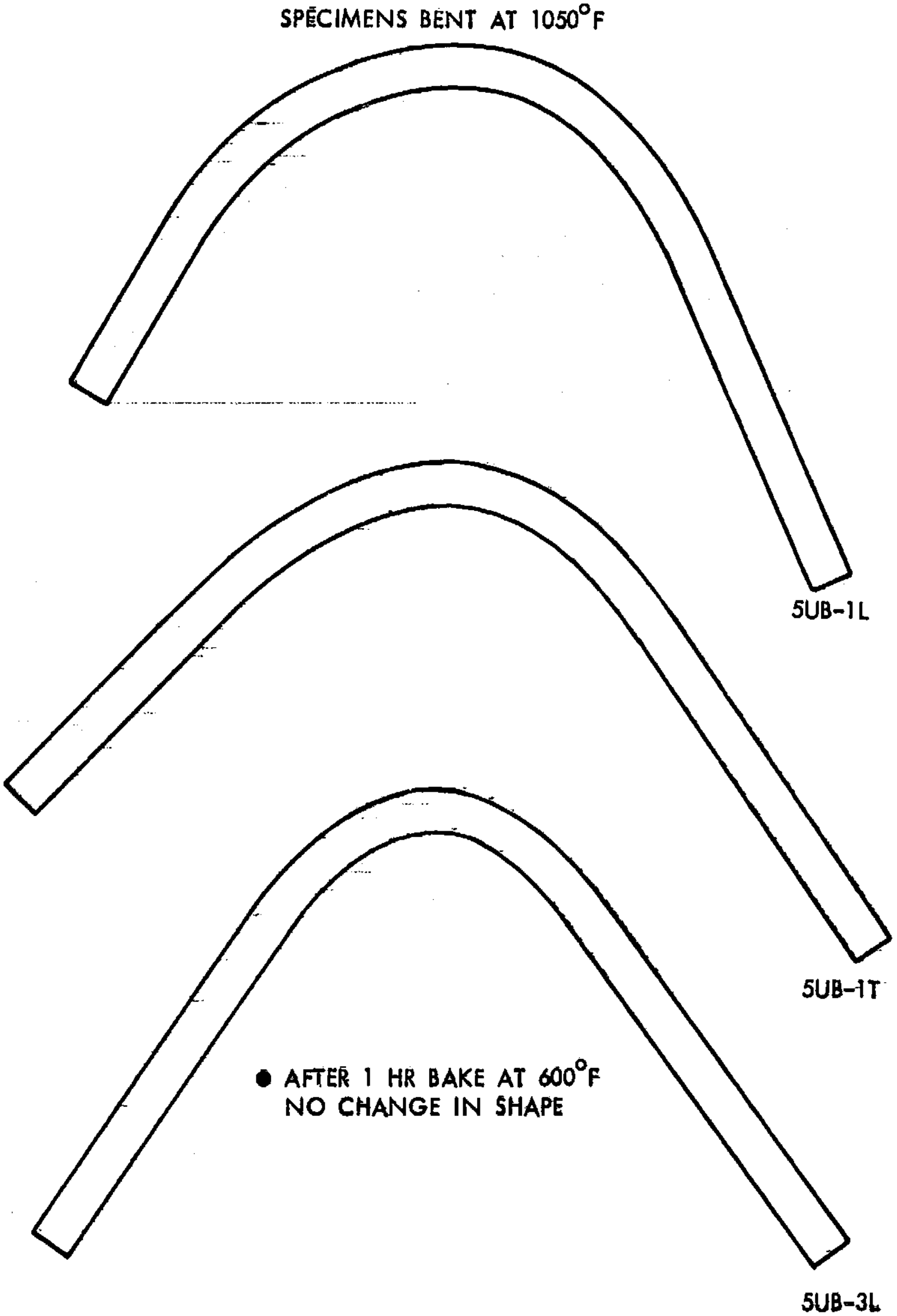


Figure 3.3.1.3-4 Bend Specimens

3.3.1.4 Notched Tensile Tests - The notched tensile specimens configuration shown on page B-11 of the Appendix are pin loaded and have the same geometric configuration as the smooth tensile specimen with the exception of the machined $K_T = 3$ notch. The specimens were installed in a 30,000 lb. Baldwin Mark B Universal Testing Machine and loaded at a constant rate to reach failure in not less than one minute or approximately 50,000 psi per minute maximum. Only ultimate notch tensile strength is reported for these specimens.

The results of the notched tensile tests for the .25 inch thick Be-43Al alloy are presented in Table 3.3.1.4-1 along with the results of unnotched tensile tests to show the notched to unnotched ratio for the Be-43 Al alloy. Identical tests performed on .25 thick 7075-T6 bare aluminum alloy yielded average ratio values for triplicate specimens of 1.190 in the longitudinal direction and 1.142 in the transverse direction as compared to 1.036 and .994, respectively for the Be-43Al alloy.

CONDITION	DIRECTION	SPECIMEN I.D.	NOTCHED ULTIMATE KSI	SPECIMEN I.D.	UNNOTCHED ULTIMATE KSI	NOTCHED ULTIMATE / UNNOTCHED UTLIMATE
AS REC'D	LONG	INT-1L	54.2	IT-24L	53.5	
		INT-2L	55.4	IT-2L	52.9	
		INT-3L	55.4	IT-3L	53.0	
		AVG.	55.0		53.1	1.036
AS REC'D	TRANS.	INT-1T	48.3	IT-1T	51.0	
		INT-2T	49.7	IT-2T	51.2	
		INT-3T	53.4	IT-3T	50.3	
		AVG.	50.5		50.8	.994

REF. R.N. PAGES 361009 and 550470

TABLE 3.3.1.4-1. NOTCHED TO UNNOTCHED TENSILE TEST RESULTS FOR .25 INCH THICK Be-43Al LOCKALLOY PLATE TESTED AT ROOM TEMP.

3.3.2 Lap Shear Joint Tests - To provide designers and stress personnel with advanced preliminary design information from which the necessary fastener sizes and spacings commensurate with the design loads could be established, lap shear joint tests were performed. The specimens conformed to MIL-STD-1312 (except for length and riveted instead of spotwelded doublers) and were machined from a .250 inch thick Be-43Al alloy plate to the .125 and .150 inch thicknesses required for the ventral fin skin gages.

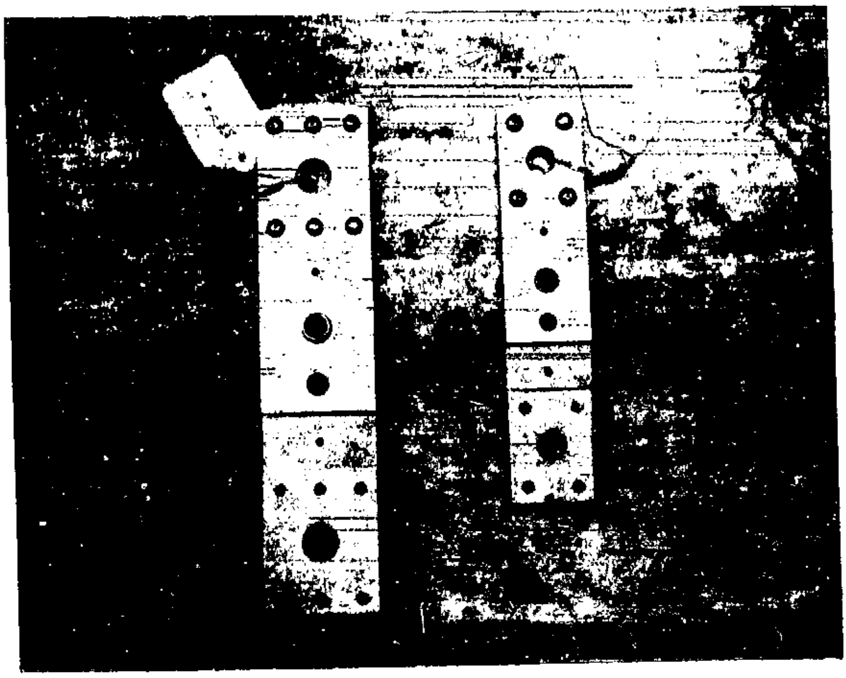
Due to the limited amount of available material, only duplicate specimens were fabricated to the configuration shown on page B-3 of the Appendix. Flush shear-head type 6Al-4V titanium bolts of .190 inch and .250 inch diameters were utilized in both the .125 inch and .150 inch thicknesses for the room temperature tests but only in the .150 inch thickness for the 600°F tests. Also tested at room temperature only, were duplicate specimens utilizing a self-aligning flush A-286 CRES nut and flush .190 inch diameter 6Al-4V titanium bolt. These fasteners were used in the .125 inch thick skin attachment to the leading and trailing edges of the ventral fin. A photo of typical lap-shear joints showing a .190 inch and .250 inch diameter flush titanium fastener in .150 inch Be-43Al alloy is shown in Figure 3.3.2-1.

The lap-shear joint specimens were installed in a 30,000 lb. Baldwin Mark B Testing Machine and loaded at a constant rate to a value corresponding to the approximate yield deflection specified in MIL-STD-1312 for the particular fastener size being tested. At this deflection, the specimen was unloaded to near zero load to more accurately determine the true permanent deformation. The specimen was then re-loaded to failure. A Lockheed designed extensometer compatible with the Baldwin x-y plotter provided an autographic load-deformation curve for both room temperature and 600°F testing and is shown in Figure 3.3.2-2. A typical joint test set-up is shown in Figure 3.3.2-3, and a typical joint load deformation curve is shown in Figure 3.3.2-4.

The lap-shear joint test results are tabulated in Table 3.3.2-1 and a photograph of all the failed specimens tested of the Be-43Al material are shown in Figure 3.3.2-5.

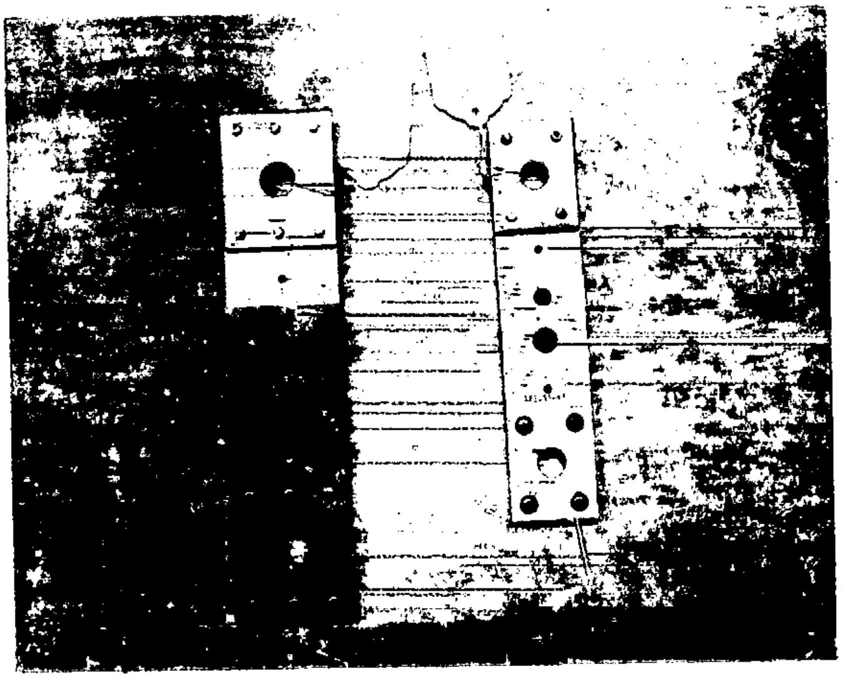
To conserve the limited amount of expensive Lockalloy material, all end doublers used on the lap-shear joint specimens, in either Be-43Al or Be-38Al Lockalloy, were 321 corrosion resistant steel installed with squeezed A-286 rivets.

Lap-shear joint specimen 1J4.15-2 was deliberately marked with a torque set driver from the edge of the flush screw countersink across the specimen to the edge, normal to the applied load. The specimen failed across the net-section of the specimen, however, the failure was in an area away from the marked surface.



75-5220-1

Front Side



75-5220-2

Back Side

Figure 3.3.2-1 Typical Lap Shear Joint Specimens. Flush 1/4 in. dia. on left & Flush 3/16" in. dia. on right.

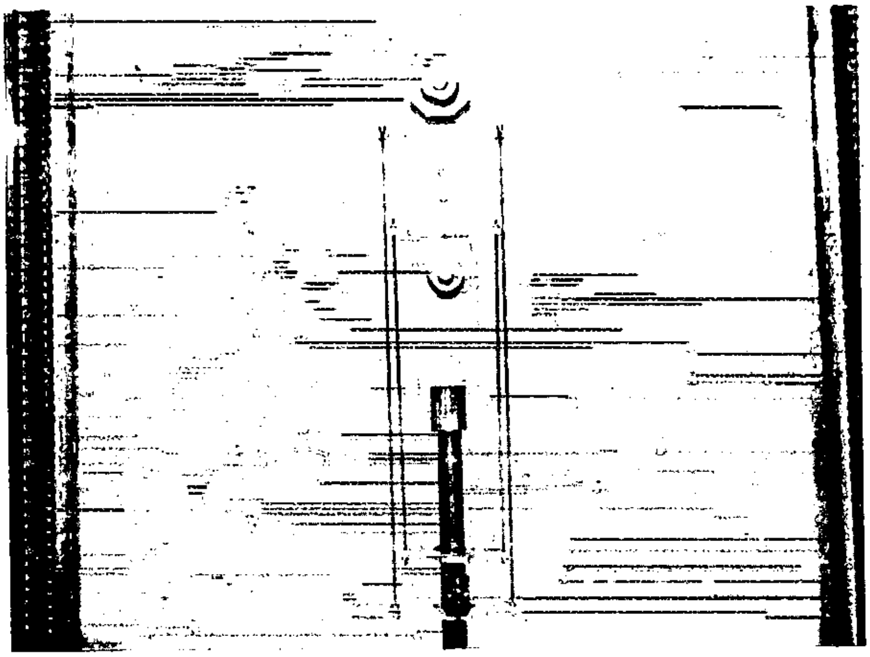


Figure 3.3.2-2 Photograph Showing Lockheed Designed Extensometer Used for Both Room Temp. Tests and Tests at 600°F.

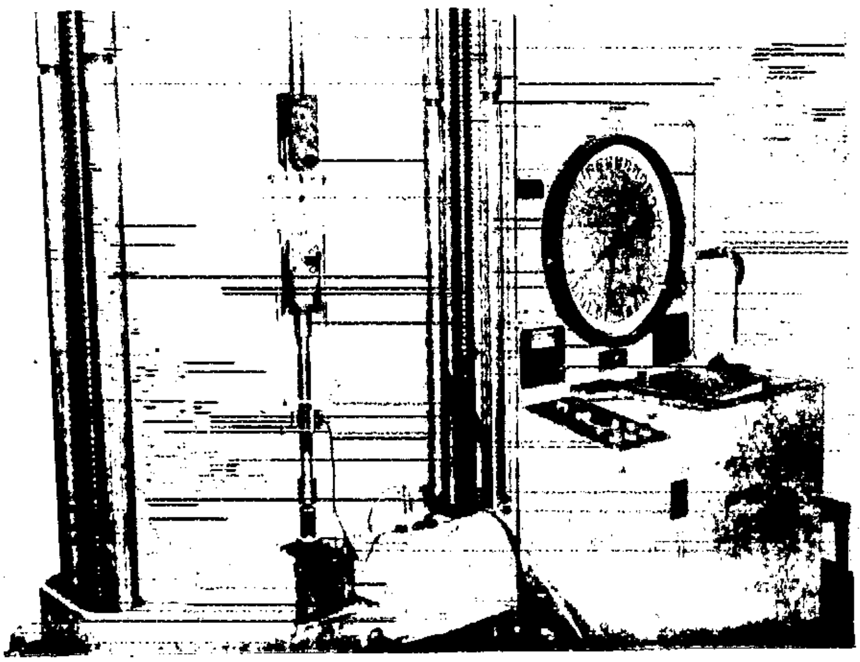


Figure [illegible] A Typical Lap-Shear Joint Test Set-Up Arrangement for Room Temperature Testing.

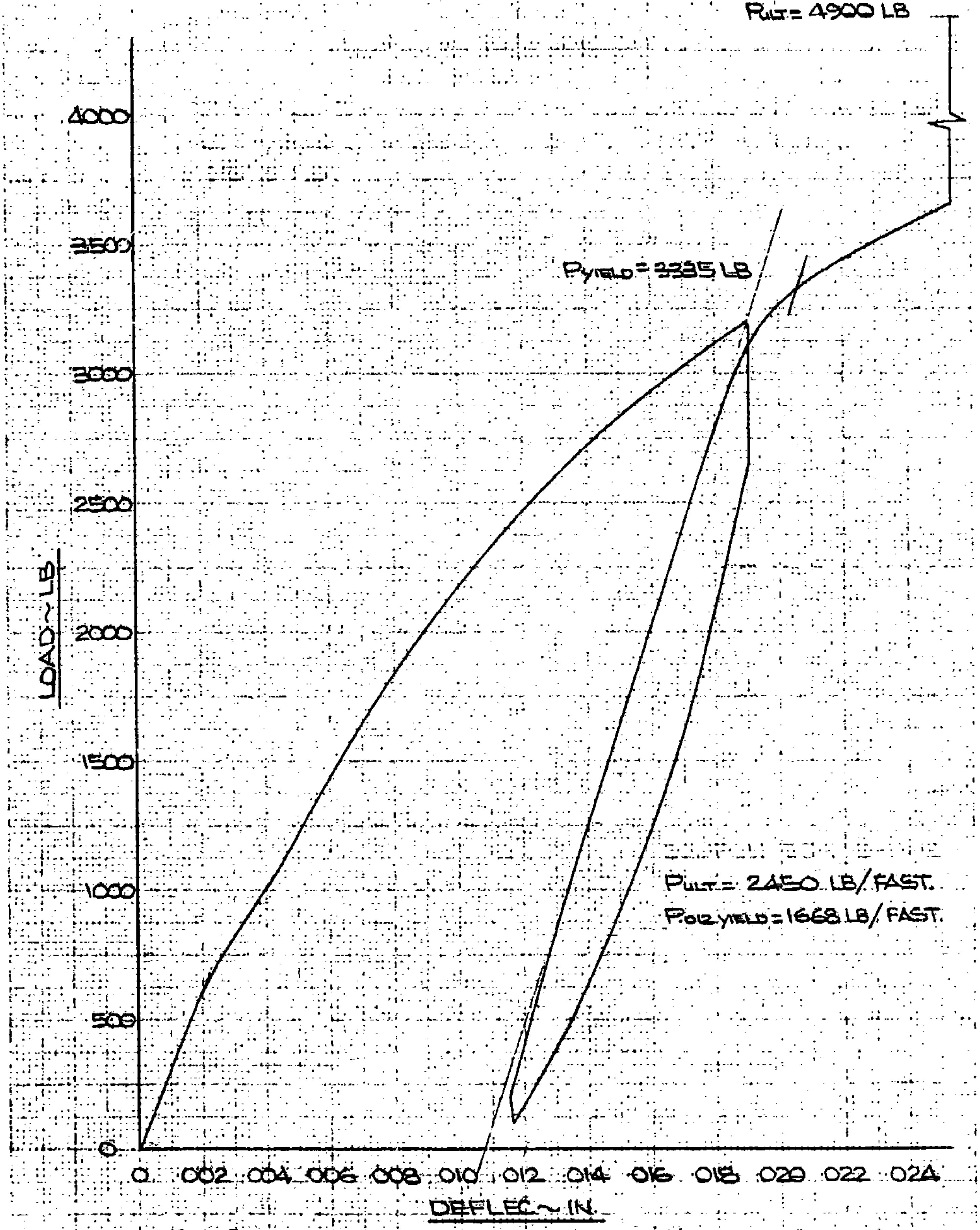


FIG. 3.3.2-4 TYPICAL JOINT AUTOGRAPHIC CURVE FOR LOCKALLOY SHEET (.15 THICK) WITH 1/4 DIA. SCREWS

FAST. MAT'L - 6AL-4V STA. TITANIUM NUT-A-286 CRES.						
SPECIMEN I.D.	TEST TEMP. -°F	FAST. DIA. IN.	SHEET THICK IN.	Pu/FAST. LBS.	Py/FAST. LBS.	TYPE FAILURE
1J3.15-1 1J3.15-2 AVERAGE	ROOM TEMP.	.190	.150	2420 2472 2446	1570 1500 1535	FASTENER TENSION FASTENER TENSION
1J4.15-1 1J4.15-2* AVERAGE		.250	.150	3575 3475 3525	2195 2180 2188	BEARING & NET SECTION NET SECTION-DID NOT FAIL THRU MARK.
2J3.125-1 2J3.125-2 AVERAGE		.190	.125	2225 2222 2224	1342 1385 1364	NET SECTION BEARING & FAST. SHEAR
2J3.125-3 2J3.125-4 AVERAGE		.250**	.125	2050 2258 2154	1350 1038 1194	FLUSH NUT SHANK SHEAR FLUSH NUT SHANK SHEAR
1J3.15-3 1J3.15-4 AVERAGE	600	.190	.150	1688 1690 1689	1078 1122 1100	BEARING BEARING
1J4.15-3 1J4.15-4 AVERAGE		.250	.150	2175 2142 2158	1375 1680 1528	BEARING BEARING

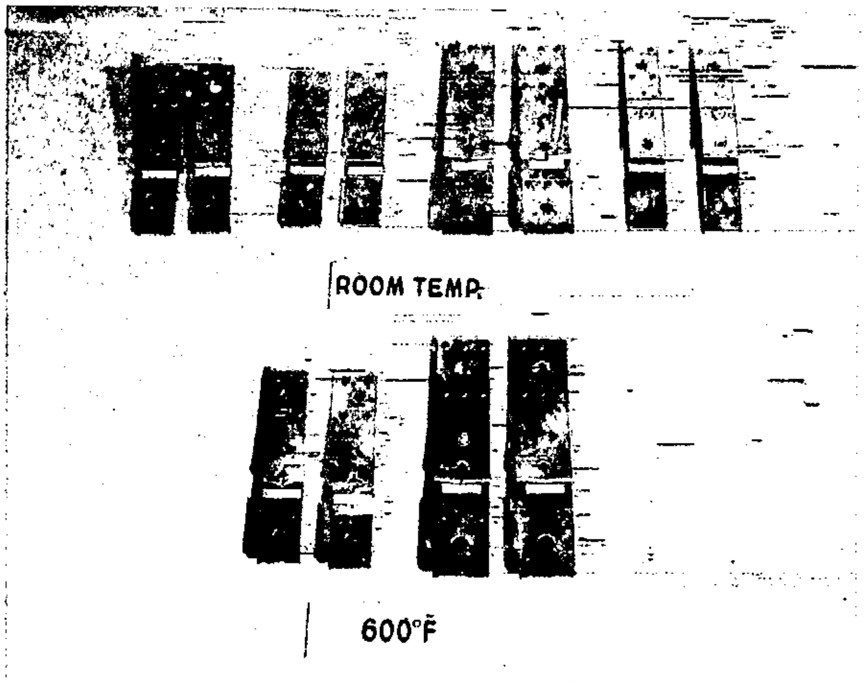
* MARKED SURFACE - C' SUNK SIDE WITH TORQUE SET DRIVER NORMAL TO LOADING.

REF. RN PAGE 550454

** A-286 SELF-ALIGNING NUT.

REF. RN PAGE 550454

TABLE 3.3.2-1. Be-43Al LOCKALLOY JOINT TEST RESULTS AT ROOM TEMP. AND 600°F - NO SOAK



75-5222-1

Figure 3.3.2-5 Photograph Showing All of The Failed Specimens in The Be-43Al Alloy.

3.4 TESTING OF .250 INCH THICK Be-38Al PLATE

Characterization tests of .250-inch thick Be-38Al plate were performed to test its forming characteristics and its mechanical properties. The formability tests performed consisted of tension, bend, and notched tension tests. The results of these tests are needed for comparison with similar tests performed in conjunction with .250-inch thick Be-43Al plate and .150-inch thick Be-38Al sheet. In addition, a series of tests was performed to determine the mechanical properties of the .250-inch thick Be-38Al material. These tests are summarized in Tables 3.4-1 and 3.4-2 and are described in succeeding paragraphs.

3.4.1 Forming Characteristics - Be-38Al .250 Thickness - The tests performed on .250 Be-38Al Lockalloy in connection with formability are shown in Table 3.4-1. These tests are identical to the tests performed on Be-43Al which are described and analyzed in Section 3.3.1

The strain rate variations at R.T. and 1050°F have the same effects on Be-38Al as on Be-43Al. In general, slower straining rates again improve formability, while higher rates of deformation decrease material formability. Data is presented in Table 3.4.1-1 and 3.4.1-2.

Straining of the material to 5% at room temperature shows the same effects of work hardening observed on the Be-43Al. Annealing at 1050°F for one hour, after stretching, seems to restore material properties. Repeating the stretching and stress relieving cycles shows effectively no change in the strength properties, with an approximate 70% increase in the elongation. Test results are presented in Table 3.4.1-3.

Coupons strained to 5% at 1050°F do not exhibit the work hardening effects that the coupons strained at room temperature exhibit. Repeating the stretch-stress relief cycles has a moderate softening effect. Test data shown in Table 3.4.1-4.

Stress relieving (exposure to 1050°F for one hour) without prior stretching has no effect on material properties, Table 3.4.1-5.

Although the stress relieving cycle of 1050°F for one hour seems to better approach a full annealing treatment for the Be-38Al material, further work in this area will be useful in defining formability of Lockalloy.

3.4.1.1 Tensile Tests - The procedure used for testing the Be-38Al material is the same as that employed for the Be-43Al material. This is described in Section 3.3.1.1 and is not repeated here.

The results of the tensile tests for the .25 thick Be-38Al alloy are presented in Tables 3.4.1-1 through 3.4.1-6.

3.4.1.2 Bend Tests-Three Point - The procedure used for testing the Be-38Al material is essentially identical to that used for the Be-43Al material. Section 3.3.1.2 describes this procedure so it is not repeated.

A photograph of the bend specimens after testing are shown in Fig. 3.4.1.2-1 and the results of the room temperature and 1050°F bend tests for the .25 thick Be-38Al alloy are shown in Table 3.4.1.2-1. Based on these tests, the remarks made for the Be-43Al alloy are also applicable here. However, at room temperature, the Be-38Al alloy is slightly less workable, requiring an R/t = 20 as compared to R/t = 15 for the Be-43Al alloy.

3.4.1.3 Stress Relieving - The remarks made in Section 3.3.1.3 apply equally to this section.

3.4.1.4 Notched Tensile Tests - The procedure used for testing the Be-38Al material is essentially the same as that used for the Be-43Al material. Section 3.3.1.4 describes this procedure so it is not repeated.

The results of the notched tensile tests for the .25 inch thick Be-38Al alloy, both at room temperature at at 600°F and in both the longitudinal and transverse directions are presented in Table 3.4.1.4-1. Unnotched tensile tests for the same conditions and directions are also presented to show the notched to unnotched ratio for the .25 inch thick Be-38Al alloy. The room temperature ratios of 1.012 in the longitudinal direction and 1.006 in the transverse direction compare quite favorably to those obtained for 7075-T6 aluminum alloy of 1.190 and 1.142 for the same respective directions. At 600°F, the higher ratios of 1.359 and 1.306 in the longitudinal and transverse directions respectively, indicates the material to be more tolerant of notches at elevated temperatures.

ITEM	TEST	SPECIMEN TYPE	GRAIN DIRECTION	MATERIAL CONDITION AND TEST DESCRIPTION	TEST TEMP °F	NO. OF SPECIMENS	SPECIMEN IDENT.
1	TENSION	S-12	L	AS RECEIVED - TEST AT 3 DIFFERENT STRAIN RATES	R.T.	9	5T-13L ← 5T-21L
2				STRESS RELIEVE - 1 HOUR AT 1050°F	R.T.	3	5T-22L, -23L, -24L
3				AS RECEIVED - TEST AT 3 DIFFERENT STRAIN RATES	1050	9	5T-25L ← 5T-33L
4				STRETCH 5% (PERMANENT STRAIN) - RELAX	R.T.	3	5T-34L, -35L, -36L
5				STRETCH 5% - RELAX - STRESS RELIEVE	R.T.	3	5T-37L, -38L, -39L
6				STRETCH 5% - RELAX - STRESS RELIEVE - REPEAT CYCLE	R.T.	3	5T-40L, 41L, -42L
7				STRETCH 5% - RELAX - STRESS RELIEVE - REPEAT CYCLE TWICE	R.T.	3	5T-43L, -44L, -45L
7.1				STRETCH 5% AT 1050°F - RELAX	R.T.	3	5T-46L, -47L, -48L
8				STRETCH 5% AT 1050°F - STRESS RELIEVE	R.T.	3	5T-49L, -59L, -51L
9				STRETCH 5% AT 1050°F - STRESS RELIEVE - REPEAT CYCLE	R.T.	3	5T-52L, -53L, -54L
10			T	AS RECEIVED - TEST AT ONE STRAIN RATE	R.T.	3	5T-7T, -8T, -9T
11				SAME AS ITEM 2	R.T.	3	5T-10T, -11T, -12T
12				SAME AS ITEM 8	R.T.	3	5T-13T, -14T, -15T
13	BEND	S-50	L	AS RECEIVED - BEND AT R.T. TO ESTABLISH MIN. B.R.	R.T.	5	5BM-1L ← 5BM-5L
14		S-46		AS RECEIVED - BEND AT 1050°F TO ESTABLISH MIN. B.R.	1050	5	5UB-1L ← 5UB-5L
15		S-50	T	SAME AS ITEM 13	R.T.	5	5BM-1T ← 5BM-5T
16		S-46		SAME AS ITEM 14	1050	5	5UB-1T ← 5UB-5T
17	NOTCHED TENSION $K_t = 3$	S-49	L	AS RECEIVED	R.T.	3	5NT-1L, -2L, -3L
18			T	AS RECEIVED	R.T.	3	5NT-1T, -2T, -3T

NOTE: FIRST DIGIT 5 OF SPECIMEN IDENTIFICATION INDICATES SHEET NO. HC 161-3

TABLE 3.4-1. TEST SUMMARY FOR .250 INCH THICK Be-38Al LOCKALLOY PLATE, PART I

ITEM	TEST	SPECIMEN TYPE	GRAIN DIRECTION	MATERIAL CONDITION	TEST TEMP-°F	NO. OF SPECIMENS	SPECIMEN IDENT.
1	TENSION	S-12	L	AS RECEIVED - NO SOAK	R.T.	3	5T-1L, 2L, -3L
					600	3	5T-4L, -5L, -6L
			T		R.T.	3	5T-1T, -2T, -3T
					600	3	5T-4T, -5T, -6T
			L	SOAK 100 HOURS AT 600°F	R.T.	3	5T-7L, -8L, -9L
					600	3	5T-10L, -11L, -12L
2	COMPRESSION	S-13	L	AS RECEIVED - NO SOAK	R.T.	3	5C-1L, -2L, -3L
					600	3	5C-4L, -5L, -6L
				SOAK 100 HOURS AT 600°F	R.T.	3	5C-7L, -8L, -9L
					600	3	5C-10L, -11L, -12L
3	SHEAR	S-35 OR S-36	ST	AS RECEIVED - NO SOAK	R.T.	3	6B1.5-1T, -2T, -3T
					600	3	6B1.5-7T, -8T, -9T
				SOAK 100 HOURS AT 600°F	R.T.	3	6B1.5-4T, -5T, -6T
					600	3	6B1.5-10T, -11T, -12T
4	BEARING e/D = 2.0	S-35	T	AS RECEIVED - NO SOAK	R.T.	3	6B2-1T, -2T, -3T
					600	3	6B2-4T, -5T, -6T
				SOAK 100 HOURS AT 600°F	R.T.	3	6B2-7T, -8T, -9T
					600	3	6B2-10T, -11T, -12T
5	BEARING e/D = 1.5	S-36	T	AS RECEIVED - NO SOAK	R.T.	3	6B1.5-1T, -2T, -3T
					600	3	6B1.5-4T, -5T, -6T
				SOAK 100 HOURS AT 600°F	R.T.	3	6B1.5-7T, -8T, -9T
					600	3	6B1.5-10T, -11T, -12T
6	FRACTURE TOUGHNESS AND CRACK GROWTH RATE	S-48	L	AS RECEIVED - NO SOAK	R.T.	3	6FT-1L, -2L, -3L
					600	3	6FT-4L, -5L, -6L
			T		R.T.	3	6FT-1T, -2T, -3T
					600	3	6FT-4T, -5T, -6T
			L	SOAK 100 HOURS AT 600°F	R.T.	3	6FT-7L, -8L, -9L
					600	3	6FT-10L, -11L, -12L
			T		R.T.	3	6FT-7T, -8T, -9T
					600	3	6FT-10T, -11T, -12T
7	FATIGUE $K_t = 1$	S-29	L	AS RECEIVED - NO SOAK	R.T.	3	6UF-1L, -2L, -3L
					600	3	6UF-4L, -5L, -6L
				SOAK 100 HOURS AT 600°F	R.T.	3	6UF-7L, -8L, -9L
					600	3	6UF-10L, -11L, -12L
8	FATIGUE $K_t = 3$	S-51	L	AS RECEIVED - NO SOAK	R.T.	3	6NF-1L, -2L, -3L
					600	3	6NF-4L, -5L, -6L
				SOAK 100 HOURS AT 600°F	R.T.	3	6NF-7L, -8L, -9L
					600	3	6NF-10L, -11L, -12L
9	STRESS CORROSION	S-47	T	AS RECEIVED - NO SOAK BARE + 3 1/2% NaCl	R.T.	3	6SC-1T, -2T, -3T
					600	3	6SC-4T, -5T, -6T
				AS RECEIVED - NO SOAK ALODINE COAT + 3 1/2% NaCl	R.T.	3	6SC-7T, -8T, -9T
					600	3	6SC-10T, -11T, -12T
				AS RECEIVED - NO SOAK PAINT + 3 1/2% NaCl	R.T.	3	6SC-13T, -14T, -15T
					600	3	6SC-16T, -17T, -18T
10	CREEP	S-7	L	AS RECEIVED - NO SOAK	600	3	6CR-1L, -2L, -3L
			T			3	6CR-2T, -2T, -3T
11	POISSON'S RATIO	S-7	L	AS RECEIVED - NO SOAK	R.T.	4	6PR-2L, -4L, -5L, -6L
					600	2	6PR-1L, -3L
				SOAK 100 HOURS AT 600°F	R.T.	3	6PR-10L, -11L, -12L
					600	3	6PR-7L, -8L, -9L
12	NOTCHED TENSION	S-49	L	AS RECEIVED - NO SOAK	600	3	5NT-4L, -5L, -6L
			T			3	5NT-4T, -5T, -6T

NOTE: FIRST DIGIT OF SPECIMEN IDENTIFICATION INDICATES THE FOLLOWING

5 - SHEET NO. HC 161-3
6 - SHEET NO. HC 160-1

TABLE 3.4-2. TEST SUMMARY FOR .250 INCH THICK Be-38Al LOCKALLOY PLATE, PART II

SPECIMEN IDENTIFICATION	DIRECTION	TEST TEMP	STRAIN RATE IN/IN/MIN	ULTIMATE KSI	YIELD KSI	% ELONG IN 1 INCH	E X 10^{-6} PSI
5T-13L	LONG	ROOM TEMP	.005	51.8	37.1	8	25.1
5T-14L				51.8	37.3	9	37.1
5T-15L				52.0	37.7	10	26.9
AVG.				51.9	37.4	9	29.7
5T-7T	TRANS	ROOM TEMP	.005	49.9	35.5	10	29.4
5T-8T				49.9	35.6	9	27.1
5T-9T				49.8	35.9	9	28.0
AVG.				49.9	35.7	9	28.2
5T-16L	LONG	ROOM TEMP	.0005	51.3	36.3	9	38.0
5T-17L				49.4	36.4	8	38.2
5T-18L				51.5	37.0	12	31.6
AVG.				50.6	36.6	10	34.4
5T-19L	LONG	ROOM TEMP	.050	52.0	38.4	7	34.4
5T-20L				51.1	37.9	7	35.5
5T-21L				52.1	38.0	8	34.3
AVG.				51.7	38.1	7	34.7

REF: RN 550495
RN 550497

TABLE 3.4.1-1. TENSILE TEST RESULTS OF .250 THICK Be-38Al LOCKALLOY PLATE TESTED @ ROOM TEMPERATURE - AT DIFFERENT STRAIN RATES

SPECIMEN IDENTIFICATION	DIRECTION	TEST TEMP	STRAIN RATE IN/IN/MIN	ULTIMATE KSI	YIELD KSI	% ELONG. IN 1 INCH	E X 10^{-6} PSI
5T-25L	LONG	1050°F	.001	4.0	3.5	21	-
5T-26L			.005	5.6	4.7	15	15.8
5T-27L			.005	5.4	4.6	15	15.7
AVG.				5.0	4.3	17	15.8
5T-28L	LONG	1050°F	.0005	2.7	2.3	21	10.4
5T-29L				2.8	2.5	20	8.4
5T-30L				3.1	2.7	20	9.9
AVG.				2.9	2.5	20	9.6
5T-31L	LONG	1050°F	.050	-	-	9	13.5
5T-32L				11.6	10.4	9	13.2
5T-33L				11.0	10.2	9	-
AVG.				11.3	10.3	9	13.4

REF RN 550499

TABLE 3.4.1-2 TENSILE TEST RESULTS OF .250 INCH THICK Be-38Al LOCKALLOY PLATE TESTED @ 1050°F AT DIFFERENT STRAIN RATES

SPECIMEN IDENTIFICATION	CONDITIONING	DIRECTION	TEST TEMP	ULTIMATE KSI	YIELD KSI	% ELONG IN 1 INCH	E X 10^{-6} PSI
5T-34L	STRETCH 5%, RELAX, TEST	LONG	ROOM TEMP	51.4	46.3	8	26.1
5T-35L				53.6	47.2	10	24.5
5T-36L				53.5	46.2	10	26.2
AVG.				52.8	46.6	9	25.6
5T-37L	STRETCH 5%, RELAX, STRESS RELIEVE 1 HR @ 1050°F, TEST	LONG	ROOM TEMP	53.5	36.4	9	32.1
5T-38L				52.2	35.6	8	29.5
5T-39L				53.3	35.7	10	27.6
AVG.				53.0	35.9	9	29.7
5T-40L	STRETCH 5%, RELAX, STRESS RELIEVE 1 HR @ 1050°F; REPEAT CYCLE, TEST	LONG	ROOM TEMP	49.0	37.3	14	31.2
5T-41L				53.6	37.3	19	27.0
5T-42L				54.4	37.9	19	31.2
AVG.				52.3	37.5	17	29.8
5T-43L	STRETCH 5%, RELAX, STRESS RELIEVE 1 HR @ 1050°F; REPEAT CYCLE 2 TIMES, TEST	LONG	ROOM TEMP	-	-	14	-
5T-44L				44.6	39.9	17	17.7
5T-45L				51.0	39.1	19	27.2
AVG.				47.8	39.5	18	22.5

REF. RN 550497, 550498, 550500

TABLE 3.4.1-3. TENSILE TEST RESULTS OF .250 INCH THICK Be-38Al LOCKALLOY AFTER STRETCHING AT ROOM TEMPERATURE

SPECIMEN IDENTIFICATION	CONDITIONING	ROLLING DIRECTION	TEST TEMP	ULTIMATE KSI	YIELD KSI	% ELONG. IN 1 INCH	E X 10^{-6} PSI
5T-46L	STRETCH 5% @ 1050°F, RELAX, TEST	LONG	ROOM TEMP	47.4	37.2	12	19.4
5T-47L				49.1	37.7	12	18.4
5T-48L				47.5	37.4	11	22.7
AVG				48.0	37.4	12	20.2
5T-49L	STRETCH 5% @ 1050°F, RELAX STRESS RELIEVE 1 HR @ 1050°F, TEST	LONG	ROOM TEMP	50.2	37.3	13	23.2
5T-50L				51.7	38.1	15	24.8
5T-51L				48.6	37.8	12	18.8
AVG				50.2	37.7	13	22.3
5T-13T	STRETCH 5% @ 1050°F RELAX STRESS RELIEVE 1 HR @ 1050, TEST	TRANS.	ROOM TEMP	42.4	35.8	9	19.9
5T-14T				47.8	36.1	12	19.7
5T-15T				47.1	35.9	13	19.5
AVG				47.5	36.0	11	19.7
5T-52L	STRETCH 5% @ 1050°F RELAX, STRESS RELIEVE 1 HR @ 1050°F; REPEAT CYCLE, TEST	LONG	ROOM TEMP	38.1	34.9	12	33.0
5T-53L				39.1	34.7	12	23.2
5T-54L				40.2	34.5	14	17.1
AVG				39.1	34.7	13	24.4

REF RN 550500, 568952, 568953

TABLE 3.4.1-4. TENSILE TEST RESULTS OF .250 INCH THIC Be-38Al LOCKALLOY AFTER STRETCHING AT 1050°F

SPECIMEN IDENTIFICATION	CONDITION	DIRECTION	ULTIMATE KSI	YIELD KSI	% ELONG. IN 1 INCH	E X 10^{-6} PSI
5T-1L	AS REC'D	LONG	51.6	36.4	9	27.1
5T-2L			51.4	36.6	9	28.9
5T-3L			50.9	36.5	9	28.6
AVG			51.3	36.5	9	28.2
5T-1T	AS REC'D	TRANS	49.7	36.0	8	26.6
5T-2T			50.2	36.2	9	29.4
5T-3T			49.6	36.2	9	30.2
AVG			49.8	36.1	9	28.7
5T-7L	EXPOSED 100 HRS @ 600°F	LONG	51.7	37.4	9	29.8
5T-8L			52.6	37.8	12	30.0
5T-9L			52.5	36.2	12	25.0
AVG			52.6	37.1	11	28.3
5T-22L	STRESS RELIEVED 1 HOUR @ 1050°F	LONG	53.3	37.6	13	36.9
5T-23L			53.0	37.6	13	35.9
5T-24L			52.5	36.1	14	40.7
AVG			52.9	37.1	13	37.8
5T-10T	STRESS RELIEVED 1 HOUR @ 1050°F	TRANS	50.8	35.9	11	33.4
5T-11T			50.2	35.8	10	33.8
5T-12T			49.7	35.6	10	36.1
AVG			50.2	35.8	10	34.4

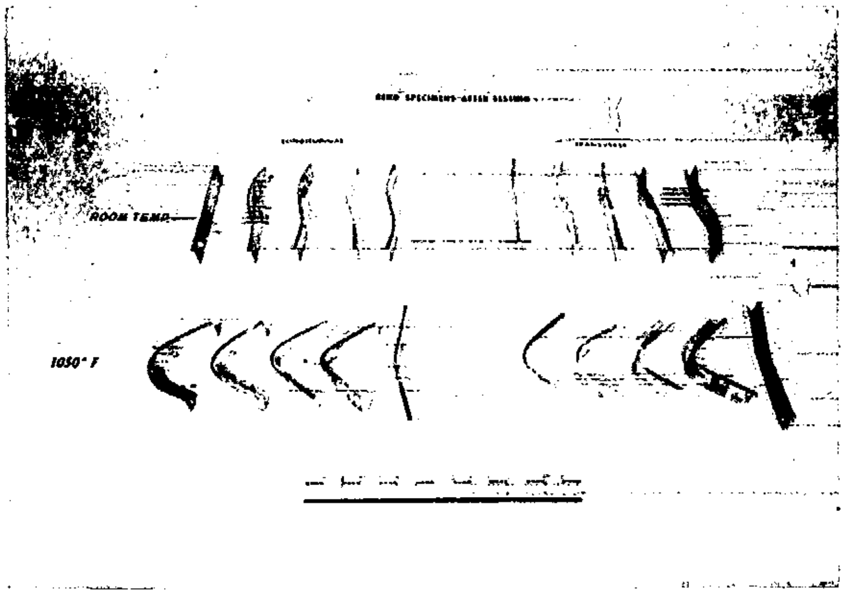
REF: 550495, 550497, 550498

TABLE 3.4.1-5. TENSILE TEST RESULTS FOR .250 INCH THICK Be-38Al LOCKALLOY PLATE AT ROOM TEMPERATURE, WITH AND WITHOUT EXPOSURE FOR 100 HOURS AT 600°F, AND 1 HR @ 1050°F

SPECIMEN IDENTIFICATION	CONDITION	ROLLING DIRECTION	ULTIMATE KSI	YIELD KSI	% ELONG IN 1 INCH	E X 10^{-6} PSI
5T-4L	AS REC'D	LONG	25.0	23.3	9	19.9
5T-5L			24.5	23.5	7	29.9
5T-6L			24.9	24.3	12	-
AVG			24.8	23.7	9	24.9
5T-4T	AS REC'D	TRANS	24.0	23.4	9	19.8
5T-5T			24.1	23.5	10	23.6
5T-6T			24.5	23.5	10	17.3
AVG			24.2	23.5	10	20.2
5T-10L	EXPOSED 100 HRS @ 600°F	LONG	24.8	24.1	11	30.7
5T-11L			24.9	23.9	12	23.8
5T-12L			24.7	22.4	11	17.6
AVG			24.8	23.5	11	24.0

REF RN 550496

TABLE 5.4.1-4. TENSILE TEST RESULTS FOR .250 INCH THICK Be-38Al LOCKALLOY PLATE AT 600°F, WITH AND WITHOUT EXPOSURE FOR 100 HOURS @ 600°F



75-5354-11

Figure 3.4.1.2-1 Photograph of Be-38Al .250 Inch Thick Bend Specimens After Testing.

THICKNESS - .25 INCHES				BEND RATES AT TEMP. APPROX. .06 INCHES/MINUTE
FORMING TEMP.	RADIUS THICKNESS	GRAIN DIRECTION	SPECIMEN NUMBER	RESULTS
ROOM TEMP.	20	LONG.	5BM-5L	NO FAILURE WHEN BENT THROUGH 30° WITH RUBBER BACK-UP. BOTH SURFACES.
		TRANS.	5BM-5T	
	15	LONG.	5BM-1L	NO FAILURE AT 3° BEND - WITH OR WITHOUT RUBBER BACK-UP.
		TRANS.	5BM-1T	
		LONG.	5BM-2L	NO FAILURE WHEN BENT THROUGH 35° WITH RUBBER BACK-UP. - ONE SURFACE. FAILED AT 17° BEND WITHOUT RUBBER BACK-UP - OTHER SURFACE.
		TRANS.	5BM-2T	NO FAILURE WHEN BENT THROUGH 35° WITH RUBBER BACK-UP - ONE SURFACE. FAILED AT 19° BEND WITHOUT RUBBER BACK-UP - OTHER SURFACE.
		LONG.	5BM-3L	FAILED AT 25° BEND WITH RUBBER BACK-UP - BOTH SURFACES.
		TRANS.	5BM-3T	FAILED AT 25° BEND WITH RUBBER BACK-UP - BOTH SURFACES.
		LONG.	5BM-4L	NO FAILURE WHEN BENT THROUGH 38.5° WITH RUBBER BACK-UP - ONE SURFACE. FAILED AT 13° BEND WITH RUBBER BACK-UP - OTHER SURFACE.
		TRANS.	5BM-4T	FAILED AT 21° BEND WITH RUBBER BACK-UP - BOTH SURFACES.
1050°F	7	LONG.	5UB-1L	NO FAILURE AT 127° BEND. (OVERFORMED 22°)
		TRANS.	5UB-1T	NO FAILURE AT 101° BEND. (UNDERFORMED 4°)
	6	LONG.	5UB-2L	ONE SURFACE CRACK AT 114° BEND. (OVERFORMED 9°)
		TRANS.	5UB-2T	SEVERAL SURFACE CRACKS AT 110° BEND. (OVERFORMED 5°)
	5	LONG.	5UB-3L	NO FAILURE AT 109° BEND. (OVERFORMED 4°)
		TRANS.	5UB-3T	MULTIPLE SURFACE CRACKS AT 106° BEND. (OVERFORMED 1°)
	4	LONG.	5UB-4L	SEVERE SURFACE CRACKS AT 105° BEND.
		TRANS.	5UB-4T	SEVERE SURFACE CRACKS AT 107° BEND. (OVERFORMED 2°)
600°F	8	LONG.	5UB-5L	FAILED AT 29° BEND.
		TRANS.	5UB-5T	FAILED AT 16° BEND.

TABLE 3.4.1.2-1. LOCKALLOY Be-38Al (LX-62) BEND TEST RESULTS

CONDITION	DIRECTION	TEST TEMP. - °F	SPECIMEN I.D.	NOTCHED ULTIMATE KSI	SPECIMEN I.D.	UNNOTCHED ULTIMATE KSI	NOTCHED ULTIMATE / UNNOTCHED ULTIMATE
AS REC'D	LONG.	ROOM TEMP.	5NT-1L 5NT-2L 5NT-3L AVG.	52.4 52.0 51.4 51.9	5T-1L 5T-2L 5T-3L AVG.	51.6 51.4 50.9 51.3	1.012
AS REC'D	TRANS.	ROOM TEMP.	5NT-1T 5NT-2T 5NT-3T AVG.	50.0 49.7 50.6 50.1	5T-1T 5T-2T 5T-3T AVG.	49.7 50.2 49.6 49.8	1.006
AS REC'D	LONG.	600	5NT-4L 5NT-5L 5NT-6L AVG.	33.4 33.7 33.9 33.7	5T-4L 5T-5L 5T-6L AVG.	25.0 24.5 24.9 24.8	1.359
AS REC'D	TRANS.	600	5NT-4T 5NT-5T 5NT-6T AVG.	30.5 32.3 32.1 31.6	5T-4T 5T-5T 5T-6T AVG.	24.0 24.1 24.5 24.2	1.306

REF. R.N. PAGES 550490, 550495, 550496.

TABLE 3.4.1.4-1. NOTCHED TO UNNOTCHED TENSILE TEST RESULTS FOR .250 INCH THICK Be-38Al LOCKALLOY PLATE TESTED AT ROOM TEMP. AND 600°F

3.4.2 Mechanical Properties

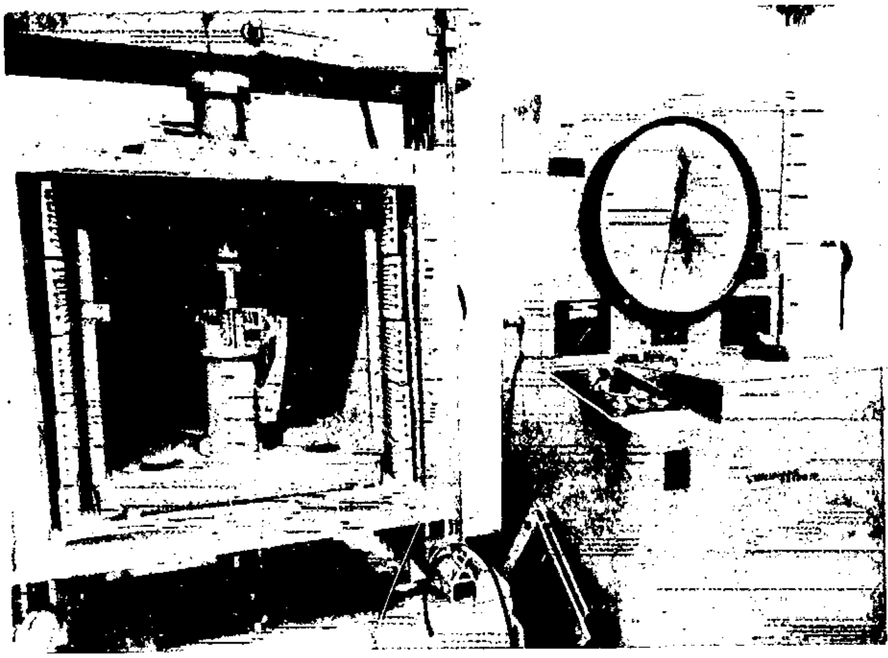
3.4.2.1 Compression Tests - Compressive tests were conducted according to standard ASTM E9-70 practices. Compressive test specimens of the configuration shown on Page B-4 of the Appendix were installed in a Lockheed designed compressive fixture between the platens of a 30,000 lb. Baldwin Mark B Universal Testing Machine. A photograph of the general set-up is shown in Fig. 3.4.2.1-1 which was used for both room and elevated temperature testing.

The Lockheed designed compressive fixture features full support along the length of the specimen to inhibit buckling when thin sheet is being tested. A close-up view of the specimen installed in the fixture is shown in Fig. 3.4.2.1-2. The fixture incorporates an internal extensometer that is compatible with the Baldwin recorder. Strain is recorded over a two inch gage length which is centered on the specimen.

The specimens were loaded at a constant head travel rate that produced a strain of .005 inch per inch per minute through approximately .020 inch strain on an autographic load-strain curve. A graphical determination was then made to obtain the compressive modulus, compressive yield at .2 percent off-set, .70 secant and .85 secant modulii. The Ramberg-Osgood shape parameter, n, is then calculated and reported in the data.

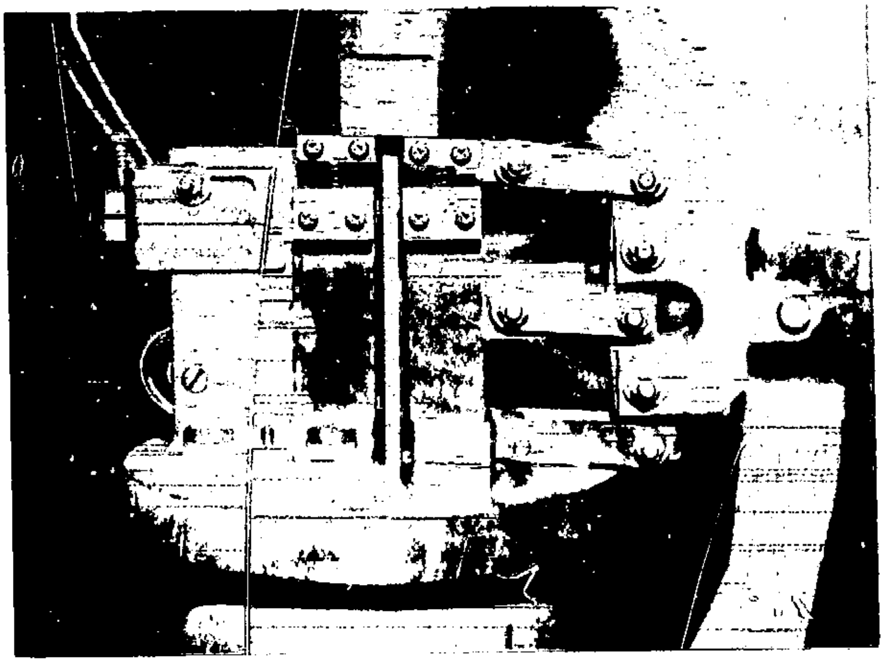
The compressive test results for the .25 inch thick Be-38Al alloy at room temperature and 600°F, with and without soak for 100 hours at 600°F in the longitudinal direction are presented in Table 3.4.2.1-1.

Soaking for 100 hours at 600°F appears to have an insignificant effect on the as received properties at either room or elevated temperature.



75-5405-3

Fig. 3.4.2.1-1 - Overall view of Test Machine, Furnace and Compression Fixture with Specimen Installed.



75-5405-4

Fig. 3.4.2.1-2 - Close-up View of Compression Fixture Showing Method of Clamping Specimen.

LONGITUDINAL DIRECTION

COUPON IDENTIFICATION	CONDITION	TEST TEMP. - °F	F_{CY} KSI	$F_{0.7}$ KSI	$F_{0.85}$ KSI	E_c PSI x 10^{-6}	n
5C-1L	AS RECEIVED NO SOAK	ROOM TEMP.	33.4	24.0	18.1	22.7	4.1
5C-2L			34.0	25.6	19.6	20.8	4.3
5C-3L			33.7	24.9	18.5	22.2	4.0
AVERAGE			33.7	24.8	18.7	21.9	4.1
5C-4L	AS RECEIVED NO SOAK	600	23.1	19.8	16.1	18.1	5.4
5C-5L			22.6	17.1	13.0	21.7	4.2
5C-6L			21.9	18.7	15.8	17.2	6.2
AVERAGE			22.5	18.5	15.0	19.0	5.3
5C-7L	SOAKED 100 HRS AT 600°F	ROOM TEMP.	33.4	22.0	15.0	25.7	3.3
5C-8L			34.8	26.8	19.6	21.1	3.8
5C-9L			34.8	27.0	20.1	20.8	4.0
AVERAGE			34.3	25.3	18.2	22.5	3.7
5C-10L	SOAKED 100 HRS AT 600°F	600	21.9	17.7	15.6	21.8	8.0
5C-11L			22.3	18.4	14.5	19.2	4.8
5C-12L			22.4	19.8	17.3	17.4	7.4
AVERAGE			22.2	18.6	15.8	19.5	6.7

REF. R.N. PAGE 550492.

TABLE 3.4.2.1-1. COMPRESSION TEST RESULTS OF .250 INCH THICK Be-38Al LOCKALLOY PLATE AT ROOM TEMPERATURE AND 600°F, WITH AND WITHOUT SOAK FOR 100 HOURS AT 600°F.

3.4.2.2 Flatwise Shear Tests - The specimens utilized for the sheet shear strength evaluations were previously used to determine sheet bearing strength. The shear punch is applied to the center of the specimen between the bearing hole and the load application hole in the opposite end of the specimen. A tested specimen of this type is shown in Fig. 3.4.2.2-1.

The flatwise sheet shear strength at both room temperature and 600°F was determined using a Lockheed designed punch and die subpress. The subpress has a .500 inch diameter punch and die, and uses a clamp plate to keep the material flat on the die plate during testing. A photograph of the subpress with a bearing coupon installed ready for testing is shown in Fig. 3.4.2.2-2.

The subpress is installed between the platens of the 30,000 lb. Baldwin Mark B Universal Testing Machine, as shown in 3.4.2.2-3. Shear ultimate strength was determined by applying load to the punch of the shear fixture at a constant rate not exceeding 5,000 pounds per minute until a load drop off occurred as indicated by the dial pointer.

The ultimate shear stress is determined by dividing the maximum load indicated on the test machine dial by the product of the sheet thickness times the circumference of the .500 inch diameter punch.

The flatwise sheet shear test results for .040 thick bearing specimens machined from .250 inch thick Be-38Al alloy plate are presented in Table 3.4.2.2-1 at room temperature and at 600°F, with and without exposure to 600°F for 100 hours.

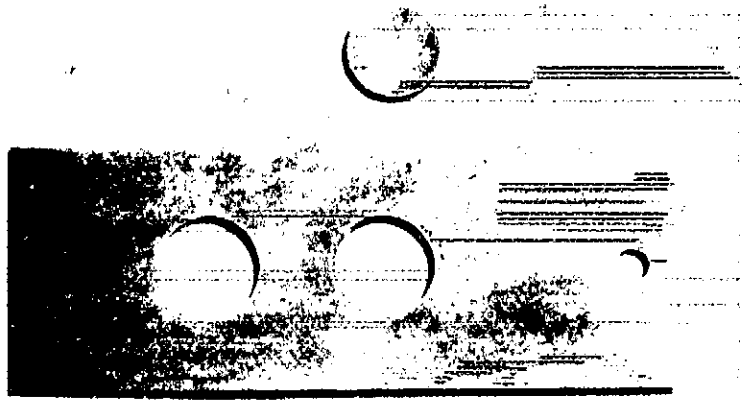
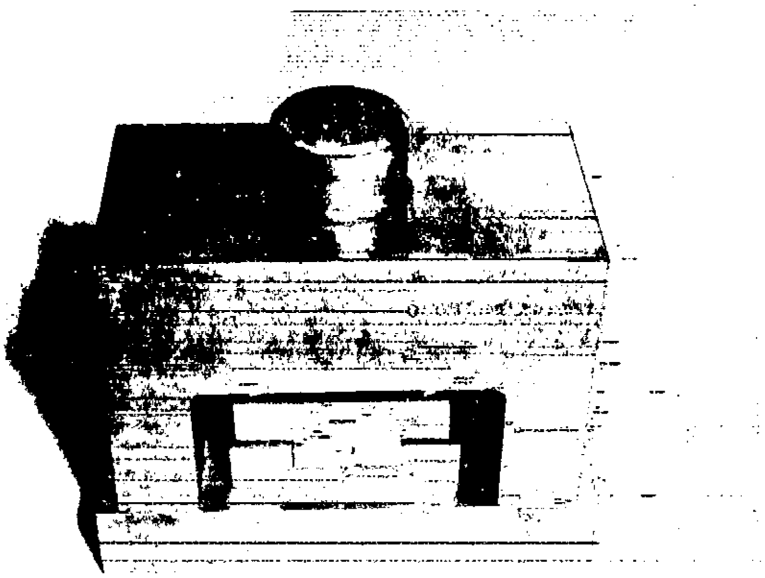
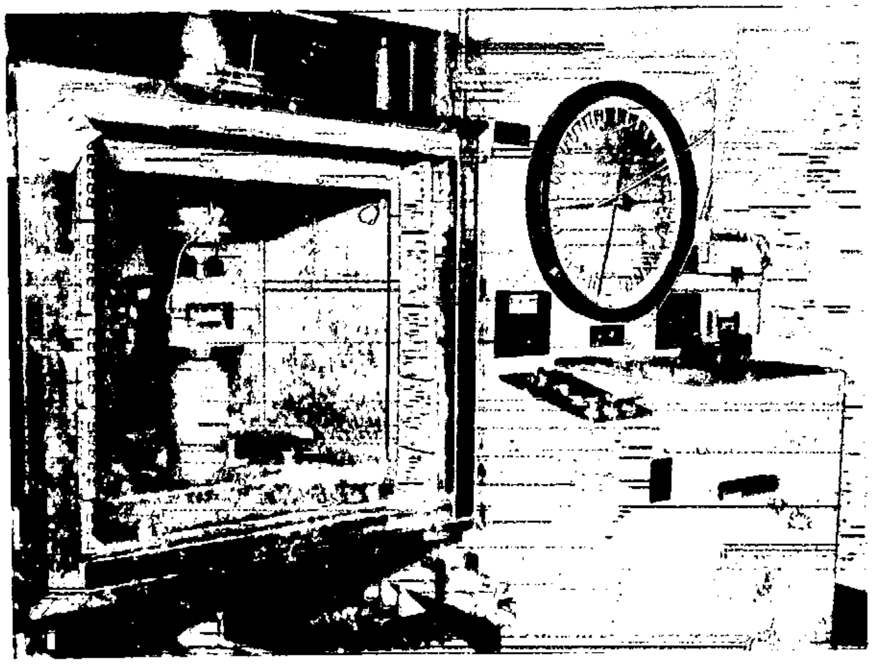


Fig. 3.4.2.2-1 Typical View of Failed Sheet Shear Specimen.



75-5362-4

Fig. 3.4.2.2-2 View of Sheet Shear Test Fixture With Specimen Installed.



75-5362-3

Fig. 3.4.2.2-3 View Showing Sheet Shear Fixture Installed in Furnace in Test Machine.

SPECIMEN IDENTIFICATION	CONDITION	TEST TEMP. °F	ULTIMATE SHEAR STRENGTH KSI
6B1.5-1T	AS RECEIVED	ROOM TEMP.	38.1
6B1.5-2T			38.6
6B1.5-3T			40.2
AVG.			39.0
6B1.5-4T	EXPOSED 100 HRS @ 600°F	ROOM TEMP.	37.6
6B1.5-5T			36.5
6B1.5-6T			37.1
AVG.			37.1
6B1.5-7T	AS RECEIVED	600°F	20.6
6B1.5-8T			20.4
6B1.5-9T			21.0
AVG.			20.7
6B1.5-10T	EXPOSED 100 HRS @ 600°F	600°F	20.5
6B1.5-11T			19.2
6B1.5-12T			16.9
AVG.			18.9

* SHEET SHEAR SPECIMENS ARE THE UNUSED PORTION OF THE SHEET BEARING SPECIMENS, WHICH HAVE BEEN MACHINED TO APPROXIMATELY .040 FROM THE ORIGINAL .250 INCH THICKNESS (REF: R.N. 550491)

TABLE 3.4.2.2-1. FLATWISE SHEET SHEAR TEST RESULTS FOR SOME .250 INCH THICK* Be-38Al LOCKALLOY PLATE

3.4.2.3 Bearing Tests - Bearing tests were conducted at the Rye Canyon test facility of Lockheed. Test procedures used conformed to the general requirements of ASTM E238-68.

Bearing specimens of the configuration shown on pages B-6 and B-7 of the Appendix for an e/D = 2.0 and 1.5, respectively, were machined to an .040 inch thickness from a .250 inch thick Be-38Al alloy plate. Bearing tests were conducted in a 60,000 lb. Baldwin Static Test Machine using a 600 pound full scale load range for maximum sensitivity. An overall set-up of the bearing test system is shown in Figure 3.4-1. A close-up view of the bearing deformation measurement system is shown in Figure 3.4-2 where the deflectometer measurement arm rests on the specimen above the bearing pin. A check of the loading system deflection at loads to 700 lb. showed it to be negligible.

Deflectometer measurements were made using a 4 inch deflectometer patterned after the O.S. Peters Co. PDI M-111 model deflectometer. (Reference Figure 3.4-2). A scale factor of .005 inch per inch of chart paper was found to be adequate, Autographic load versus deflection curves were continuously recorded during the test on the Baldwin x-y plotter.

Elevated temperature tests were conducted by adding a resistance furnace with a thermal controller to the test system. The furnace enclosed the specimen and test fixtures. Temperature was monitored by a thermocouple attached to the specimen. A temperature stabilization time of 15 minutes was allowed after the specimen reached 600 ± 2°F prior to testing. Bearing yield and ultimate were determined using the standard procedures in ASTM E238-68*.

---

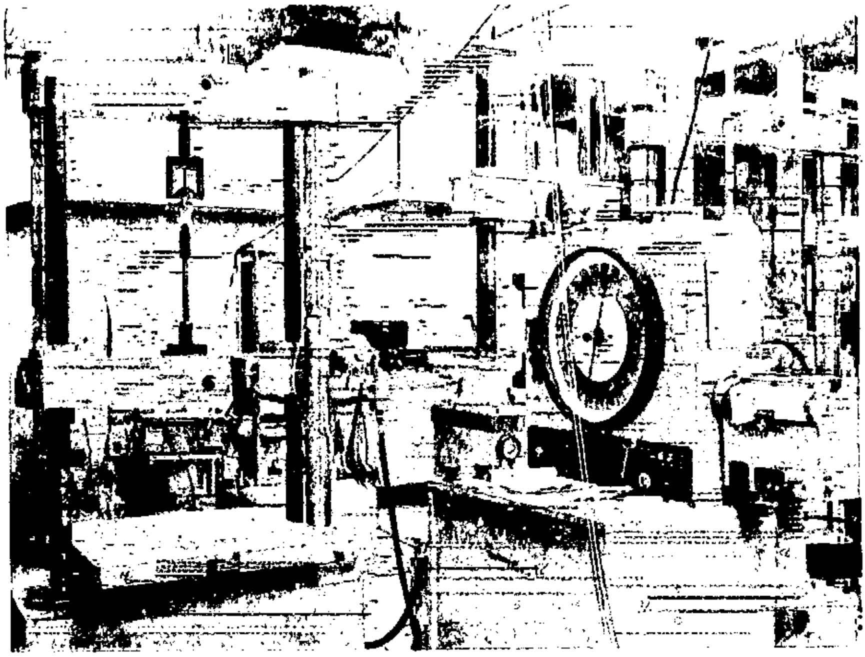
* "Standard Method for Pin-Type Bearing Test of Metallic Materials," ASTM E 238-68, 1973 Annual Book of ASTM Standards, Part 31.

The results of the bearing tests of the .040 inch thick bearing specimens machined from a .250 inch thick Be-38Al alloy plate, tested in the transverse direction at room temperature and 600°F, with and without exposure to 600°F for 1000 hours are presented in Table 3.4.2.3-1.

CONDITION	TEST TEMP. °F	e/D = 2.0			e/D = 1.5		
		SPECIMEN IDENTIFICATION	F_{bru} ksi	F_{bry} ksi	SPECIMEN IDENTIFICATION	F_{bru} ksi	F_{bry} ksi
AS RECEIVED NO SOAK	ROOM TEMP.	6B2-1T	95.4	-	6B1.5-1T	81.7	70.7
		6B2-2T	106.4	77.9	6B1.5-2T	85.0	74.3
		6B2-3T	97.1	74.6	6B1.5-3T	81.7	73.0
		AVERAGE	99.6	76.2	AVERAGE	82.8	72.7
AS RECEIVED NO SOAK	600	6B2-4T	51.7	46.6	6B1.5-4T	40.3	39.8
		6B2-5T	50.7	45.9	6B1.5-5T	43.4	41.9
		6B2-6T	51.1	43.2	6B1.5-6T	43.6	43.3
		AVERAGE	51.2	45.2	AVERAGE	42.4	41.7
SOAKED 100 HRS AT 600°F	ROOM TEMP.	6B2-7T	98.9	78.9	6B1.5-7T	79.1	69.2
		6B2-8T	103.3	78.7	6B1.5-8T	81.2	69.4
		6B2-9T	100.0	79.8	6B1.5-9T	82.2	72.1
		AVERAGE	100.7	79.1	AVERAGE	80.8	70.2
SOAKED 100 HRS AT 600°F	600	6B2-10T	53.3	46.6	6B1.5-10T	42.2	41.4
		6B2-11T	52.2	45.2	6B1.5-11T	43.1	42.4
		6B2-12T	52.2	43.7	6B1.5-12T	42.6	42.1
		AVERAGE	52.6	45.2	AVERAGE	42.6	41.9

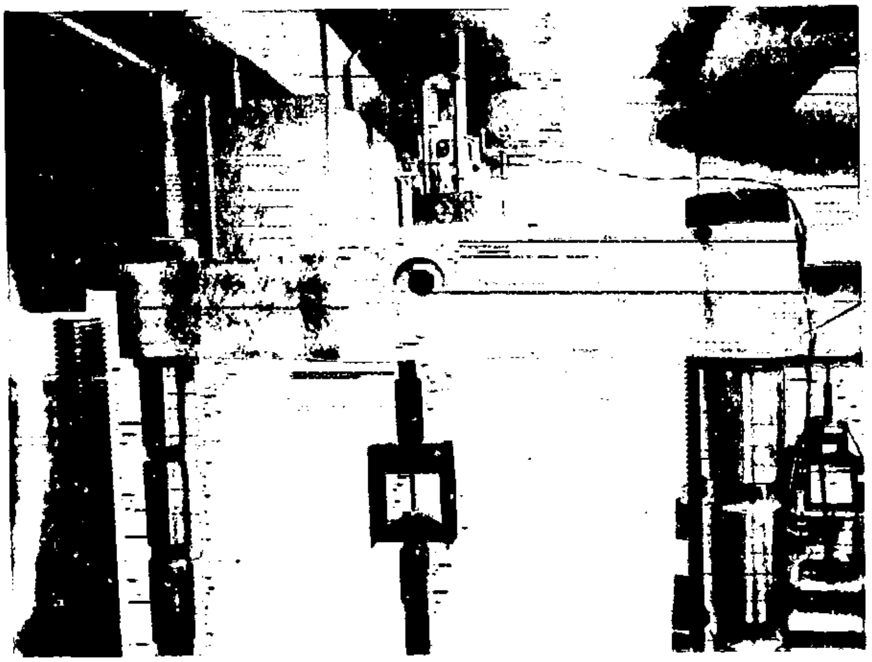
REF: R. N. PAGES 538886 AND 538887

TABLE 3.4.2.3-1. BEARING TEST RESULTS OF .040 INCH THICK Be-38Al LOCKALLOY SPECIMENS AT ROOM TEMPERATURE AND 600°F, WITH AND WITHOUT SOAK FOR 100 HOURS AT 600°F



75-5402-14

Fig. 3.4.2.3-1 Overall Set-Up of Bearing Test Arrangement.



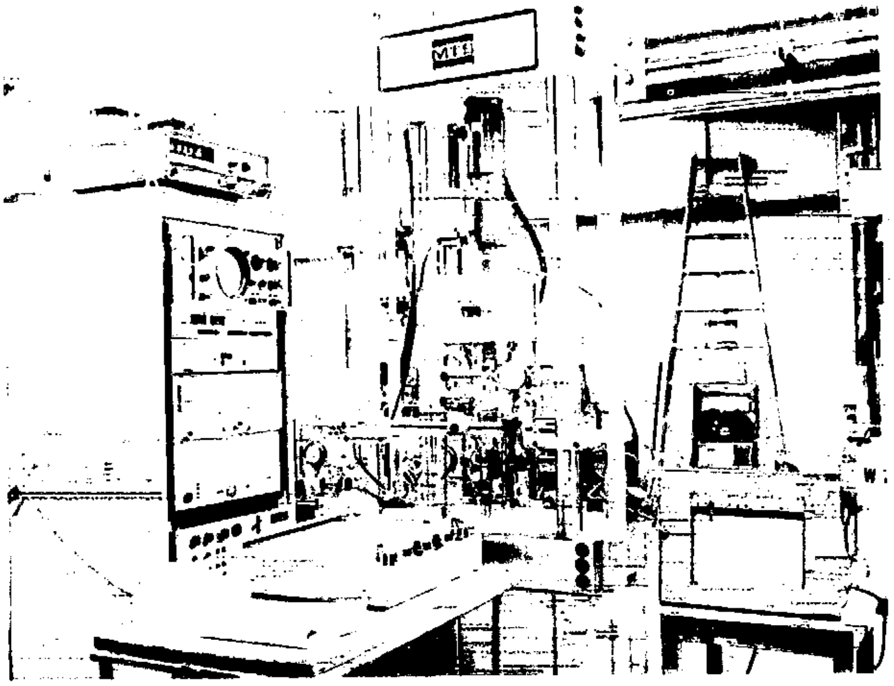
75-5402-7

Fig. 3.4.2.3-2 Close-Up View Showing Deflectometer and Measurement Arm Resting on The Specimen Above The Bearing Pin.

3.4.2.4 Fracture Toughness Test - Fracture toughness tests were conducted at the Lockheed Rye Canyon Facility using duplicate compact tension specimens of the configuration shown on page B-10 of the Appendix according to the requirements of ASTM E399-72. The specimens were precracked by fatigue cycling in a closed loop Electrohydraulic MTS Test Machine in room temperature laboratory air at a range ratio ($R = \frac{P_{MIN}}{P_{MAX}}$) of 0.1. Crack length measurements were made of both sides of the specimen using diametrically opposite traversing tool maker's microscopes accurate to .001 inch. A typical set-up for room temperature testing is shown in Figure 3.4.2.4-1. A close-up view of the compact tension specimen installed in the grips with the tool maker's microscope is shown in Figure 3.4.2.4-2. The precrack loads were selected in accordance with the requirements of ASTM E399-72. Final precrack length was approximately 0.5 inch.

Room temperature fracture tests were conducted in accordance with ASTM E399-72. Fracture tests at 600°F were conducted by attaching a thermocouple to the specimen; installing it in the MTS Closed Loop Electrohydraulic Test Machine, and lowering a resistance furnace which enclosed the specimen and grips. Specimen temperature was stabilized at 600° ± 3°F for 15 minutes prior to test. Temperature control was maintained by use of an automatic thermal control with continuous monitoring on a Brown Recorder. The test was then conducted as per ASTM E399-72 with the exception that the crosshead motion was recorded rather than crack opening displacement (COD) since no 600°F compliance gage was available. All analyses were then conducted as per ASTM E399-72.

In all cases the ratio of P_Q/P_{MAX} was found to be greater than the accepted limit of 1.1. This implies that the failures were not valid plane strain fractures, and that sustantial plastic flow at the crack tip occurred prior to the final fracture for this thickness and specimen size. As a result, the computed K_Q values are not indicative of plain strain fracture and cannot be considered valid K_{Ic} values.



75-5-01-13

Fig. 3.4.2.4-1 - Typical Over-all Setup for Fracture Toughness Test Arrangement

since the failures occurred primarily due to net section yield in the specimen. Thus, the onset of yielding failure limits the capacity of the specimen configuration to hold load, thus putting an apparent upper limit on the K the specimen is valid for.

For such test results, a relative measure of the crack resistance of the material can be computed as per ASTM E399-72. This term called the residual strength parameter, R_{S_C}, is defined by the equation:

$$R_{S_C} = \frac{2P_{MAX}\ (2w + a)}{B(w-a)^2\ F_{ty}}$$

where, P_{MAX} = Maximum Tension Load at Failure ≈ lb.

w = Specimen Width ≈ (1.00 inch)

a = Crack Length ≈ (.500 inch)

B = Specimen Thickness - inch.

F_{ty} = Material Yield Stress - PSI

A relative fracture value which is a ratio of the net section stress in the specimen at failure to the material yield stress is thus provided.

The computed values for R_{S_C} are presented in Table 3.4.2.4-1 for room temperature results and in Table 3.4.2.4-2 for tests at 600°F. The measured overall average value at room temperature of 1.394 for Lockalloy would indicate substantial crack tolerance. To provide a relative comparison to more common materials, samples of 2024-T3 aluminum alloy of identical size and thickness were fabricated and tested, the results are presented in Table 3.4.2.4-3. The average residual strength parameter of 1.340 for aluminum alloy is essentially equivalent to the 1.394 value for Lockalloy, thus indicating comparable crack tolerance in the .25 inch thickness.

To provide a relative comparison of Be-38Al Lockalloy extruded material to sheet and plate material, duplicate specimens of extruded material (used in ventral fin trailing edge), identical in size and thickness, were machined, in both the "L" and "T" directions, and tested. The results are presented in Table 3.4.2.4-1.

The average value of $R_{sc} = 1.820$ for the extruded material in the longitudinal direction indicates a much better crack tolerance than sheet or plate material. However, the one R_{sc} value of .897 (although invalid per ASTM E399-72) obtained in the transverse direction implies the material may have poorer fracture toughness than exhibited by sheet or plate.

SPECIMEN I.D.	DIRECTION	CONDITION	TEST TEMP. °F	B IN.	P_{MAX} LBS.	a IN.	W IN.	F_{ty} KSI	R_{SC}
6FT-1L 6FT-3L	LONG	AS REC'D	ROOM	0.250 0.254	686 496	0.461 0.503	1.000 1.000	35.0 35.0 AVG.	1.328 1.160 1.244
6FT-1T 6FT-3T	TRANS	AS REC'D	ROOM	0.255 0.254	552 580	0.537 0.519	1.000 1.000	35.0 35.0 AVG.	1.464 1.503 1.484
6FT-7L 6FT-9L	LONG	SOAK 100 HRS AT 600°F	ROOM	0.254 0.254	542 583	0.517 0.516	1.001 1.001	35.0 35.0 AVG.	1.323 1.404 1.364
6FT-7T 6FT-9T	TRANS.	SOAK 100 HRS. AT 600°F	ROOM	0.255 0.255	580 606	0.532 0.517	1.000 1.000	35.0 35.0 AVG.	1.503 1.465 1.484
2024-T3 ALUMINUM									
1A 2A 3A	-	AS REC'D	ROOM	0.252 0.253 0.252	868 848 847	0.516 0.531 0.526	1.000 1.004 1.002	56.0 56.0 56.0 AVG.	1.321 1.357 1.342 1.340
*EXT-1L EXT-2L	LONG	AS REC 'D	ROOM	0.251 0.251	718 725	0.528 0.517	1.000 0.999	35.0 35.0 AVG.	1.856 1.785 1.820
EXT-1L EXT-2L	TRANS.	AS REC 'D	ROOM	0.250	318**	0.546	1.000	35.0	.897**
	OPERATOR ERROR - NO LOAD DISPLACEMENT CURVE OBTAINED								

*SHEET NO. HC 150-1

**FINAL PRECRACK LOAD >0.6 PQ, INVALID PER ASTM E399-72.

TABLE 3.4.2.--1. RESIDUAL STRENGTH PARAMETER FOR .250 INCH THICK Be-38Al ALLOY AT ROOM TEMPERATURE, WITH AND WITHOUT EXPOSURE TO 600°F FOR 100 HOURS

SPECIMEN I.D.	DIRECTION	CONDITION	TEST TEMP. °F	B IN.	P_{MAX} LBS.	a IN.	W IN.	F_{ty} KSI	R_{SC}
6FT-4L 6FT-6L	LONG	AS REC'D	600	0.255 0.254	400 410	0.514 0.510	0.999 1.000	25.0 25.0 AVG.	1.340 1.350 1.345
6FT-4T 6FT-6T	TRANS.	AS REC'D	600	0.254 0.254	422 415	0.512 0.534	1.001 1.001	25.0 25.0 AVG.	1.397 1.519 1.458
6FT-10L 6FT-12L	LONG	SOAK 100 HRS @ 600°F	600	0.255 0.253	397 395	0.513 0.510	1.000 1.001	25.0 25.0 AVG.	1.319 1.301 1.310
6FT-10T 6FT-12T	TRANS.	SOAK 100 HRS @ 600°F	600	0.255 0.255	488 418	0.517 0.510	0.999 1.000	25.0 25.0 AVG.	1.657 1.371 1.514

TABLE 3.4.2.4-2. RESIDUAL STRENGTH PARAMETER FOR .250 INCH THICK Be-38Al LOCKALLOY AT 600°F, WITH AND WITHOUT EXPOSURE TO 600°F FOR 100 HOURS

3.4.2.5 Fatigue Crack Growth Tests - Fatigue Crack Propagation Tests were conducted at the Lockheed Rye Canyon Facility using one (1) .25-inch thick compact tension specimen of the configuration shown on Page B-10 of the Appendix according to the requirements of ASTM E399-72.

All specimens were tested in a 100,000 lb. electro-hydraulic MTS closed loop test machine in laboratory air, at R = 0.1, and at a frequency of 20 Hz. An over-all-arrangement of the test setup for elevated temperature testing is shown in Figure 3.4.2.5-1. The same arrangement is used for room temperature tests with the exception that the furnace is raised up out of the way. Tests were conducted under constant load cycling conditions with the first 0.020 inch of crack growth eliminated from the analysis to avoid effects of the machined starter notch. Crack length measurements were made of both sides of the specimen using diametrically opposite traversing tool marker's microscopes accurate to 0.001 inch.

Elevated temperature tests were conducted by lowering a resistance furnace enclosing the test specimen. Temperature was controlled by a thermal controller using a thermocouple attached to the test specimen. Optical crack length measurements were again made through quartz view ports on both sides of the furnace. A close-up photograph of the setup is shown in Figure 3.4.2.5-2.

Data reduction was accomplished using the incremental slope method where:

$$\frac{da}{dN} \doteq \frac{\Delta a}{\Delta N} = \frac{a_{i+1} - a_i}{N_{i+1} - N_i}$$

A Lockheed developed computer program, "Compact Tension Program", was used to reduce the data, provide a computer tabulation of the data as presented in Tables 3.4.2.5-1 through 3.4.2.5-7, and print a graphical presentation of Log da/dN versus Log ΔK (noted as DELK on plot) as presented in Figures 3.4.2.5-5 through 3.4.2.5-11.

The alternating stress intensity factor, $\Delta K = K_{MAX} - K_{MIN}$, was determined using the expression* for the compact tension specimen

* ASTM E399-72.

$$\Delta K = \frac{\Delta P}{BW^{\frac{1}{2}}}\left[29.6\,\frac{a}{W}^{\frac{1}{2}} - 185.5\,\frac{a}{W}^{3/2} + 655.7\,\frac{a}{W}^{5/2} - 1017.0\,\frac{a}{W}^{7/2} + 638.9\,\frac{a}{W}^{9/2}\right]$$

Note that a newer form for the stress intensity factor has recently been proposed*, but for the range of crack lengths covered in this study ($0.3 \leq a/w \leq 0.65$), the difference is less than 1 percent between the two expressions as shown in Figure 3.4.2.5-3.

To provide a basis of comparison between the fatigue crack growth data for Lockalloy and other structural materials, fatigue crack propagation data for Ti-6Al-4V, 7075 and 2024 aluminum alloys were taken from the Damage Tolerance Handbook for range ratios of 0 to .1, room temperature in laboratory air, and frequencies of from 2 to 20 Hz. The data is presented in terms of normalized alternating stress intensity obtained by dividing the stress intensity by the material density. This provides a parameter which allows a comparison of the results for structural conditions involving a common crack size and operating structural efficiency (strength divided by density).

When the results of the current Lockalloy tests are compared on this basis as shown in Figure 3.4.2.5-4, the crack growth rates are shown to be slower or equivalent to those obtainable from either the aluminum or the titanium materials.

For example: For an assumed through crack size 0.2 inch long with center of a wide panel operating at a structural efficiency (strength to density ratio) of 200,000 inches, the crack growth rate in Lockalloy would be approximately 3×10^{-6} inches per cycle as compared to a typical growth rate in titanium or aluminum of approximately 2×10^{-5} inches per cycle. Thus, for the same size defect or crack in structural components made of various materials operating at equivalent structural efficiencies (strength to density ratio), Lockalloy will display a lower or equivalent crack growth rate then either the titanium or aluminum alloy.

---

* "A Digest of a Tentative Standard Method of Test for Fatigue Crack Growth Rate of Metallic Materials", ASTM E 4.04.01, Working Document, [illegible].

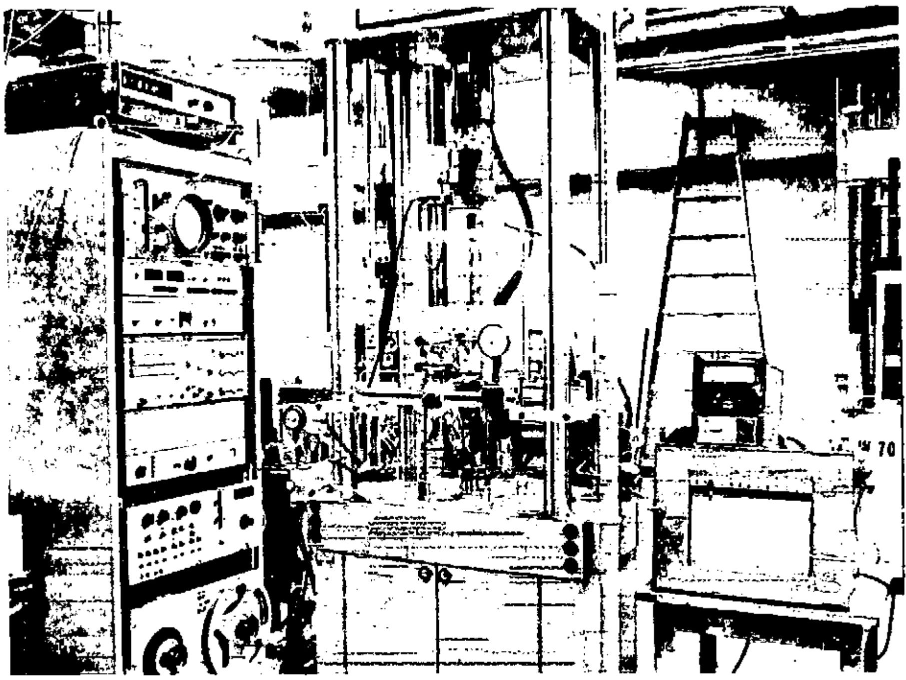
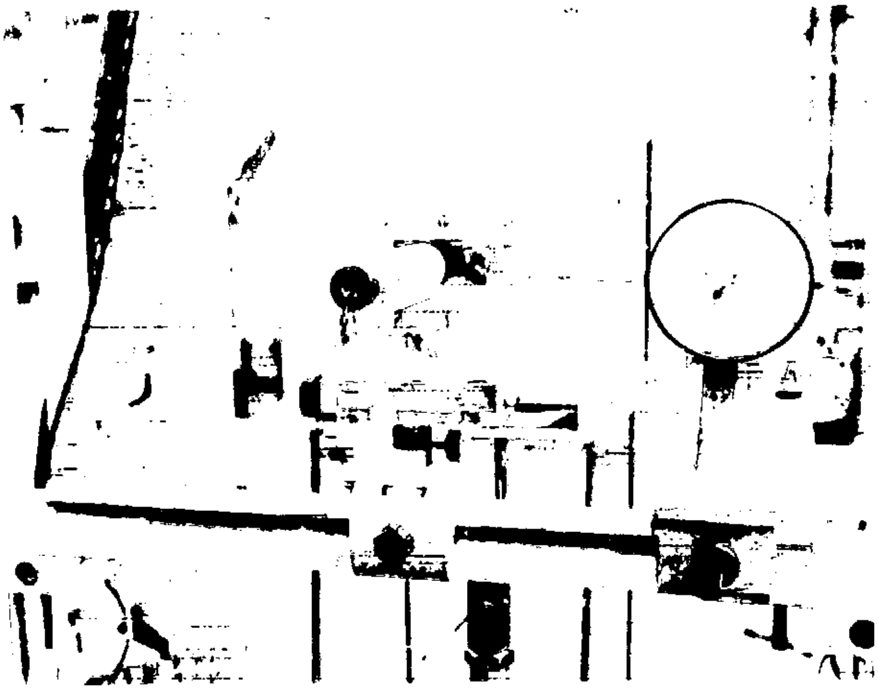


Fig. [illegible] – Overall Test Arrangement for Conducting
Elevated Temperature Fatigue Crack
Propagation Tests
(NOTE: For room temperature tests
furnace is rolled up out of
the way)



[illegible]

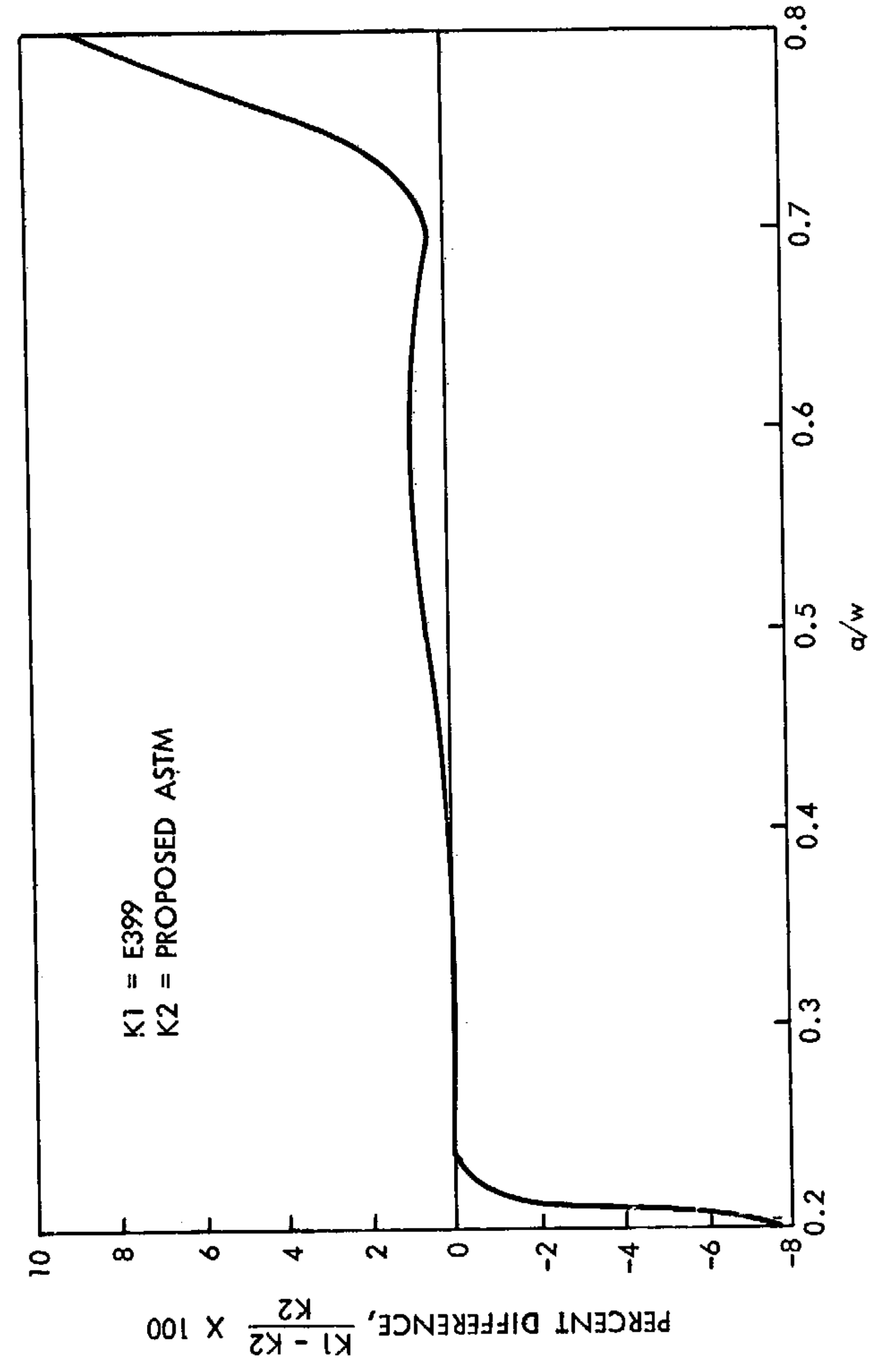


Figure 3.4.2.5-3 - Stress Intensity Factor Comparison

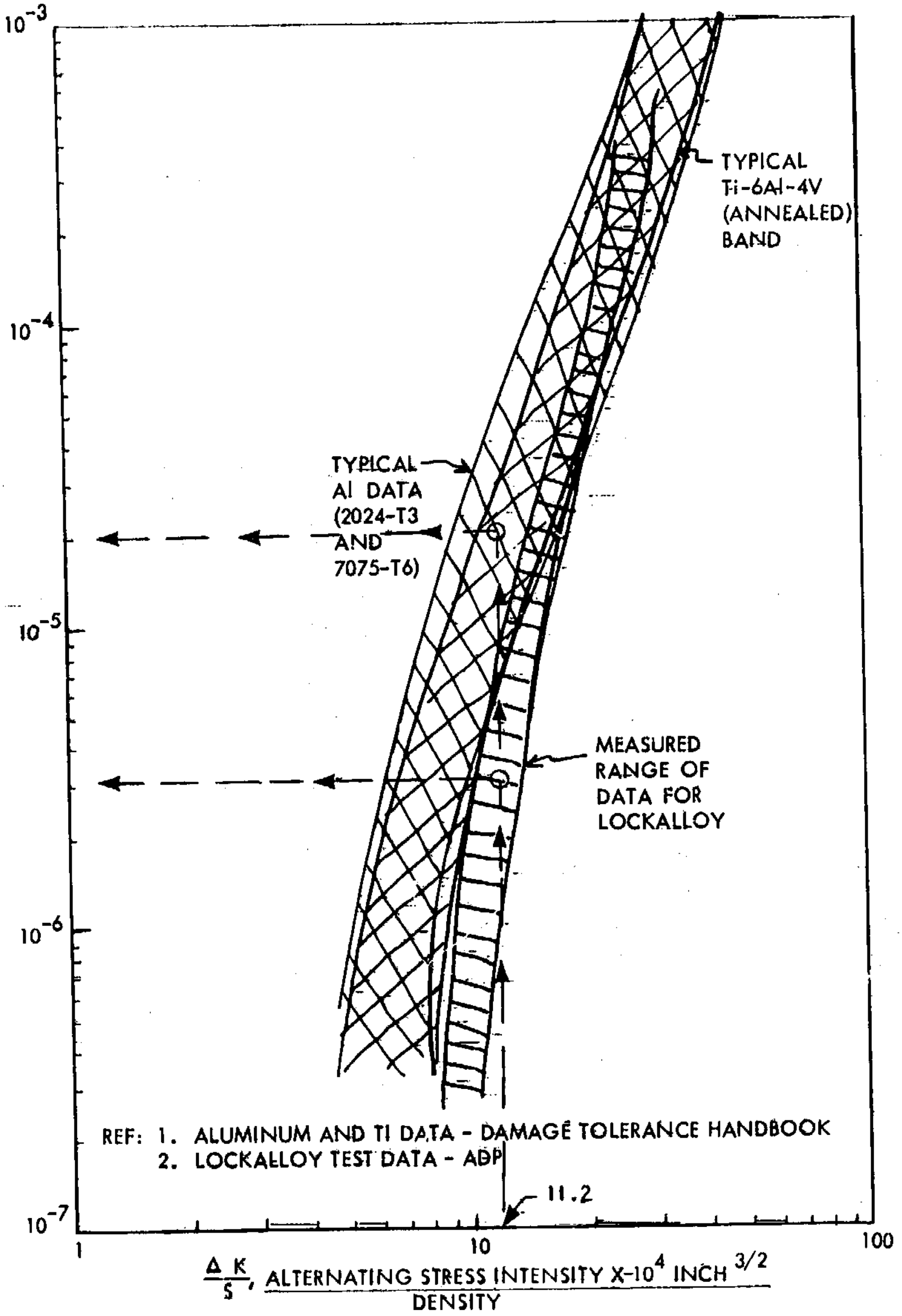


FIGURE 3.4.2.5-4. CRACK GROWTH RATE CHARACTERISTICS

C.

```
                                   C O M P A C T * T E N S I O N * P R O G R A M
(CT) SPEC.6FT.2L  LAB AIR                                                                  09:17 JAN 06.'76

    INPUT CONSTANTS:

        RANGE RATIO(R)              =     .1
        SPECIMEN WIDTH(W)           =    1.000
        SPECIMEN THICKNESS(B)       =     .254
        INITIAL CRACK LENGTH(AO)    =     .301
        TEST FREQUENCY(HZ)          =   20.0

NUMBER     MAXIMUM    SIDE 1     SIDE 2     AVERAGE    CHANGE IN    CHANGE       CRACK       ALTERNATING
  OF        LOAD       CRACK      CRACK      CRACK      CRACK        IN         GROWTH        STRESS
CYCLES                LENGTH     LENGTH     LENGTH     LENGTH       CYCLES        RATE        INTENSITY
                                                                               DA / DN
  N          P          A1         A2        ABAR        DA           DN        MICROINCH       DELK
x 1000      KIPS      INCHES     INCHES     INCHES     INCHES       x 1000     PER CYCLE      x 1000

40.000       .39       .329       .313       .321
                                                        .028        20.000        1.42          8.69
60.000       .39       .342       .357       .349
                                                        .014        10.000        1.45          9.12
70.000       .39       .352       .376       .364
                                                        .030        10.000        2.95          9.61
80.000       .39       .397       .390       .393
                                                        .026         5.000        5.30         10.29
85.000       .39       .428       .412       .420
                                                        .044         5.000        8.70         11.27
90.000       .39       .470       .457       .464
                                                        .039         2.000       19.50         12.63
92.000       .39       .489       .516       .502
```

TABLE 3.4.2.5-1 FATIGUE CRACK GROWTH RATE DATA OF SPECIMEN 6FT-2L AT ROOM TEMPERATURE - NO SOAK, LONGITUDINAL.

```
                                C O M P A C T * T E N S I O N * P R O G R A M
(CT) SPEC.6FT-2T  LAB AIR                                                                  09:17 JAN 06,'76

    INPUT CONSTANTS:

       RANGE RATIO(R)                =     .1
       SPECIMEN WIDTH(W)             =   1.002
       SPECIMEN THICKNESS(B)         =    .255
       INITIAL CRACK LENGTH(AO)      =    .301
       TEST FREQUENCY(HZ)            =   20.0

 NUMBER     MAXIMUM     SIDE 1      SIDE 2     AVERAGE     CHANGE IN     CHANGE        CRACK       ALTERNATING
   OF        LOAD        CRACK       CRACK      CRACK        CRACK          IN         GROWTH         STRESS
 CYCLES                 LENGTH      LENGTH     LENGTH       LENGTH       CYCLES         RATE        INTENSITY
                                                                                      DA / DN
   N           P          A1          A2        ABAR          DA            DN       MICROINCH        DELK
 X 1000       KIPS      INCHES      INCHES     INCHES       INCHES        X 1000     PER CYCLE       X 1000

 30.000        .39        .319        .313       .316
                                                             .012         30.000         .42           8.40
 60.000        .39        .331        .326       .328
                                                             .025         10.000        2.50           8.74
 70.000        .39        .353        .354       .353
                                                             .019         20.000         .97           9.20
 90.000        .39        .368        .378       .373
                                                             .018         10.000        1.80           9.62
100.000        .39        .371        .411       .391
                                                             .036         10.000        3.60          10.28
110.000        .39        .433        .421       .427
                                                             .051          5.000       10.30          11.52
115.000        .39        .496        .461       .479
```

TABLE 3.4.2.5-2 FATIGUE CRACK GROWTH RATE DATA OF SPECIMEN 6FT-2T AT ROOM TEMPERATURE - NO SOAK, TRANSVERSE.

```
                         C O M P A C T * T E N S I O N * P R O G R A M
(CT) SPEC.6FT-8L  LAB AIR  SY = 35,000                                         09117 JAN 06,'76

    INPUT CONSTANTS:

        RANGE RATIO(R)              =     .1
        SPECIMEN WIDTH(W)           =     .999
        SPECIMEN THICKNESS(B)       =     .253
        INITIAL CRACK LENGTH(AO)    =     .300
        TEST FREQUENCY(HZ)          =   20.0

NUMBER    MAXIMUM   SIDE 1    SIDE 2    AVERAGE   CHANGE IN   CHANGE     CRACK       ALTERNATING
  OF       LOAD      CRACK     CRACK     CRACK     CRACK       IN        GROWTH        STRESS
CYCLES              LENGTH    LENGTH    LENGTH    LENGTH     CYCLES      RATE       INTENSITY
                                                                        DA / DN
  N         P         A1        A2       ABAR        DA         DN     MICROINCH       DELK
X 1000     KIPS     INCHES    INCHES    INCHES     INCHES     X 1000   PER CYCLE      X 1000

10.000     .39       .310      .315      .313
                                                    .016      10.000      1.65          8.47
20.000     .39       .320      .338      .329
                                                    .021      10.000      2.10          8.81
30.000     .39       .350      .350      .350
                                                    .042      10.000      4.15          9.47
40.000     .39       .401      .382      .391
                                                    .016       2.000      8.25         10.17
42.000     .39       .423      .393      .408
                                                    .024       2.000     12.00         10.71
44.000     .39       .432      .432      .432
                                                    .024       3.000      8.00         11.40
47.000     .39       .455      .457      .456
                                                    .018       1.000     18.00         12.07
48.000     .39       .470      .478      .474
                                                    .037       1.000     36.50         13.05
49.000     .39       .499      .522      .510
                                                    .037        .300    123.33         14.61
49.300     .39       .550      .545      .547
```

TABLE 3.4.2.5-3 FATIGUE CRACK GROWTH RATE DATA OF SPECIMEN 6FT-8L AT ROOM TEMPERATURE AFTER 100 HOUR SOAK AT 600°F, LONGITUDINAL.

```
                              C O M P A C T * T E N S I O N * P R O G R A M
(CT) SPEC.6FT-8T  LAB AIR                                                             09:17 JAN 06.'76

    INPUT CONSTANTS:

        RANGE RATIO(R)             =     .1
        SPECIMEN WIDTH(W)          =   1.001
        SPECIMEN THICKNESS(B)      =    .255
        INITIAL CRACK LENGTH(AO)   =    .300
        TEST FREQUENCY(HZ)         =   20.0

NUMBER    MAXIMUM    SIDE 1    SIDE 2    AVERAGE    CHANGE IN    CHANGE       CRACK        ALTERNATING
  OF       LOAD      CRACK     CRACK     CRACK      CRACK          IN         GROWTH          STRESS
CYCLES               LENGTH    LENGTH    LENGTH     LENGTH       CYCLES        RATE         INTENSITY
                                                                              DA / DN
  N          P         A1        A2       ABAR        DA            DN       MICROINCH        DELK
X 1000     KIPS      INCHES    INCHES    INCHES     INCHES       X 1000      PER CYCLE       X 1000

20.000      .39       .320      .334      .327
                                                      .017       10.000        1.70            8.65
30.000      .39       .332      .356      .344
                                                      .019       10.000        1.95            9.01
40.000      .39       .355      .372      .363
                                                      .013       10.000        1.35            9.36
50.000      .39       .376      .378      .377
                                                      .021        8.000        2.56            9.75
58.000      .39       .405      .390      .397
                                                      .020        7.000        2.86           10.26
65.000      .39       .410      .425      .418
                                                      .020        4.700        4.26           10.80
69.700      .39       .438      .437      .438
                                                      .015        2.300        6.74           11.31
72.000      .39       .459      .447      .453
                                                      .030        2.380       12.82           12.04
74.380      .39       .494      .473      .484
                                                      .050        2.420       20.45           13.52
76.800      .39       .539      .527      .533
```

TABLE 3.4.2.5-4 FATIGUE CRACK GROWTH RATE DATA OF SPECIMEN 6FT-8T AT ROOM TEMPERATURE AFTER 100 HOUR SOAK AT 600°F, TRANSVERSE.

```
                        C O M P A C T * T E N S I O N * P R O G R A M
(CT) SPEC.6FT.5T   600 DEG.F.   SY = 25,000                                    09:17 JAN 06.'76

   INPUT CONSTANTS:

        RANGE RATIO(R)               =     .1
        SPECIMEN WIDTH(W)            =    1.000
        SPECIMEN THICKNESS(B)        =     .252
        INITIAL CRACK LENGTH(AO)     =     .000
        TEST FREQUENCY(HZ)           =   20.0

 NUMBER     MAXIMUM    SIDE 1    SIDE 2    AVERAGE    CHANGE IN    CHANGE      CRACK      ALTERNATING
   OF        LOAD      CRACK     CRACK     CRACK      CRACK        IN          GROWTH     STRESS
 CYCLES                LENGTH    LENGTH    LENGTH     LENGTH       CYCLES      RATE       INTENSITY
                                                                               DA / DN
   N          P         A1        A2        ABAR       DA           DN         MICROINCH    DELK
 X 1000      KIPS      INCHES    INCHES    INCHES     INCHES      X 1000      PER CYCLE   X 1000

 50.000      .26       .313      .349      .331
                                                      .020        20.000        1.00        5.90
 70.000      .26       .334      .368      .351
                                                      .012        30.000         .38        6.11
100.000      .26       .340      .385      .362
                                                      .023        20.000        1.13        6.36
120.000      .26       .369      .401      .385
                                                      .026        30.000         .87        6.75
150.000      .26       .389      .433      .411
                                                      .020        20.000        1.00        7.16
170.000      .26       .408      .454      .431
                                                      .020        15.000        1.30        7.54
185.000      .26       .421      .480      .451
                                                      .027        15.000        1.80    [illegible].03
200.000      .26       .445      .510      .477
                                                      .027         6.000        4.58        8.67
206.000      .26       .480      .530      .505
                                                      .017         4.000        4.25        9.27
210.000      .26       .496      .548      .522
                                                      .016         4.000        4.00        9.77
214.000      .26       .512      .564      .538
                                                      .024         2.000       12.00       10.44
216.000      .26       .536      .588      .562
```

TABLE 3.4.2.5-5 FATIGUE CRACK GROWTH RATE DATA FOR SPECIMEN 6FT-5T AT 600°F - NO SOAK, TRANSVERSE.

```
                              C O M P A C T * T E N S I O N * P R O G R A M
(CT) SPEC.6FT-11L  600 DEG.F.                                                                    09:17 JAN 06,176

     INPUT CONSTANTS:

         RANGE RATIO(R)              =      .1
         SPECIMEN WIDTH(W)           =    1.002
         SPECIMEN THICKNESS(B)       =     .253
         INITIAL CRACK LENGTH(AO)    =     .000
         TEST FREQUENCY(HZ)          =    20.0

 NUMBER     MAXIMUM    SIDE 1     SIDE 2     AVERAGE     CHANGE IN    CHANGE        CRACK       ALTERNATING
   OF        LOAD      CRACK      CRACK      CRACK        CRACK         IN          GROWTH         STRESS
 CYCLES                LENGTH     LENGTH     LENGTH       LENGTH      CYCLES         RATE        INTENSITY
                                                                                   DA / DN
   N          P          A1         A2        ABAR          DA          DN        MICROINCH        DELK
 X 1000      KIPS      INCHES     INCHES     INCHES       INCHES      X 1000      PER CYCLE       X 1000

  70.000      .26       .328       .335       .331
                                                          .020       30.000          .65          5.88
 100.000      .26       .356       .346       .351
                                                          .020       30.000          .67          6.15
 130.000      .26       .381       .361       .371
                                                          .023       20.000         1.15          6.47
 150.000      .26       .408       .380       .394
                                                          .025       20.000         1.22          6.86
 170.000      .26       .435       .402       .419
                                                          .023       15.000         1.53          7.29
 185.000      .26       .463       .420       .442
                                                          .023       10.000         2.30          7.75
 195.000      .26       .481       .448       .465
                                                          .023        9.000         2.61          8.26
 204.000      .26       .508       .468       .488
                                                          .033        8.000         4.12          8.97
 212.000      .26       .540       .502       .521
                                                          .016        3.000         5.33          9.67
 215.000      .26       .555       .519       .537
                                                          .030        3.000        10.00         10.44
 218.000      .26       .584       .550       .567
                                                          .020         .400        50.00         11.41
 218.400      .26       .604       .570       .587
                                                          .015         .200        74.99         12.19
 218.600      .26       .615       .589       .602
                                                          .017         .200        85.00         12.99
 218.800      .26       .636       .602       .619
```

TABLE 3.4.2.5-6 FATIGUE CRACK GROWTH RATE DATA FOR SPECIMEN 6FT-11L AT 600°F AFTER 100 HOUR SOAK AT 600°F, LONGITUDINAL

```
                               C O M P A C T * T E N S I O N * P R O G R A M
(CT) SPEC.6FT.11T  600 DEG.F.                                                     09:17 JAN 06,'76

    INPUT CONSTANTS:

        RANGE RATIO(R)              =     .1
        SPECIMEN WIDTH(W)           =   1.003
        SPECIMEN THICKNESS(B)       =    .252
        INITIAL CRACK LENGTH(AO)    =    .000
        TEST FREQUENCY(HZ)          =   20.0

 NUMBER     MAXIMUM    SIDE 1    SIDE 2    AVERAGE    CHANGE IN   CHANGE      CRACK     ALTERNATING
   OF        LOAD      CRACK     CRACK     CRACK       CRACK        IN        GROWTH       STRESS
 CYCLES                LENGTH    LENGTH    LENGTH      LENGTH     CYCLES       RATE       INTENSITY
                                                                              DA / DN
   N           P         A1        A2       ABAR         DA         DN      MICROINCH      DELK
 X 1000       KIPS     INCHES    INCHES    INCHES      INCHES     X 1000    PER CYCLE     X 1000

125.000       .26       .434      .406      .420
                                                        .021      15.000       1.40         7.32
140.000       .26       .456      .426      .441
                                                        .025      10.000       2.45         7.77
150.000       .26       .473      .458      .465
                                                        .016       8.000       1.94         8.21
158.000       .26       .494      .468      .481
                                                        .026       8.000       3.31         6.72
166.000       .26       .521      .494      .507
                                                        .032       6.000       5.42         9.53
172.000       .26       .551      .529      .540
                                                        .018       2.000       9.25        10.36
174.000       .26       .572      .545      .558
                                                        .036       2.000      18.00        11.40
176.000       .26       .607      .582      .594
                                                        .025        .500      51.00        12.83
176.500       .26       .632      .608      .620
```

TABLE 3.4.2.5-7 FATIGUE CRACK GROWTH RATE DATA OF SPECIMEN 6FT-11T AT 600°F AFTER 100 HOUR SOAK AT 600°F, TRANSVERSE.

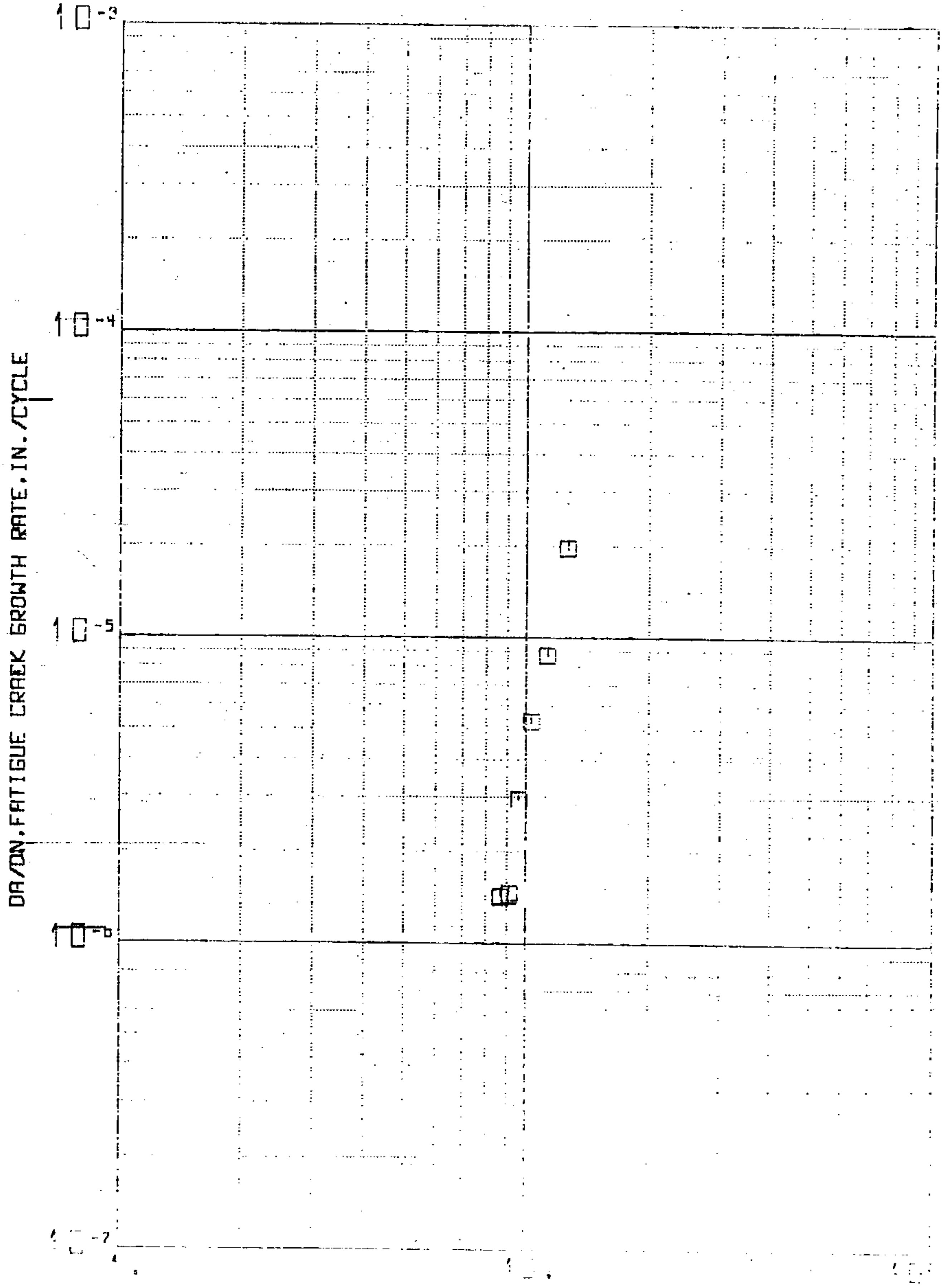


Figure 3.4.2.5-5 FATIGUE CRACK GROWTH RATE OF SPECIMEN 6FT-2L AT ROOM TEMPERATURE - NO SOAK, LONGITUDINAL.

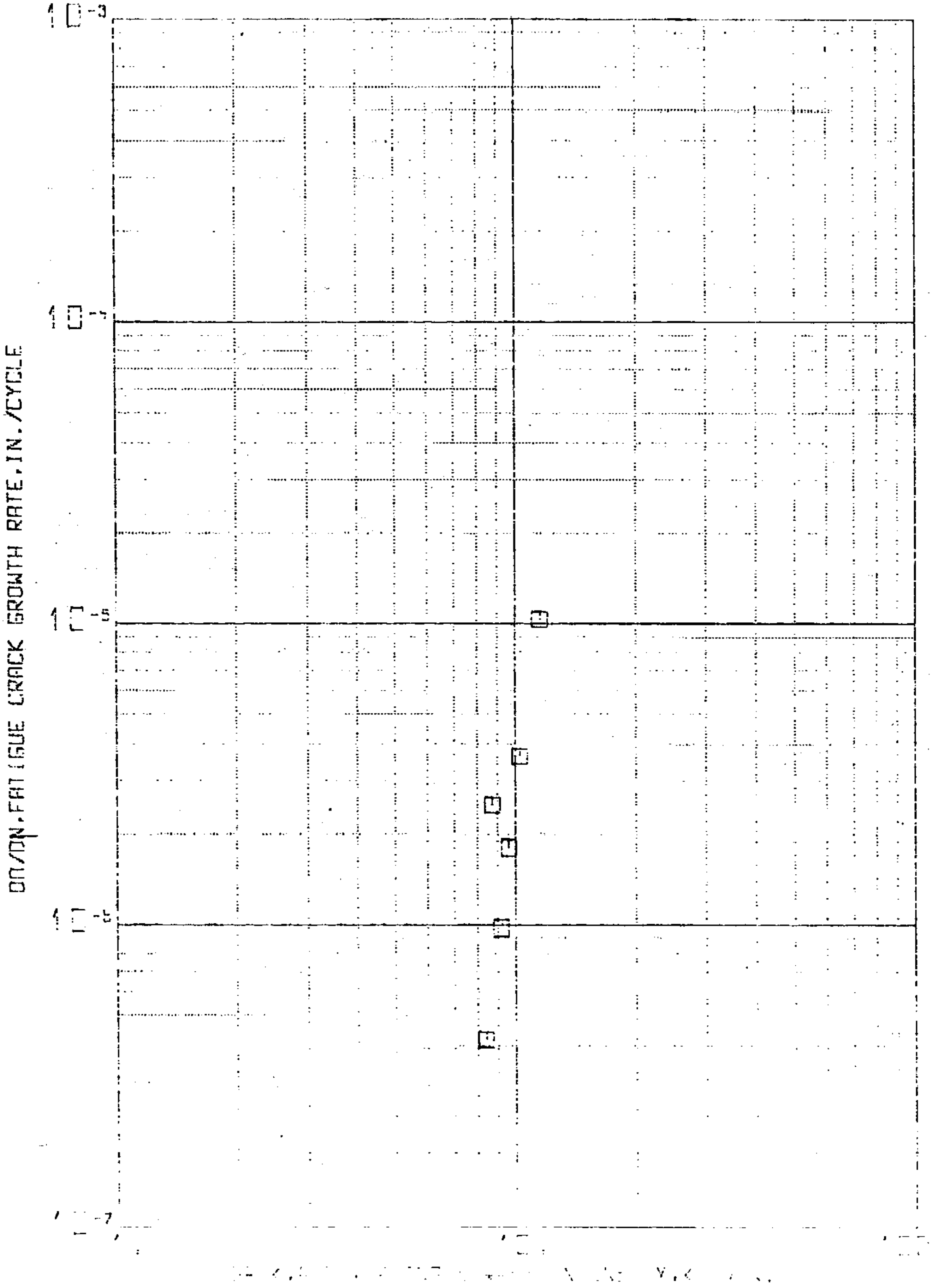


FIGURE 3.4.2.5-6 FATIGUE CRACK GROWTH RATE OF SPECIMEN 6FT-2T AT ROOM TEMPERATUE - NO SOAK, TRANSVERSE.

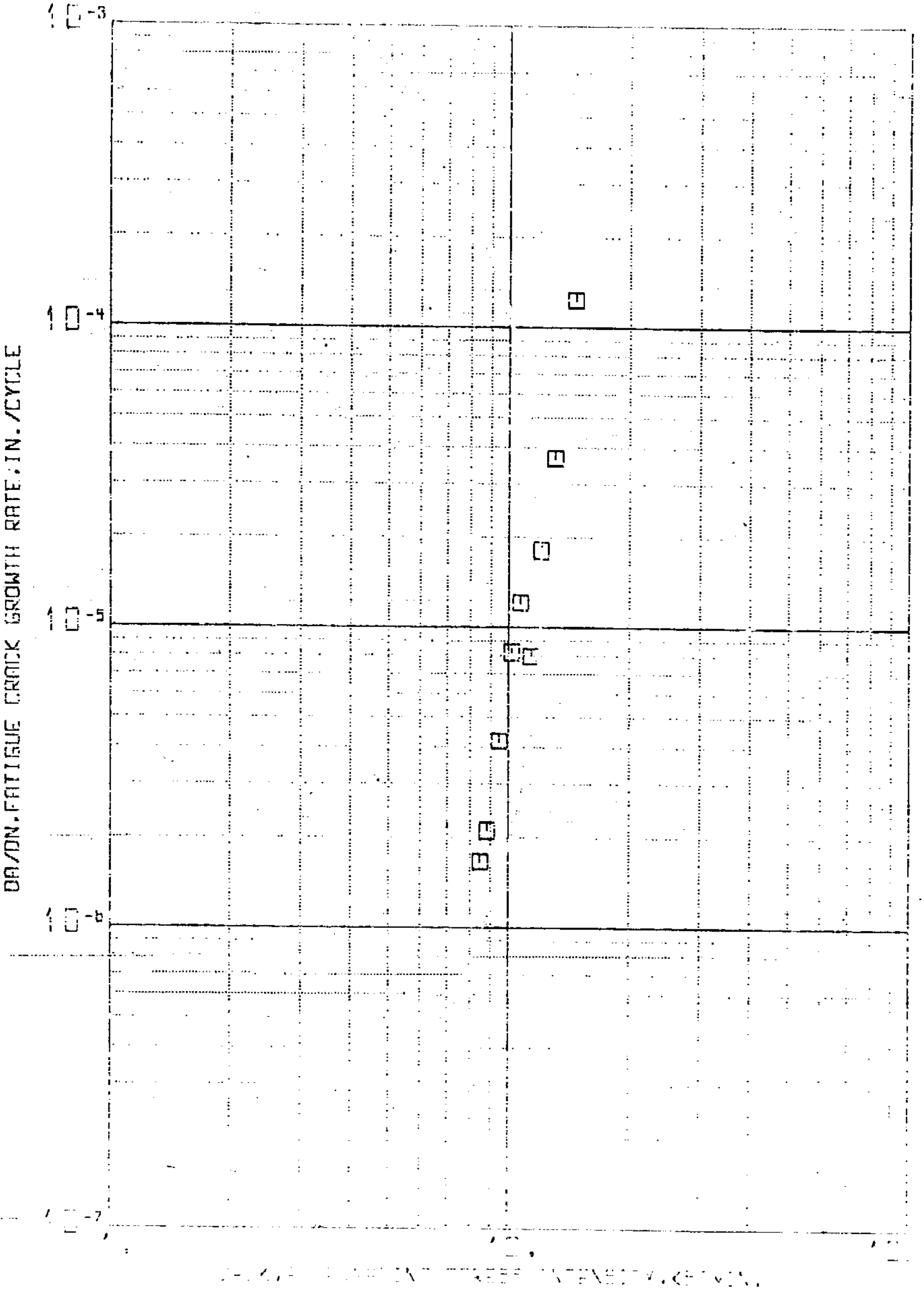


FIGURE 3.4.2.5-7 FATIGUE CRACK GROWTH RATE OF SPECIMEN 6FT-8L AT ROOM TEMPERATURE AFTER 100 HOUR SOAK AT 600°F, LONGITUDINAL

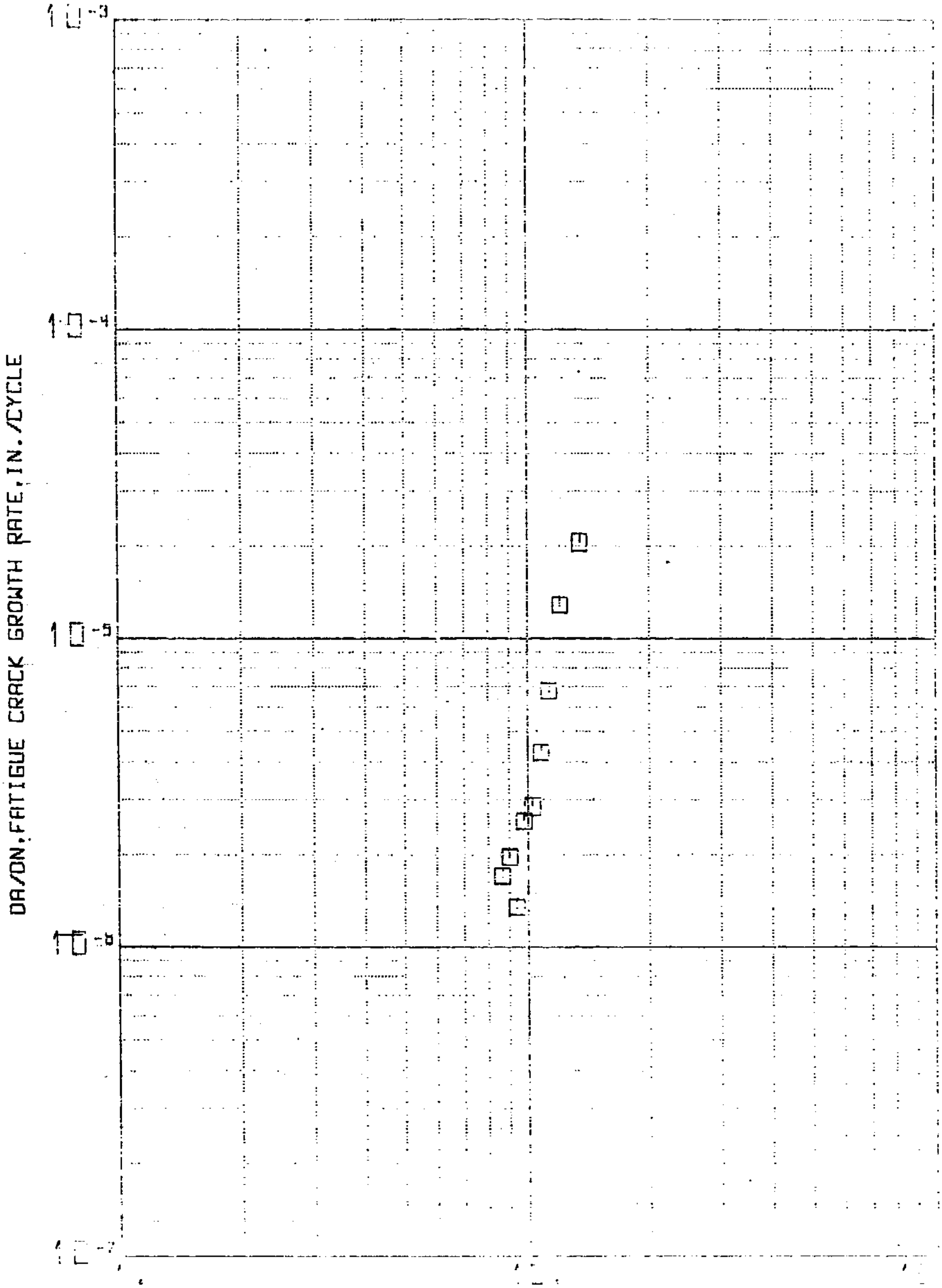


FIGURE 3.4.2.5-8 FATIGUE CRACK GROWTH RATE OF SPECIMEN GFT-8T AT ROOM TEMPERATURE AFTER 100 HOUR SOAK AT 600°F, TRANSVERSE.

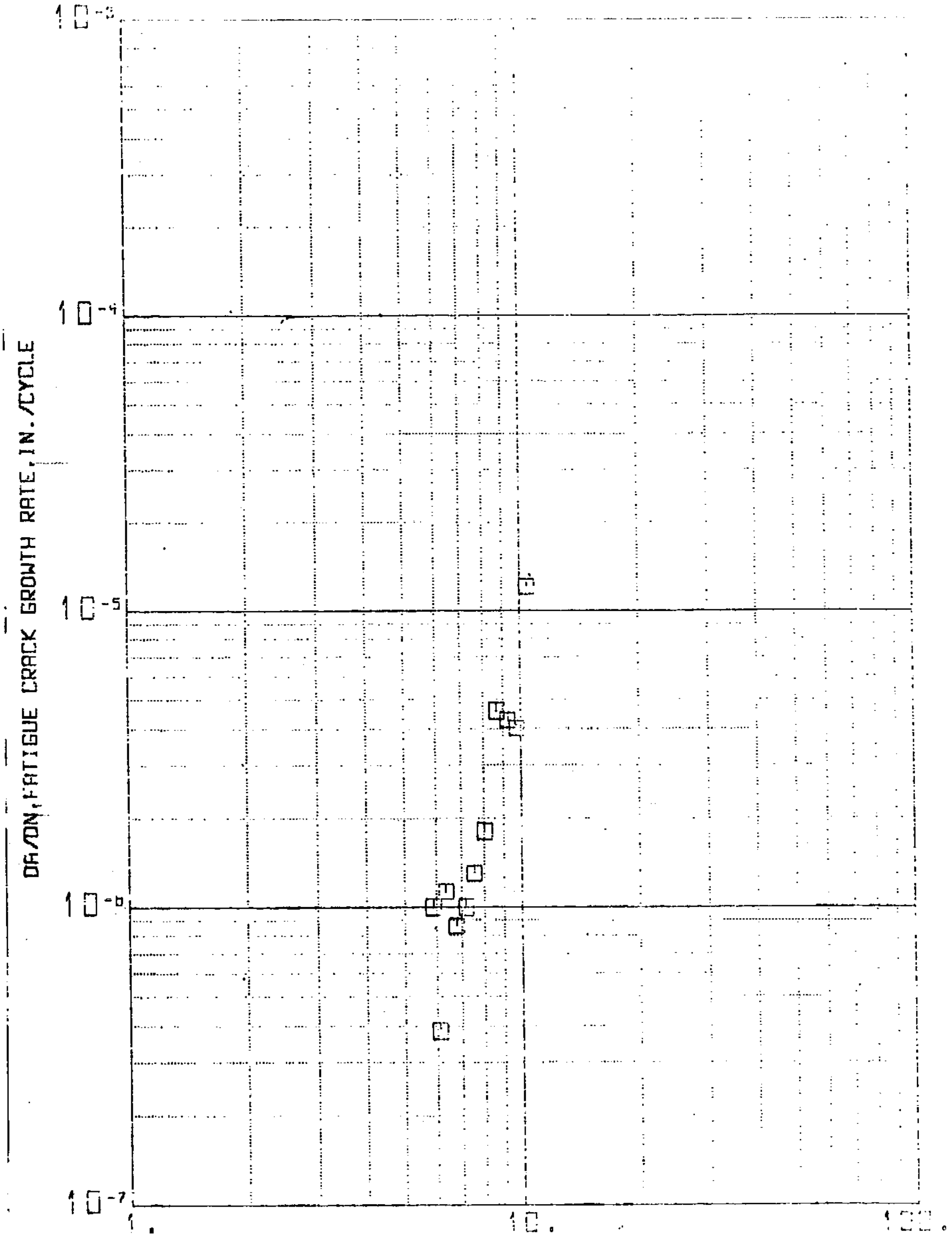


FIGURE 3.4.2.5-9 FATIGUE CRACK GROWTH RATE OF SPECIMEN 6FT-5T AT 600°F - NO SOAK, TRANSVERSE.

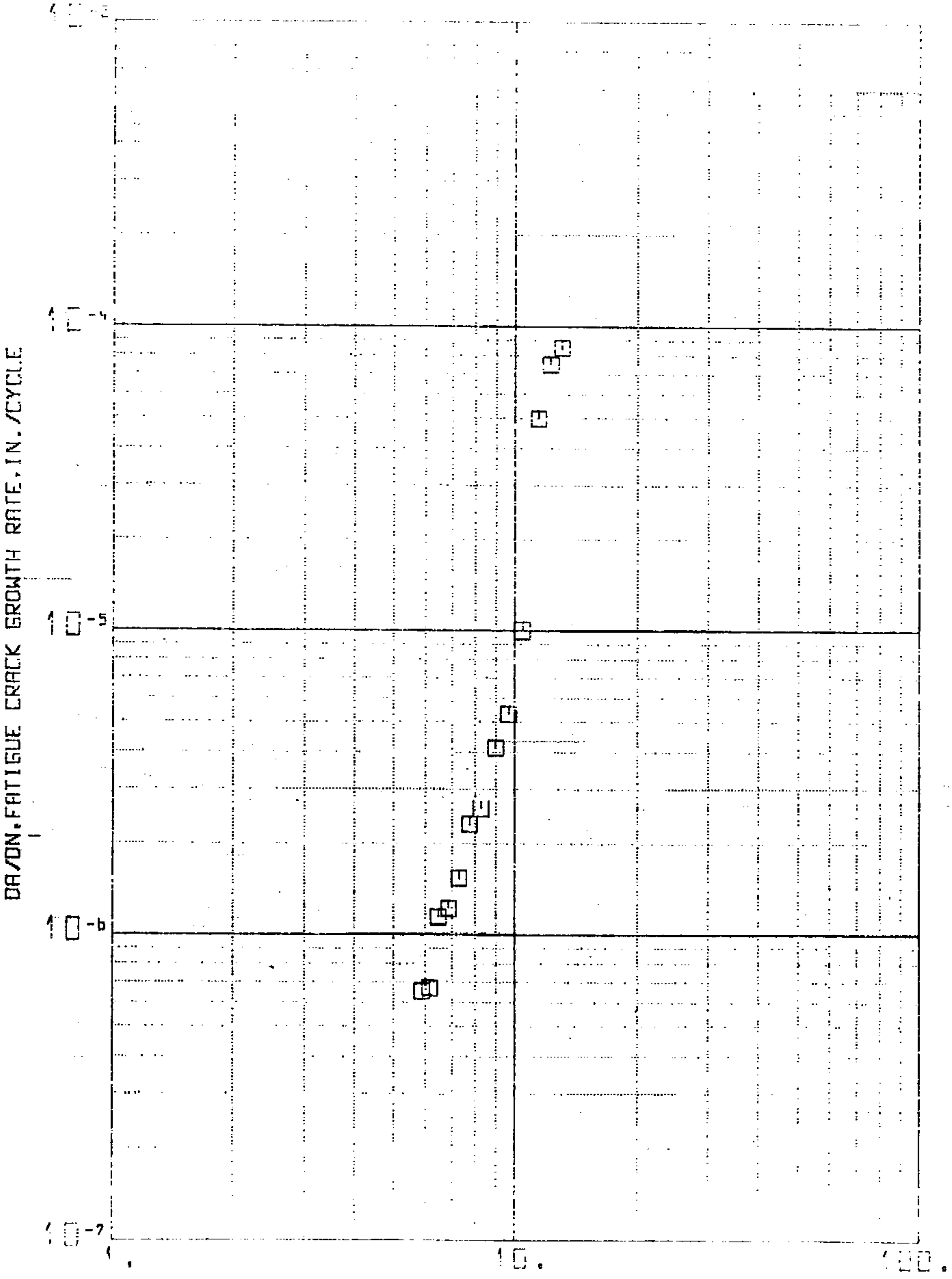


FIGURE 3.4.2.5-10 FATIGUE CRACK GROWTH RATE OF SPECIMEN 6FT-11L AT 600°F AFTER 100 HOUR SOAK AT 600°F, LONGITUDINAL.

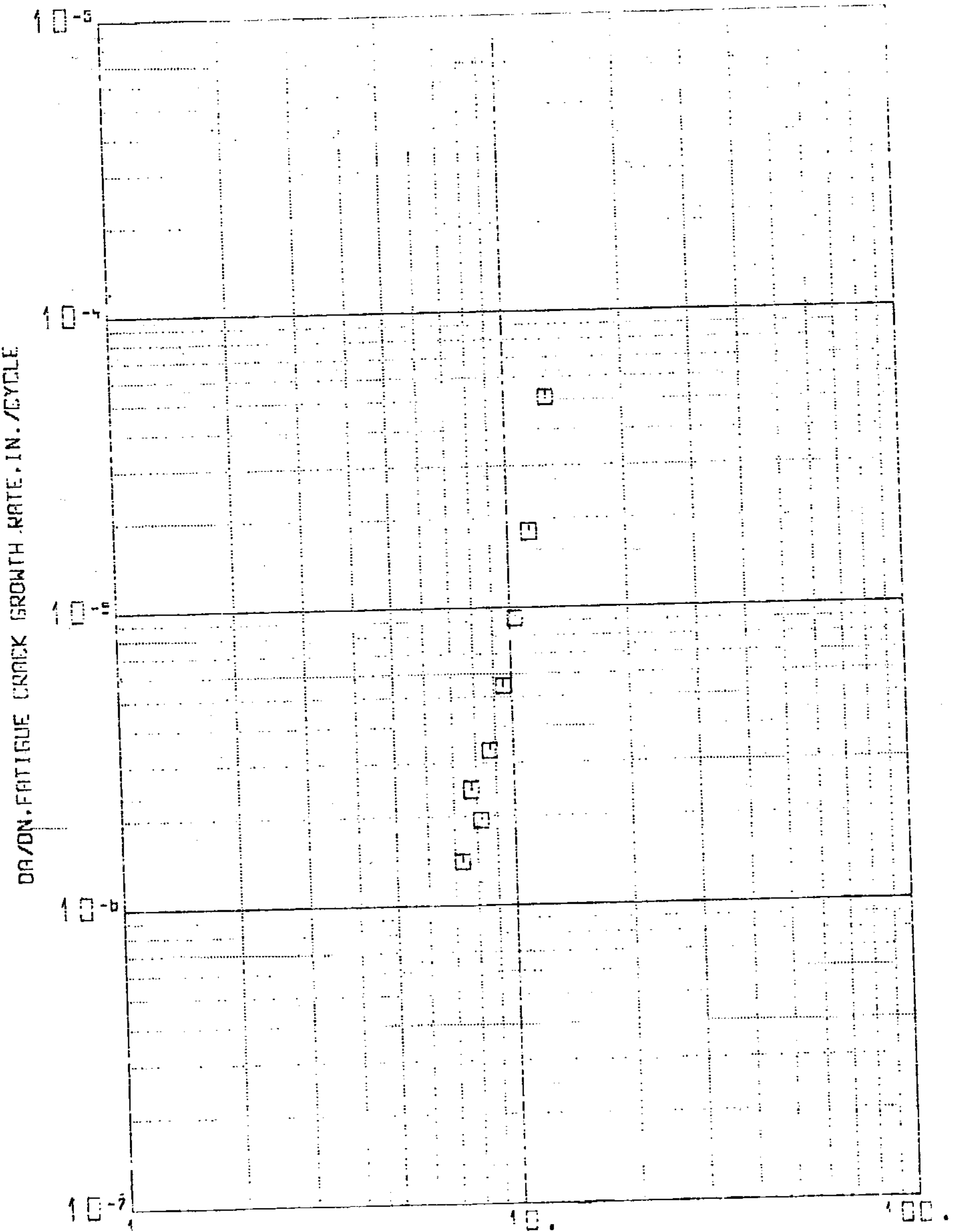


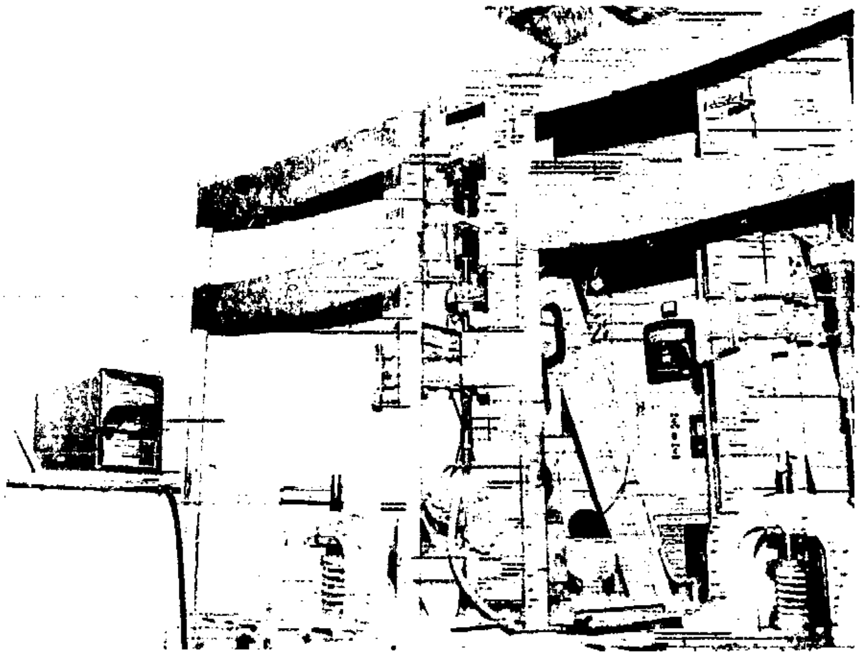
FIGURE 3.4.2.5-11 FATIGUE CRACK GROWTH RATE OF SPECIMEN 6FT-11T AT 600°F AFTER 100 HOUR SOAK AT 600°F, TRANSVERSE.

3.4.2.6 Fatigue Endurance Tests - Fatigue endurance limit tests were conducted at the Lockheed Rye Canyon Test Facility.

Fatigue tests were conducted in a 10,000 lb. Lockheed designed constant amplitude resonant fatigue machine as shown in Fig. 3.4.2.6-1 at frequencies of from 1800 to 2300 CPM. Both $K_T = 1$ and $K_T = 3$ fatigue specimens of the configuration shown on pages B-5 and B-13 of the Appendix were tested in the longitudinal direction at room temperature and 600°F, with and without exposure to 600°F for 100 hours. A close-up photograph of an installed specimen ready for testing at room temperature is shown in Fig. 3.4.2.6-2. Load cell size was selected based on the maximum load of the tests to assure maximum load accuracy during the tests. All tests were conducted at a range ratio, R = 0.1 until failure or until 10^7 cycles were reached at which time the test was terminated. Cycle count was monitored by measuring the test frequency of the loading beam with a Frahm Tachometer and multiplying the cycles per minute by the test time as recorded on a real time totalizer (accurate to 0.1 minute) attached to the test machine. Loads were monitored by an electronic digital fatigue load monitor attached to the load cell located in line with the test specimens. The instrumentation control panel for monitoring four resonant fatigue machines simultaneously is shown in Fig. 3.4.2.6-3.

Elevated temperature control was maintained by use of radiant heat furnaces placed around the specimen and grips of the machine as shown in Fig. 3.4.2.6-4. Specimens were heated to 600°F and stabilized for 15 minutes prior to testing. A thermocouple attached to the specimen and a thermal temperature control maintained the temperature at 600 ± 3°F during the test. A record of temperature was made on a 12 channel Brown recorder.

The endurance limit test results for $K_T = 1$ specimens are presented in Table 3.4.2.6-1 and the $K_T = 3$ specimens are presented in Table 3.4.2.6-2. Based on these results the endurance limit for $K_T = 1$ specimens at room temperature, with or without exposure to $600^{\circ}F$ for 100 hours is 30 KSI and at $600^{\circ}F$, with or without exposure to $600^{\circ}F$ for 100 hours, is 15 KSI. For $K_T = 3$ specimens the endurance limits for room temperature and $600^{\circ}F$, with or without exposure to $600^{\circ}F$ for 100 hours are 15 KSI and 10 KSI, respectively.

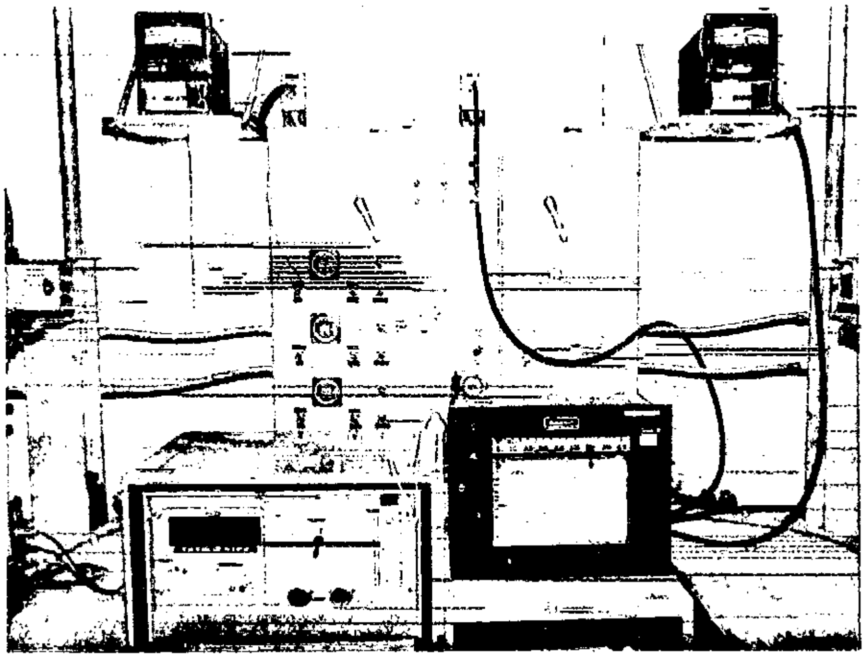


75-5402-4

Fig. 3.4.2.6-1 - Lockheed Designed and Built 10,000 lb. Resonant Type Fatigue Machine.

75-5402-3

Fig. 3.4.2.6-2 - Close-Up View of Specimen Installed [illegible]
[illegible]



75-5402-6

Fig. 3.4.2.6-3 - Instrumentation Control Panel for Monitoring Four Resonant Fatigue Machines.

75-5402-5

Fig. 3.4.2.6-4 - [illegible] [illegible] [illegible] Axial [illegible] and Grips for [illegible] [illegible] Temperature Testing.

SPECIMEN I.D.	CONDITION	TEST TEMP. °F	MAXIMUM STRESS - KSI	CYCLES TO FAILURE N
6UF-1L	AS RECEIVED	ROOM	30	10^7 N.F.
-2L			35	298,200
-3L			32.5	551,000
6UF-7L	SOAKED 100 HRS AT 600°F	ROOM	30	10^7 N.F.
-8L			32.5	216,000
-9L			31.0	1,484,000
6UF-4L	AS RECEIVED	600	20	164,900
-5L			20	1,721,000 *
-6L			15	10^7 N.F.
6UF-10L	SOAKED 100 HRS AT 600°F	600	20	1,164,000
-11L			15	10^7 N.F.
-12L			17.5	10^7 N.F.

* MISLOADED - 15 KSI CALLED OUT
N.F. - NO FAILURE
REF. - 538896

TABLE 3.4.[illegible]-1. FATIGUE ENDURANCE LIMIT TEST RESULTS OF .250 INCH THICK Be-38Al LOCKALLOY AT ROOM TEMPERATURE AND 600°F, WITH AND WITHOUT EXPOSURE TO 600°F FOR 100 HOURS. $K_t = 1$

SPECIMEN I.D.	CONDITION	TEST TEMP. °F	MAXIMUM STRESS - KSI	CYCLES TO FAILURE N
6NF-1L -2L -3L	AS RECEIVED	ROOM	20 15 35	1,135,000 10^7 N.F. 1,200 *
6NF-7L -8L -9L	SOAKED 100 HRS AT 600°F	ROOM	15 20 25	10^7 N.F. 10^7 N.F. 57,900
6NF-4L -5L -6L	AS RECEIVED	600	10 15 15	10^7 N.F. ** 1,012,245
6NF-10L -11L -12L	SOAKED 100 HRS AT 600°F	600	15 12.5 10	1,615,800 2,627,800 10^7 N.F.

* ERRONEOUSLY LOADED 2 TIMES AS ACTUALLY INTENDED - SHOULD HAVE BEEN 17.5 KSI
** MACHINE MALFUNCTIONED - TEST INVALID
N.F. - NO FAILURE
REF. - R.N. PAGES 538896

TABLE 3.4.2.6-2. FATIGUE ENDURANCE LIMIT TEST RESULTS OF .250 INCH THICK Be-38Al LOCKALLOY AT ROOM TEMPERATURE AND 600°F, WITH AND WITHOUT EXPOSURE TO 600°F FOR 100 HOURS. $K_t = 3$.

3.4.2.7 Stress Corrosion Tests - Stress corrosion tests were conducted at the Rye Canyon test facility of Lockheed utilizing the Satec Creep Rupture Test Machines shown in Figure 3.4.2.7-1.

Specimens of the configuration shown on page B-9 of the Appendix were machined from the .250 inch thick Be-38Al alloy plate in the transverse direction. Triplicate specimens for both room and 600°F testing were coated with 3.5 percent salt solution and allowed to dry over each of the following coatings.

1) As received

2) Chemical conversion coating (Alodine 1200)

3) ADP developed high temperature aluminized paint

The room temperature specimens were to be dead weight loaded in the Satec Creep Machines so as to produce a 35 KSI stress on the net section and for the 600°F tests utilize a stress level so as to not fail by creep before 100 hours of loading. Exposure times of 10, 50, and 100 hours were used prior to unloading and examining the specimens for evidence of cracking.

For the elevated temperature tests, a thermocouple was attached to the specimen and a Satec Resistance Furnace placed over the specimen. Specimen temperature was stabilized at 600°F and the test load applied. Temperature was maintained at 600° ± 3°F throughout the test duration by a Barber Coleman Capacitrol #477 Temperature Control. A continuous record of the temperature was made on a 24 channel Barber Coleman Recorder as shown in Figure 3.4.2.7-2.

The stress corrosion test results are presented in Table 3.4.2.7-1. Although none of the specimens failed by stress corrosion cracking, specimen numbers 6SC-2T, 6SC-13T, and 6SC-14T failed during testing and so were submitted for electron microscope fractographic studies to determine cause of failure.

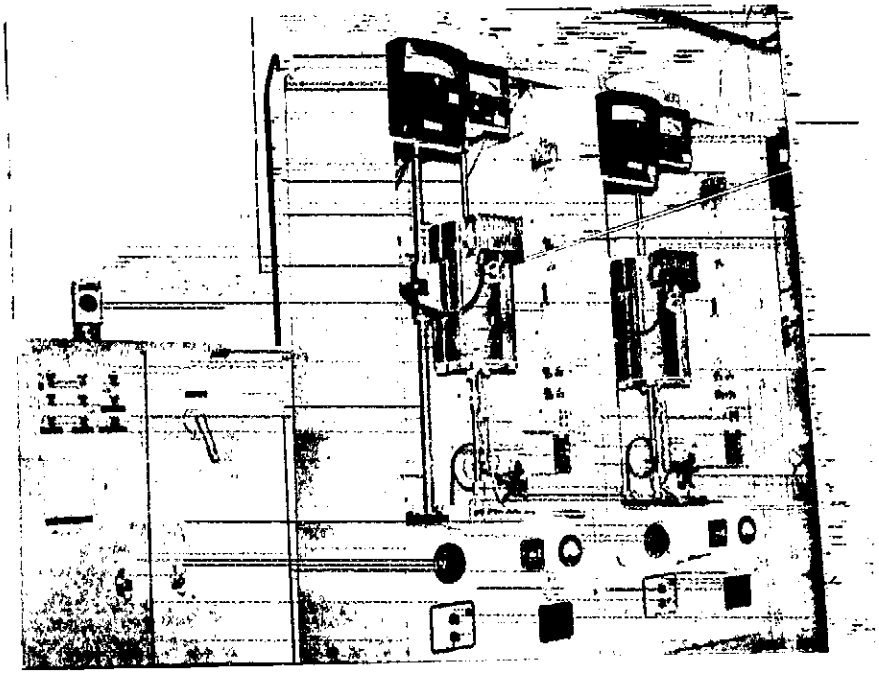


Fig. 3.4.2.7-1 - Satec Creep Rupture Test Machines Used for Stress Corrosion Testing.

Fig. 3.4.2.7-2 - Temperature Recorders for Banks of Satec Creep Rupture Machines.

SPECIMEN I.S.	CONDITION	TEST TEMP. °F	TEST STRESS - KSI	HOURS UNDER STRESS
6SC-2T -3T -5T	BARE + 3.5% SALT	ROOM	43.75 * 37.5 43.75 *	23.4 FAILED 114.3 N.F. 121.9 N.F.
6SC-1T -4T -6T		600	7.5 10.0 9.0	143.6 N.F. 140.8 N.F. 103.1 N.F.
6SC-7T -8T -9T	ALODINE COAT + 3.5% SALT	ROOM	43.75 * 43.75 * 43.75 *	138.5 N.F. 50.0 N.F. 16.3 N.F.
6SC-10T -11T -12T		600	10.0 10.0 10.0	50.0 N.F. 100.7 N.F. 10.5 N.F.
6SC-13T -14T -15T	PAINT + 3.5% SALT	ROOM	43.75 * 43.75 * 43.75 *	47.0 FAILED 89.1 FAILED 16.3 N.F.
6SC-16T -17T -18T		600	10.0 10.0 10.0	100.0 N.F. 121.5 N.F. 57.0 N.F.

* INADVERTENTLY OVERLOADED USING INCORRECT LEVER ARM - USED 20 INCHES RATHER THAN 16 INCHES
N.F - NO FAILURE
REF. - R.N. PAGE 538894

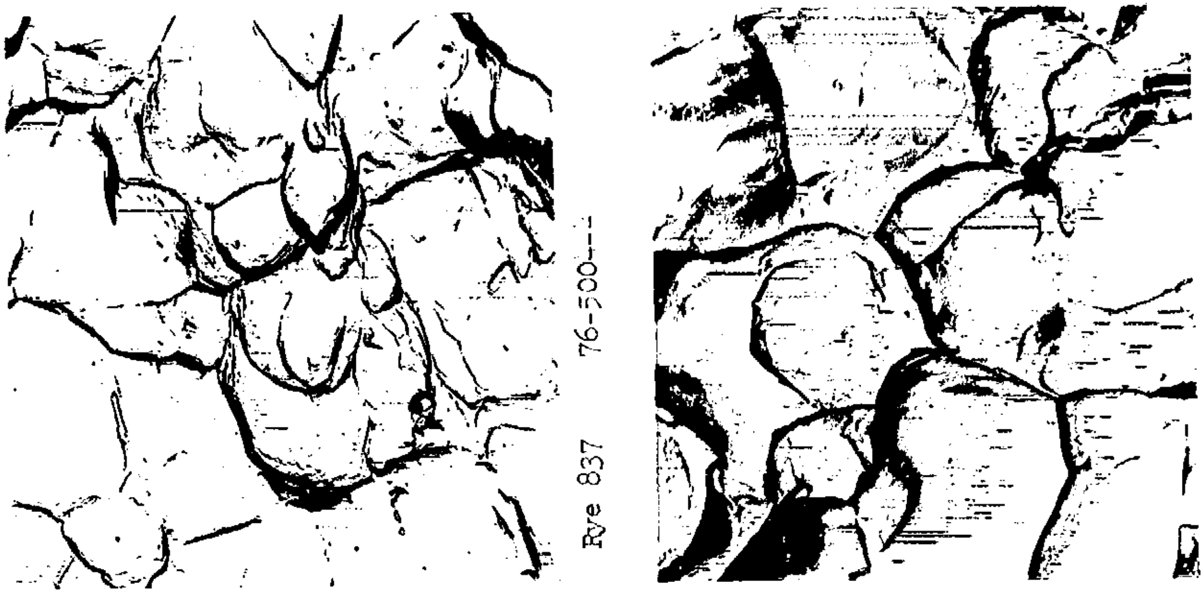
TABLE [illegible]-1. STRESS CORROSION TEST RESULTS OF .250 INCH THICK Be-38%Al LOCKALLOY AT ROOM TEMPERATURE AND 600°F, IN THE TRANSVERSE DIRECTION.

Three failed stress-corrosion (SCC) specimens and one tensile test specimen were submitted for electron microscope fractographic studies. These specimens were machined from Lockalloy, Be-38Al, 0.25 inch thick, sheet No. HC 160-1. The samples were identified as shown below:

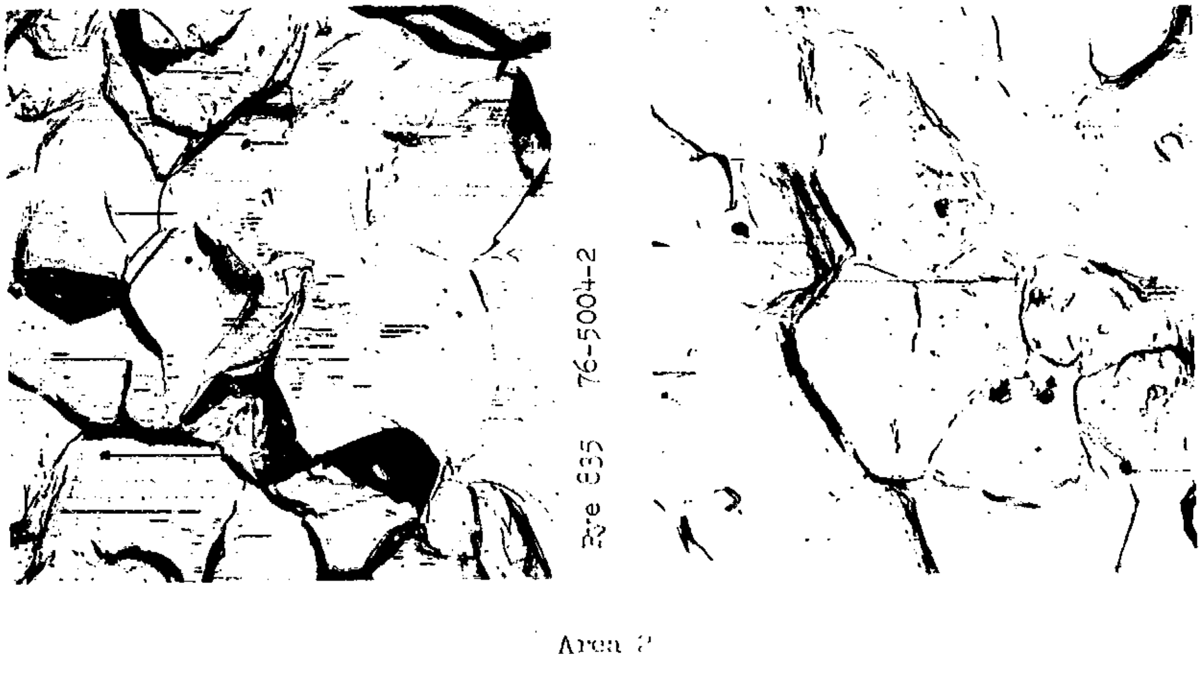
Specimen No.	Type of Test	Test Stress KSI	Time to Failure Hrs.	Coating	Apparent Location of Failure Origin
6SC-2T	SCC	43.7	23.4	Bare	At a depression on the corner of the coupon
6SC-13T	SCC	43.7	47.0	Paint	At center of coupon
6SC-14T	SCC	43.7	89.1	Paint	At center of coupon

Tensile Specimen	Ultimate	Yield	Elong.
3NAS 766-1-3T	49.7 KSI	33.2 KSI	13%

Two-stage plastic/carbon replicas were made of the fracture origin regions (Area 1) and of a region away from the fracture origin (Area 2). Examination of these replicas showed that all of the specimens exhibited a similar fracture pattern, i.e., the fracture features on the stress-corrosion specimens were similar to those on the tensile coupon. The fractures did not appear to be characteristic for stress corrosion failures. Thus, it appeared that the failures in the submitted stress corrosion specimens were caused by overload; or they possibly may have been caused by creep mechanisms, in view of the high applied load (greater than the yield stress) and the delayed nature of the failure. Figures 3.4.2.7-3 through 3.4.2.7-6 show the fractographs.

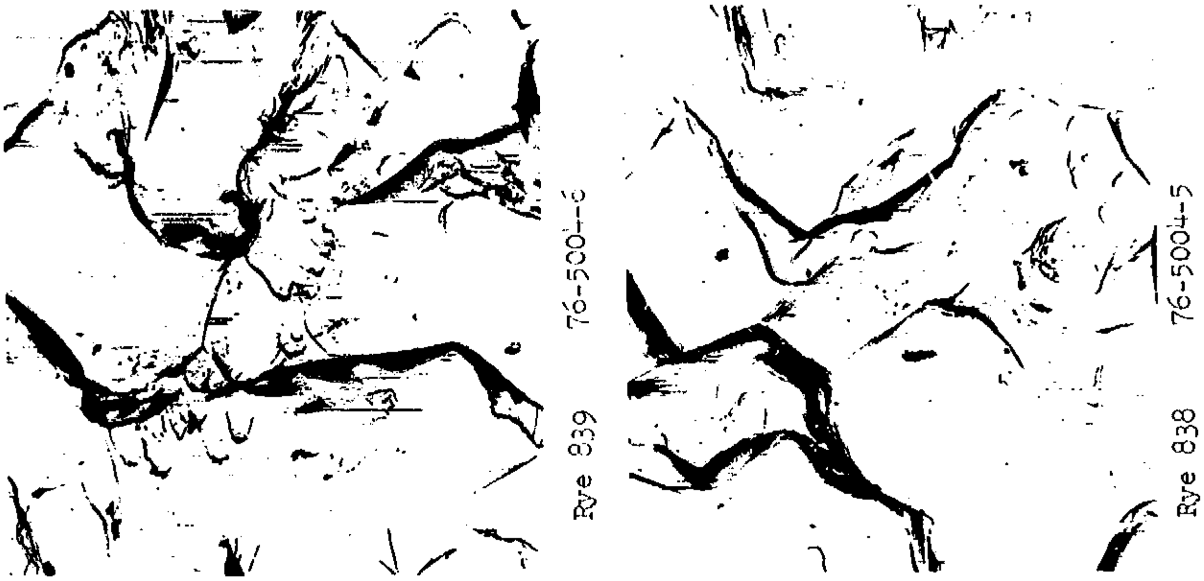


Area 1

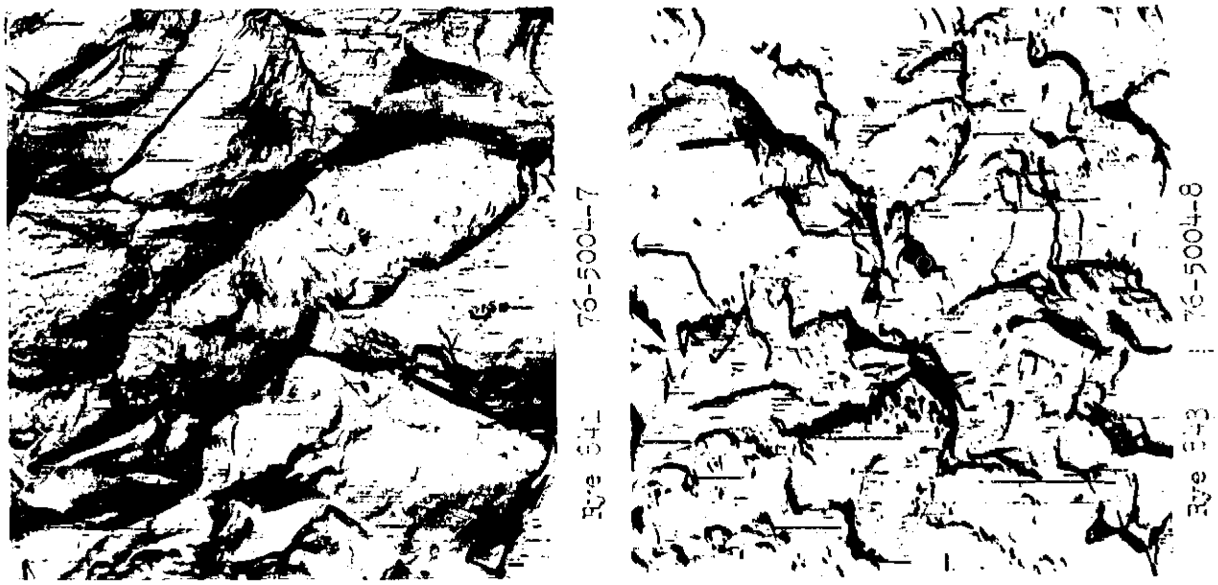


Area 2

Fig. 3.4.2.7-3 - Electron microscope fractographs of Lockalloy test specimen 63C-2T which failed during a stress-corrosion test. Area 1 was the fracture origin region, and Area 2 was away from the fracture origin. The material was Lockalloy Be-38%Al, 0.25" thick sheet HC 160-1. Mag. 6500X

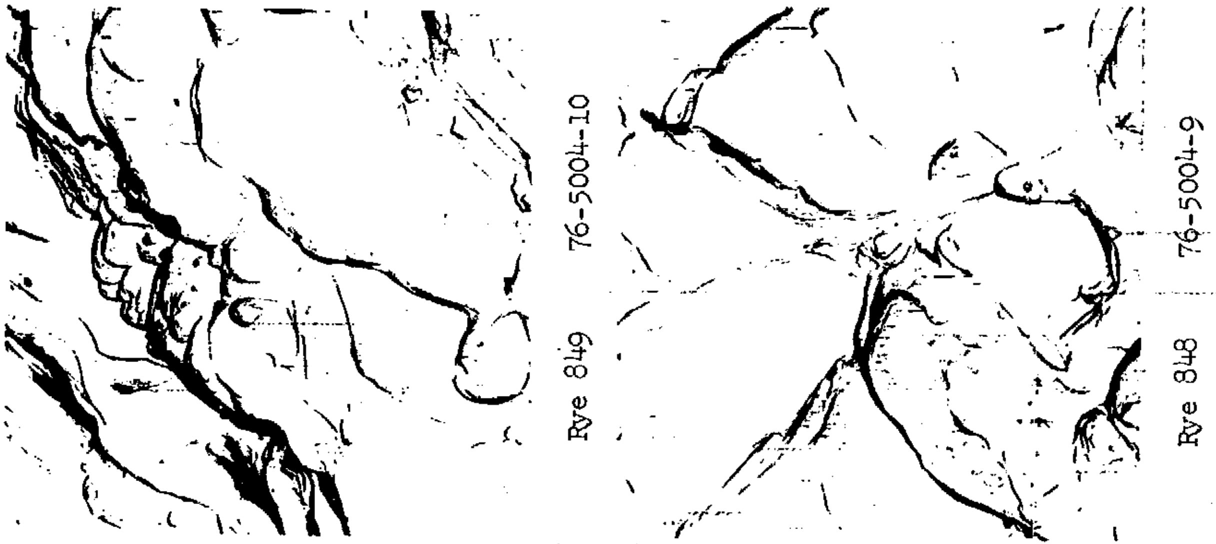


Area 1

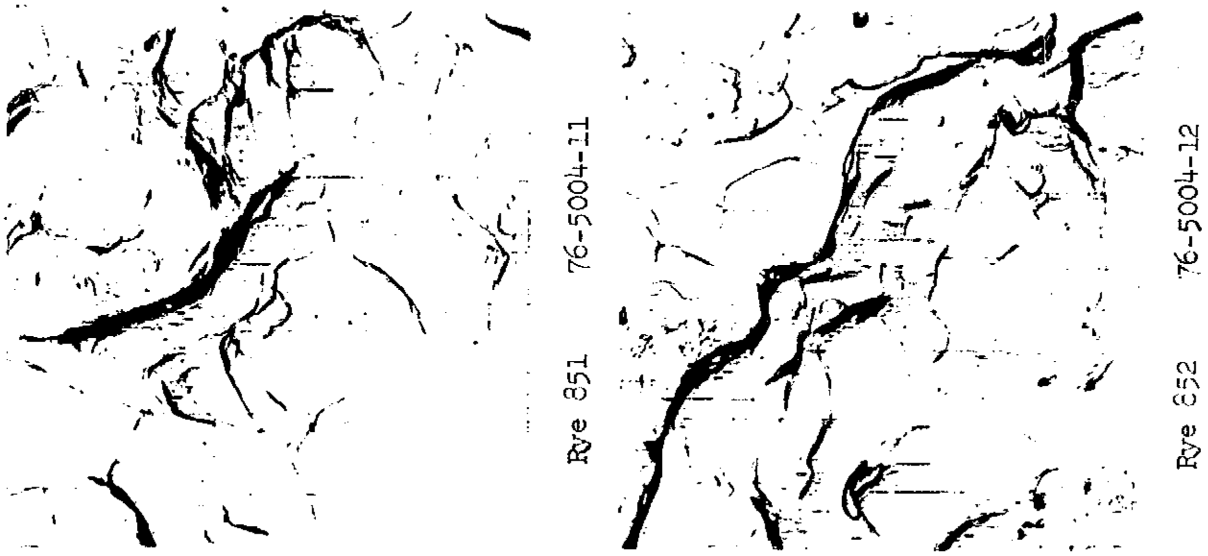


Area 2

Fig. 3.4.[illegible]7-4 – Electron microscope fractographs of Lockalloy test specimen GSC-13T which failed during a stress-corrosion test. Area 1 was the fracture origin region, and Area 2 was away from the fracture origin. The material was Lockalloy Be-38%Al, 0.[illegible]" thick, sheet HC [illegible]. Mag. 6[illegible]00X



Area 1



Area 2

Fig. 3.4.2.7-5 - Electron microscope fractographs of Lockalloy test specimen 6SC-14T which failed during a stress-corrosion test. Area 1 was the fracture origin region, and Area 2 was away from the fracture origin. The material was Lockalloy Be-38%Al, 0.25" thick, sheet HC 160-1. Mag. 6500X

Rye 858 76-5004-14

Rye 857 76-5004-13

Fig. 3.4.2.7-6 - Electron microscope fractographs of a Lockalloy tensile coupon, No. 3NAS 766-1-3T. The material was Lockalloy Be-38%Al. Mag. 6500X

Two Lockalloy specimens (Be-38%Al, 0.25 inch thick, sheet HC 160-1) were submitted to the Rye Canyon Materials Laboratory for a seven day (168 hours) salt spray test. These specimens had been previously exposed to stress-corrosion tests without failing. These specimens were identified as shown below:

Specimen Number	Test Load KSI	Test Time Hrs.	Coating	Observations
6SC-3T	37.5	114.3	Bare	No failure
6SC-5T	43.7	121.9	Bare	No failure

The specimens were examined visually under a binocular microscope, at magnifications of 10 to 40 diameters prior to the salt spray exposure. The 6SC-3T specimen appeared to relatively clean and free of surface corrosion. However, specimen 6SC-5T showed a line of small pits along one side, in the reduced area, and there were a few scattered corrosion pits on the surfaces.

The specimens were placed in the salt spray chamber, and they were examined daily, except Saturday and Sunday. At the end of 40 hours exposure, both specimens showed a considerable amount of corrosion products on their surfaces. The samples were removed from the salt spray chamber and photographed (Figure 3.4.2.7-7). The specimens were then returned to the salt spray chamber for the remaining exposure time. At the end of the exposure period the specimens were removed from the chamber and photographed (Figure 3.4.2.7-8). The specimens were then rinsed with distilled water and lightly swabbed to remove the salt deposits and the loosely adherent corrosion products. Figure 3.4.2.7-9 is a photograph of the specimens after this cleaning operation. As shown in these photographs a considerable quantity of corrosion products formed on the surfaces of the samples, and there was an appreciable amount of staining and general corrosion of the surfaces.

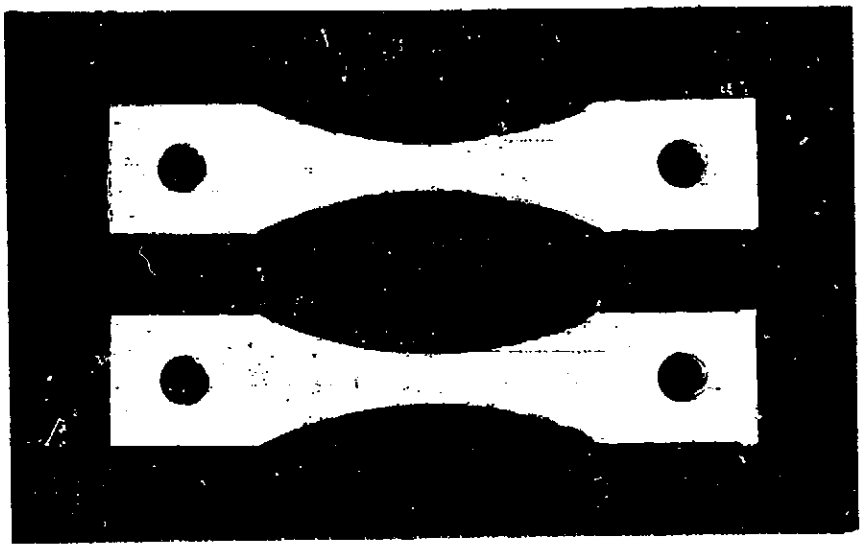


Fig. 3.4.2.7-7 - Photograph showing the extent of corrosion on Lockalloy (Be-38%Al, 0.25" thick, sheet HC 160-1) specimens (6SC-3T and 6SC-5T) after 40 hours of exposure to salt spray.

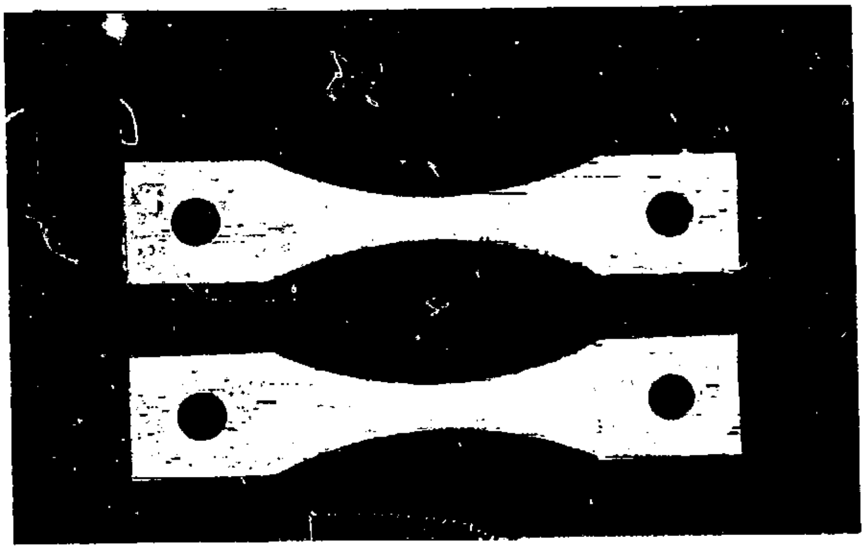
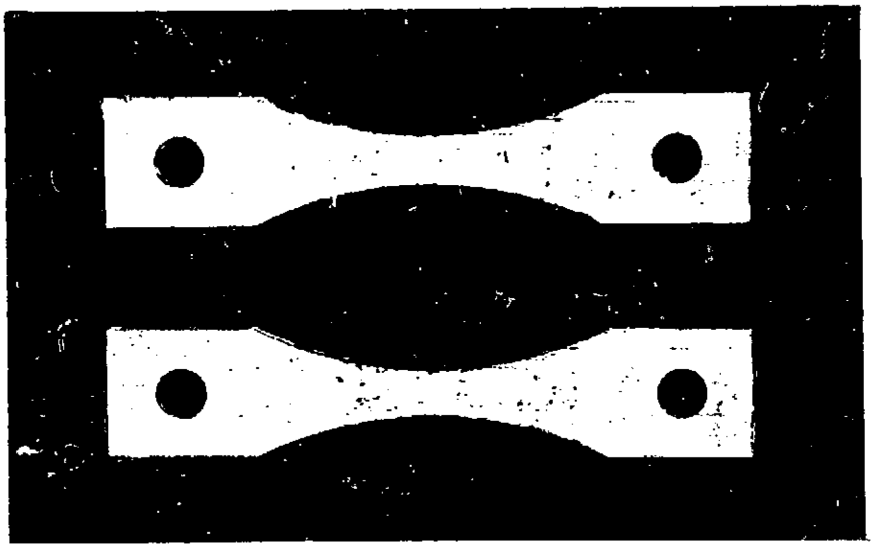


Fig. 3.4.2.7-8 - Photograph [illegible] (Be-38%Al, 0.[illegible] [illegible] HC [illegible]) [illegible] ([illegible] and [illegible]) [illegible] ([illegible]) [illegible]



Rye 134 323R 76-5002-3

Fig. 3.4.2.7-9 - Photograph showing the extent of corrosion on Lockalloy (Be-38%Al, 0.25" thick, sheet HC 160-1) specimen (6SC-3T and 6SC-5T) after 168 hours (7 days) of exposure to salt spray. Samples were rinsed with distilled water and lightly swabbed to remove the loosely adherent salt deposits and corrosion products.

Two painted Lockalloy specimens (Be-38%Al, 0.25 inch thick, sheet HC 160-1) were submitted to the Rye Canyon Materials Laboratory for a seven day (168 hours) salt spray test. An X-shaped scratch was made in the paint film on both specimens using a sharp pointed steel scribe. Most of the scratches were approximately 0.01" wide; however, one of the scratches was approximately 0.03" wide. The specimens were examined visually under a binocular microscope at magnifications of 10 to 40 diameters prior to the salt spray exposure. There was slight chipping or flaking of the paint at the center of "X". Except for this area, the adherence of the paint film appeared to be good. The appearance of the specimens prior to the salt spray exposure is shown in Figure 3.4.2.7-10.

The specimens were placed in the salt spray chamber, and they were examined periodically during the test. The salt spray test was conducted in accordance with the American Society for Testing Materials Standard B117 (5 ± 1 parts by weight of sodium chloride in 95 parts of distilled water). At the end of the seven day exposure period, the specimens were removed from the chamber; and they were rinsed with distilled water and lightly swabbed to remove the salt deposits. A photograph of the specimens after the salt spray test appears in Figure 3.4.2.7-11. As shown in this photograph, very little corrosion occurred on these specimens. Examination of the specimens under a binocular microscope showed only a very few, small, isolated areas of corrosion products on the scratched surface. The condition of the specimens at the center of the X-shaped scratches is illustrated in Figure 3.4.2.7-12. As shown by these photographs, the paint system provided good protection to the Lockalloy base metal.

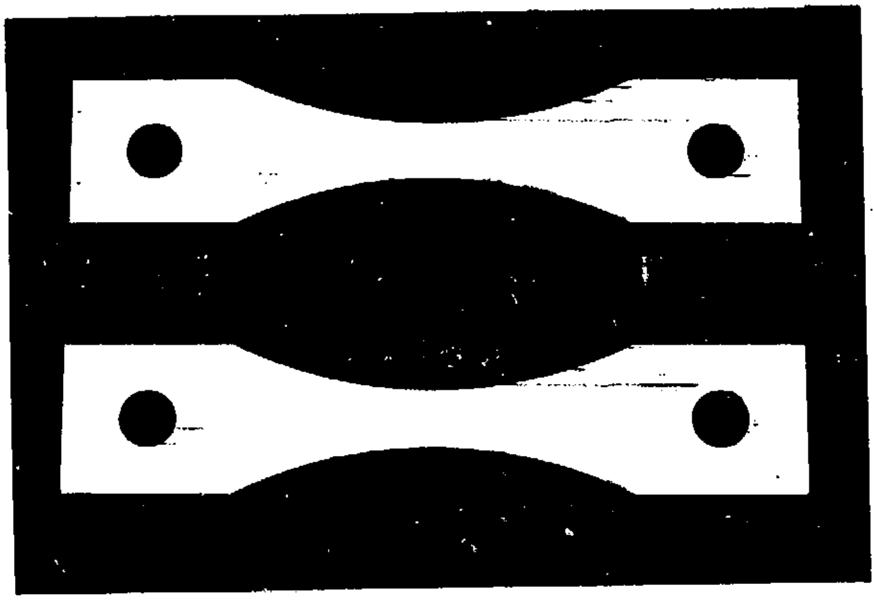


Fig. 3.4.2.7-10 - Photograph showing the two painted Lockalloy (Be-38%Al, 0.25" thick, sheet HC 160-1) specimens before salt spray exposure.

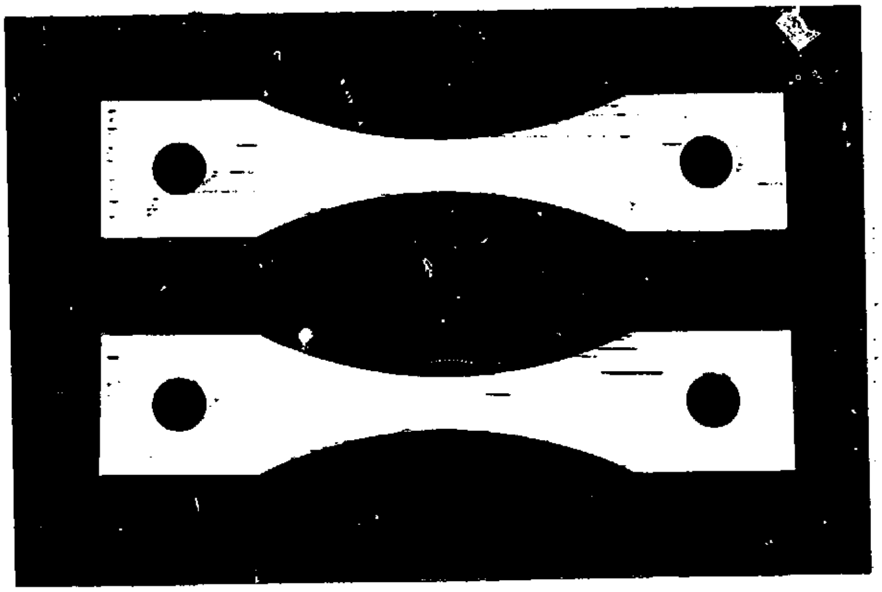
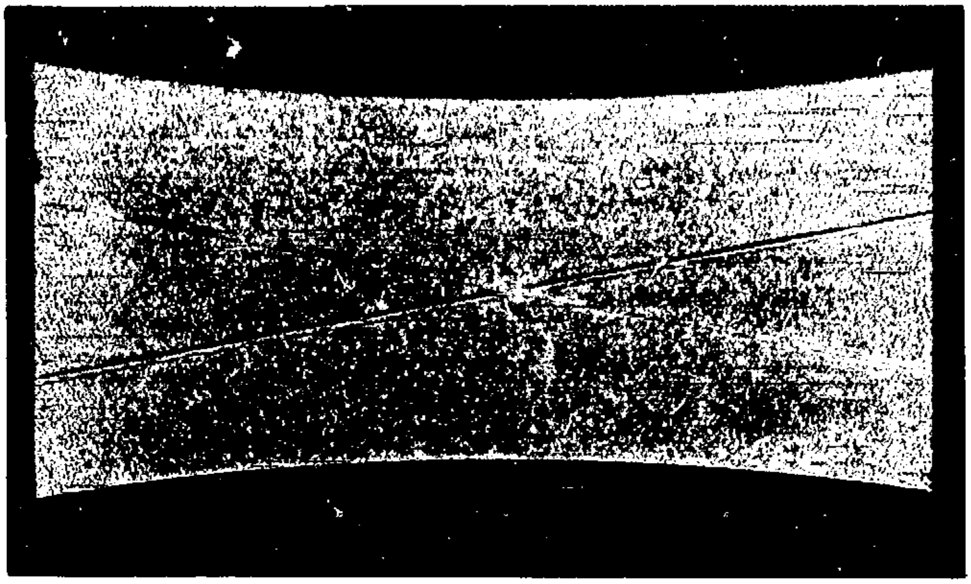


Fig. 3.4.2.7-11 - Photograph showing the two painted Lockalloy (Be-38%Al, 0.25" thick, sheet HC 160-1) specimens after [illegible] ([illegible]) of exposure to salt spray.



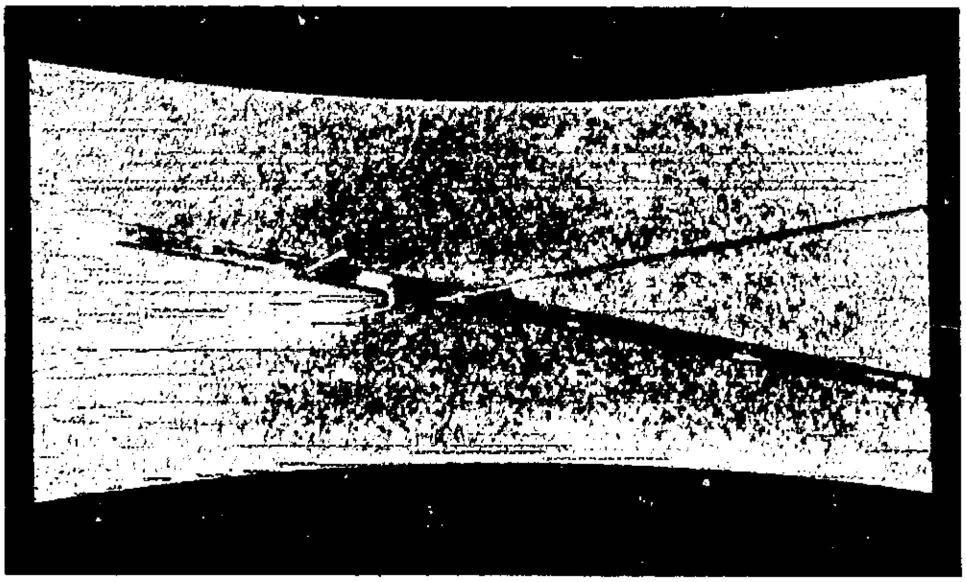
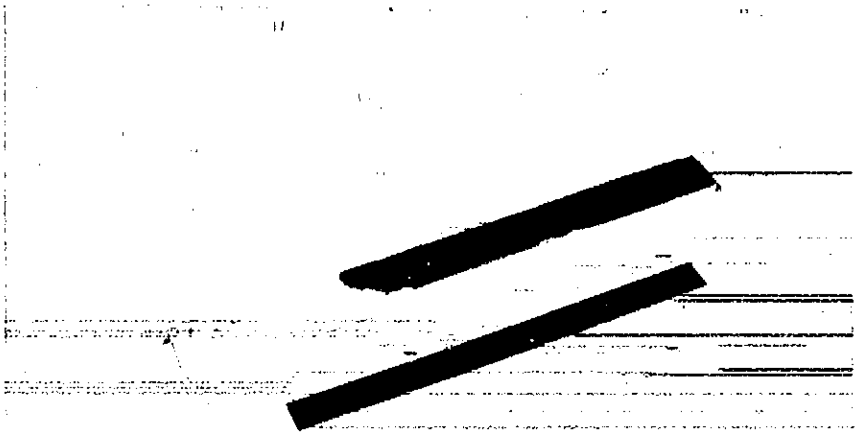


Fig. [illegible] - Close-up views of the center of the two [illegible] [illegible] specimens after the 7 day ([illegible]) [illegible] spray test. Mag. [illegible]

A .25 inch thick Be-38Al Alloy specimen shown in Figure 3.4.7.2-13 was painted with ADP developed high temperature paint leaving one end unprotected and then submitted to a 3.5% salt spray test for 4630 hours.

The appearance of corrosive products on the protected paint surface illustrated dramatically the excellent protection provided by this paint spray.

Since titanium screws are used in joint assemblies of Be-38Al Lockalloy, a protective barrier must be provided if galvanic corrosion is to be avoided. A simulated joint of .25 inch Be-38Al alloy protected with ADP developed high temperature paint and bolted with a titanium screw was compared to an identical unprotected joint after being immersed in a 3.5% salt solution for approximately 2-1/3 months, as shown in Figure 3.4.7.2-14. The unprotected specimen shown on the left has been considerably attacked by corrosive products in contrast to the clean unaffected paint protected specimen on the right.



76-5007-9

Fig. 3.4.7.2-13 - Photograph of Be-38Al alloy specimen exposed to salt spray test for 4630 hours

Figure [illegible] - [illegible]

3.4.2.8 Creep Strength Tests - Creep strength tests were conducted at the Rye Canyon test facility of Lockheed in accordance with ASTM E139-700 utilizing the Satec Creep Testing Machines shown in Figure 3.4.2.7-1. Triplicate specimens of the configuration shown on page B-2 of the Appendix were machined from .250 inch thick Be-38Al alloy in both the longitudinal and transverse directions.

All specimens were first measured, and mounting clamps for a two inch gage length Satec Model 9234-K Remote Extensometer were attached using a two inch spacing block. With the extensometer attached, the specimen was placed into a 6,000 lb. Satec Creep Rupture Test Machine under zero load. The extensometer was then zeroed and the appropriate scale setting chosen to give a full scale deflection reading on a 12 channel Barber Coleman Time Base Recorder. Full scale corresponded to 10 inches on the recorder. A thermocouple was then attached to the specimen and the Satec Resistance Furnace, as shown in Figure 3.4.2.7-1, was placed over the specimen. Specimen temperature was increased to 600°F for 15 minutes and the test load then applied. Temperature was maintained at 600° ± 3°F throughout the test duration by a Barber Coleman Capacitol #477 Temperature Control. A continuous record of the temperature was on a 24 channel Barber Coleman Recorder. Strain data as a function of time was read directly from the 12 channel Barber Coleman Recorder as shown in Figure 3.4.2.7-2.

A dead-weight load was applied at 600°F so as to produce a stress level in both the longitudinal and transverse directions of the specimens as follows:

Specimen I.D.	Stress KSI
6CR-1T, 1L	20.0
6CR-3T, 2L	12.5
6CR-2T, 3L	7.5

A plot of Creep-Rupture curves at 600°F in the longitudinal and transverse directions are presented in Figure 3.4.2.8-1 and Figure 3.4.2.8-2, respectively.

A plot of Creep curves at various total deformations at 600°F in the longitudinal and transverse directions are presented in Figure 3.4.2.8-3 and Figure 3.4.2.8-4.

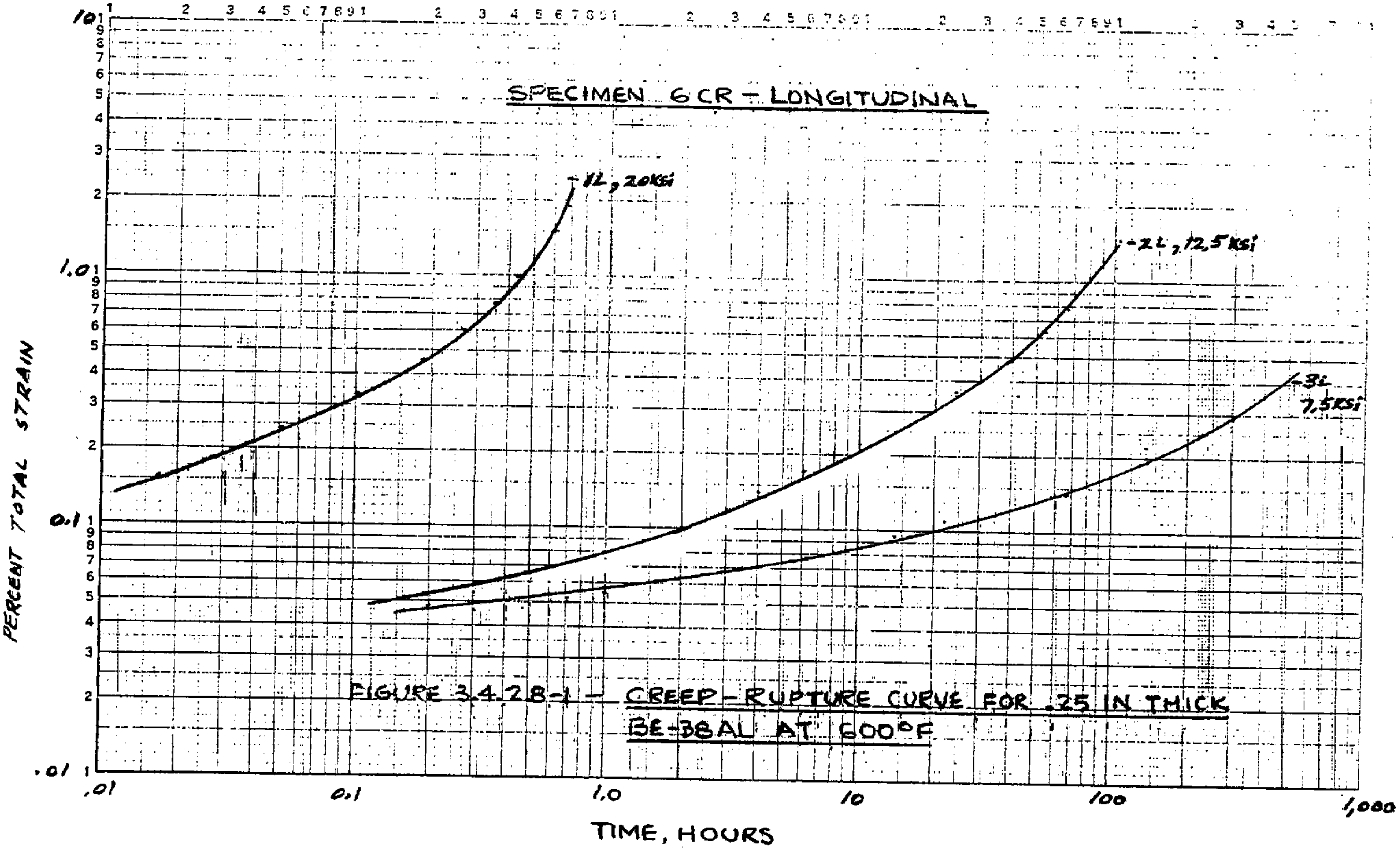
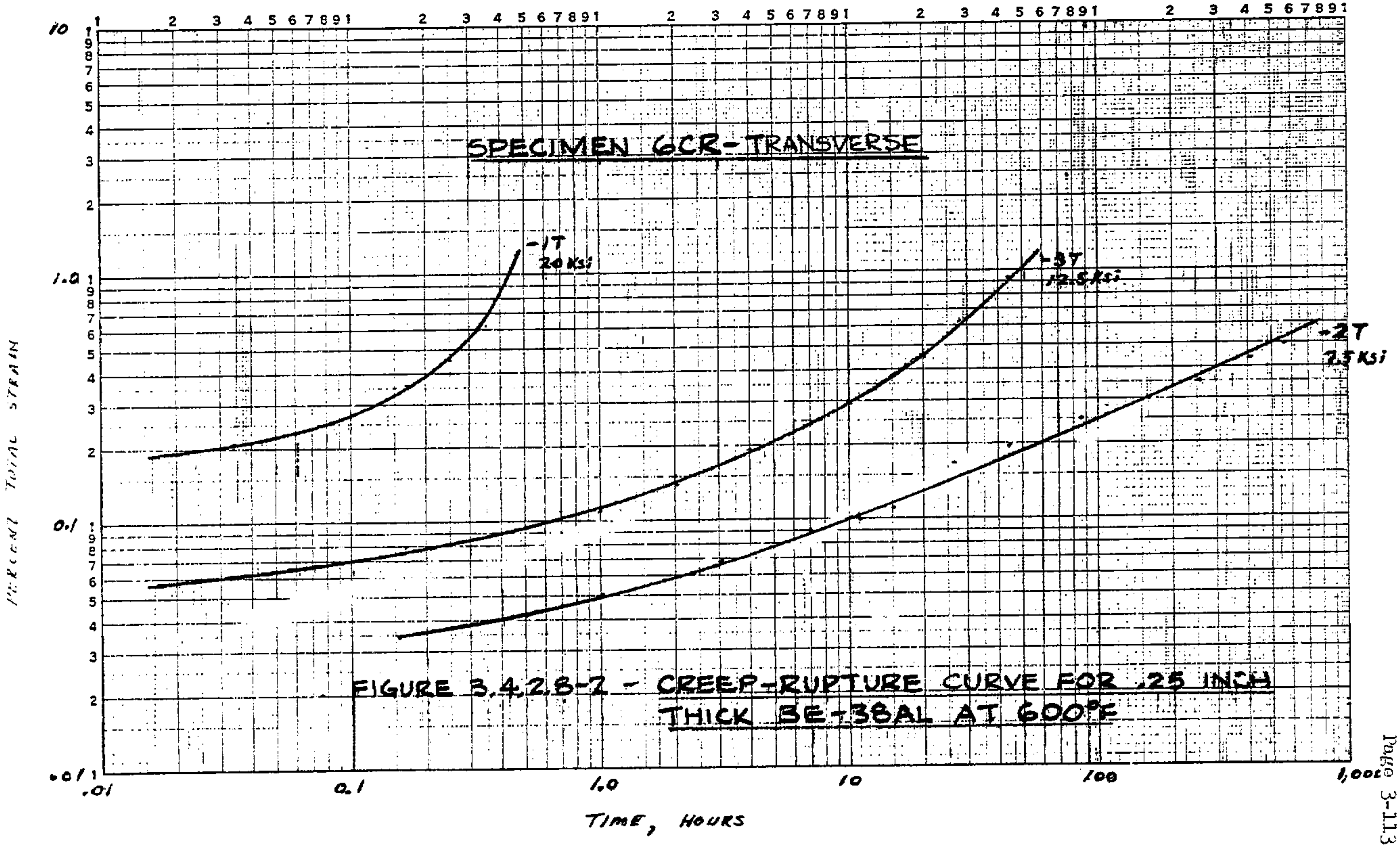


FIGURE 3.4.2.8-1 – CREEP–RUPTURE CURVE FOR .25 IN THICK BE-38AL AT 600°F



SPECIMEN 6CR-TRANSVERSE

FIGURE 3.4.2.8-7 - CREEP-RUPTURE CURVE FOR .25 INCH THICK BE-38AL AT 600°F

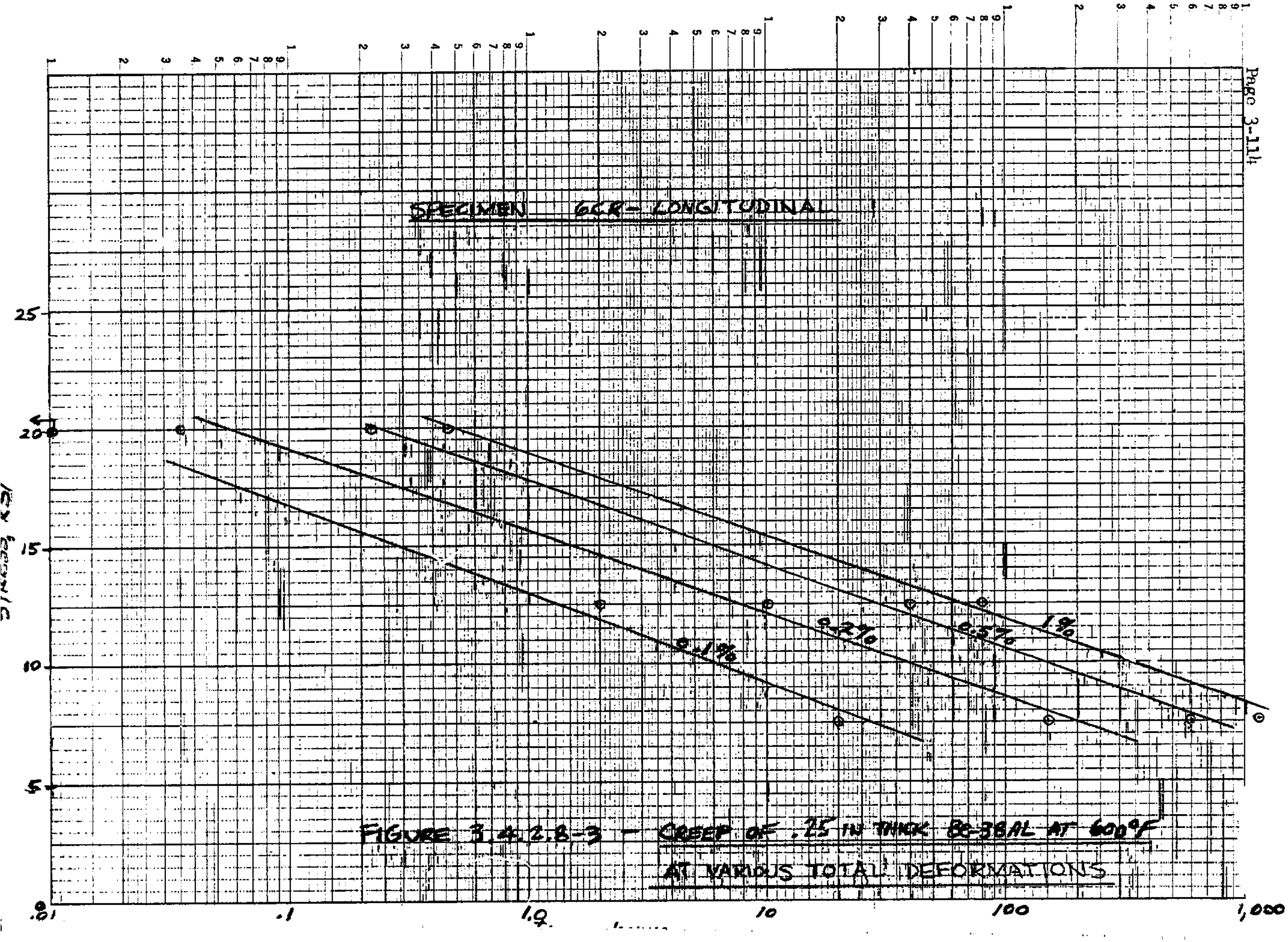


FIGURE 3.4.2.8-3 - CREEP OF .25 IN THICK 80-38AL AT 600°F AT VARIOUS TOTAL DEFORMATIONS

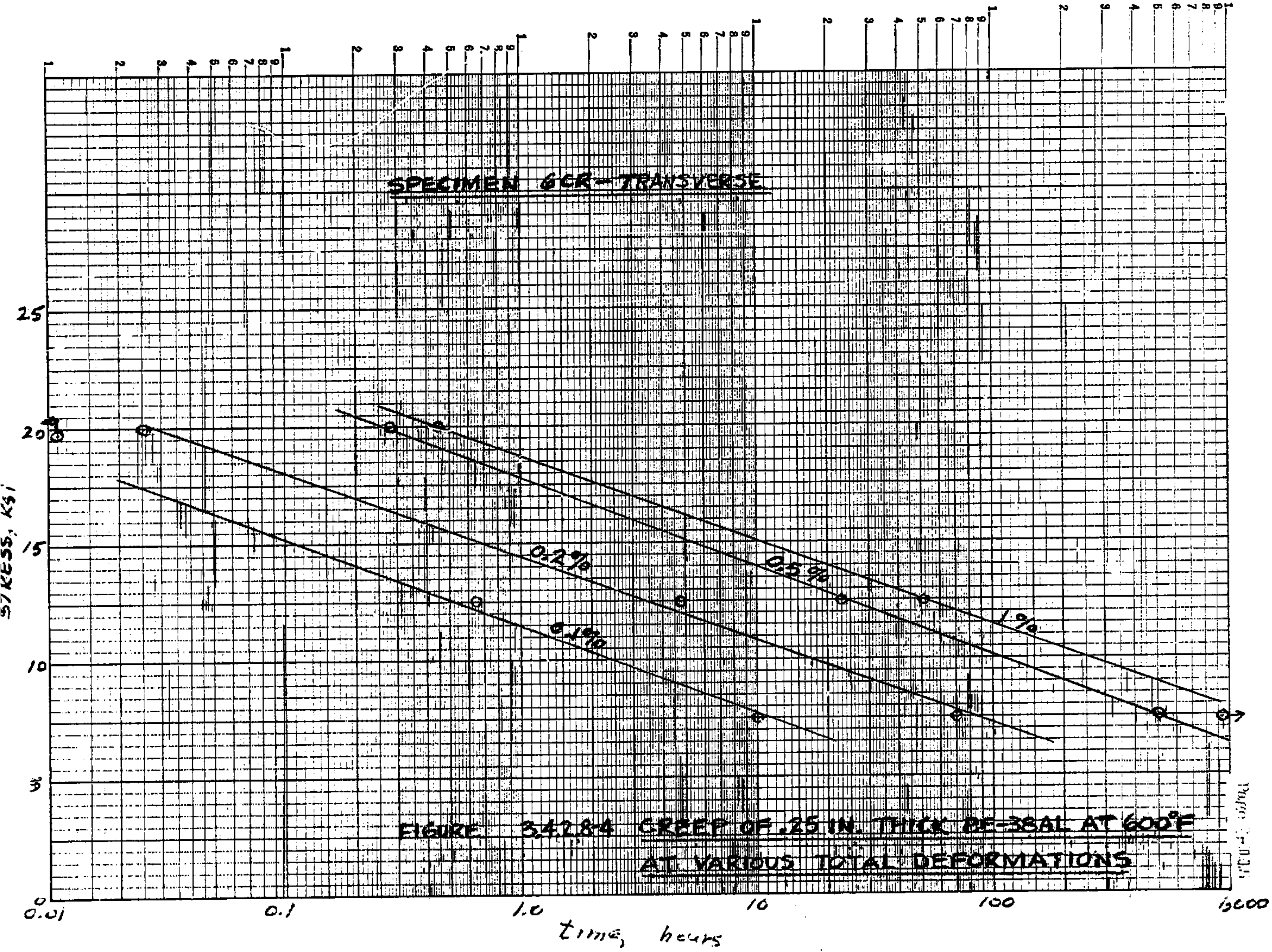


FIGURE 3.4.2.8-4 CREEP OF .25 IN. THICK BE-38AL AT 600°F AT VARIOUS TOTAL DEFORMATIONS

3.4.2.9 <u>Poisson's Ratio Tests</u> - Poisson's Ratio Tests were conducted at room temperature and 600°F, with and without exposure to 600°F for 100 hours and in the longitudinal direction, utilizing specimens conforming to the configuration shown on Page B-2 of the Appendix.

On the room temperature test specimens, BLH Paper Back Strain Gages were installed using SR-4 Cement. Four separate strain gages were used on each specimen - 2 axial back-to-back and 2 transverse back-to-back. Another specimen having four of the same type paper gages used to provide the matching dummy gages required to complete the one-half bridge installation for each gage on the test specimen.

For the specimens tested at 600°F, four high temperature strain gages were installed on each specimen as on the room temperature test specimens. M-Bond 600 adhesive was used for the gage installation and heated to 225°F under clamping pressure for initial gage cure. A 3-wire system was silver-soldered to each gage, and the one-half bridge was completed for each gage by use of a similar specimen having like strain gages. Prior to load testing at 600°F, each specimen was heated to 600°F and cooled to room temperature for curing the strain gage installations.

The first specimen to be tested was installed into a test structure utilized for fatigue test similar to the one shown in Figure 3.4.2.6-1. The four strain gages were read on one strain indicator through a switch box. Because of the relatively small strain outputs from the Poisson Gages (transverse), it was felt that the switch box system should not be used due to the possibility of switching transients. Also, alignment of the grips could cause bending of the specimen since both upper and lower grips were rigidly mounted.

A new test structure was fabricated where specimen bending was minimized by use of universal joints at both ends of the loading structure. The specimen was oriented vertically in the structure. Loads were applied by a hydraulic jack with a hand pump supplying the hydraulic pressure. A load cell and indicator system was used to monitor the loadings. For elevated temperature tests, heat was supplied by a heat gun, placed into a small insulated "Maronite" box installed around the specimen and grips as shown in Figure 3.4.2.9-1. A thermocouple tied to the specimen was used to monitor the temperature at 600° ± 10°F. Four strain indicators were used to read the strain gage outputs. A photograph showing the entire test arrangement is shown in Figure 3.4.2.9-2.

The specimen was installed in both grips, fitting freely in both grips with the pins installed. The lower grip was connected with a rod through the lower side of the oven to a U-joint. One pin of the U-joint was removed to prevent any load on the specimen. This position was called Zero Load. A stop was installed to prevent the hydraulic actuator from drifting down when the specimen was at Zero Load. This Zero Load reading at room temperature and at 600°F for the elevated temperature tests was that reading from which all the data was referenced for any particular specimen test.

For the room temperature tests, four loading runs were accomplished and strain readings obtained for each gage as follows:

Run No. 1 0 to 500 lbs. in 100 lb. increments
Run No. 2 0 to 1000 lbs. in 200 lb. increments
Run No. 3 0 to 3500 lbs. in 500 lb. increments
Run No. 4 0 to 5000 lbs. in 500 lb. increments

(or highest load possible at reasonable stabilization).

For elevated tests at 600°F, three loading runs were made and strain readings obtained for each gage as follows:

Run No. 1 0 to 500 lbs. in 100 lb. increments
Run No. 2 0 to 2500 lbs. in 500 lb. increments
Run No. 3 0 to 3500 lbs. in 500 lb. increments

(or highest load possible at reasonable stabilization).

NOTE: The Poisson Gages were read only to the 1000 lb. loading at room temperature and the 500 lb. loading at 600°F.

The two axial strain gage readings were averaged as were the two Poisson Gage strain readings. The average Poisson reading was corrected for the transverse effect by the equation:

$$\epsilon y = \left[1-(.285)(K_t)\right]\left[\hat{\epsilon} y-K_t\ \hat{\epsilon} x\right]$$

Where

ϵy = Corrected Poisson Strain

K_t = Strain Gage Transverse Sensitivity Coefficient in Decimal Form

$\hat{\epsilon} y$ = Average Poisson Strain before Correction

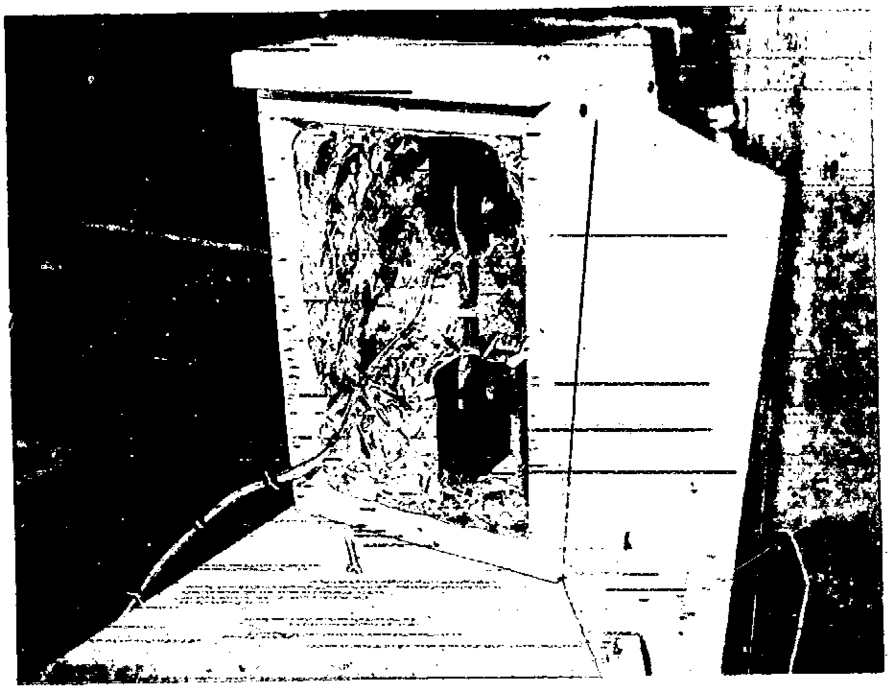
$\hat{\epsilon} x$ = Average Axial Strain

The axial readings were not corrected because of the small Poisson strain outputs which were negligible in effect on the axial gages.

The results of the Poisson Ratio Tests for the .25 inch thick Be-38Al alloy are tabulated in Table 3.4.2.9-1 and were obtained from the graphical presentations shown in Figures 3.4.2.9-1a and -1b through 3.4.2.9-9a and -9b.

An added benefit from the Poisson Ratio Tests was the ability to obtain modulus of elasticity values from the axial strain gages as contrasted to the conventional method of using extensometers. These results are shown in Table 3.4.2.9-1. Comparing the values obtained with the strain gage read-outs to those obtained with extensometers, a smaller range is realized for the strain gaged values particularly at 600°F as shown below:

	Modulus of Elasticity - psi x 10^{-6}	
	Room	600°F
Strain Gage	28.5 Min. - 31.0 Max.	21.7 Min. - 26.5 Max.
Extensometer	25.0 Min. - 30.2 Max.	17.5 Min. - 30.7 Max.



75-5354-8

Fig. 3.4.2.9-1 - A Photograph of Insulated "Maronite" Box Installed around Gaged Poisson Ratio Specimen for Elevated Temperature Testing

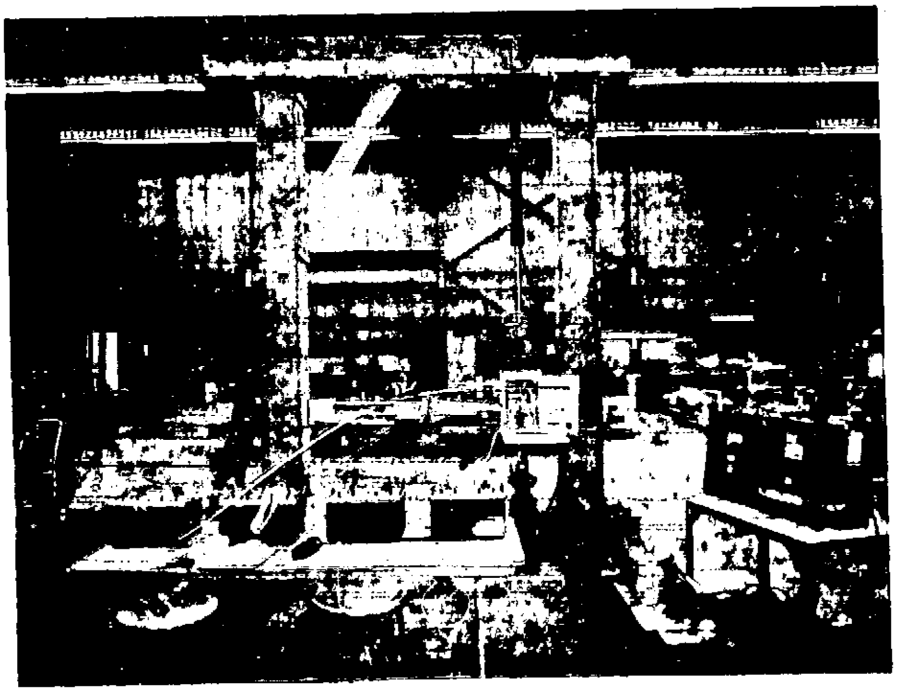


Fig. [illegible] - [illegible]

SPECIMEN NO.	CONDITION	TEST TEMP.	FROM GRAPHS		AVERAGE
			μ	MODULUS	
6PR-12L	100 HRS. AT 600°F	ROOM TEMP	.147	31×10^6 PSI	μ = .144 MODULUS = 29.7×10^6 PSI
6PR-4L	NONE	ROOM TEMP	.138	29.8×10^6 PSI	
6PR-5L	NONE	ROOM TEMP	.147	29.5×10^6 PSI	
6PR-6L	NONE	ROOM TEMP	.142	28.5×10^6 PSI	
6PR-2L	NONE	ROOM TEMP	.148	29.6×10^6 PSI	
6PR-8L	100 HRS AT 600°F	600°F	.175	23.5×10^6 PSI	μ = .172 MODULUS = 22.9×10^6 PSI
6PR-9L	100 HRS AT 600°F	600°F	.17	21.8×10^6 PSI	
6PR-1L	NONE	600°F	.153	21.7×10^6 PSI	
6PR-3L	NONE	600°F	.19	24.5×10^6 PSI	
6PR-7L 6PR-10L 6PR-11L	} *				

* SPECIMENS SACRIFICED ESTABLISHING TEST TECHNIQUES

TABLE 3.4.2.9-1 POISSON'S RATIO AND YOUNG'S MODULUS TABULATION FOR 1/4" THICK X 1/2" WIDE Be-38Al SPECIMENS

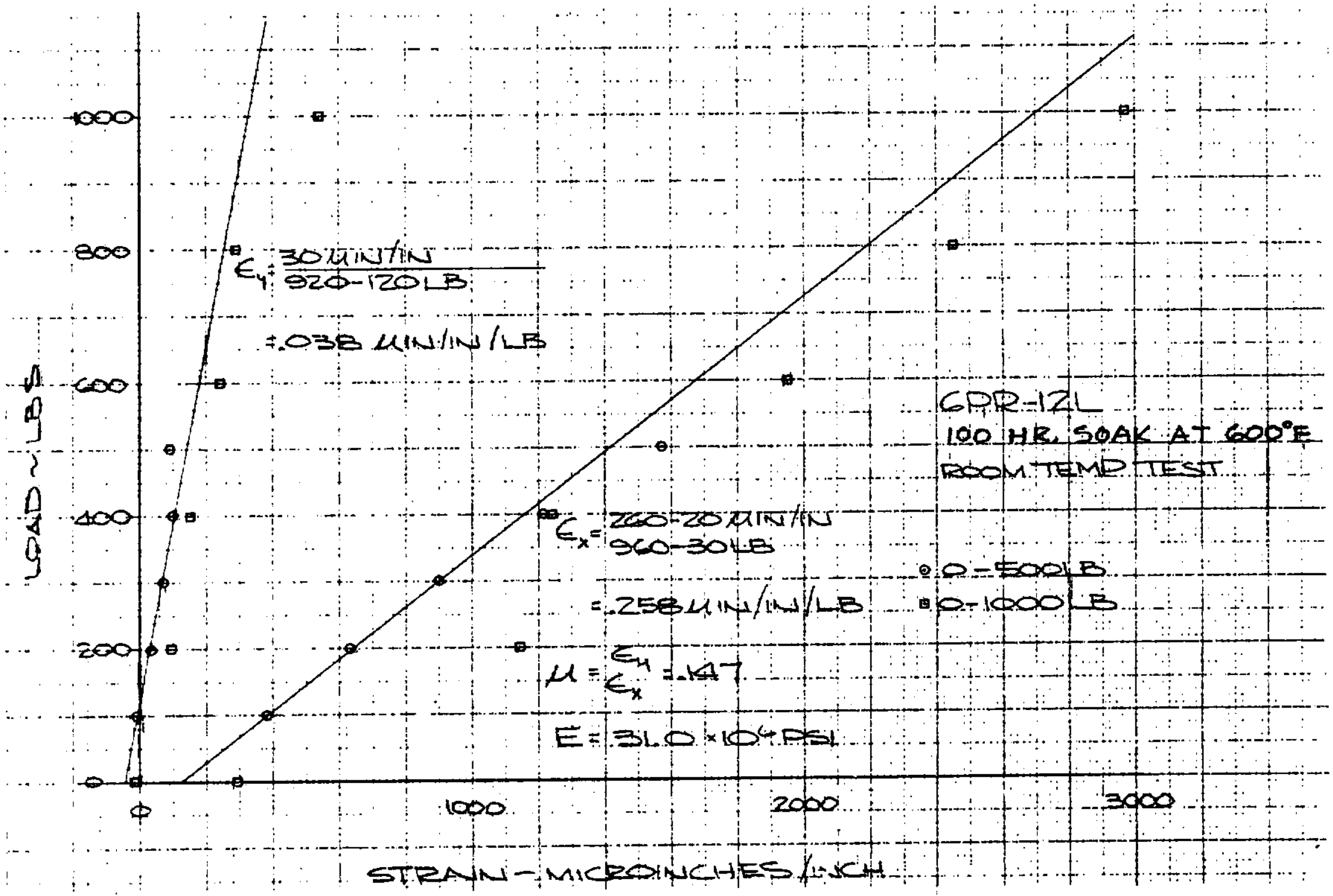


FIGURE 3.4.2.9-1a DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 6PR-12L AT ROOM TEMPERATURE AFTER 100 HOUR SOAK AT 600°F, LONGITUDINAL. (SHEET 1 OF 2)
]

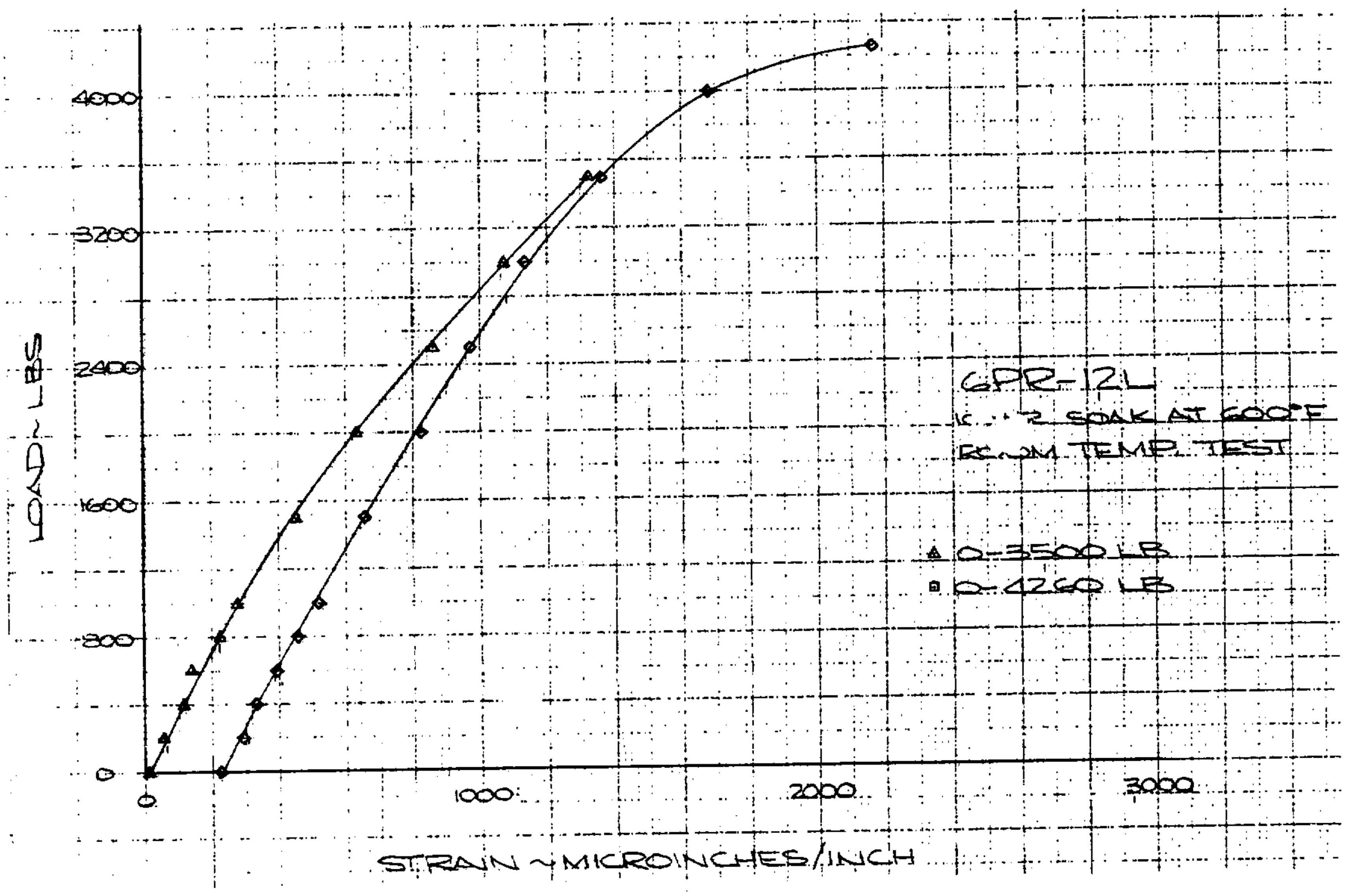


FIGURE 3.4.2.9-1b DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 6PR-12L AT ROOM TEMPERATURE AFTER 100 HOUR SOAK AT 600°F, LONGITUDINAL. (SHEET 2 OF 2)

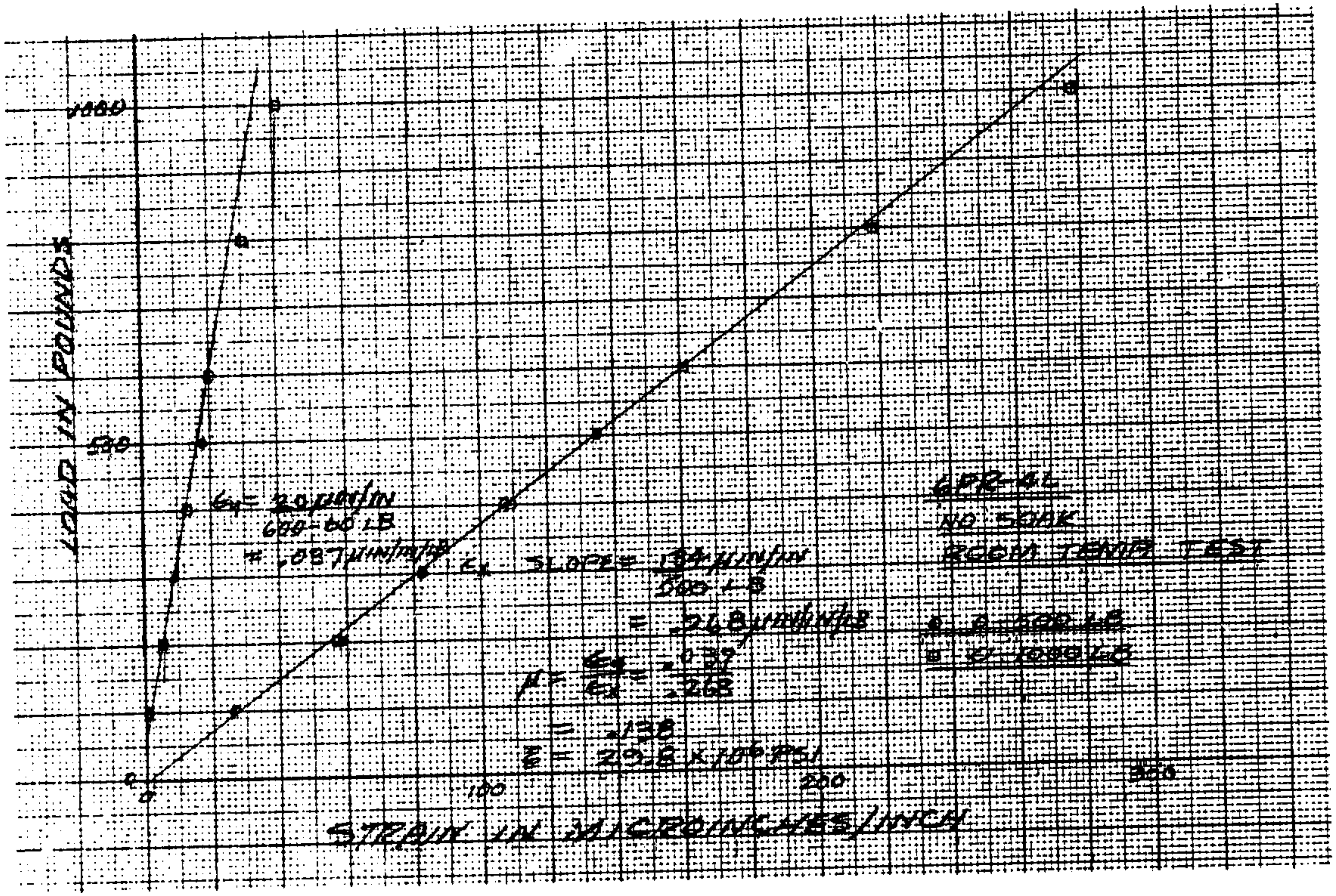


FIGURE 3.4.2 [illegible]-2a DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 6PR-4L AT ROOM TEMPERATURE - NO SOAK, LONGITUDINAL. (SHEET 1 OF 2)

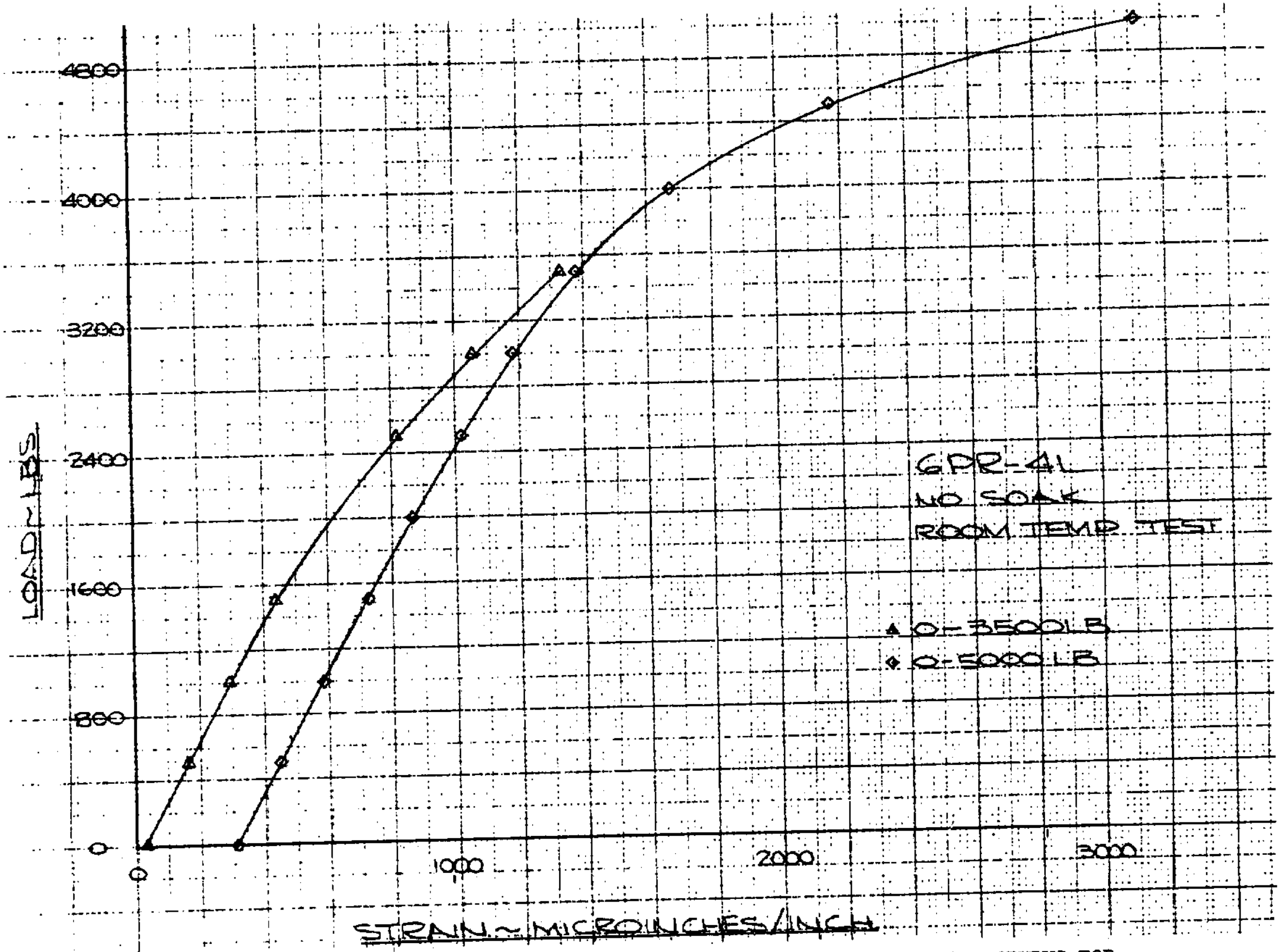


FIGURE 3 4.2 9-2b DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 6PR-4L AT ROOM TEMPERATURE - NO SOAK, LONGITUDINAL. (SHEET 2 OF 2)

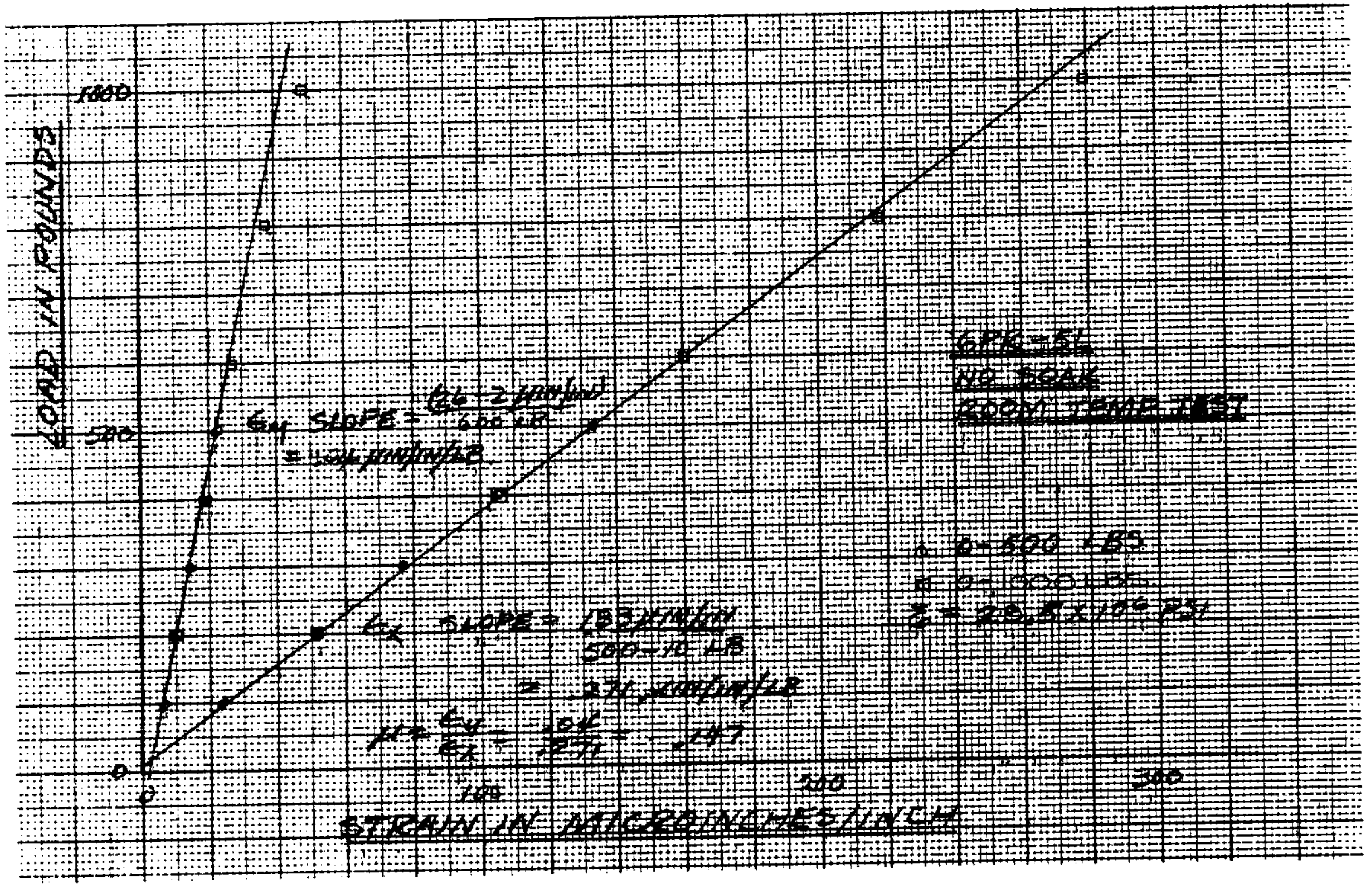


FIGURE 3.4.2.9-3a DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 6PR-5L AT ROOM TEMPERATURE - NO SOAK, LONGITUDINAL. (SHEET 1 OF 2)

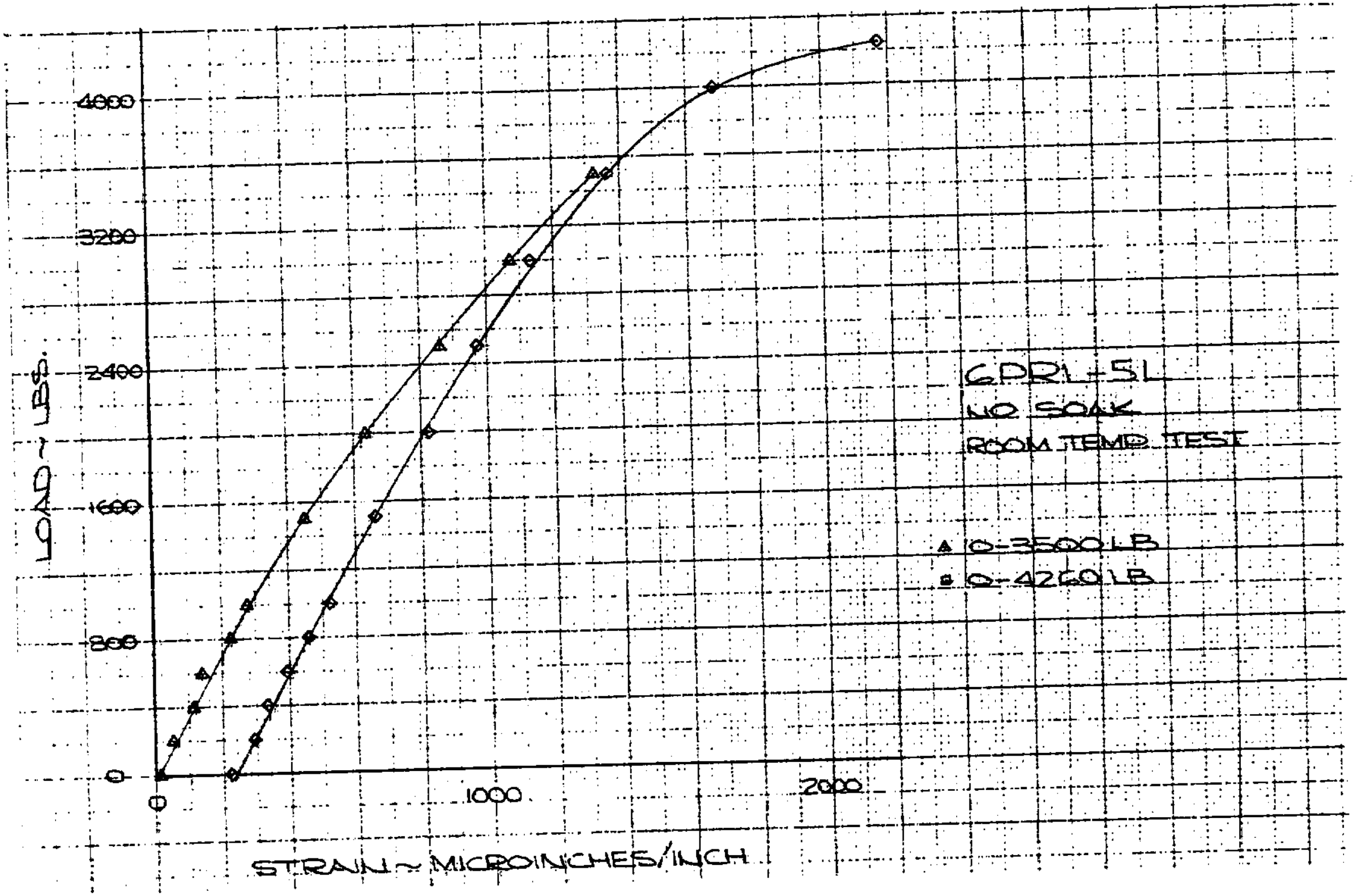


FIGURE 3 4.2 9-3b DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 6PR-5L AT ROOM TEMPERATURE - NO SOAK, LONGITUDINAL. (SHEET 2 OF 2)

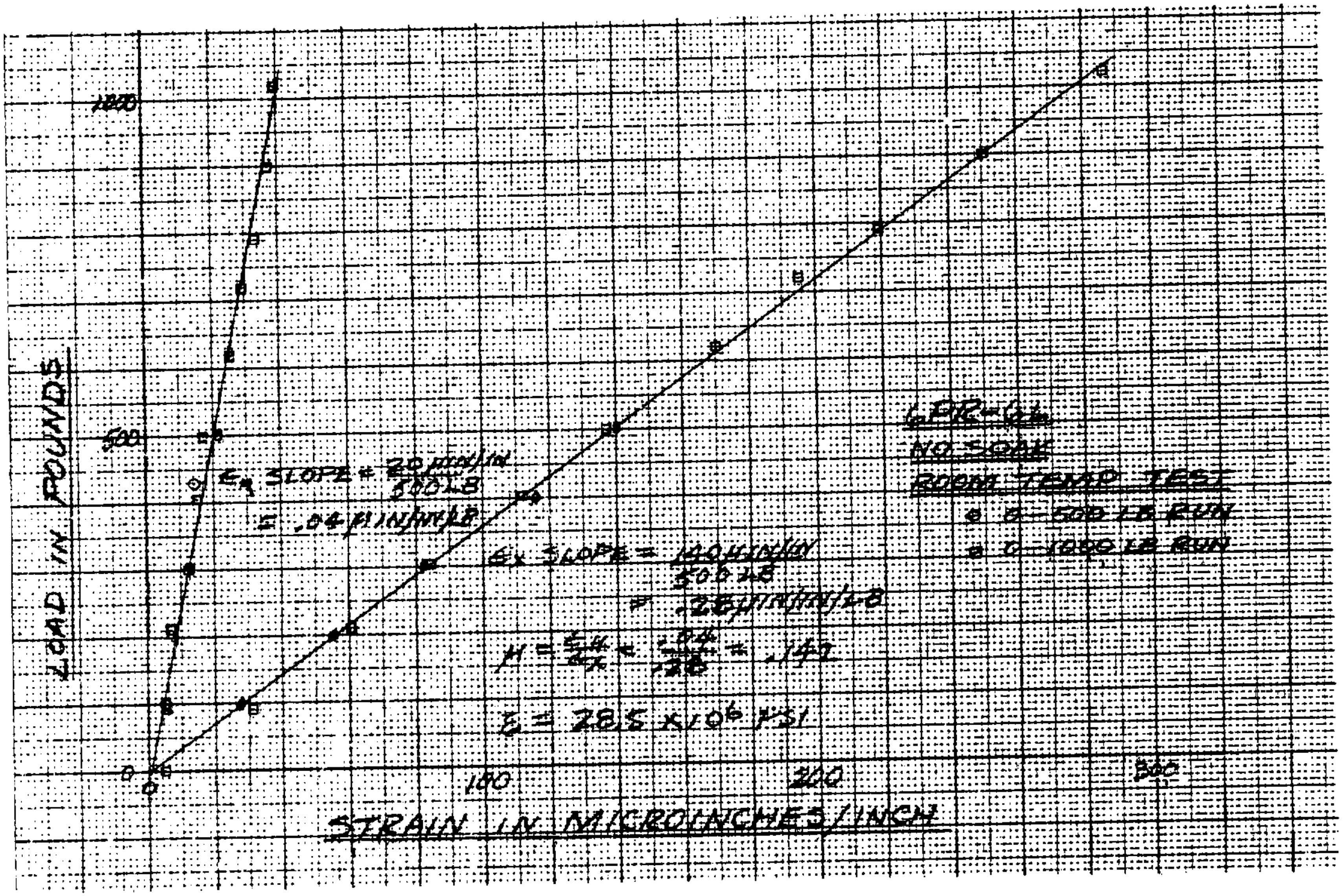


FIGURE 3.4.2.0-4a DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 6PR-6L AT ROOM TEMPERATURE - NO SOAK, LONGITUDINAL. (SHEET 1 OF 2)

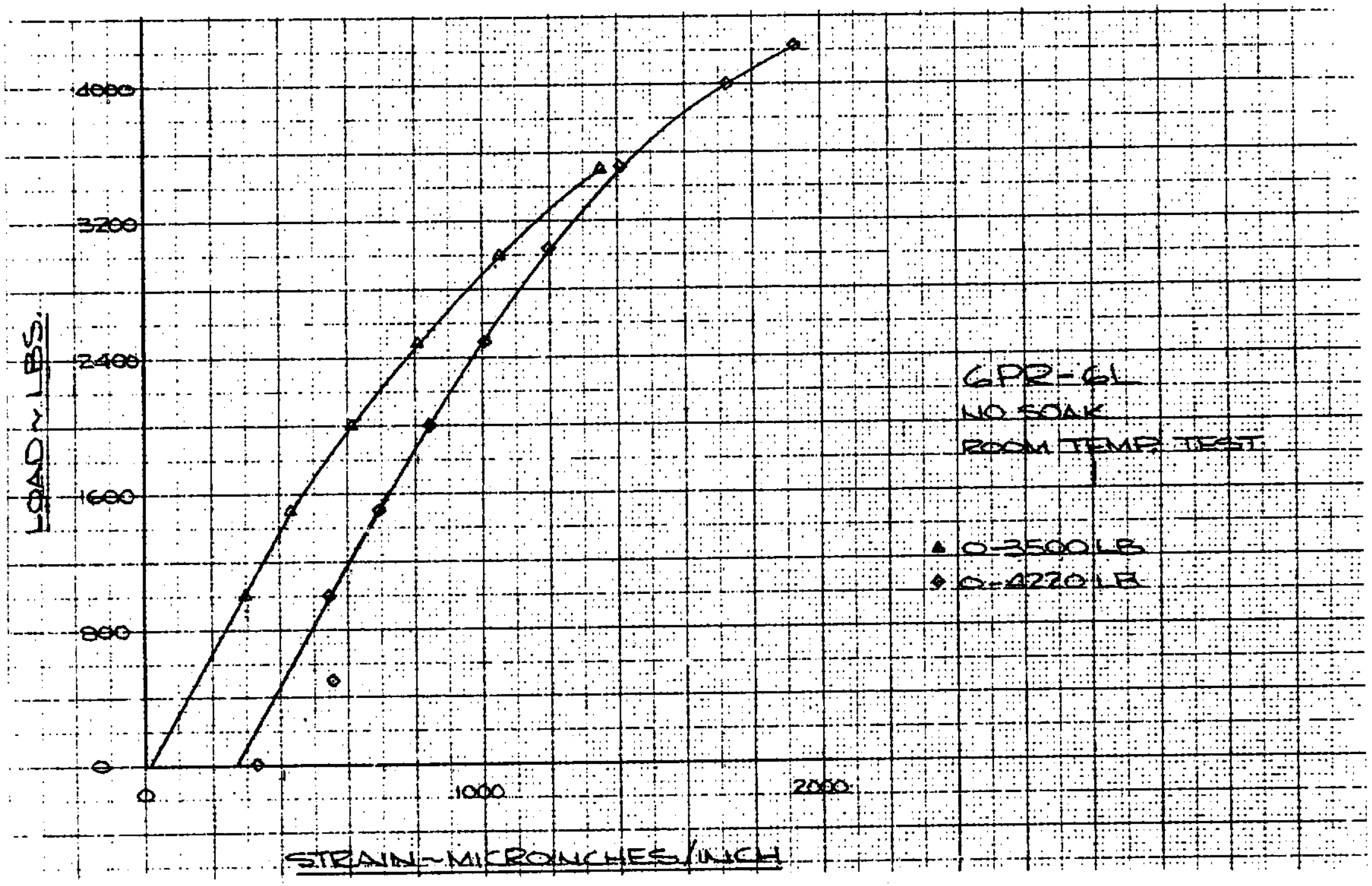


FIGURE 3.4.2.9-4b DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 6PR-6L AT ROOM TEMPERATURE - NO SOAK, LONGITUDINAL. (SHEET 2 OF 2)

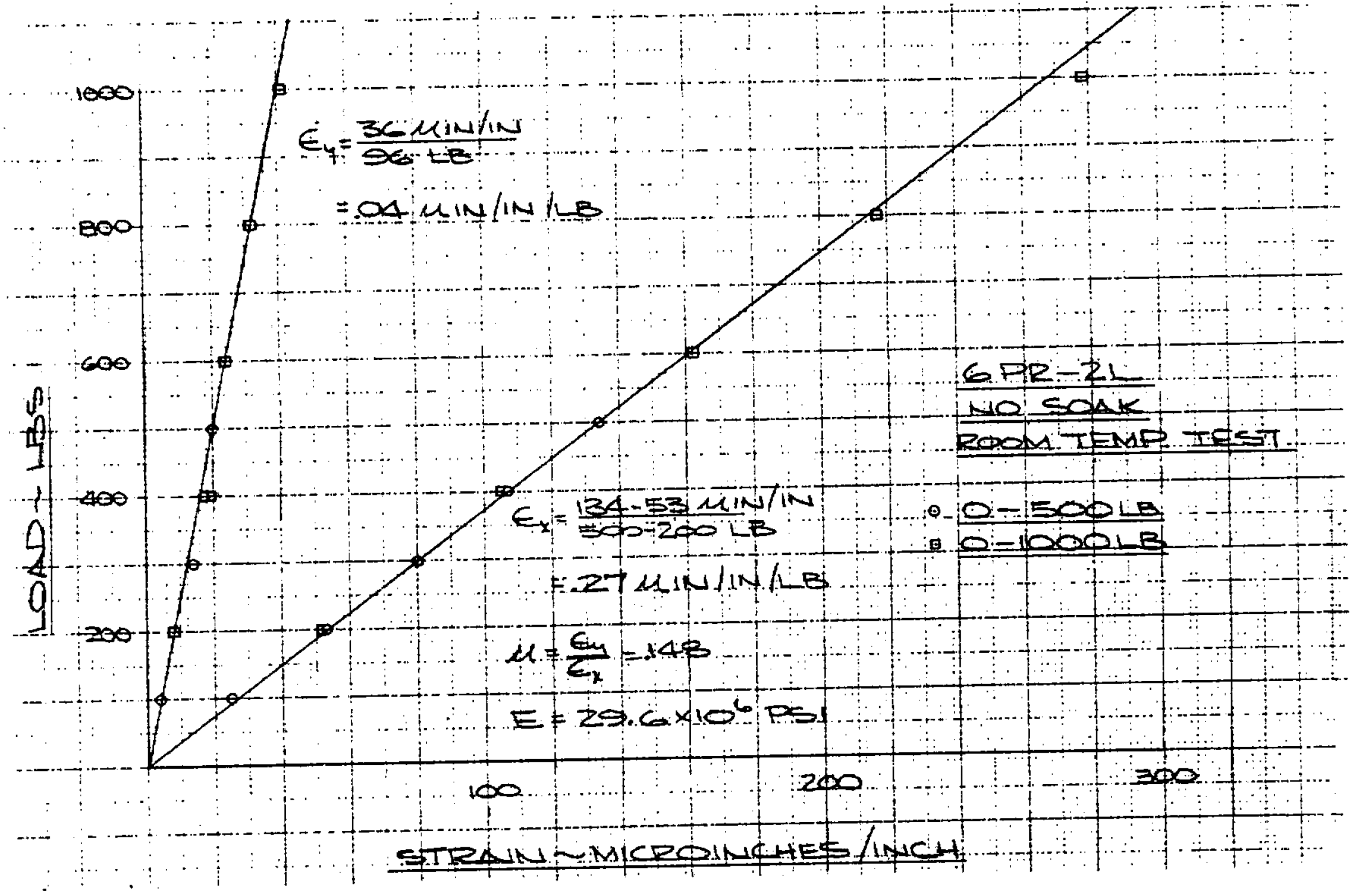


FIGURE 3.4.2 9-5a DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 6PR-2L AT ROOM TEMPERATURE - NO SOAK, LONGITUDINAL. (SHEET 1 OF 2)

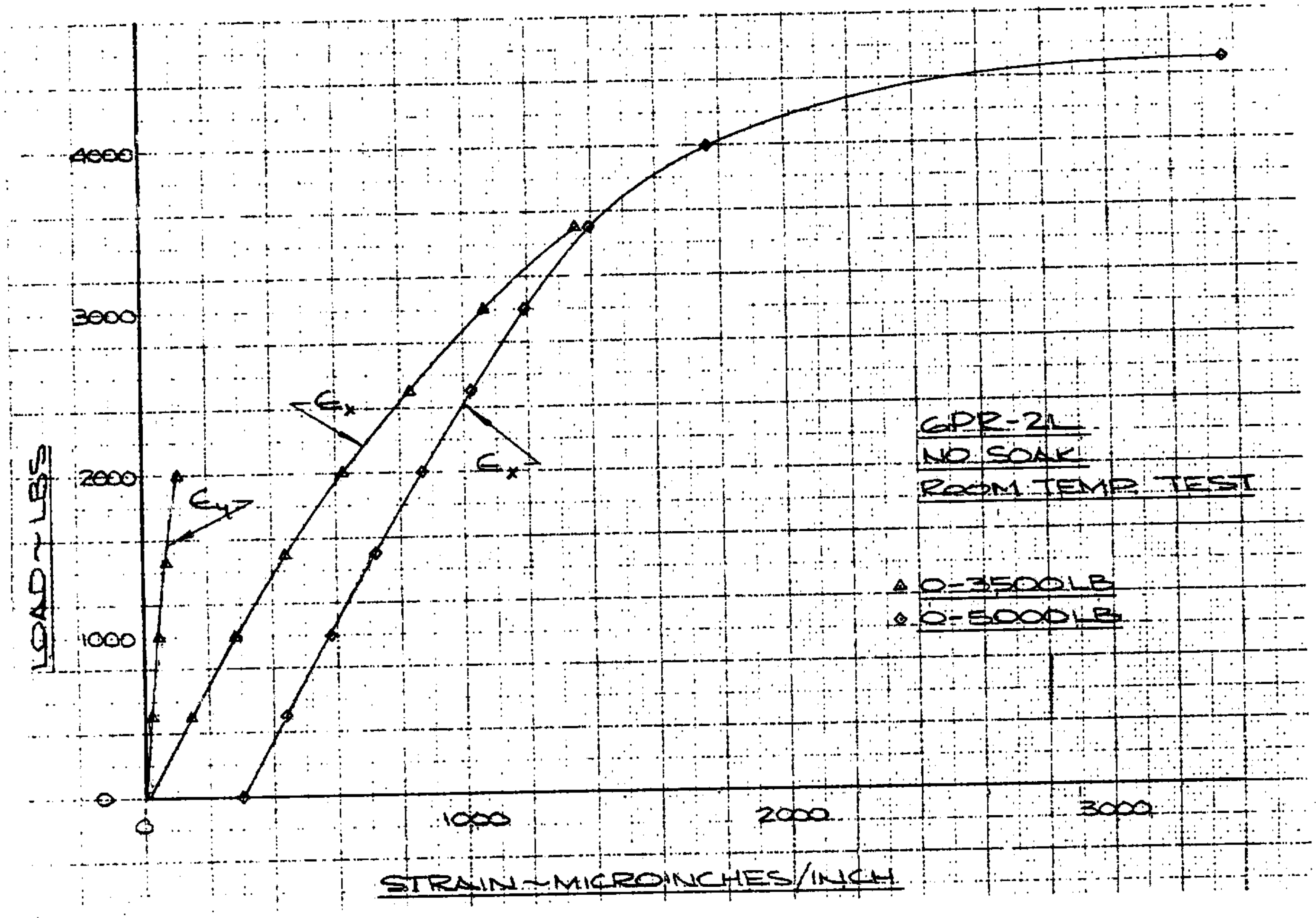


FIGURE 3.4.2.9-5b DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 6PR-2L AT ROOM TEMPERATURE - NO SOAK, LONGITUDINAL. (SHEET 2 OF 2)

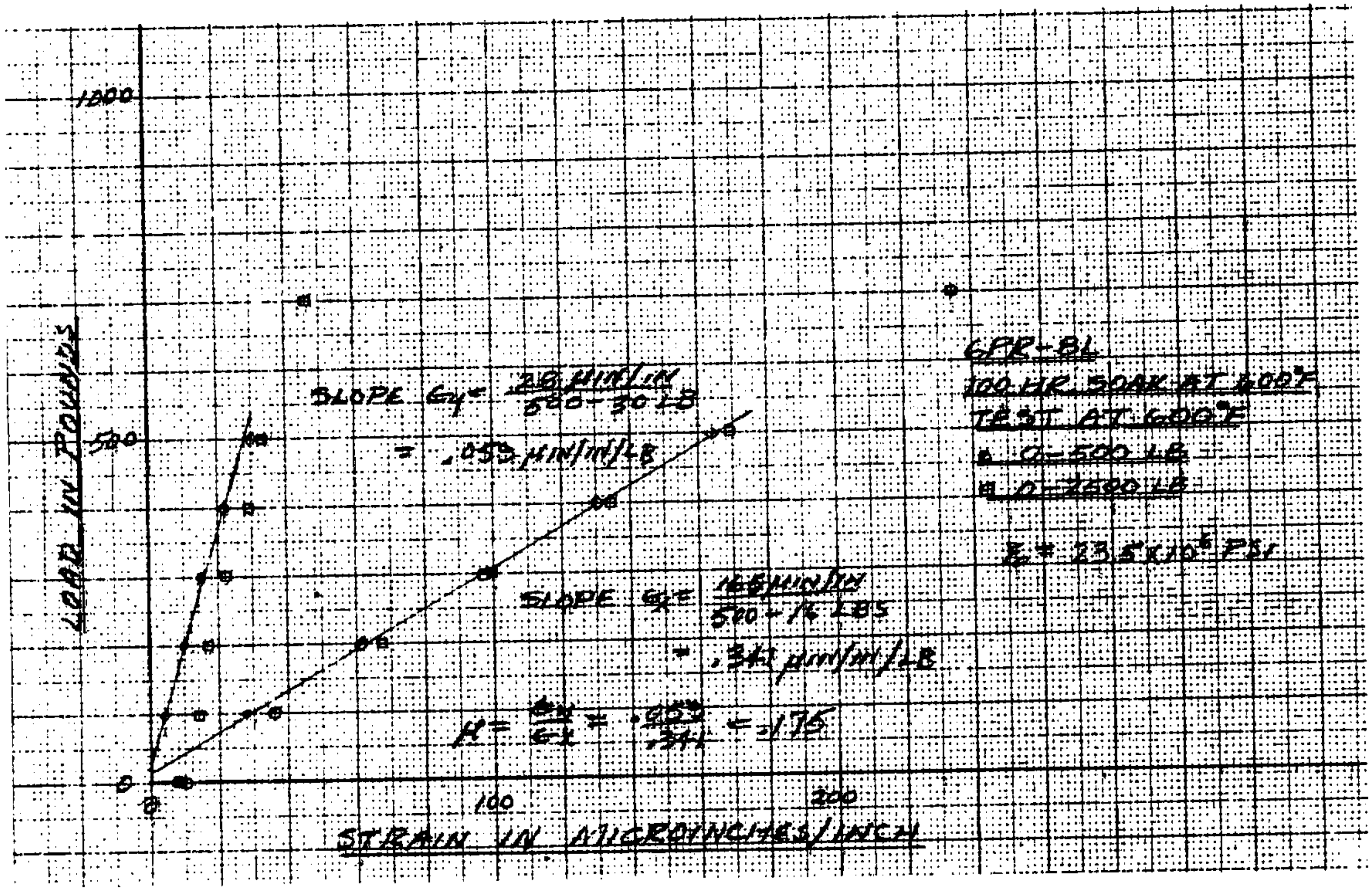


FIGURE 3.4.2 9-6a DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 6PR-8L AT 600°F AFTER 100 HOUR SOAK AT 600°F, LONGITUDINAL. (SHEET 1 OF 2)

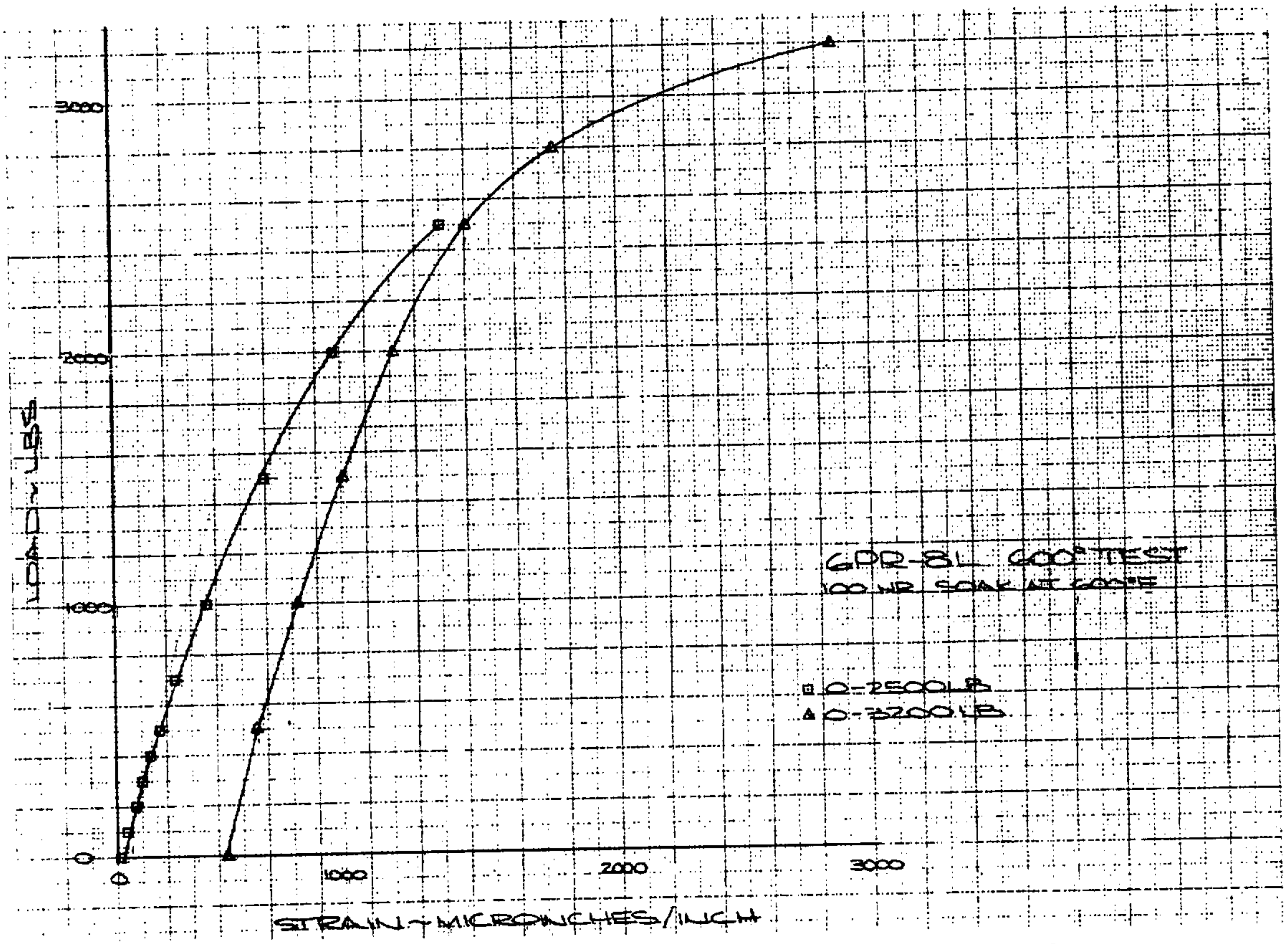


FIGURE 3.4.2.9-6b DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 6PR-8L AT 600°F AFTER 100 HOUR SOAK AT 600°F, LONGITUDINAL. (SHEET 2 OF 2)

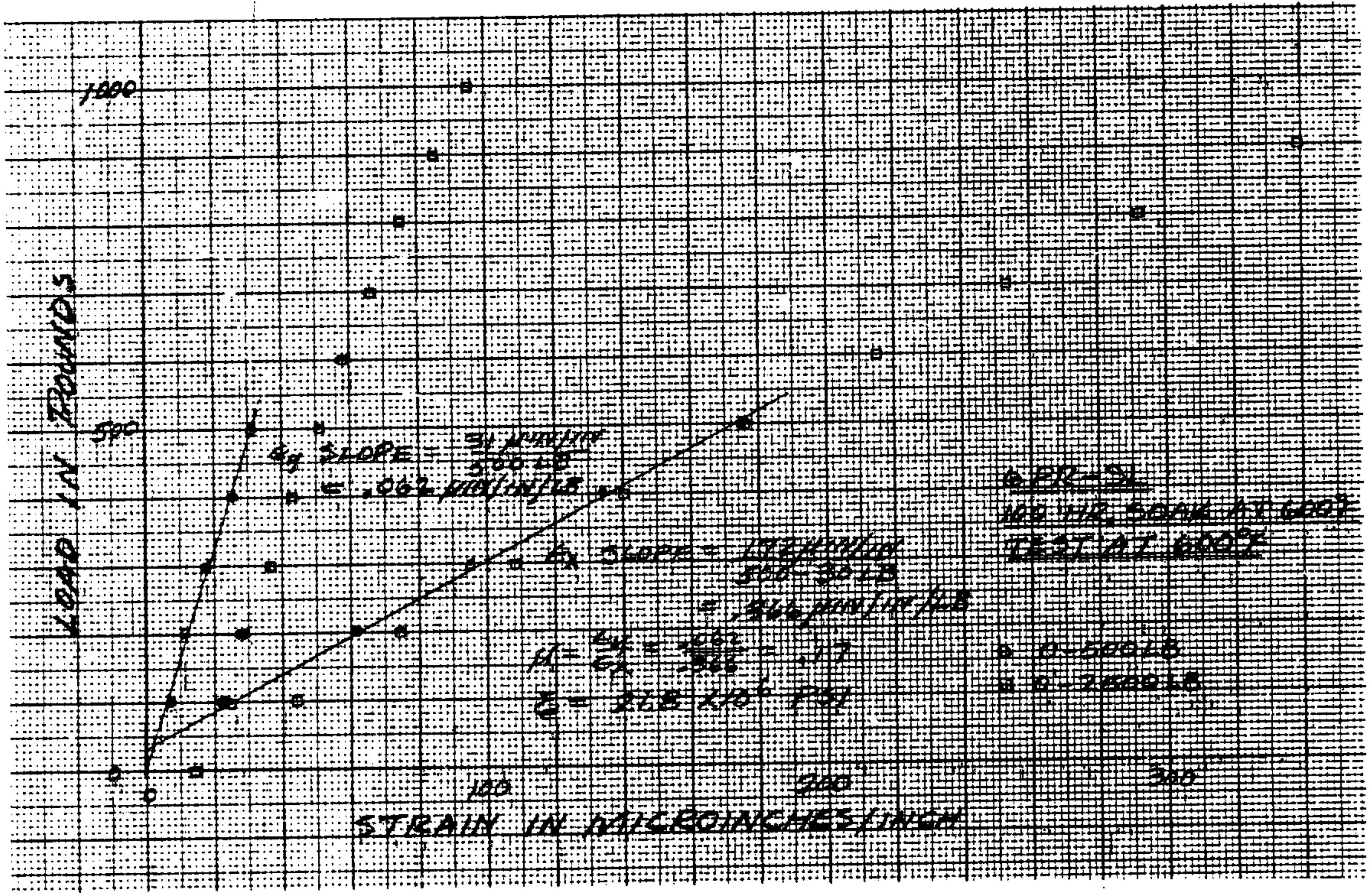


FIGURE 3.4.2.9-7a DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 6PR-9L AT 600°F AFTER 100 HOUR SOAK AT 600°F, LONGITUDINAL. (SHEET 1 OF 2)

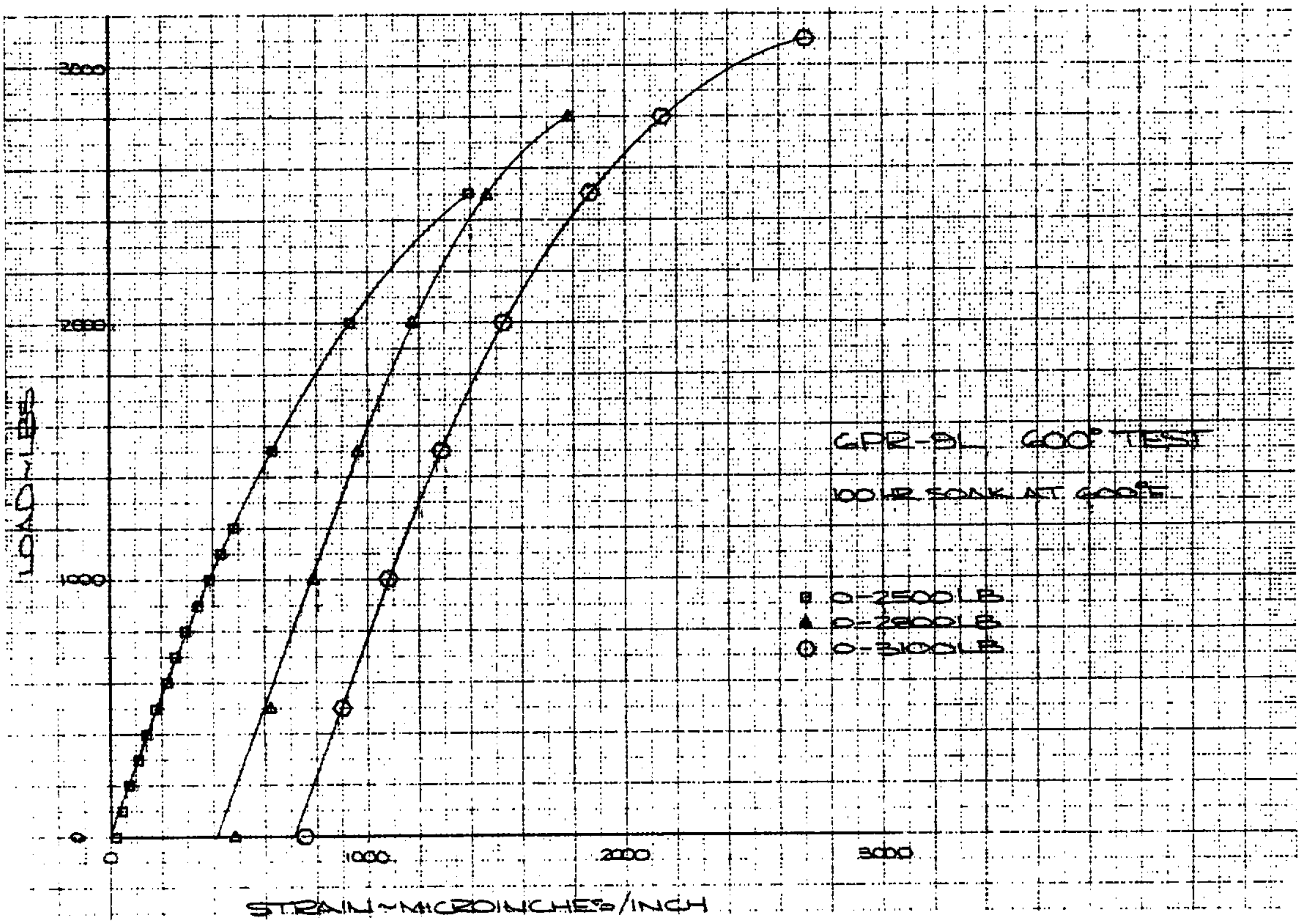


FIGURE 3.4.2.9-7b DETERMINATION OF POISSON'S RATIO AND YOUNG's MODULUS FOR SPECIMEN 6PR-9L AT 600°F AFTER 100 HOUR SOAK AT 600°F, LONGITUDINAL. (SHEET 2 OF 2)

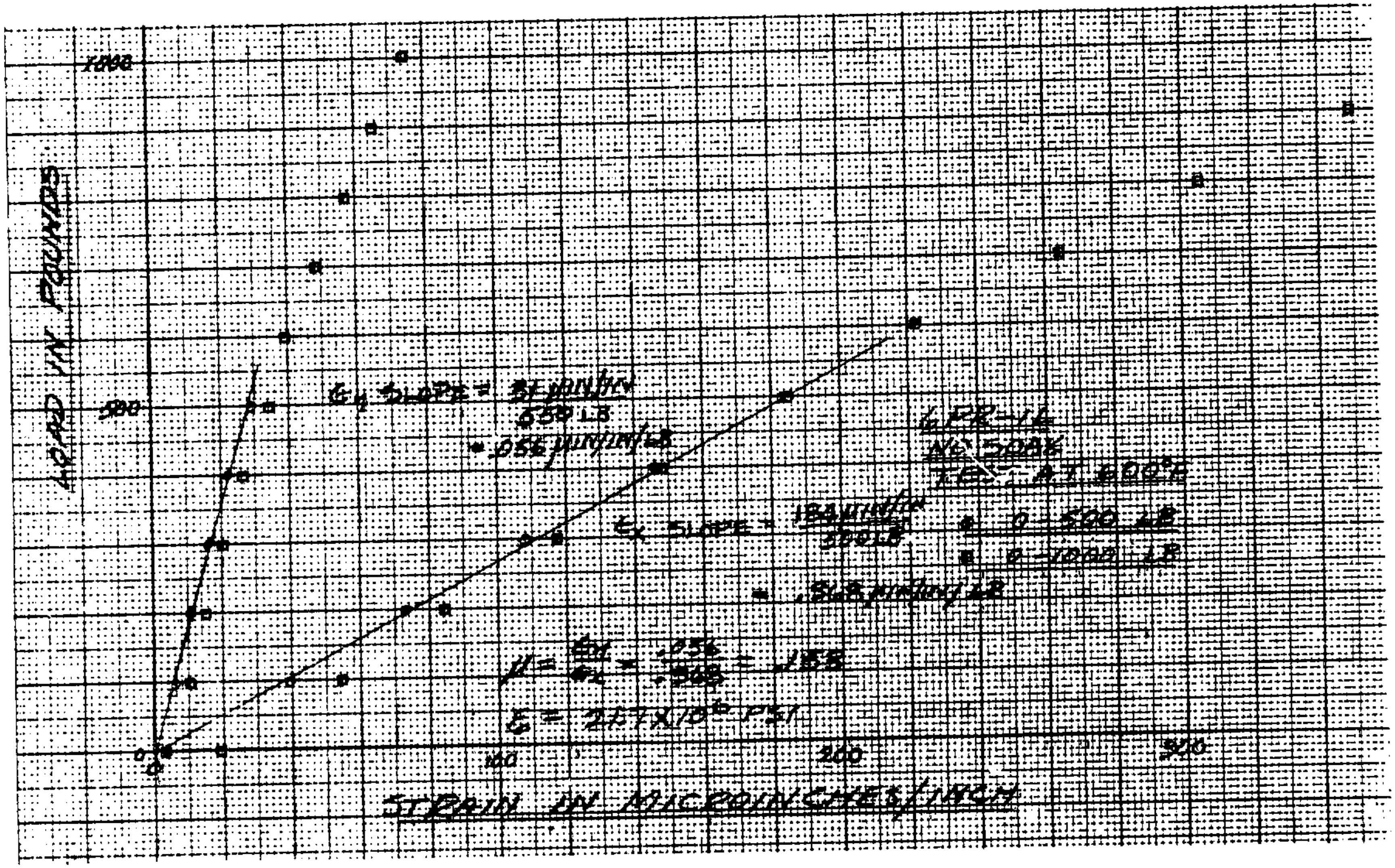


FIGURE 3.4.2.9-8a DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 6PR-1L AT 600°F - NO SOAK, LONGITUDINAL. (SHEET 1 OF 2)

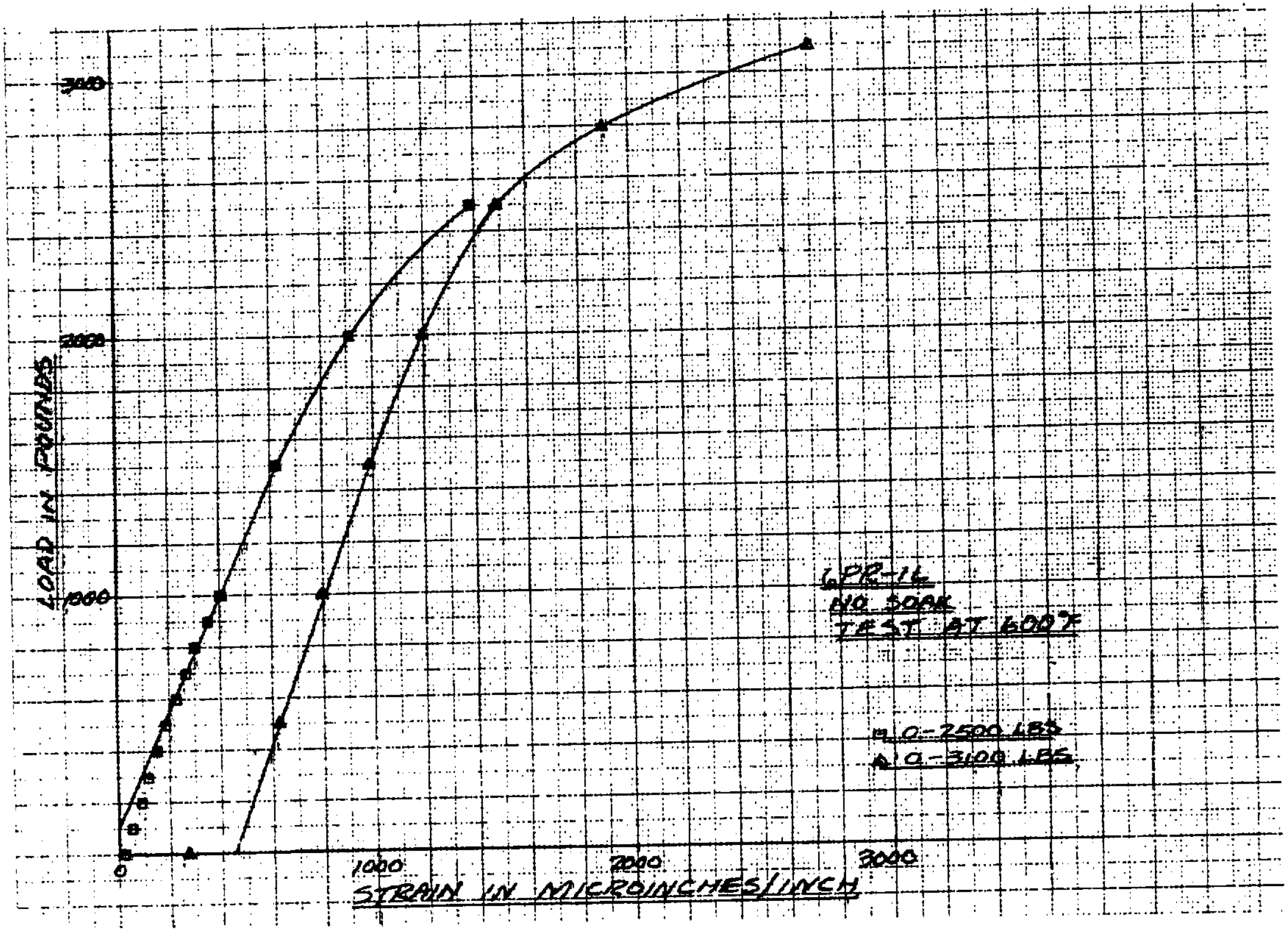


FIGURE 3.4.2.9-8b DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 6PR-1L AT 600°F - NO SOAK, LONGITUDINAL (SHEET 2 OF 2)

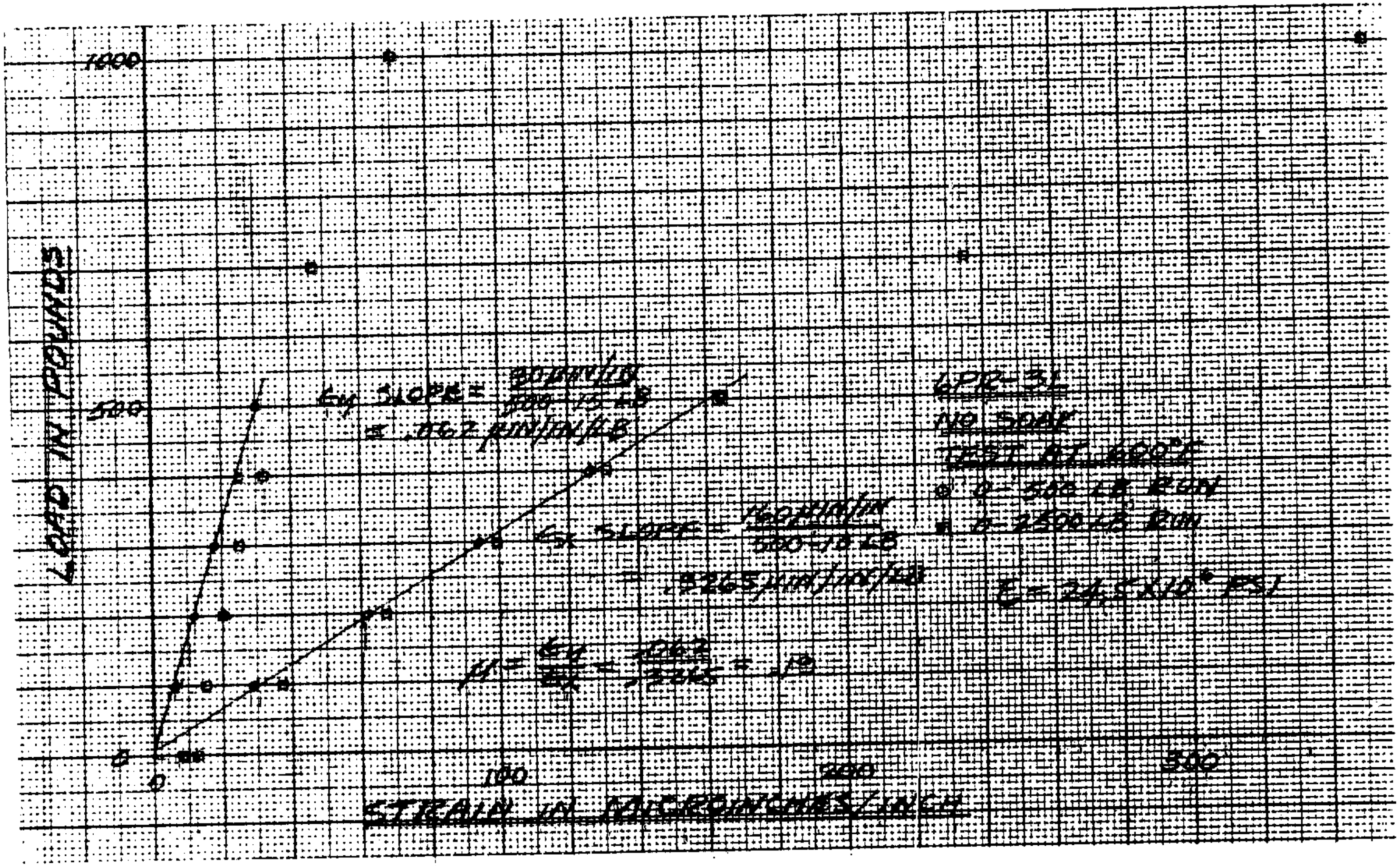


FIGURE 3.4.2.9-9a DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 6PR-3L AT 600°F - NO SOAK, LONGITUDINAL. (SHEET 1 OF 2)

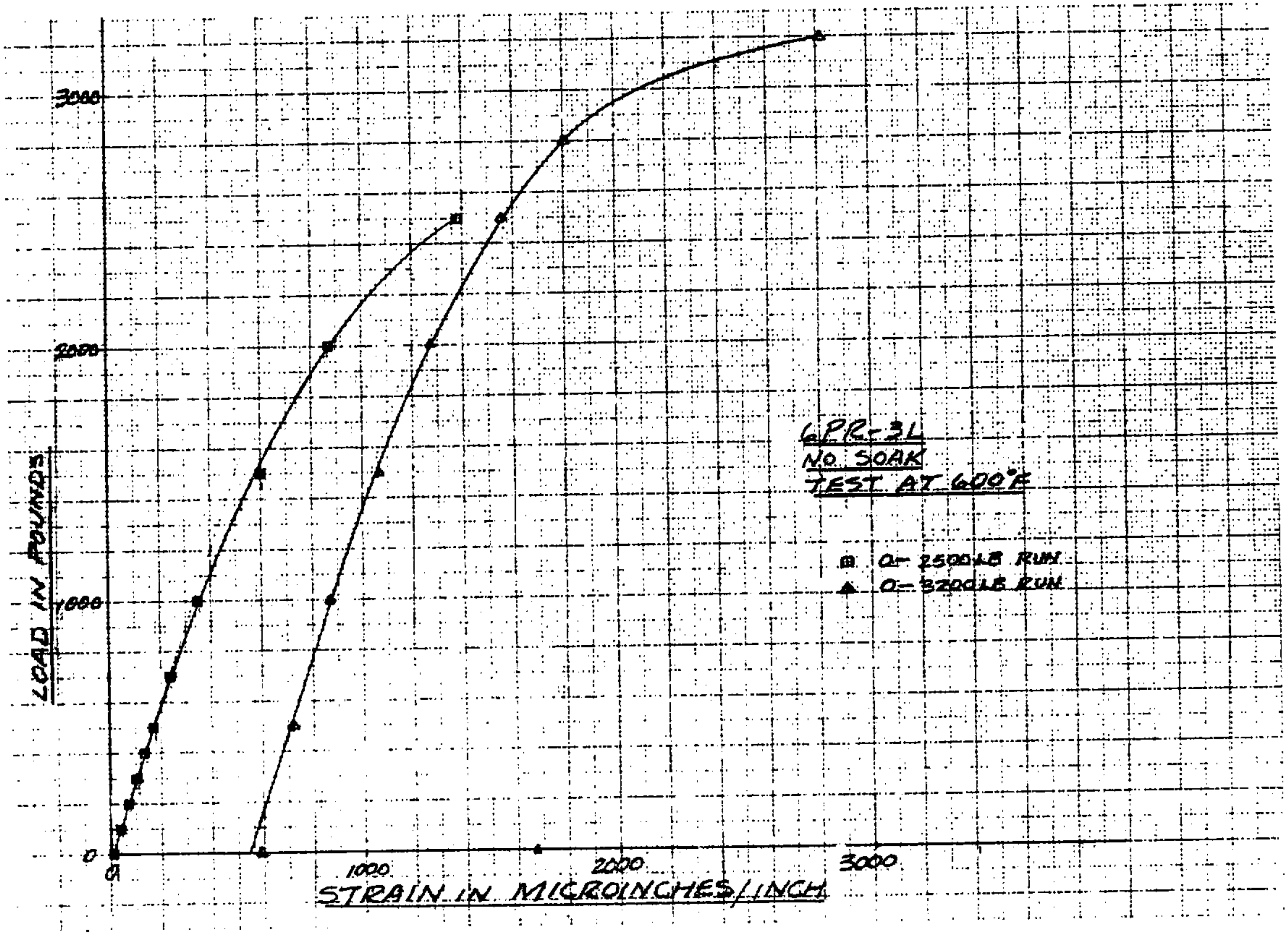


FIGURE 3.4.2.9-9b DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 6PR-3L AT 600°F - NO SOAK, LONGITUDINAL. (SHEET 2 OF 2)

3.5 TESTING OF .150 INCH THICK Be-38Al SHEET

Characterization tests on test specimens prepared from .150-inch thick Be-38Al sheet were performed to test the forming characteristics, the lap shear joint strength, and the mechanical properties of this material. These tests were especially significant because Be-38Al of the same thickness was used extensively in the fabrication of the ventral fin. The results of these tests are needed for comparison with the results of similar tests performed on .250-inch thick Be-38Al and Be-43Al plate. These tests are summarized in Table 3.5-1 and described in succeeding paragraphs. Figures 3.5-1 through 3.5-12 are presented to graphically illustrate the quantity of test specimens that were involved in these tests.

ITEM	TEST	SPECIMEN TYPE	GRAIN DIRECTION	MATERIAL CONDITION	TEST TEMP., -°F	SPECIMENS COUPONS	SPECIMEN IDENT.
1	TENSION	S-12	L	AS RECEIVED-NO SOAK	R.T.	3	3T-1L, -2L, -3L
					600	3	3T-4L, -5L, -6L
			T		R.T.	3	3T-1T, -2T, -3T
					600	3	3T-4T, -5T, -6T
			L	SOAK 100 HOURS AT 600°F	R.T.	3	3T- 7L, -8L, -9L
					600	3	3T-10L, -11L, -12L
			T		R.T.	3	3T-7T, -8T, -9T
					600	3	3T-10T, -11T, -12T
2	COMPRESSION	S-13	L	AS RECEIVED-NO SOAK	R.T.	3	3C-1L, -2L, -3L
					600	3	3C-4L, -5L, -6L
			T		R.T.	3	3C-1T, -2T, -3T
					600	3	3C-4T, -5T, -6T
			L	SOAK 100 HOURS AT 600°F	R.T.	3	3C-7L, -8L, -9L
					600	3	3C-10L, -11L, -12L
			T		R.T.	3	3C-7T, -8T, -9T
					600	3	3C-10T, -11T, -12T
3	SHEAR	S-35 or S-36	ST	AS RECEIVED-NO SOAK	R.T.	3	3B1.5-1L, -2L, -3L
					600	3	3B1.5-1T, -2T, -3T
				SOAK 113 HOURS AT 600°F	R.T.	3	3B2.0-9L, 3B1.5-8L, -9L
					600	3	3B1.5-7T, -8T, -9T
4	BEARING e/D = 2.0	S-35	L	AS RECEIVED-NO SOAK	R.T.	3	3B2-1L, -2L, -3L
					600	3	3B2-4L, -5L, -6L
			T		R.T.	3	3B2-1T, -2T, -3T
					600	3	3B2-4T, -5T, -6T
			L	SOAK 113 HOURS AT 600°F	R.T.	3	3B2-7L, -8L, -9L
					600	3	3B2-10L, -11L, -12L
			T		R.T.	3	3B2-7T, -8T, -9T
					600	3	3B2-10T, -11T, -12T
5	BEARING e/D = 1.5	S-36	L	AS RECEIVED-NO SOAK	R.T.	3	3B1.5-1L, -2L, -3L
					600	3	3B1.5-4L, -5L, -6L
			T		R.T.	3	3B1.5-1T, -2T, -3T
					600	3	3B1.5-4T, -5T, -6T
			L	SOAK 113 HOURS AT 600°F	R.T.	3	3B1.5-7L, -8L, -9L
					600	3	3B1.5-10L, -11L, -12L
			T		R.T.	3	3B1.5-7T, -8T, -9T
					600	3	3B1.5-10T, -11T, -12T
6	FRACTURE TOUGHNESS AND CRACK GROWTH RATE	S-48	L	AS RECEIVED-NO SOAK	R.T.	3	3FT-1L, -2L, -3L
					600	3	3FT-4L, -5L, -6L
			T		R.T.	3	3FT-1T, -2T, -3T
					600	3	3FT-4T, -5T, -6T
			L	SOAK 100 HOURS AT 600°F	R.T.	3	3FT-7L, -8L, -9L
					600	3	3FT-10L, -11L, -12L
			T		R.T.	3	3FT-7T, -8T, -9T
					600	3	3FT-10T, -11T, -12T
7	FATIGUE $K_t = 1$	S-29	L	AS RECEIVED-NO SOAK	R.T.	3	3UF-1L, -2L, -3L
					600	3	3UF-4L, -5L, -6L
			T		R.T.	3	3UF-1T, -2T, -3T
					600	3	3UF-4T, -5T, -6T
			L	SOAK 164 HOURS AT 600°F	R.T.	3	3UF-7L, -8L, -9L
					600	3	3UF-10L, -11L, -12L
			T		R.T.	3	3UF-7T, -8T, -9T
					600	3	3UF-10T, -11T, -12T

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 3.5-1. TEST SUMMARY FOR .150 INCH THICK Be-38Al LOCKALLOY SHEET

ITEM	TEST	SPECIMEN TYPE	GRAIN DIRECTION	MATERIAL CONDITION	TEST TEMP. -°F	NO. OF SPECIMENS	SPECIMEN IDENT.
8	FATIGUE $K_t = 3$	S-51	L	AS RECEIVED-NO SOAK	R.T.	3	3NF-1L, -2L, -3L
					600	3	3NF-4L, -5L, -6L
			T		R.T.	3	3NF-1T, -2T, -3T
					600	3	3NF-4T, -5T, -6T
			L	SOAK 164 HOURS AT 600°F	R.T.	3	3NF-7L, -8L, -9L
					600	3	3NF-10L, -11L, -12L
			T		R.T.	3	3NF-7T, -8T, -9T
					600	3	3NF-10T, -11T, -12T
9	STRESS CORROSION	S-47	T	AS RECEIVED-NO SOAK BARE - 3 1/2% NaCl	R.T.	3	3SC-1T, -2T, -3T
					600	3	3SC-4T, -5T, -6T
				AS RECEIVED-NO SOAK ALODINE COAT+ 3 1/2% NaCl	R.T.	3	3SC-7T, -8T, -9T
					600	3	3SC-10T, -11T, -12T
				AS RECEIVED-NO SOAK PAINT + 3 1/2% NaCl	R.T.	3	3SC-13T, -14T, -15T
					600	3	3SC-16T, -17T, -18T
10	CREEP	S-7	L	AS RECEIVED-NO SOAK	600	3	3CR-1L, -2L, -3L
			T			3	3CR-1T, -2T, -3T
11	POISSON'S RATIO	S-7	L	AS RECEIVED-NO SOAK	R.T.	3	3PR-1L, -2L, -3L
					600	3	3PR-4L, -5L, -6L
				SOAK 100 HOURS AT 600°F	R.T.	3	3PR-7L, -8L, -9L
					600	3	3PR-10L, -11L, -12L
12	NOTCHED TENSION		L	AS RECEIVED-NO SOAK	R.T.	3	3NT-1L, -2L, -3L
			T		600	3	3NT-1T, -2T, -3T
13	LAP SHEAR JOINT	S-54-4	-	AS RECEIVED-NO SOAK FLUSH SCREW-3/16 IN. DIA.	R.T.	3	5J3.15-1A, 1B; -2A, 2B; -3A, -3B.
					600	3	5J3.15-4A, 4B; -5A, 5B; -6A, 6B.
		S-54-5		AS RECEIVED-NO SOAK FLUSH SCREW-1/4 IN. DIA.	R.T.	3	6J4.15-1A, 1B; -2A, 2B; -3A, 3B.
					600	3	6J4.15-4A, 4B; -5A, 5B; -6A, 6B.
		S-54-4		AS RECEIVED-NO SOAK (.125 IN. THICK MATERIAL) FLUSH SCREW-3/16 IN. DIA.	R.T.	3	3J3.125-1A, 1B; -2A, 2B; -3A, 3B.
					600	3	3J3.125-4A, 4B; -5A, 5B; -6A, 6B.
		S-55-4		AS RECEIVED-NO SOAK (.125 IN. THICK MATERIAL) FLUSH NUT/FLUSH SCREW-3/16 IN. DIA.	R.T.	3	4J3.125-1A, 1B; -2A, 2B; -3A, 3B.
					600	3	4J3.125-4A, 4B; -5A, 5B; -6A, 6B.
14	TENSION	S-12	L	AS RECEIVED-TEST AT TWO DIFFERENT STRAIN RATES	R.T.	6	3T-13L ← 3T-18L
15				STRESS RELIEVE - 1 HOUR AT 1050°F	R.T.	3	3T-19L, -20L, -21L
16				AS RECEIVED-TEST AT 3 DIFFERENT STRAIN RATES	1050	9	3T-22L ← 3T-30L
17				STRETCH 5% AT 1050°F-STRESS RELIEVE	R.T.	3	3T-31L, -32L, -33L
18			T	SAME AS ITEM 15	R.T.	3	3T-13T, -14T, -15T
19				SAME AS ITEM 17		3	3T-16T, -17T, -18T
20	BEND	S-50	L	AS REC'D - BEND AT R.T. TO ESTABLISH MINIMUM BEND RADIUS	R.T.	5	4BM-[illegible] ← 4BM-5L
			T			3	4BM-1T, -3T, -5T
21		S-46	L	AS REC'D - BEND AT 1050°F TO ESTABLISH MINIMUM BEND RADIUS	1050	5	4UB-1L ← 4UB-5L
			T			5	4UB-1T ← 4UB-5T

NOTES:

1. FIRST DIGIT OF SPECIMEN IDENTIFICATION INDICATES THE FOLLOWING: 3-SHEET NO. HC 243-3, 4-SHEET NO. HC 243-1 EXCEPT LAP-SHEAR JOINT SPECIMENTS.
2. SPECIMENS IDENTIFIED 3B1.5 THRU -7T, 3B1.5-12T, 3PR-1L THRU -12L, 3CR-1L THRU 3L AND 3CR-1T THRU -3T WERE OBTAINED FROM SHEET NO. HC 243-1 (SHOULD HAVE BEEN IDENTIFIED WITH THE FIRST DIGIT OF 4).
3. LAP-SHEAR JOINT SPECIMENS WERE PREPARED FROM REMNANTS OF SHEET MATERIAL INTENDED FOR FIN FABRICATION AS FOLLOWS
   3J3.125-1A, -1B THRU 3J3.125-6A - SHEET NO. HC 137-5, 3J3.125-6B - SHEET NO. HC 197-3
   4J3.125-1A, -1B THRU 4J3.125-6A, 6B - SHEET NO. HC 160-3
   5J3.15-1A, 1B THRU 5J3.15-3A, 3B - SHEET NO. HC 127-3, 5J3.15-4A, 4B THRU 5J3.15-6A, 6B - SHEET NO. HC 161-2.
   6J4.15-1A, 1B AND -2A, 2B - SHEET NO. HC 227-1; 6J4.15-3A, 3B AND 4A - SHEET NO. JC 161-4, 6J4.15-6A, 6B AND -4B - SHEET NO. HC 161-5
   6J4.15-5A, 5B - SHEET NO. HC 227-3.

TABLE 3.5-3. TEST SUMMARY FOR . [illegible] INCH THICK Be-38%Al LOCKALLOY SHEET (CONTINUED)

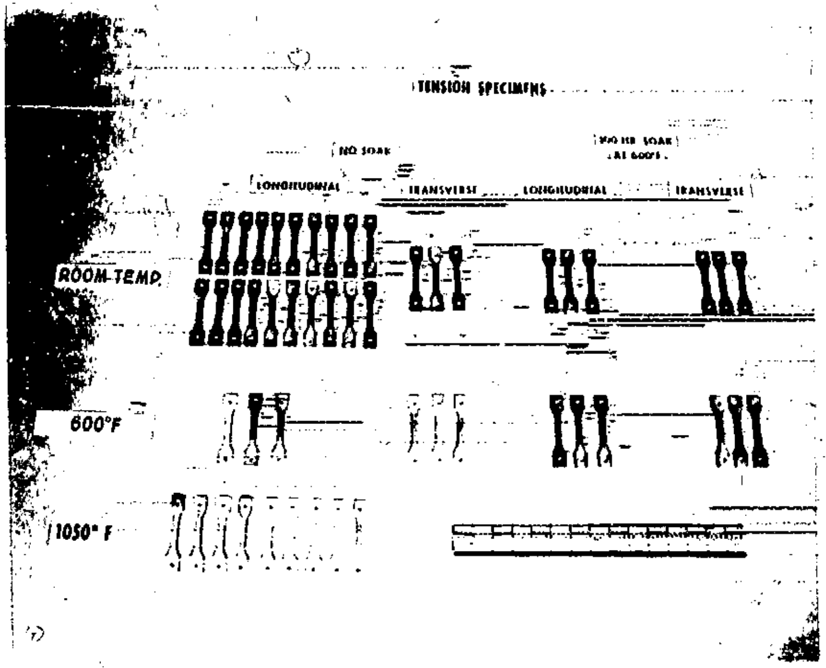


Fig. 3.5-1 - Tension Specimens

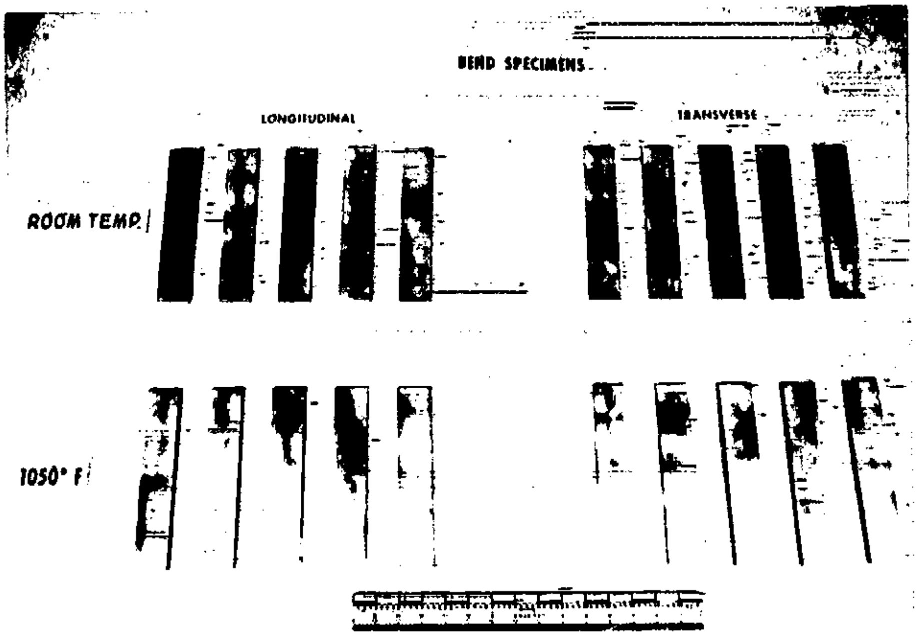
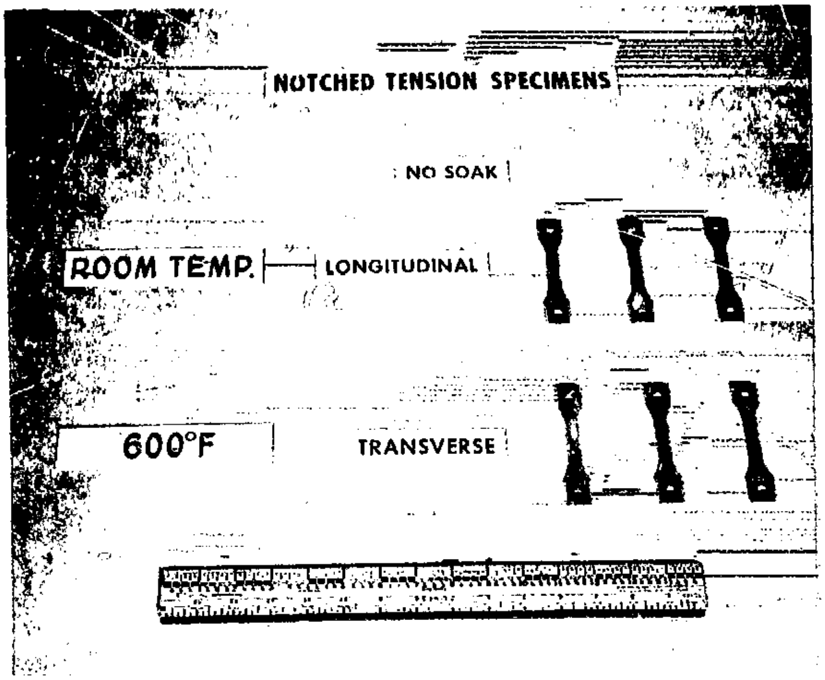
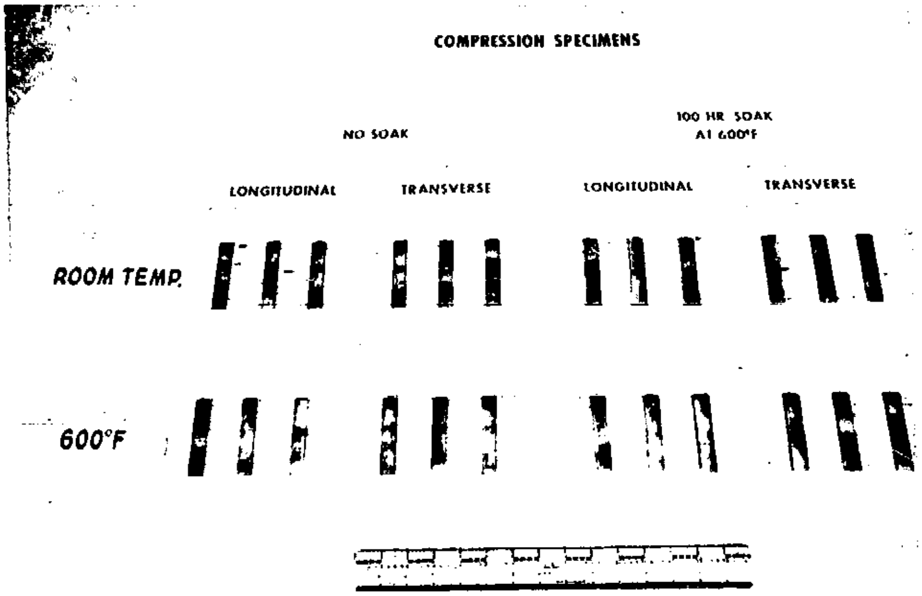


Fig. 3.5-2 - Bend Specimens



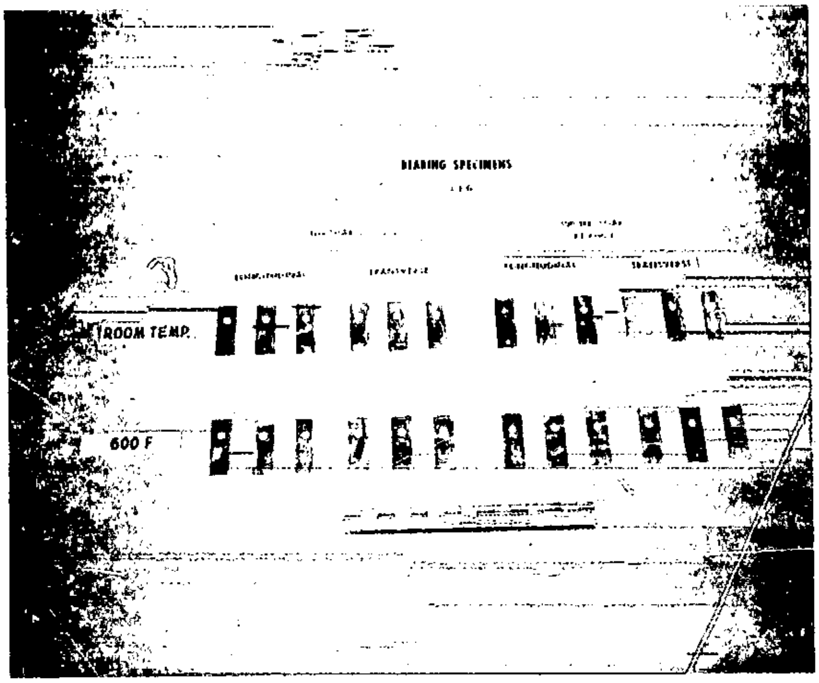
75-5354-13

Fig. 3.5-3 - Notched Tension Specimens



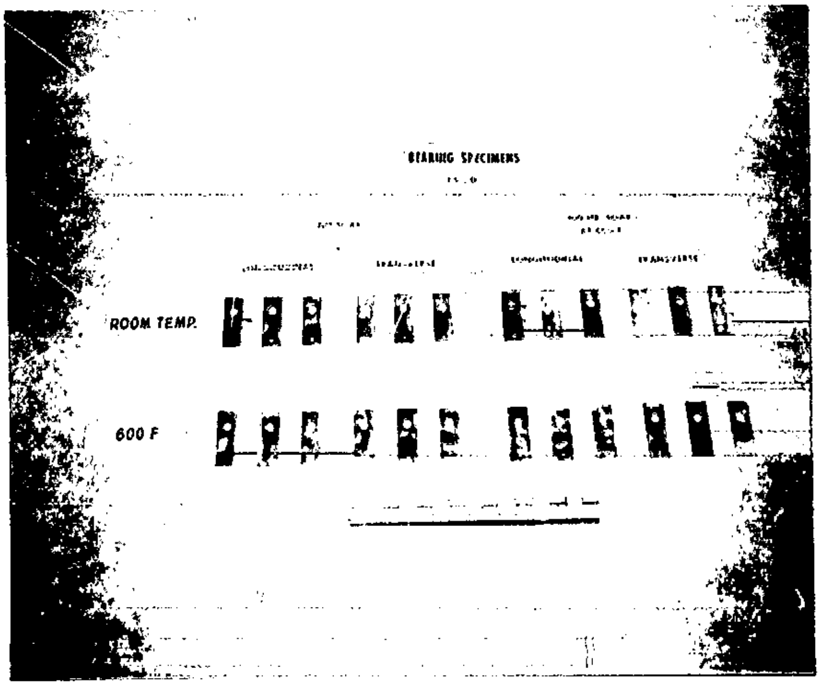
75-5172-3

Fig. 3.5-4 - Compression Specimens



75-5358-4

Fig. 3.5-5 - Bearing Specimens (1.5 e/D)



75-5358-1

Fig. 3.5-6 - Bearing Specimens (2 e/D)

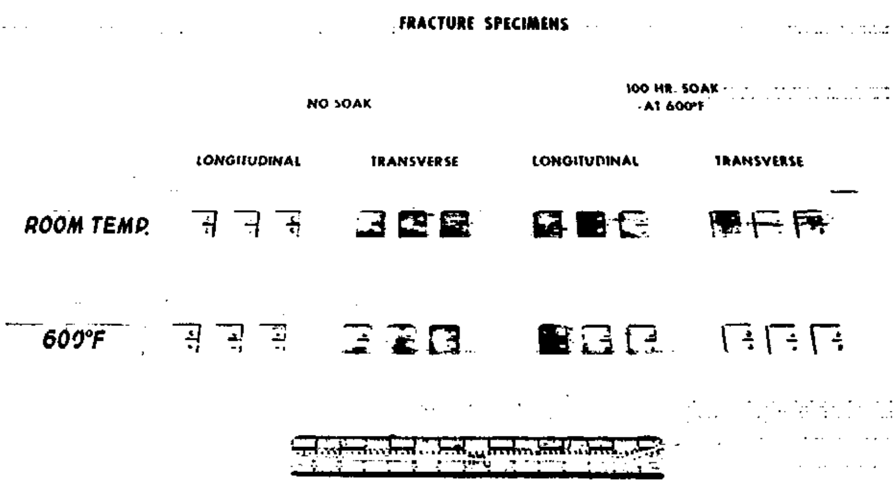


Fig. 3.5-7 - Fracture Specimens

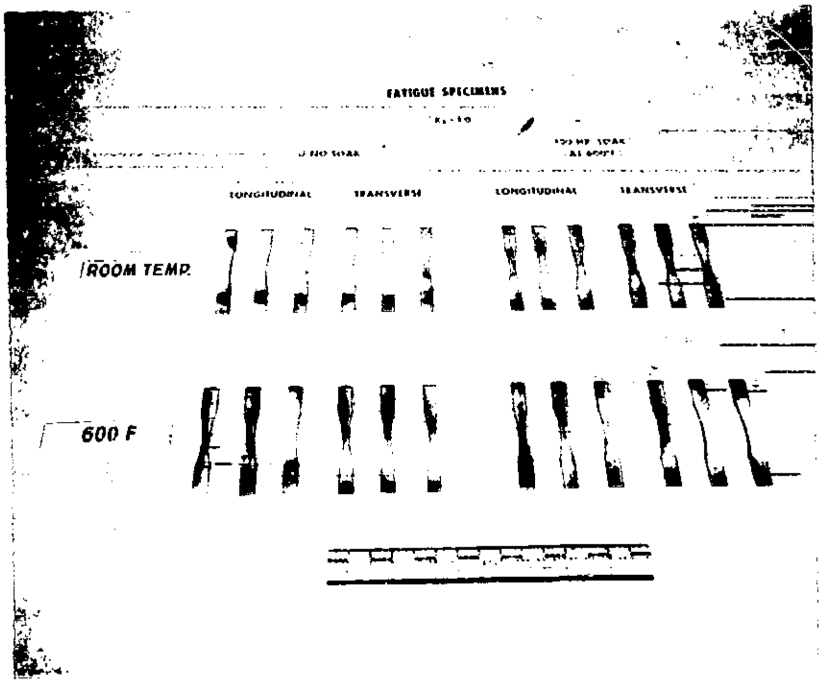


Fig. 3.5-8 - Fatigue Specimens (K_t = 1.0)

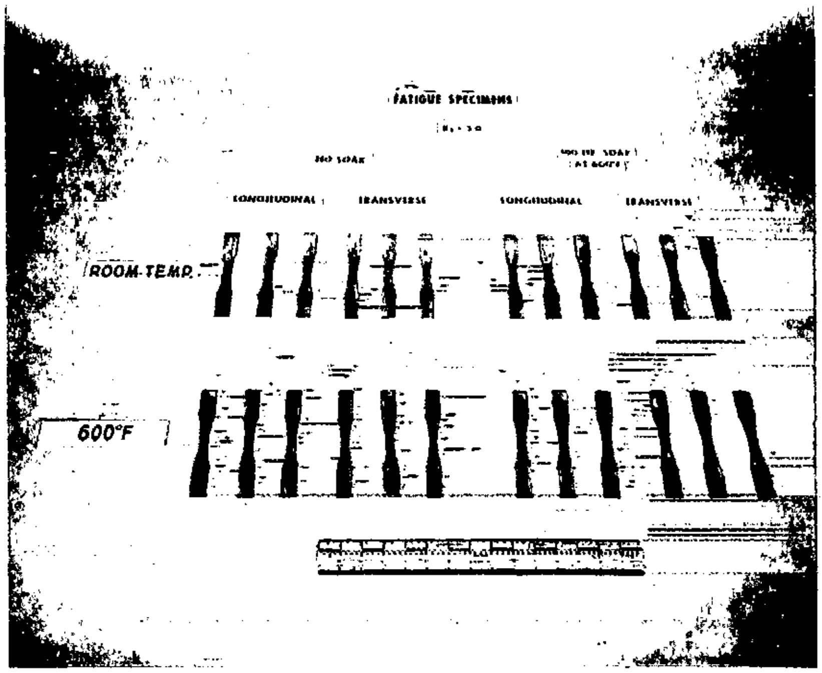


Fig. 3.5-9 - Fatigue Specimens ($K_t = 3.0$)

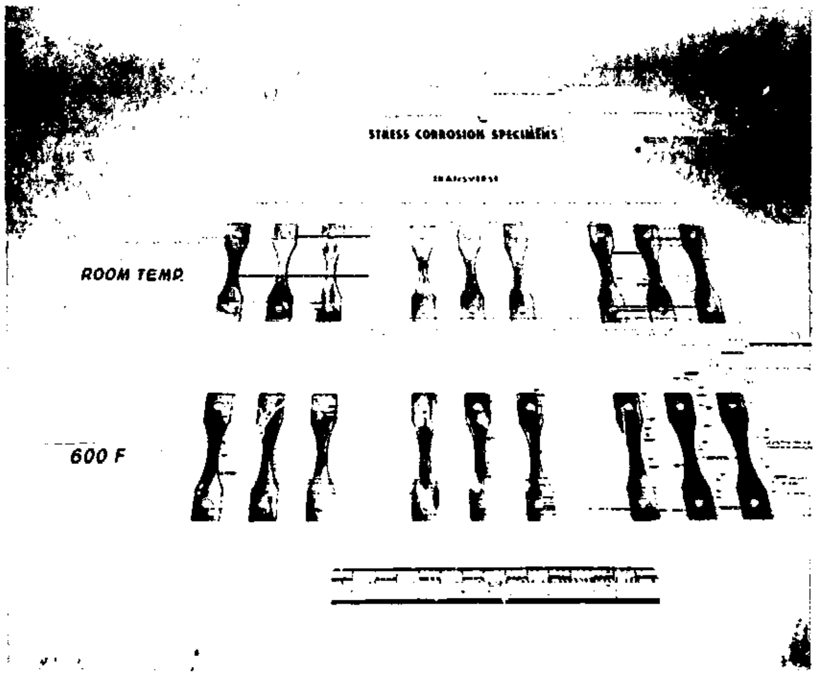


Fig. 3.5-10 - Stress Corrosion Specimens

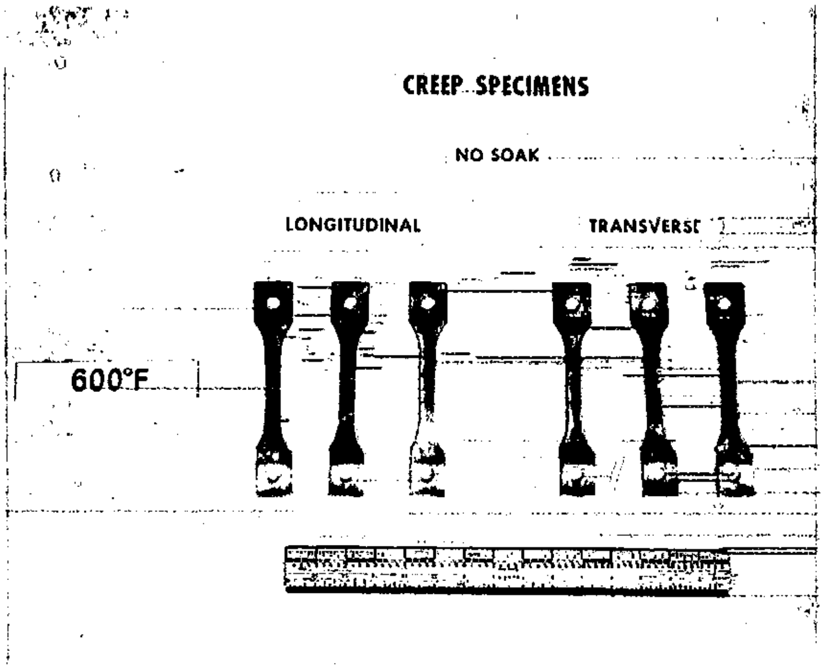


Fig. 3.5-11 - Creep Specimens

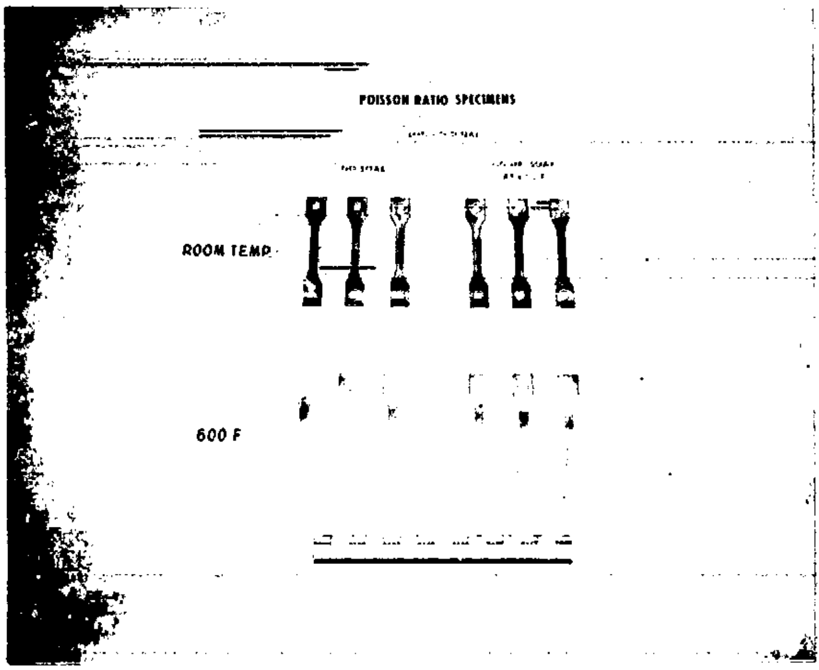


Fig. 3.5-12 - Poisson's Ratio Specimens

3.5.1 Formability Characteristics - Be-38Al .150 Thickness - Only spot tests were performed in connection with the formability characteristics of Be-38Al .150 thickness and are listed in Table 3.5.1-1. Test data is shown in Tables 3.5.1-1 through 3.5.1-4. The same comments and observations made for the Be-38Al .250 thick material also applies to the .150 thick material.

SPECIMEN IDENTIFICATION	STRAIN RATE IN/IN/MIN	DIRECTION	TEST TEMP	ULTIMATE KSI	YIELD KSI	% ELONG IN 1 INCH	E X 10^{-6} PSI
3T-13L	.005	LONG	ROOM TEMP	51.2	35.6	10	26.1
3T-14L				51.1	35.7	10	26.7
3T-15L				50.5	35.4	9	26.6
AVG				50.9	35.6	10	26.5
3T-16L	.050	LONG	ROOM TEMP	50.7	36.3	9	24.5
3T-17L				49.4	36.4	7	27.2
3T-18L				51.5	36.5	10	27.8
AVG				50.5	36.4	9	26.5
3T-22L	.005	LONG	1050°F	5.5	3.4	14	4.6
3T-23L				5.6	3.4	17	5.3
3T-24L				5.5	3.5	13	5.7
AVG				5.5	3.4	15	5.2
3T-25L	.0005	LONG	1050°F	5.2 (1.)	1.7	13	3.5
3T-26L				5.3 (1.)	1.6	11	3.2
3T-27L				5.3 (1.)	1.3	13	4.0
AVG				5.3	1.5	13	3.6
3T-28L	.050	LONG	1050°F	5.5	4.6	13	7.2
3T-29L				6.3	5.6	13	7.1
3T-30L				7.2	6.3	11	8.9
AVG				6.3	5.5	12	7.7

(1.) TEST RATE INCREASED AFTER YIELD

REF: 568958, 568961

TABLE 3.5.1-1. TENSILE TEST RESULTS OF .150 THICK Be-38Al LOCKALLOY SHEET TESTED AT DIFFERENT STRAIN RATES AT ROOM TEMP. AND 1050°F

SPECIMEN IDENTIFICATION	CONDITION	ROLLING DIRECTION	TEST TEMP	ULTIMATE KSI	YIELD KSI	% ELONG IN 1 INCH	E X 10^{-6} PSI
3T-31L	STRETCH 5% @ 1050°F, RELAX, STRESS RELIEVE 1 HR @ 1050°F, TEST	LONG	ROOM TEMP	42.9	34.9	11	16.8
3T-32L				42.7	33.7	11	25.7
3T-33L				44.6	34.7	11	29.6
AVG				43.4	34.4	11	24.0
3T-16T	STRETCH 5% @ 1050°F, RELAX, STRESS RELIEVE 1 HR @ 1050°F, TEST	TRANS	ROOM TEMP	42.4	33.3	10	26.4
3T-17T				43.8	32.0	11	41.8
3T-18T				43.0	33.6	10	25.4
AVG				43.1	33.0	10	31.2

REF: RN 568962

TABLE 3.3.1-[illegible]. TENSILE TEST RESULTS OF .150 THICK Be-38Al LOCKALLOY SHEET AFTER STRETCHING @ 1050°F

SPECIMEN IDENTIFICATION	CONDITION	DIRECTION	ULTIMATE KSI	YIELD KSI	% ELONG IN 1 INCH	E X 10^{-6} PSI
3T-1L	AS RECEIVED	LONG	47.1	37.4	5	24.7
3T-2L			51.2	37.2	10	29.1
3T-3L			51.1	37.0	10	27.9
AVG			49.8	37.2	8	27.2
3T-1T	AS RECEIVED	TRANS	51.2	34.9	10	28.7
3T-2T			51.4	35.0	10	29.8
3T-3T			51.4	35.0	11	24.7
AVG			51.3	35.0	10	27.7
3T-7L	EXPOSED 100 HR @ 600°F, TEST	LONG	51.4	36.7	11	27.4
3T-8L			51.5	36.6	12	27.3
3T-9L			51.5	36.5	12	23.3
AVG			51.5	36.6	12	26.0
3T-7T	EXPOSED 100 HR @ 600°F, TEST	TRANS	51.4	35.0	11	25.8
3T-8T			51.8	34.8	13	25.8
3T-9T			51.7	34.8	13	24.8
AVG			51.6	34.9	12	25.3
3T-19L	EXPOSED 1 HR @ 1050°F, TEST	LONG	51.0	35.2	12	24.2
3T-20L			50.7	34.7	10	39.8
3T-21L			50.5	35.0	10	32.3
AVG			50.7	35.0	11	32.1
3T-13T	EXPOSED 1 HR @ 1050°F, TEST	TRANS	51.0	33.6	11	37.8
3T-14T			51.2	34.0	13	34.5
3T-15T			51.1	34.1	11	27.0
AVG			51.1	33.9	12	33.1

REF: RN568957 and RN568958

TABLE 3.7.1-3. TENSILE TEST RESULTS OF .150 THICK Be-38Al LOCKALLOY AT ROOM TEMPERATURE, WITH AND WITHOUT EXPOSURE FOR 100 HRS @ 600°F, AND ONE HOUR AT 1050°F

SPECIMEN IDENTIFICATION	CONDITION	DIRECTION	ULTIMATE KSI	YIELD KSI	% ELONG IN 1 INCH	E X 10^{-5} PSI
3T-4L	AS RECEIVED	LONG	24.1	22.7	10	16.3
3T-5L			24.8	23.5	9	16.5
3T-6L			24.6	23.2	9	20.2
AVG			24.5	23.1	9	17.6
3T-4T	AS RECEIVED	TRANS	23.3	21.4	11	15.2
3T-5T			23.3	21.2	10	17.8
3T-6T			23.2	21.2	9	18.7
AVG			23.3	21.3	10	17.2
3T-10L	EXPOSED 100 HRS @ 600°F	LONG	24.2	22.3	11	20.5
3T-11L			23.9	21.8	11	18.3
3T-12L			24.4	22.4	11	17.0
AVG			24.2	22.2	11	18.6
3T-10T	EXPOSED 100 HRS @ 600°F	TRANS	23.4	21.2	10	19.2
3T-11T			23.3	21.2	10	21.5
3T-12T			23.3	21.2	10	19.0
AVG			23.3	21.2	10	19.9

REF: RN 568960

TABLE [illegible]. TENSILE TEST RESULTS OF .150 THICK Be-38Al LOCKALLOY PLATE @ 600°F.
WITH AND WITHOUT EXPOSURE TO 600°F FOR 100 HRS

3.5.1.1 Tensile Tests - The procedure used for testing the Be-38Al material is the same as that employed for the Be-43Al material. This is described in Section 3.3.1.1 and is not repeated here.

The results of tensile tests of .15 thick Be-38Al alloy are presented in Tables 3.5.1-1 through 3.5.1-4.

For the .150 inch thick Be-38Al alloy typical stress-strain curves in the as received condition, tested at both room temperature and at 600°F and in both the longitudinal and transverse directions are presented in Figures 3.5.1.1-1 and 3.5.1.1-2.

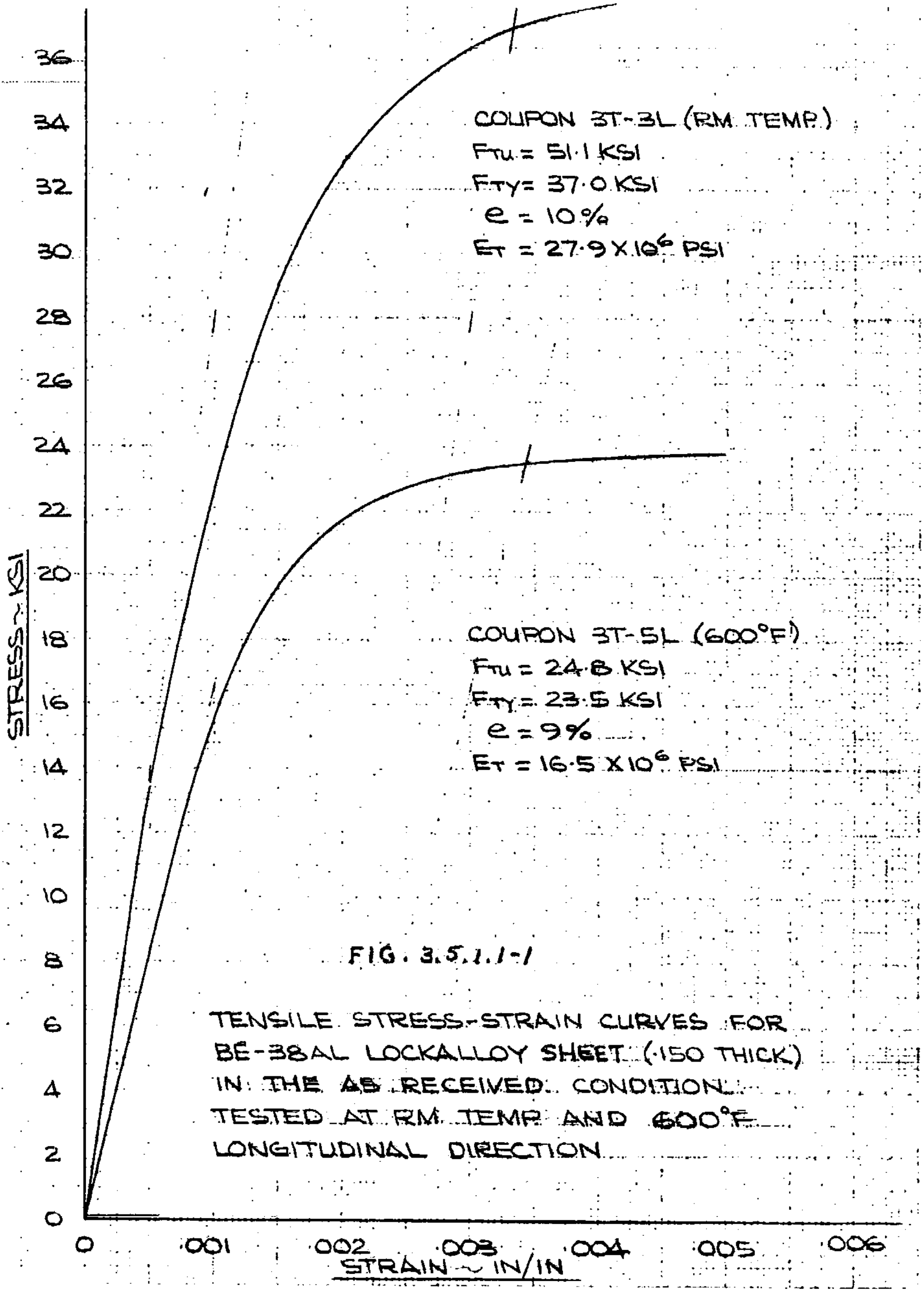


FIG. 3.5.1.1-1

TENSILE STRESS-STRAIN CURVES FOR BE-38AL LOCKALLOY SHEET (.150 THICK) IN THE AS RECEIVED CONDITION TESTED AT RM. TEMP. AND 600°F LONGITUDINAL DIRECTION

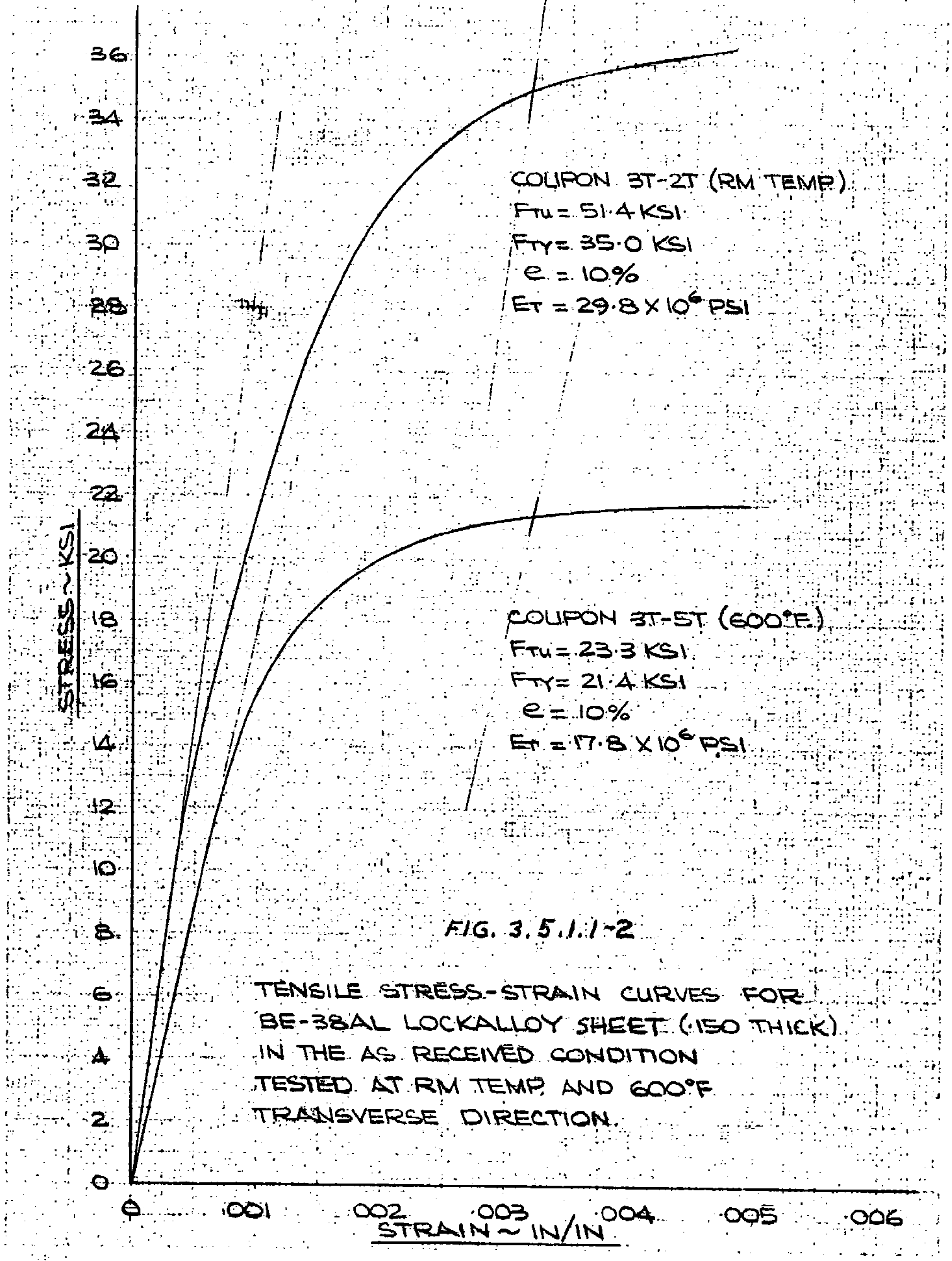


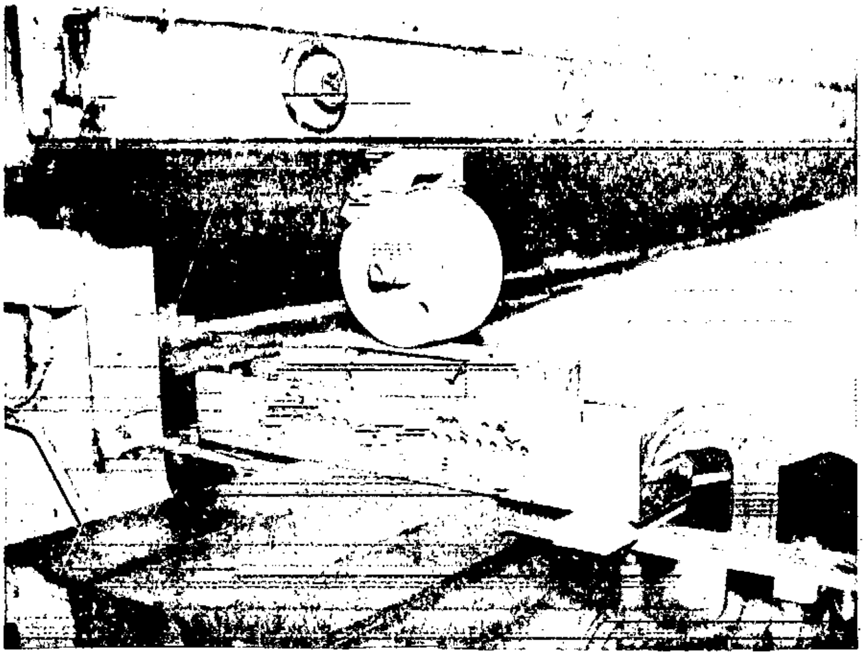
FIG. 3.5.1.1-2

TENSILE STRESS-STRAIN CURVES FOR BE-38AL LOCKALLOY SHEET (.150 THICK) IN THE AS RECEIVED CONDITION TESTED AT RM TEMP AND 600°F TRANSVERSE DIRECTION.

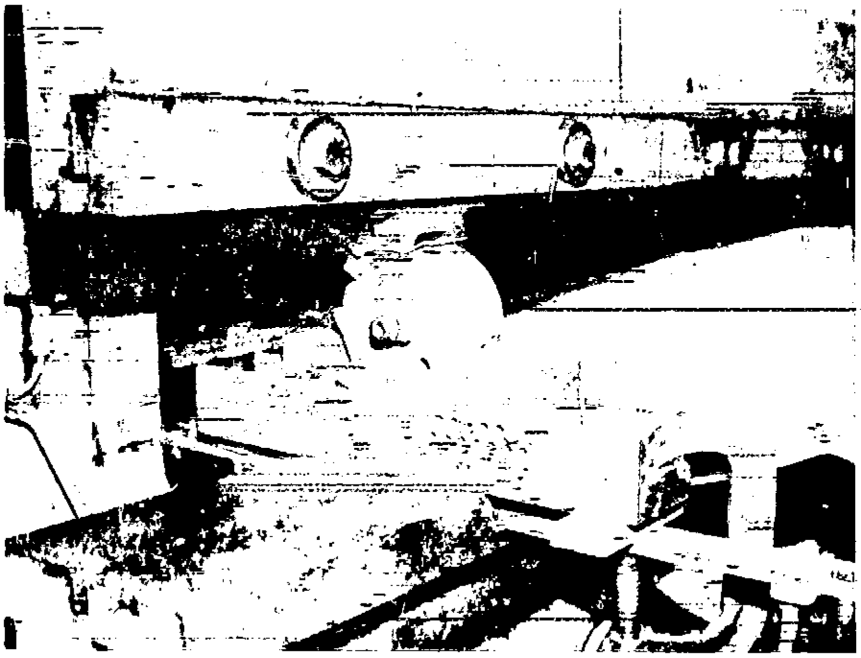
3.5.1.2 Bend Tests-Three Point - The procedure used for testing the Be-38Al material is the same as that employed for the Be-43Al material. This is described in Section 3.3.1.2 and is not repeated.

The room temperature bend tests were accomplished in a power brake utilizing the same bending fixture as was also used for the 1050°F bend tests. This is possible because of the reduced thickness of the bend specimen (.15 versus .25) a typical set-up in the power brake before and after bending is shown in Figure 3.5.1.2-1

The results of the room temperature and 1050°F tests for the .150 thick Be-38Al alloy are presented in Table 3.5.1.2-1. Based on these tests, the remarks made for the .25 inch thick Be-38Al alloy in Section 3.4.1.2 are also applicable here.



Before Bending



After Bending

Figure 3.5.1.2-1 Typical Set-Up of Room Temperature Bend Test at R/t = 15.0 in Power Brake

FORMING TEMP.	RADIUS / THICKNESS	GRAIN DIRECTION	SPECIMEN NUMBER	RESULTS
ROOM TEMP.	20	LONG.	4BM-5L	NO FAILURE AT 105° BEND.
		TRANS.	4BM-5T	
	15	LONG.	4BM-3L	NO FAILURE AT 105° BEND.
		TRANS.	4BM-3T	
	13.3	LONG.	4BM-2L	FAILED AT 25° BEND.
			4BM-1L	NO FAILURE AT 105° BEND.
		TRANS.	4BM-1T	FAILED AT 32.5° BEND.
1050°F	6.7	LONG.	4UB-2L	NO FAILURE AT 105° BEND.
			4UB-3L	
		TRANS.	4UB-2T	NO FAILURE AT 105° BEND.
			4UB-3T	
	5.8	LONG.	4UB-1L	NO FAILURE AT 105° BEND.
		TRANS.	4UB-1T	MULTIPLE SURFACE CRACKS AT 105° BEND.

NOTE:

1. ALL ROOM TEMPERATURE TESTS MADE WITH RUBBER BACK-UP.
2. BEND RATES AT TEMPERATURE APPROXIMATELY .06 INCHES/MINUTE.

TABLE [illegible]-1. LOCKALLOY Be-38Al (LX-62) BEND TEST RESULTS (t = .150 in.)

3.5.1.3 Stress Relieving - The discussion and accompanying data presented previously in Paragraph 3.3.1.3 are equally applicable here.

3.5.1.4 Notched Tensile Tests - The procedure used for testing the Be-38Al materials is the same as that used for the Be-43Al material. Section 3.3.1.4 describes this procedure.

The results of the notched tensile tests for the .150 inch thick Be-38Al Alloy at room temperature in the longitudinal direction and at 600°F in the transverse direction are presented in Table 3.5.14-1. Unnotched tensile tests for identical test conditions are also presented to show the notched to unnotched ratio for the .15 inch thick Be-38Al alloy. Comparing the ratios of the .150 inch thick to the .250 inch thick Be-38Al alloy, it appears the thinner material to be less tolerant of notches at both room and elevated temperature.

CONDITION	DIRECTION	TEST TEMP. - °F	SPECIMEN I.D.	NOTCHED ULTIMATE KSI	SPECIMEN I.D.	UNNOTCHED ULTIMATE KSI	NOTCHED ULTIMATE / UNNOTCHED ULTIMATE
AS REC'D	LONG.	ROOM TEMP.	3NT-1L 3NT-2L 3NT-3L AVG.	47.8 47.8 48.7 48.1	3T-1L 3T-2L 3T-3L AVG.	47.1 51.2 51.1 49.8	.966
AS REC'D	TRANS.	600	3NT-1T 3NT-2T 3NT-3T AVG.	29.1 29.4 29.0 29.2	3T-4T 3T-5T 3T-6T AVG.	23.3 23.3 23.2 23.3	1.253

REF. R.N. PAGES 568959, 568957, 568960.

TABLE 3.5.1.4-1. NOTCHED TO UNNOTCHED TENSILE TEST RESULTS FOR .15 INCH THICK BE-38AL LOCKALLOY SHEET TESTED AT ROOM TEMP. AND 600°F

3.5.2 Lap Shear Joint Tests - In order to provide designers and stress personnel with more accurate fastener allowable loads for the Be-38Al alloy prior to the ventral fin proof test, lap shear joint tests were performed. The specimens conformed to MIL-STD-1312 (except for length and riveted instead of spotwelded doublers) and were machined from remnant pieces of .125 and .150 Be-38Al alloy skin panel material.

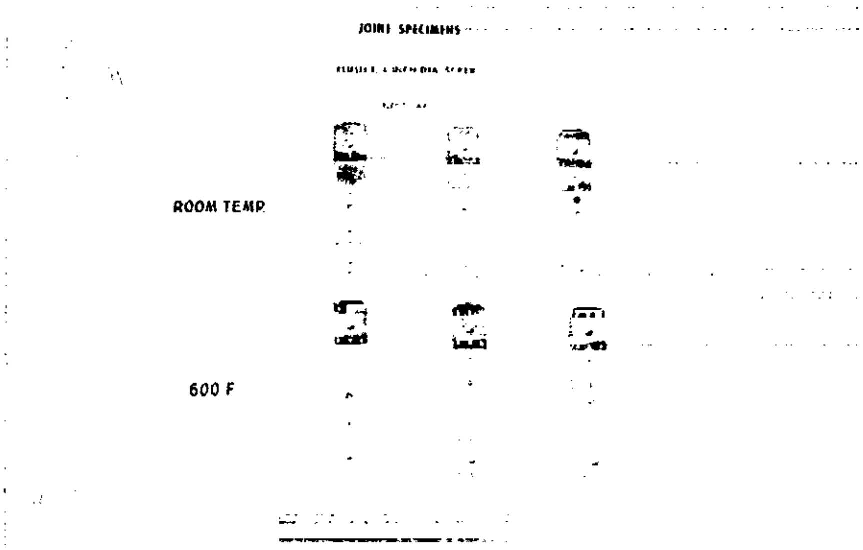
Triplicate specimens were fabricated to the configuration shown on page B-14 of the Appendix. Both .190 Dia. and .250 Dia. flush titanium small headed fasteners were tested. Large tension type heads on .250 diameter fasteners in .150 inch thickness joints were also tested. All tests were run at 600°F as well as at room temperature.

Testing was also accomplished on the self aligning A-286 CRES nut at 600°F as well as at room temperature.

The lap-shear joint specimens were installed in a 30,000 lb. Baldwin Mark B Testing Machine and loaded at a constant rate to a value corresponding to the approximate yield deflection specified in MIL-STD-1312 for the particular fastener size being tested. At this deflection, the specimen was unloaded to near zero load to more accurately determine the true permanent deformation. The specimen was then re-loaded to failure. A Lockheed designed extensometer compatible with the Baldwin x-y plotter provided an autographic load-deformation curve for both room temperature and 600°F testing.

A photograph of typical lap-shear joints of .250 inch Dia. tension type flush head titanium fasteners before testing are shown in Fig. 3.5.2-1.

The lap-shear joint test results of the .125 inch and .150 inch thick Be-38Al alloy are tabulated in Tables 3.5.2-1 and 3.5.2-2 for room temperature and 600°F respectively. A photograph of all of the specimens after failure at room temperature and 600°F are shown in Figs. 3.5.2-2 and 3.5.2-3, respectively.



75-5355-1

Fig. 3.5.2-1 - Typical Lap-Shear Joint Specimens Of 1/4 Inch Tension Type Head Titanium Fasteners in .250 Be-38Al Alloy Before Testing.

FAST. MAT'L - 6AL-4V STA TITANIUM NUT - A-286 CRES

SPECIMEN I.D.	TEST TEMP. - °F	FAST. DIA.	SHEET THICK-IN.	Pu/FAST. LBS.	Py/FASTENER LBS.	TYPE FAILURE
3J3.125-1A,1B	ROOM TEMP.	.190	.125	2065	1420	BEARING AND NET SECTION
-2A,2B				2128	1415	SAME AS -1A & 1B - MARRED PERPENDICULAR TO LOAD - NO EFFECT.
-3A,3B				1812	1455	MARRED PARALLEL TO LOAD - FAILED THRU MAR BOTH 3A & 3B IN HOOP TENSION.
			AVG.	2002	1430	
4J3.125-1A,1B	ROOM TEMP.	.250*	.125	2118	1340	FAILED SELF-ALIGNING NUT IN SHEAR.
-2A,2B				2222	1378	
-3A,3B				2250	1382	
			AVG.	2197	1367	
5J3.15-1A,1B	ROOM TEMP.	.190	.150	2412	1765	NET SECTION - 1A & 1B
-2A,2B				2328	1605	SAME AS 1A & 1B - MARRED PERPENDICULAR TO LOAD - NO EFFECT.
-3A,3B				2212	1672	MARRED PARALLEL TO LOAD - FAILED THRU MAR BOTH 3A & 3B IN HOOP TENSION.
			AVG.	2317	1681	
6J4.15-1A,1B	ROOM TEMP.	.250	.150	3275	1792	NET SECTION - 1A & 1B.
-2A,2B				3225	1580	NET SECTION 2A & FAST. TENSION MAR PERPENDICULAR TO LOAD - NO EFFECT.
-3A,3B				3238	1835	NET SECTION - 3A & 3B MARRED PARALLEL TO LOAD - FAILED THRU MAR BOTH 3A & 3B IN HOOP TENSION.
			AVG.	3246	1736	

* A286 CRES SELF-ALIGNING NUT.

REF. R.N. PAGE 550493, 550494 AND 568955.

[illegible] LAP-SHEAR JOINT TEST RESULTS OF Be-38Al LOCKALLOY AT ROOM TEMPERATURE

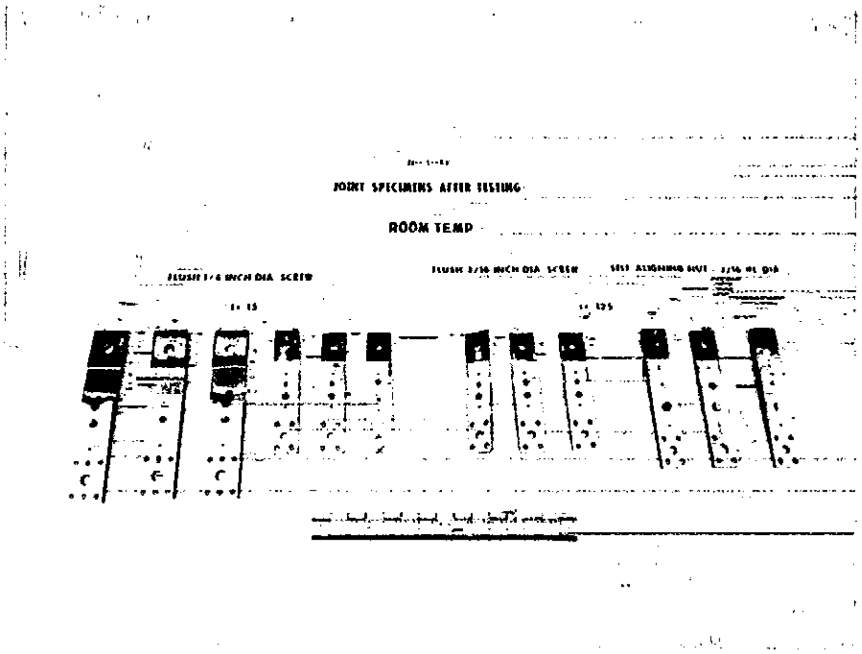
FAST. MAT'L - 6AL-4V STA TITANIUM NUT-A-286 CRES.

SPECIMEN I.D.	TEST TEMP. - °F	FAST. DIA.	SHEET THICK-IN.	Fu/FAST. LBS.	Py/FASTENER LBS.	TYPE FAILURE
3J3.125-4A,4B	600	.190	.125	1275	1022	BEARING OR TEAROUT. MAR PERPENDICULAR TO LOAD - NO EFFECT. MAR PARALLEL TO LOAD - NO EFFECT.
-5A,5B				1468	1045	
-6A,6B				1235	975	
			AVG.	1326	1014	
4J3.125-4A,4B	600	.250*	.125	1840	905	NET SECTION ACROSS RIVET HOLES ATTACHING END PLATE DOUBLERS. (TESTS INVALID).
-5A,5B				1762	860	
-6A,6B				1800	952	
			AVG.	1801	906	
5J3.15-4A,4B	600	.190	.150	1492	1118	BEARING OR TEAROUT MAR PERPENDICULAR TO LOAD - NO EFFECT. MAR PARALLEL TO LOAD - NO EFFECT.
-5A,5B				1525	1208	
-6A,6B				1455	1078	
			AVG.	1491	1135	
6J4.15-4A,4B	600	.250	.150	2300	1555	BEARING &/OR TEAROUT. MAR PERPENDICULAR TO LOAD - NO EFFECT. MAR PARALLEL TO LOAD - NO EFFECT.
-5A,5B				2105	1362	
-6A,6B				2260	1340	
			AVG.	2222	1419	

* A-236 CRES SELF-ALIGNING NUT.

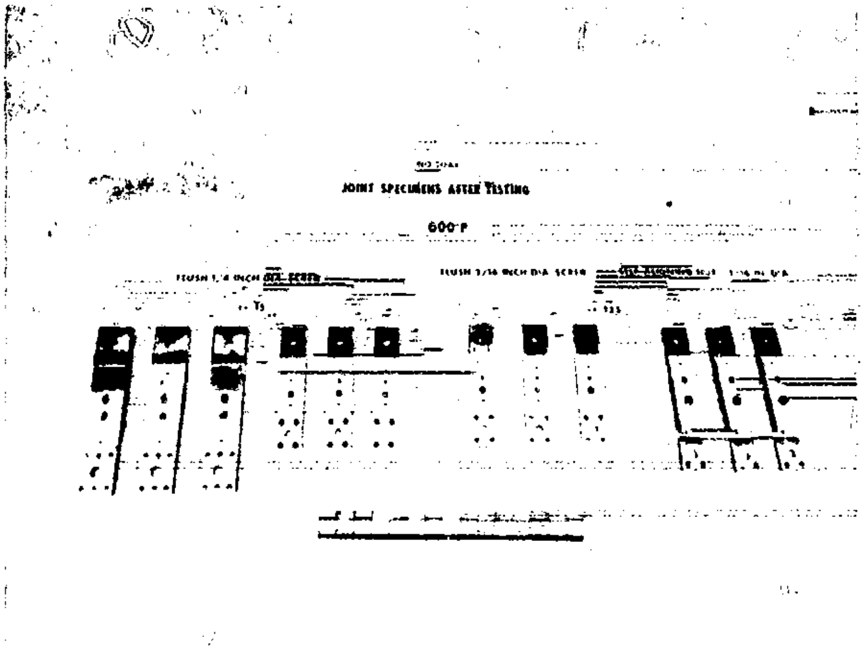
REF. R.N. PAGES 550493, 550494 and 568955

TABLE [illegible]. LAP-SHEAR JOINT TEST RESULTS OF Be-38Al LOCKALLOY AT 600°F



76-5007-11

Fig. 3.5.2-2 - Photograph of all Be-38Al Alloy Lap-Shear Joint Specimens After Failure at Room Temperature.



76-5007-10

Fig. 3.5.2-3 - Photograph of all Be-38Al Alloy Lap-Shear Joint Specimens After Failure at 600°F.

3.5.3 Mechanical Properties

3.5.3.1 Compression Tests - The procedure used for testing the .150 thick material is the same as that employed for the .250 thick material. This is described in Section 3.4.2.1 and is not repeated here.

The compression test results of .150 inch thick Be-38Al alloy at room temperature and 600°F, with and without soak for 100 hours at 600°F, are presented in Table 3.5.3.1-1 in the longitudinal direction and in Table 3.5.3.1-2 in the transverse direction.

A typical compression stress-strain curve for .15 inch Be-38Al alloy tested at room temperature and 600°F in the as received condition are presented in Figure 3.5.3.1-1 in the longitudinal direction and in Figure 3.5.3.1-2 in the transverse direction.

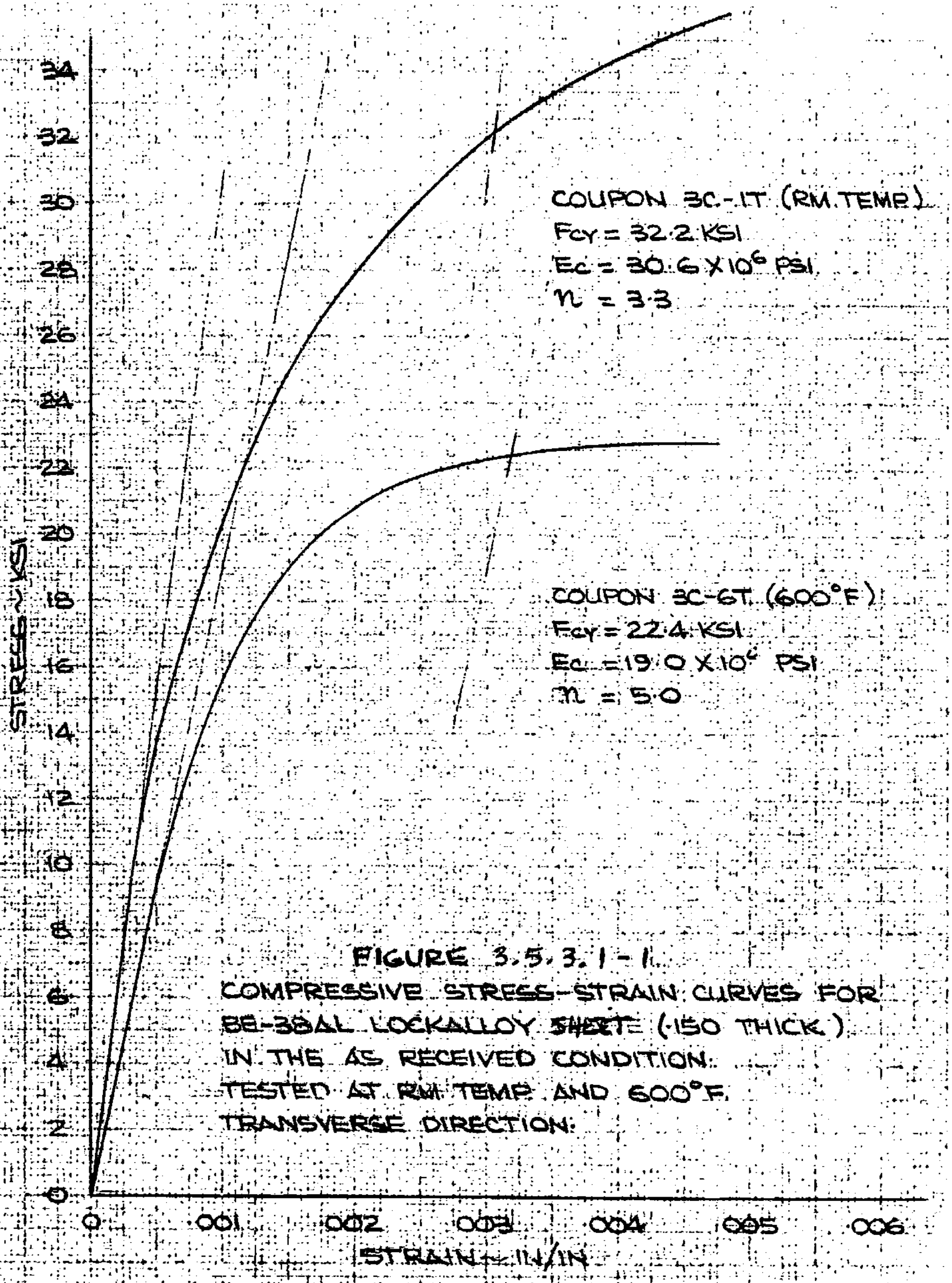


FIGURE 3.5.3.1-1
COMPRESSIVE STRESS-STRAIN CURVES FOR BE-38AL LOCKALLOY ~~SHEET~~ (.150 THICK) IN THE AS RECEIVED CONDITION. TESTED AT RM. TEMP. AND 600°F. TRANSVERSE DIRECTION.

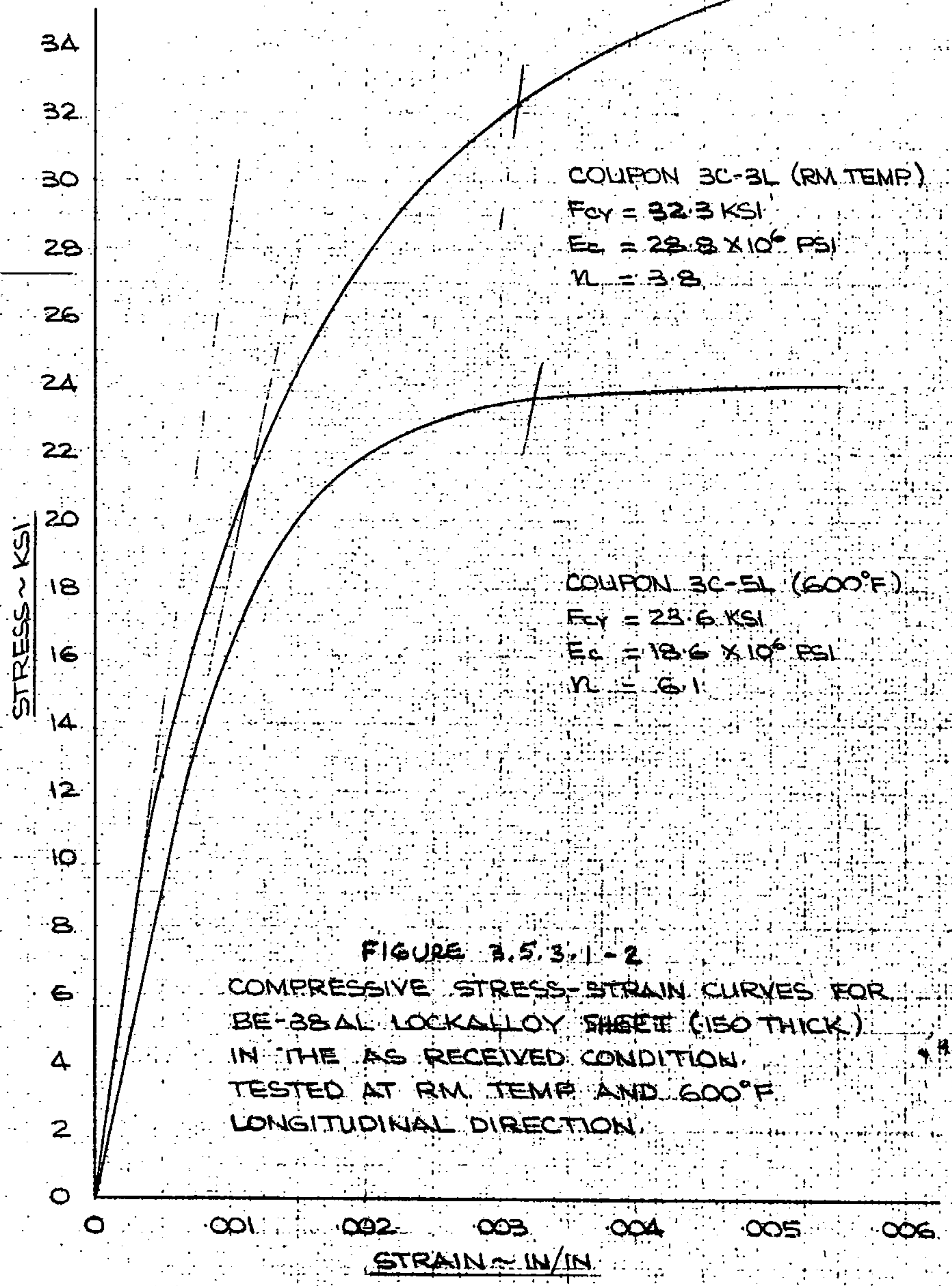


FIGURE 3.5.3.1-2
COMPRESSIVE STRESS-STRAIN CURVES FOR BE-38AL LOCKALLOY SHEET (.150 THICK) IN THE AS RECEIVED CONDITION. TESTED AT RM. TEMP. AND 600°F. LONGITUDINAL DIRECTION.

C.4

LONGITUDINAL DIRECTION

COUPON IDENTIFICATION	CONDITION	TEST TEMP. - °F	F_{CY} KSI	$F_{0.7}$ KSI	$F_{0.85}$ KSI	E_c PSI x 10^{-6}	η
3C-1L	AS RECEIVED NO SOAK	ROOM TEMP.	32.4	20.7	13.9	27.1	3.2
3C-2L			32.2	21.2	15.3	26.3	3.7
3C-3L			32.3	19.6	14.3	28.8	3.8
AVERAGE			32.3	20.5	14.5	27.4	3.6
3C-4L	AS RECEIVED NO SOAK	600	22.8	19.2	15.6	19.1	5.2
3C-5L			23.6	20.5	17.2	18.6	6.1
3C-6L			22.8	19.8	16.9	19.7	6.6
AVERAGE			23.1	19.8	16.6	19.1	6.0
3C-7L	SOAKED 100 HRS AT 600°F	ROOM TEMP.	32.1	19.6	11.5	26.1	2.7
3C-8L			31.9	18.9	11.9	26.9	2.9
3C-9L			32.7	17.4	11.3	30.6	3.0
AVERAGE			32.2	18.6	11.6	27.9	2.9
3C-10L	SOAKED 100 HRS AT 600°F	600	22.8	19.1	15.9	19.6	5.9
3C-11L			22.7	19.5	16.4	18.5	6.1
3C-12L			22.8	19.3	16.1	18.6	6.0
AVERAGE			22.8	19.3	16.1	18.9	6.0

REF. R.N. PAGES 568963 and 568964

TABLE 3.5.3.1-1. COMPRESSION TEST RESULTS OF .150 INCH THICK Be-38Al LOCKALLOY SHEET AT ROOM TEMPERATURE AND 600°F, WITH AND WITHOUT SOAK FOR 100 HOURS AT 600°F

TRANSVERSE DIRECTION

COUPON IDENTIFICATION	CONDITION	TEST TEMP. - °F	F_{CY} KSI	$F_{0.7}$ KSI	$F_{0.85}$ KSI	E_c PSI x 10^{-6}	η
3C-1T	AS RECEIVED NO SOAK	ROOM TEMP.	32.2	20.2	13.8	30.6	3.3
3C-2T			32.2	20.6	14.4	26.1	2.5
3C-3T			31.6	16.9	11.4	34.2	3.3
AVERAGE			32.0	19.2	13.2	30.3	3.4
3C-4T	AS RECEIVED NO SOAK	600	23.3	19.9	16.5	19.7	5.7
3C-5T			22.6	18.1	14.2	20.8	4.6
3C-6T			22.4	18.3	14.6	19.0	5.0
AVERAGE			22.8	18.8	15.1	19.8	5.1
3C-7T	SOAKED 100 HRS AT 600°F	ROOM TEMP.	32.1	20.5	14.1	25.4	3.4
3C-8T			32.0	17.4	9.8	27.8	2.5
3C-9T			32.6	19.5	12.0	27.8	2.8
AVERAGE			32.2	19.1	12.0	27.0	2.9
3C-10T	SOAKED 100 HRS AT 600°F	600	22.4	19.4	16.9	17.7	5.6
3C-11T			22.5	18.8	15.6	18.9	5.7
3C-12T			22.4	18.8	15.3	17.8	5.3
AVERAGE			22.4	19.0	15.9	18.1	5.5

REF. R.N. PAGES 568963 and 568964.

TABLE3.5.3.1-2. COMPRESSION TEST RESULTS OF .150 INCH THICK Be-38Al LOCKALLOY SHEET AT ROOM TEMPERATURE AND 600°F, WITH AND WITHOUT SOAK FOR 100 HOURS AT 600°F

3.5.3.2 Flatwise Shear Tests - The procedure used for testing the .150 thick material is the same as that employed for the .250 thick material. This is described in Section 3.4.2.2 and is not repeated here.

The flatwise sheet shear tests results on the unused portion of the .040 inch bearing specimens machined from .150 inch thick Be-38Al alloy sheet are presented in Table 3.5.3.2-1 at room temperature and 600°F, with and without exposure to 600°F for 100 hours.

SPECIMEN IDENTIFICATION	CONDITION	TEST TEMP. °F	ULTIMATE SHEAR STRENGTH KSI
3B1.5-1L 3B1.5-2L 3B1.5-3L AVG.	AS RECEIVED	ROOM TEMP.	29.5 30.6 32.3 30.8
3B2.0-9L 3B1.5-8L 3B1.5-9L AVG.	EXPOSED 113 HRS @ 600°F	ROOM TEMP.	33.8 34.1 33.7 33.9
3B1.5-1T 3B1.5-2T 3B1.5-3T AVG.	AS RECEIVED	600°F	16.3 17.6 16.5 16.8
3B1.5-7T 3B1.5-8T 3B1.5-9T AVG.	EXPOSED 113 HRS @ 600°F	600°F	16.4 16.8 16.9 16.7

* SHEET SHEAR SPECIMENS ARE THE UNUSED PORTION OF THE SHEET BEARING SPECIMENS, WHICH HAVE BEEN MACHINED TO .040 INCH FROM THE ORIGINAL .150 INCH STOCK THICKNESS (REF. R.N. 568966)

TABLE 3.5.3.2-1. FLATWISE SHEET SHEAR TEST RESULTS FOR SOME .150 INCH THICK* Be-38Al LOCKALLOY SHEET.

3.5.3.3 Bearing Tests - The procedure used for testing the .150 thick material is the same as that employed for the .250 thick material. This is described in Section 3.4.2.3 and is not repeated here.

The bearing tests were performed on .040 inch thick specimens machined from .150 inch thick Be-38Al alloy sheet. Tests were made at room temperature and 600°F, with and without exposure to 600°F for an inadvertent soak of 113 hours rather than 100 hours, for both e/D = 2.0 and 1.5. Results are presented in Table 3.5.3.3-1 for the longitudinal direction and in Table 3.5.3.3-2 for the transverse direction.

CONDITION	TEST TEMP. °F	e/D = 2.0			e/D = 1.5		
		SPECIMEN IDENTIFICATION	F_{bru} ksi	F_{bry} ksi	SPECIMEN IDENTIFICATION	F_{bru} ksi	F_{bry} ksi
AS RECEIVED NO SOAK	ROOM TEMP.	3B2-1L 3B2-2L 3B2-3L AVERAGE	93.8 89.7 101.2 94.9	76.0 61.9 72.1 70.0	3B1.5-1L 3B1.5-2L 3B1.5-3L AVERAGE	76.6 75.5 69.8 74.0	72.2 58.0 66.5 65.6
AS RECEIVED NO SOAK	600	3B2-4L 3B2-5L 3B2-6L AVERAGE	45.1 44.2 44.9 44.7	42.1 40.7 40.5 41.1	3B1.5-4L 3B1.5-5L 3B1.5-6L AVERAGE	36.0 35.7 34.8 35.5	34.1 33.0 34.6 33.9
SOAKED 113 HRS AT 600°F	ROOM TEMP.	3B2-7L 3B2-8L 3B2-9L AVERAGE	98.3 96.1 104.3 99.6	80.0 79.3 77.9 79.1	3B1.5-7L 3B1.5-8L 3B1.5-9L AVERAGE	81.3 70.7 76.6 76.2	58.1 65.6 66.2 63.3
SOAKED 113 HRS AT 600°F	600	3B2-10L 3B2-11L 3B2-12L AVERAGE	45.1 44.0 46.8 45.3	41.4 40.6 42.8 41.6	3B1.5-10L 3B1.5-11L 3B1.5-12L AVERAGE	36.4 34.2 41.8 37.5	35.9 31.9 41.0 36.3

REF: R. N. PAGES 529771 AND 529772

(MACHINED FROM .150 INCH THICK)
LONGITUDINAL

TABLE 3.5.3.3-1. BEARING TEST RESULTS OF .040 INCH THICK Be-38Al LOCKALLOY SPECIMENS AT ROOM TEMPERATURE AND 600°F, WITH AND WITHOUT SOAK FOR 113 HOURS AT 600°F

CONDITION	TEST TEMP. °F	e/D = 2.0			e/D = 1.5		
		SPECIMEN IDENTIFICATION	F_{bru} ksi	F_{bry} ksi	SPECIMEN IDENTIFICATION	F_{bru} ksi	F_{bry} ksi
AS RECEIVED NO SOAK	ROOM TEMP.	3B2-1T 3B2-2T 3B2-3T AVERAGE	89.5 90.3 94.7 91.5	71.4 72.8 73.4 72.5	3B1.5-1T 3B1.5-2T 3B1.5-3T AVERAGE	77.0 77.6 77.2 77.3	66.6 68.8 67.7 67.7
AS RECEIVED NO SOAK	600	3B2-4T 3B2-5T 3B2-6T AVERAGE	44.3 44.6 43.8 44.2	39.7 40.9 40.6 40.4	3B1.5-4T 3B1.5-5T 3B1.5-6T AVERAGE	37.2 40.7 39.6 39.2	37.1 39.3 - 38.2
SOAKED 113 HRS AT 600°F	ROOM TEMP.	3B2-7T 3B2-8T 3B2-9T AVERAGE	105.4 103.0 92.9 100.4	76.5 74.0 68.8 73.1	3B1.5-7T 3B1.5-8T 3B1.5-9T AVERAGE	81.3 70.7 76.6 76.2	58.1 65.6 66.2 63.3
SOAKED 113 HRS AT 600°F	600	3B2-10T 3B2-11T 3B2-12T AVERAGE	48.4 48.2 46.4 47.7	45.6 44.2 43.4 44.4	3B1.5-10T 3B1.5-11T 3B1.5-12T AVERAGE	36.4 36.1 37.3 36.6	34.2 34.3 34.0 34.2

REF: R. N. PAGES 529771 AND 529772

(MACHINED FROM .150 INCH THICK)
TRANSVERSE

TABLE 3.5.3.3-2. BEARING TEST RESULTS OF .040 INCH THICK Be-38Al LOCKALLOY SPECIMENS AT ROOM TEMPERATURE AND 600°F, WITH AND WITHOUT SOAK FOR 113 HOURS AT 600°F

3.5.3.4 Fracture Toughness Tests - The procedure used for testing the .150-thick material is the same as that employed for the .250-thick material. This is described in Section 3.4.2.4 and is not repeated here.

The computed values for R_{SC} are presented in Table 3.5.3.4-1 for room temperature results and in Table 3.5.3.4-2 for 600°F test results.

SPECIMEN I.D.	DIRECTION	CONDITION	TEST TEMP. °F	B IN	P_{MAX} LBS	a IN.	W IN.	F_{ty} KSI	R_{SC}
3FT-1L	LONG	AS REC'D	ROOM	0.1464	373	0.513	1.005	35.0	1.517
3FT-2L				0.1475	243	0.517	0.997	35.0	1.368
								AVG.	1.442
3FT-1T	TRANS.	AS REC'D	ROOM	0.1457	380	0.498	1.001	35.0	1.473
3FT-2T				0.1468	346	0.515	0.996	35.0	1.459
								AVG.	1.466
3FT-7L	LONG	SOAK 100 HRS AT 300°F	ROOM	FAILED ON PRECRACK					
3FT-8L				0.1461	366	0.508	1.000	35.0	1.483
								AVG.	1.483
3FT-7T	TRANS.	SOAK 100 HRS AT 600°F	ROOM	0.1465	338	0.505	1.000	35.0	1.348
3FT-8T				0.1458	297	0.512	1.000	35.0	1.228
								AVG.	1.288

TABLE 3.5.3.4-1. RESIDUAL STRENGTH PARAMETER FOR .150 INCH THICK Be-38Al LOCKALLOY AT ROOM TEMPERATURE, WITH AND WITHOUT EXPOSURE TO 600°F FOR 100 HOURS

SPECIMEN I.D.	DIRECTION	CONDITION	TEST TEMP. °F	B IN.	P_{MAX} LBS	a IN.	W IN.	F_{ty} KSI	R_{SC}
3FT-4L	LONG.	AS REC'D	600	FAILED ON PRECRACK					
3FT-5L				0.1476	258	0.503	1.004	25.0	1.399
								AVG.	1.399
3FT-4T	TRANS.	AS REC'D	600	0.1471	285	0.509	1.003	25.0	1.597
3FT-5T				0.1471	262	0.504	0.997	25.0	1.464
								AVG.	1.530
3FT-10L	LONG.	SOAK 100 HRS AT 600°F	600	0.1456		0.505	LOST IN TES:		
3FT-11L				0.1454	187	0.511	1.000	25.0	1.080
								AVG.	1.080
3FT-10T	TRANS.	SOAK 100 HRS AT 600°F	600	0.1450	254	0.501	1.000	25.0	1.408
3FT-11T				0.1452	235	0.510	1.001	25.0	1.349
								AVG.	1.378

TABLE 3.5.3.4-2. RESIDUAL STRENGTH PARAMETER FOR .150 INCH THICK Be-38Al LOCKALLOY AT 600°F, WITH AND WITHOUT EXPOSURE TO 600°F FOR 100 HOURS

3.5.3.5 Fatigue Crack Growth Tests - The procedure used for testing the .150 thick material is the same as that employed for the .250 thick material. This is described in Section 3.4.2.5 and is not repeated here.

The computer tabulation of fatigue crack growth data for the .150 thick material is tabulated in Tables 3.5.3.5-1 through Tables 3.5.3.5-8, and graphically presented in Figures 3~~.5.3.5-1~~ through Figures 3.5.3.5-8.

The remarks in Section 3.4.2.5 are equally pertinent to the .150 thick Be-38Al Lockalloy.

```
                      COMPACT.TENSION.PROGRAM
(GT)SPEC.3FT.3L  LAB AIR  R=.1  F=20 HZ                              11:20 DEC 16.'75

    INPUT CONSTANTS:

       RANGE RATIO(R)             =    .1
       SPECIMEN WIDTH(W)          =   1.003
       SPECIMEN THICKNESS(B)      =    .145
       INITIAL CRACK LENGTH(AO)   =    .000
       TEST FREQUENCY(HZ)         =   20.0

 NUMBER   MAXIMUM   SIDE 1   SIDE 2   AVERAGE   CHANGE IN   CHANGE     CRACK     ALTERNATING
   OF      LOAD     CRACK    CRACK    CRACK     CRACK       IN         GROWTH    STRESS
 CYCLES             LENGTH   LENGTH   LENGTH    LENGTH      CYCLES     RATE      INTENSITY
                                                                       DA / DN
   N        P        A1       A2       ABAR      DA          DN       MICROINCH  DELK
 X 1000    KIPS     INCHES   INCHES   INCHES    INCHES      X 1000    PER CYCLE  X 1000

  50.000    .22      .319     .315     .317
                                                 .021      40.000        .54      8.42
  90.000    .22      .340     .337     .338
                                                 .019      40.000        .49      8.80
 130.000    .22      .358     .358     .358
                                                 .023      20.000       1.15      9.25
 150.000    .22      .383     .379     .381
                                                 .020      20.000       1.00      9.74
 170.000    .22      .405     .397     .401
                                                 .038      20.000       1.92     10.48
 190.000    .22      .442     .437     .439
                                                 .023       6.000       3.75     11.35
 196.000    .22      .466     .458     .462
                                                 .023       3.000       7.83     12.09
 199.000    .22      .493     .478     .485
                                                 .018       1.000      18.00     12.83
 200.000    .22      .506     .501     .503
                                                 .020       1.000      20.00     13.58
 201.000    .22      .528     .519     .523
                                                 .025       1.000      25.50     14.59
 202.000    .22      .553     .545     .549
                                                 .024        .500      49.00     15.87
 202.500    .22      .576     .571     .573
```

TABLE 3.5.3.5-1 FATIGUE CRACK GROWTH RATE DATA FOR SPECIMEN 3FT-3L AT ROOM TEMPERATURE - NO SOAK, LONGITUDINAL.

```
                          COMPACT*TENSION*PROGRAM                      11:20 DEC 16,'75
(CT)SPEC.3FT-3T  LAB AIR  R=.1  F= 20 HZ

    INPUT CONSTANTS:

        RANGE RATIO(R)              =     .1
        SPECIMEN WIDTH(W)           =    1.000
        SPECIMEN THICKNESS(B)       =     .144
        INITIAL CRACK LENGTH(AO)    =     .000
        TEST FREQUENCY(HZ)          =   20.0

 NUMBER     MAXIMUM     SIDE 1     SIDE 2    AVERAGE   CHANGE IN    CHANGE      CRACK      ALTERNATING
   OF        LOAD       CRACK      CRACK      CRACK      CRACK        IN        GROWTH       STRESS
 CYCLES                 LENGTH     LENGTH     LENGTH     LENGTH     CYCLES       RATE       INTENSITY
                                                                               DA / DN
    N          P          A1         A2        ABAR        DA         DN      MICROINCH      DELK
 X 1000      KIPS       INCHES     INCHES     INCHES     INCHES     X 1000    PER CYCLE     X 1000

  30.000      .22        .320       .328       .324
                                                         .019      35.000       .53          8.58
  65.000      .22        .340       .345       .342
                                                         .020      20.000      1.00          8.96
  85.000      .22        .350       .375       .363
                                                         .031      20.000      1.57          9.52
 105.000      .22        .386       .402       .394
                                                         .026      10.000      2.60         10.22
 115.000      .22        .410       .430       .420
                                                         .023       7.000      3.36         10.89
 122.000      .22        .436       .451       .443
                                                         .024       5.000      4.80         11.60
 127.000      .22        .457       .478       .467
                                                         .030       4.000      7.50         12.51
 131.000      .22        .488       .507       .498
                                                         .027       2.000     13.50         13.61
 133.000      .22        .512       .537       .524
```

TABLE 3.5.3.5-2 FATIGUE CRACK GROWTH RATE DATA FOR SPECIMEN 3FT-3T AT ROOM TEMPERATURE - NO SOAK, TRANSVERSE.

```
                              COMPACT*TENSION*PROGRAM
(CT)SPEC.3FT.9L  LAB AIR  R=.1  F=20 HZ                                              11:20 DEC 16,'75

    INPUT CONSTANTS:

        RANGE RATIO(R)             =    .1
        SPECIMEN WIDTH(W)          =   1.002
        SPECIMEN THICKNESS(B)      =    .145
        INITIAL CRACK LENGTH(AO)   =    .000
        TEST FREQUENCY(HZ)         =   20.0

 NUMBER    MAXIMUM    SIDE 1    SIDE 2    AVERAGE    CHANGE IN    CHANGE      CRACK     ALTERNATING
   OF       LOAD      CRACK     CRACK      CRACK       CRACK        IN        GROWTH       STRESS
 CYCLES               LENGTH    LENGTH     LENGTH      LENGTH     CYCLES       RATE       INTENSITY
                                                                              DA / DN
   N          P         A1        A2        ABAR         DA          DN      MICROINCH      DELK
 X 1000      KIPS     INCHES    INCHES     INCHES      INCHES      X 1000    PER CYCLE     X 1000

 30.000      .22       .322      .319       .321
                                                        .031      20.000        1.55         8.60
 50.000      .22       .357      .346       .351
                                                        .021      10.000        2.10         9.12
 60.000      .22       .375      .370       .373
                                                        .022       7.000        3.14         9.60
 67.000      .22       .396      .393       .395
                                                        .025       4.000        6.37        10.18
 71.000      .22       .423      .417       .420
                                                        .027       2.000       13.50        10.89
 73.000      .22       .452      .442       .447
                                                        .032       3.000       10.83        11.79
 76.000      .22       .487      .472       .479
                                                        .028       2.000       14.00        12.85
 78.000      .22       .512      .503       .507
                                                        .024        .900       27.22        13.91
 78.900      .22       .537      .527       .532
                                                        .023        .600       39.17        15.03
 79.500      .22       .561      .550       .555
                                                        .023        .300       76.67        16.28
 79.800      .22       .581      .576       .578
                                                        .023        .150      153.34        17.73
 79.950      .22       .601      .602       .601
```

TABLE 3.5.3.5-3 FATIGUE CRACK GROWTH RATE DATA FOR SPECIMEN 3FT-9L AT ROOM TEMPERATURE AND 100 HOUR SOAK AT 600°F, LONGITUDINAL.

```
                                C O M P A C T . T E N S I O N . P R O G R A M          11:20 DEC 16,'75
(CT)SPEC.3FT-9T  LAB AIR  R = .1  F = 20 HZ

   INPUT CONSTANTS:

      RANGE RATIO(R)              =     .1
      SPECIMEN WIDTH(W)           =  1.001
      SPECIMEN THICKNESS(B)       =    .143
      INITIAL CRACK LENGTH(A0)    =    .000
      TEST FREQUENCY(HZ)          =   20.0

 NUMBER     MAXIMUM    SIDE 1    SIDE 2    AVERAGE    CHANGE IN    CHANGE       CRACK       ALTERNATING
   OF        LOAD      CRACK     CRACK     CRACK      CRACK          IN         GROWTH        STRESS
 CYCLES                LENGTH    LENGTH    LENGTH     LENGTH       CYCLES        RATE        INTENSITY
                                                                                DA / DN
   N          P         A1        A2        ABAR        DA           DN       MICROINCH       DELK
 X 1000      KIPS      INCHES    INCHES    INCHES     INCHES       X 1000     PER CYCLE      X 1000

 20.000      .22        .348      .322      .335       .022       10.000         2.20          8.88
 30.000      .22        .355      .359      .357       .026       10.000         2.60          9.39
 40.000      .22        .376      .390      .383       .027        6.000         4.50         10.01
 46.000      .22        .412      .408      .410       .038        4.000         9.62         10.88
 50.000      .22        .442      .455      .448       .025        1.000        25.00         11.84
 51.000      .22        .464      .483      .473       .022         .700        31.43         12.65
 51.700      .22        .493      .498      .495       .017         .700        24.29         13.39
 52.400      .22        .507      .518      .512       .035         .700        50.00         14.52
 53.100      .22        .545      .550      .547       .023         .200       117.50         16.02
 53.300      .22        .568      .574      .571       .022         .150       146.67         17.39
 53.450      .22        .589      .597      .593
```

TABLE 3.5.3.5-4 FATIGUE CRACK GROWTH RATE DATA FOR SPECIMEN 3FT-9T AT ROOM TEMPERATURE AFTER 100 HOUR SOAK AT 600°F, TRANSVERSE.

```
                              C O M P A C T . T E N S I O N . P R O G R A M
(CT)SPEC.3FT.6L  600 DEG.F.  R=.1   F = 20 HZ                                       11:20 DEC 16,'75

    INPUT CONSTANTS:

        RANGE RATIO(R)              =     .1
        SPECIMEN WIDTH(W)           =    1.000
        SPECIMEN THICKNESS(B)       =     .145
        INITIAL CRACK LENGTH(AO)    =     .000
        TEST FREQUENCY(HZ)          =   20.0

  NUMBER     MAXIMUM     SIDE 1     SIDE 2    AVERAGE    CHANGE IN    CHANGE       CRACK      ALTERNATING
    OF        LOAD       CRACK      CRACK      CRACK       CRACK        IN         GROWTH       STRESS
  CYCLES                 LENGTH     LENGTH     LENGTH      LENGTH     CYCLES        RATE       INTENSITY
                                                                                  DA / DN
    N          P          A1         A2        ABAR          DA         DN       MICROINCH       DELK
  X 1000      KIPS       INCHES     INCHES     INCHES      INCHES     X 1000     PER CYCLE      X 1000

   80.000      .13        .331       .313       .322
                                                             .019     50.000        .37          5.21
  130.000      .13        .343       .338       .340
                                                             .023     50.000        .46          5.45
  180.000      .13        .369       .358       .363
                                                             .031     40.000        .79          5.82
  220.000      .13        .405       .385       .395
                                                             .028     60.000        .47          6.26
  280.000      .13        .431       .415       .423
                                                             .019     20.000        .95          6.65
  300.000      .13        .453       .431       .442
                                                             .023     10.000       2.30          7.03
  310.000      .13        .479       .451       .465
                                                             .026     20.000       1.30          7.53
  330.000      .13        .495       .487       .491
                                                             .031     10.000       3.15          8.19
  340.000      .13        .530       .515       .522
                                                             .023      2.500       9.20          8.92
  342.500      .13        .551       .540       .545
                                                             .022      1.500      14.67          9.62
  344.000      .13        .565       .570       .567
                                                             .020       .500      41.00         10.39
  344.500      .13        .589       .587       .588
                                                             .031       .500      62.00         11.47
  345.000      .13        .620       .618       .619
```

TABLE 3.5.3.5-5 FATIGUE CRACK GROWTH RATE DATA FOR SPECIMEN 3FT-6L AT 600°F - NO SOAK, LONGITUDINAL.

```
                              C O M P A C T * T E N S I O N * P R O G R A M
(CT)SPEC.3FT-6T   600 DEG.F.   R=.1   F = 20 HZ                                  11:20 DEC 16,'75

    INPUT CONSTANTS:

        RANGE RATIO(R)               =    .1
        SPECIMEN WIDTH(W)            =   1.000
        SPECIMEN THICKNESS(B)        =    .145
        INITIAL CRACK LENGTH(A0)     =    .000
        TEST FREQUENCY(HZ)           =   20.0

  NUMBER     MAXIMUM     SIDE 1     SIDE 2     AVERAGE    CHANGE IN    CHANGE       CRACK      ALTERNATING
    OF        LOAD       CRACK      CRACK      CRACK       CRACK        IN          GROWTH       STRESS
  CYCLES                 LENGTH     LENGTH     LENGTH      LENGTH      CYCLES        RATE       INTENSITY
                                                                                   DA / DN
    N          P          A1         A2        ABAR         DA          DN        MICROINCH      DELK
  X 1000      KIPS      INCHES     INCHES     INCHES      INCHES      X 1000      PER CYCLE     X 1000

  40.000      .14        .324       .312       .318
                                                           .025       40.000         .63          5.59
  80.000      .14        .348       .338       .343
                                                           .021       20.000        1.07          5.89
 100.000      .14        .376       .353       .364
                                                           .021       20.000        1.02          6.18
 120.000      .14        .399       .371       .385
                                                           .021       20.000        1.05          6.50
 140.000      .14        .417       .395       .406
                                                           .032       20.000        1.60          6.96
 160.000      .14        .445       .431       .438
                                                           .031       10.000        3.05          7.55
 170.000      .14        .466       .471       .469
                                                           .010        7.000        1.50          7.99
 177.000      .14        .490       .468       .479
                                                           .019        4.000        4.87          8.34
 181.000      .14        .502       .495       .498
                                                           .013        4.000        3.25          8.76
 185.000      .14        .516       .507       .511
                                                           .027        5.000        5.40          9.31
 190.000      .14        .543       .534       .538
                                                           .015        1.000       15.00          9.98
 191.000      .14        .554       .553       .553
                                                           .019        1.000       18.50         10.57
 192.000      .14        .572       .572       .572
                                                           .032        1.000       32.50         11.62
 193.000      .14        .613       .596       .604
```

TABLE 3.5.3.5-6 FATIGUE CRACK GROWTH RATE FOR THE SPECIMEN 3FT - 6T AT 600° F - NO SOAK, TRANSVERSE.

```
                               C O M P A C T * T E N S I O N * P R O G R A M
(CT)SPEC.3FT-12T  600 DEG.F.  R=.1  F=20 HZ                                                11:20 DEC 16,'75

    INPUT CONSTANTS:

       RANGE RATIO(R)              =     .1
       SPECIMEN WIDTH(W)           =    1.001
       SPECIMEN THICKNESS(B)       =     .143
       INITIAL CRACK LENGTH(AO)    =     .000
       TEST FREQUENCY(HZ)          =   20.0

 NUMBER     MAXIMUM    SIDE 1     SIDE 2    AVERAGE    CHANGE IN    CHANGE      CRACK      ALTERNATING
   OF        LOAD      CRACK      CRACK      CRACK       CRACK        IN        GROWTH       STRESS
 CYCLES                LENGTH     LENGTH     LENGTH      LENGTH     CYCLES       RATE       INTENSITY
                                                                              DA / DN
   N           P         A1         A2        ABAR         DA          DN     MICROINCH       DELK
 X 1000      KIPS      INCHES     INCHES     INCHES      INCHES      X 1000   PER CYCLE      X 1000

  60.000      .14       .325       .318       .322
                                                           .023      30.000        .78         5.72
  90.000      .14       .350       .340       .345
                                                           .027      30.000        .90         6.05
 120.000      .14       .384       .360       .372
                                                           .026      30.000        .87         6.44
 150.000      .14       .404       .392       .398
                                                           .022      30.000        .72         6.84
 180.000      .14       .424       .415       .419
                                                           .021      20.000       1.05         7.22
 200.000      .14       .442       .439       .440
                                                           .027      12.000       2.25         7.69
 212.000      .14       .474       .461       .467
                                                           .038      15.000       2.57         8.43
 227.000      .14       .506       .506       .506
                                                           .024       3.000       8.00         9.26
 230.000      .14       .535       .525       .530
                                                           .028       3.500       8.14        10.08
 233.500      .14       .565       .552       .558
                                                           .026       1.500      17.33        11.08
 235.000      .14       .591       .578       .584
```

TABLE 3.5.3.5-7 FATIGUE CRACK GROWTH RATE DATA FOR SPECIMEN 3FT-12T AT 600°F AFTER 100 HOUR SOAK AT 600°F, TRANSVERSE.

```
                                  C O M P A C T . T E N S I O N . P R O G R A M
(CT)SPEC.3FT-12L  600 DEG.F.  R=.1  F= 20 HZ                                              11:20 DEC 16.'75

    INPUT CONSTANTS:

        RANGE RATIO(R)             =    .1
        SPECIMEN WIDTH(W)          =   1.000
        SPECIMEN THICKNESS(B)      =    .143
        INITIAL CRACK LENGTH(AO)   =    .000
        TEST FREQUENCY(HZ)         =  20.0

 NUMBER    MAXIMUM    SIDE 1    SIDE 2    AVERAGE    CHANGE IN    CHANGE      CRACK      ALTERNATING
   OF       LOAD      CRACK     CRACK     CRACK      CRACK         IN        GROWTH       STRESS
 CYCLES               LENGTH    LENGTH    LENGTH     LENGTH       CYCLES      RATE       INTENSITY
                                                                            DA / DN
   N          P        A1        A2        ABAR        DA           DN      MICROINCH      DELK
 X 1000      KIPS     INCHES    INCHES    INCHES     INCHES       X 1000    PER CYCLE     X 1000

 80.000      .14       .320      .312      .316
                                                      .017        60.000       .28         5.59
140.000      .14       .343      .322      .332
                                                      .017        30.000       .58         5.80
170.000      .14       .360      .340      .350
                                                      .030        60.000       .49         6.12
230.000      .14       .389      .370      .379
                                                      .023        30.000       .75         6.51
260.000      .14       .416      .388      .402
                                                      .028        40.000       .69         6.94
300.000      .14       .440      .419      .429
                                                      .020        20.000      1.02         7.38
320.000      .14       .460      .440      .450
                                                      .033        20.000      1.65         7.94
340.000      .14       .496      .470      .483
                                                      .022        10.000      2.20         8.59
350.000      .14       .515      .495      .505
                                                      .026         7.000      3.71         9.23
357.000      .14       .540      .522      .531
                                                      .030         2.500     12.20        10.12
359.500      .14       .570      .553      .561
                                                      .037         1.500     25.00        11.42
361.000      .14       .605      .593      .599
                                                      .046          .510     91.17        13.50
361.510      .14       .650      .641      .645
```

TABLE 3.5.3.5-8 FATIGUE CRACK GROWTH RATE DATA FOR SPECIMEN 3FT-12L AT 600°F AFTER 100 HOUR SOAK AT 600°F, LONGITUDINAL.

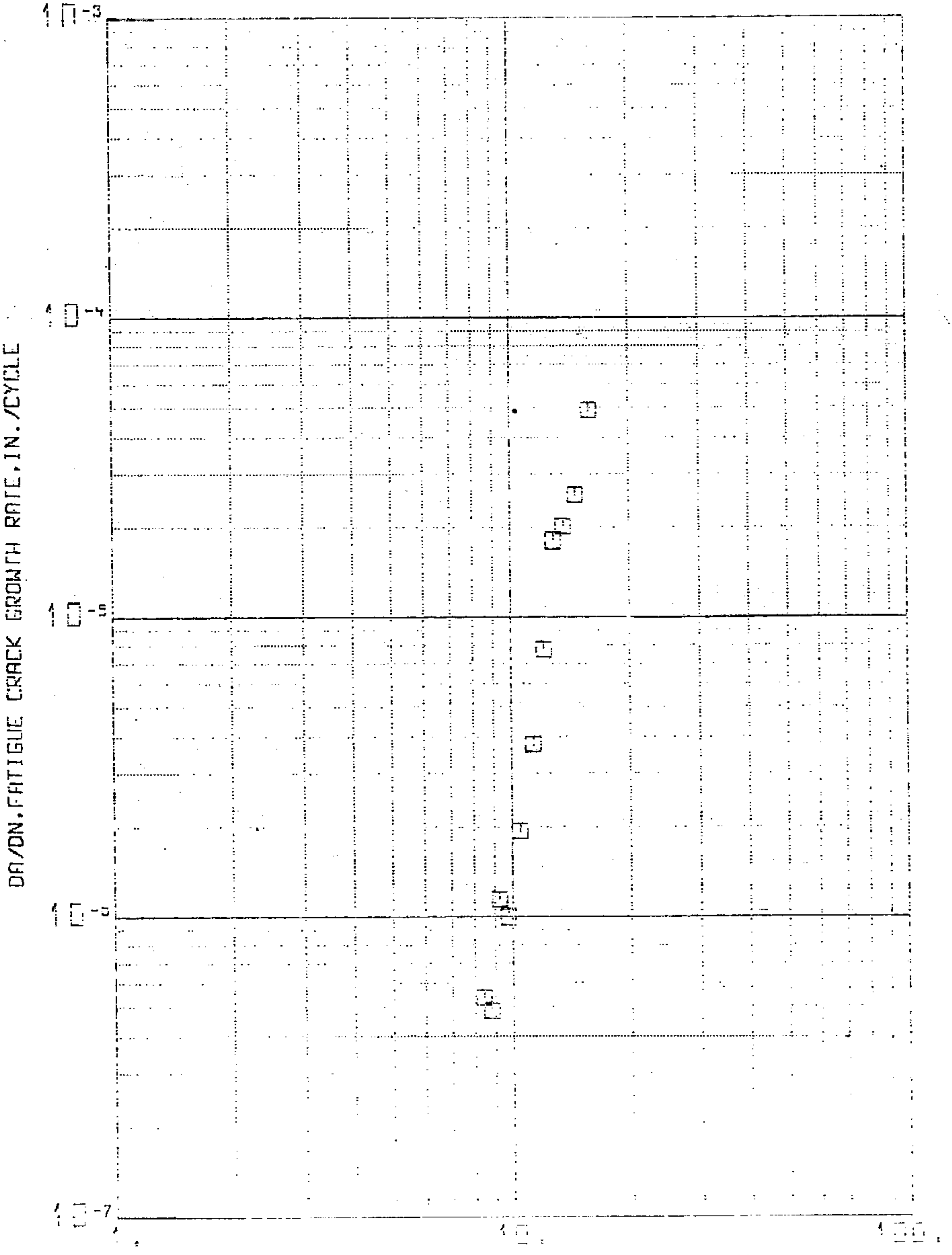


FIGURE 3.5.3.5-1 FATIGUE CRACK GROWTH RATE FOR SPECIMEN 3FT-3L AT ROOM TEMPERATURE - NO SOAK, LONGITUDINAL.

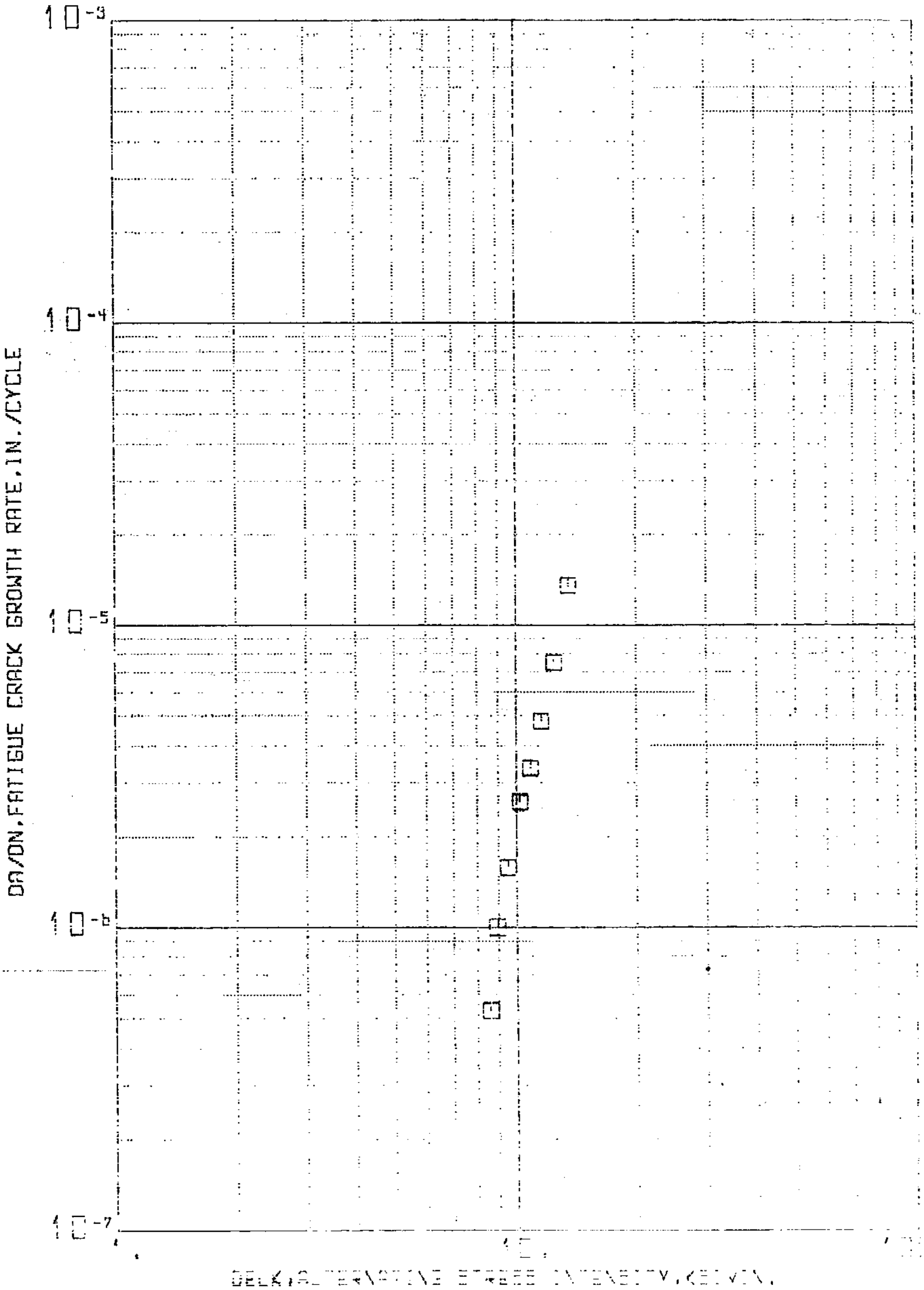


FIGURE 3.5.3.5-2 FATIGUE CRACK GROWTH RATE FOR SPECIMEN 3FT-3T AT ROOM TEMPERATURE - NO SOAK, TRANSVERSE.

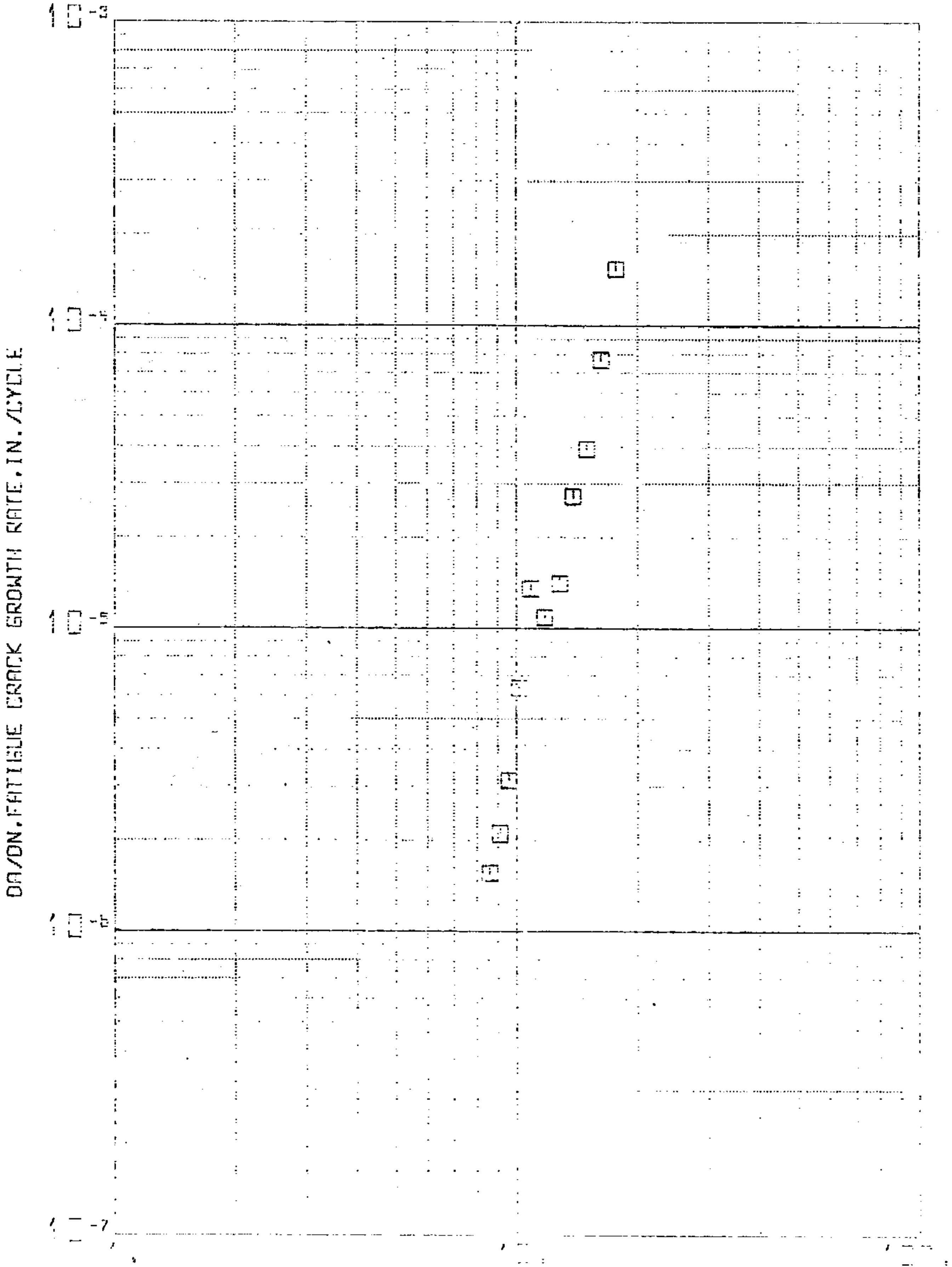


FIGURE 3.5.3.5-3 FATIGUE CRACK GROWTH RATE FOR SPECIMEN 3FT-9L AT ROOM TEMPERATURE AFTER 100 HOUR SOAK AT 600°F, LONGITUDINAL.

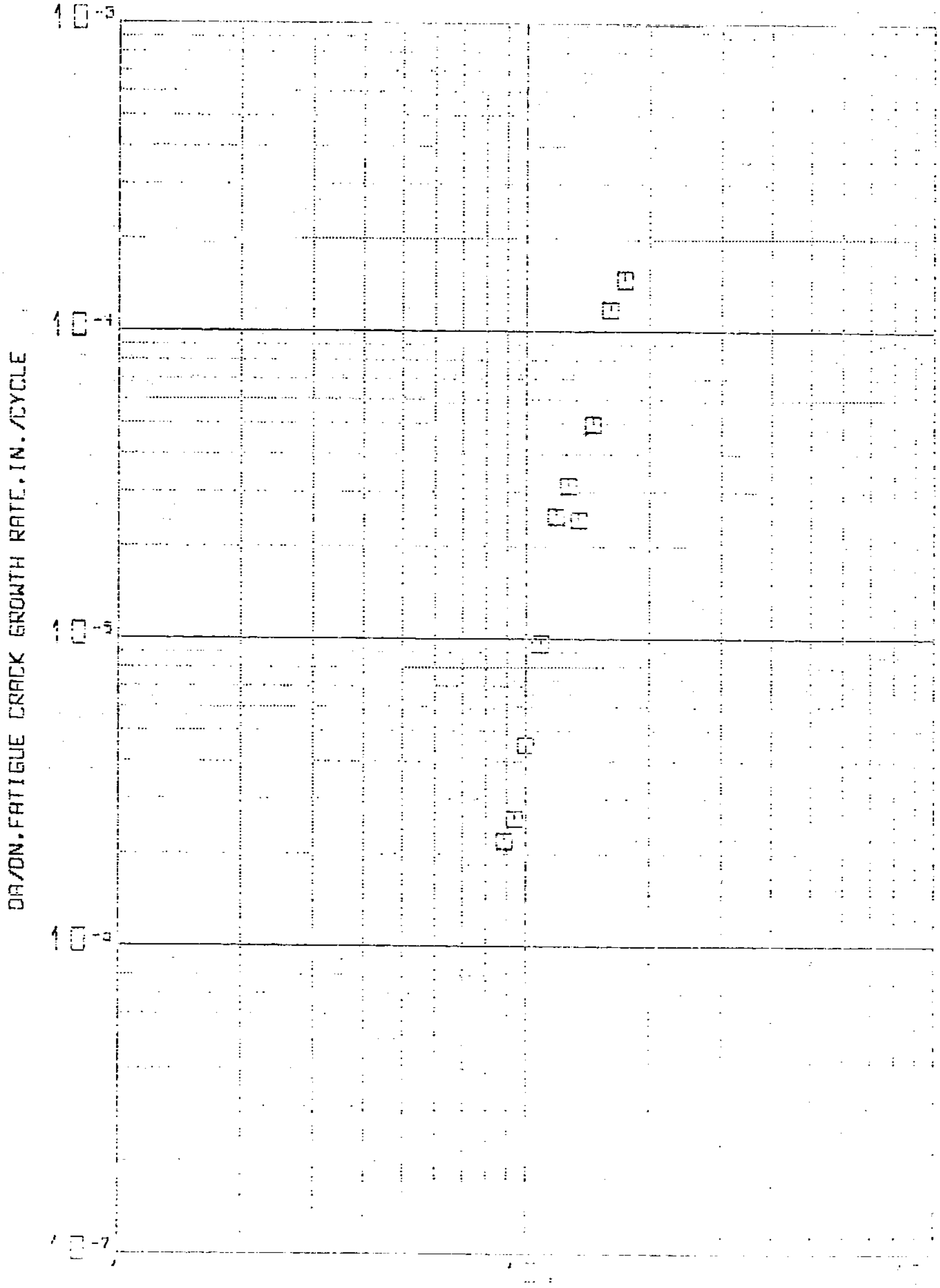


FIGURE 3.5.3.5-4 FATIGUE CRACK GROWTH RATE OF SPECIMEN 3FT-9T AT ROOM TEMPERATURE AFTER 100 HOUR SOAK AT 600°F, TRANSVERSE.

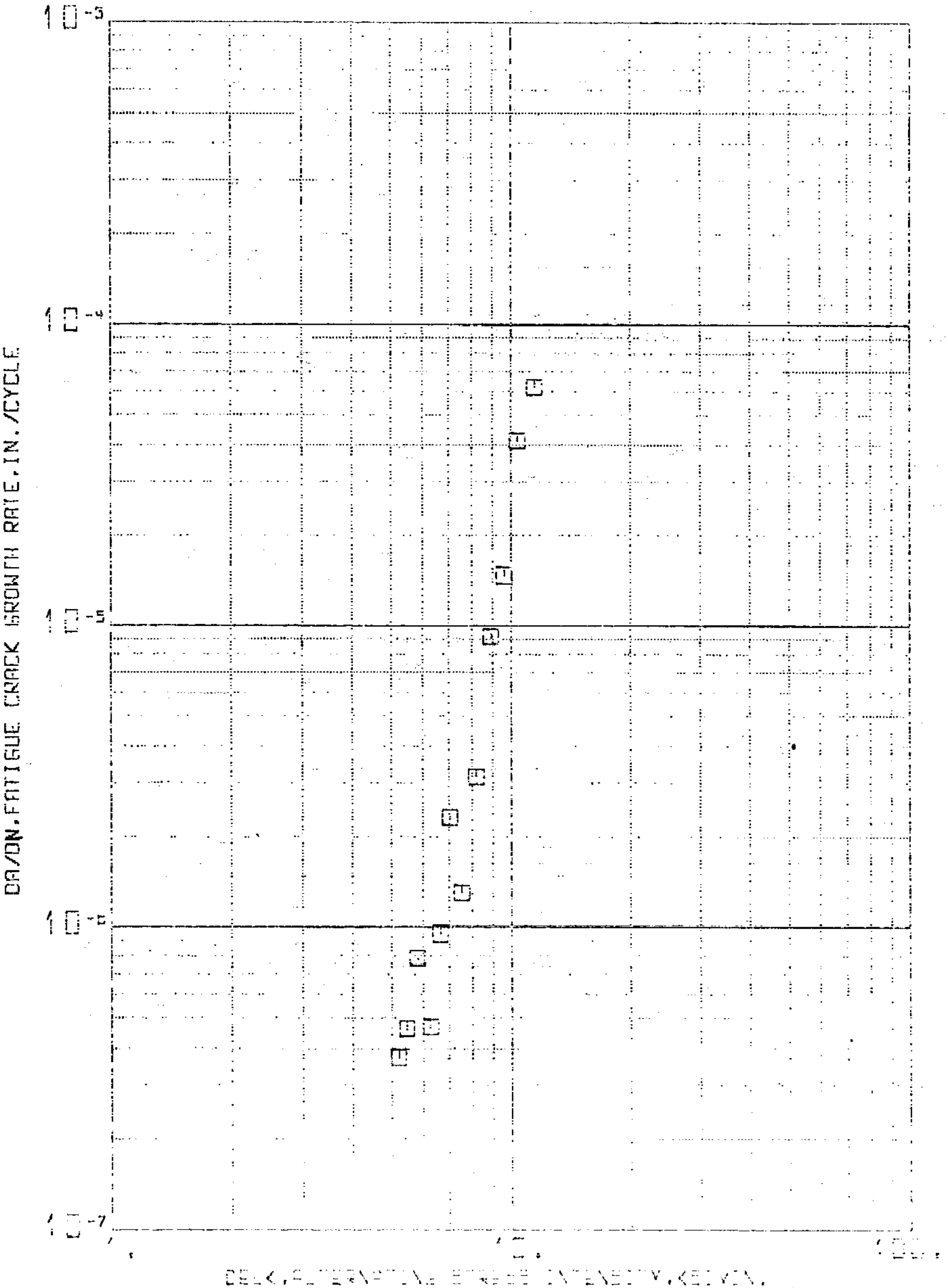


FIGURE 3.5.3.5-5 FATIGUE CRACK GROWTH RATE OF SPECIMEN 3FT-6L AT 600°F - NO SOAK, LONGITUDINAL.

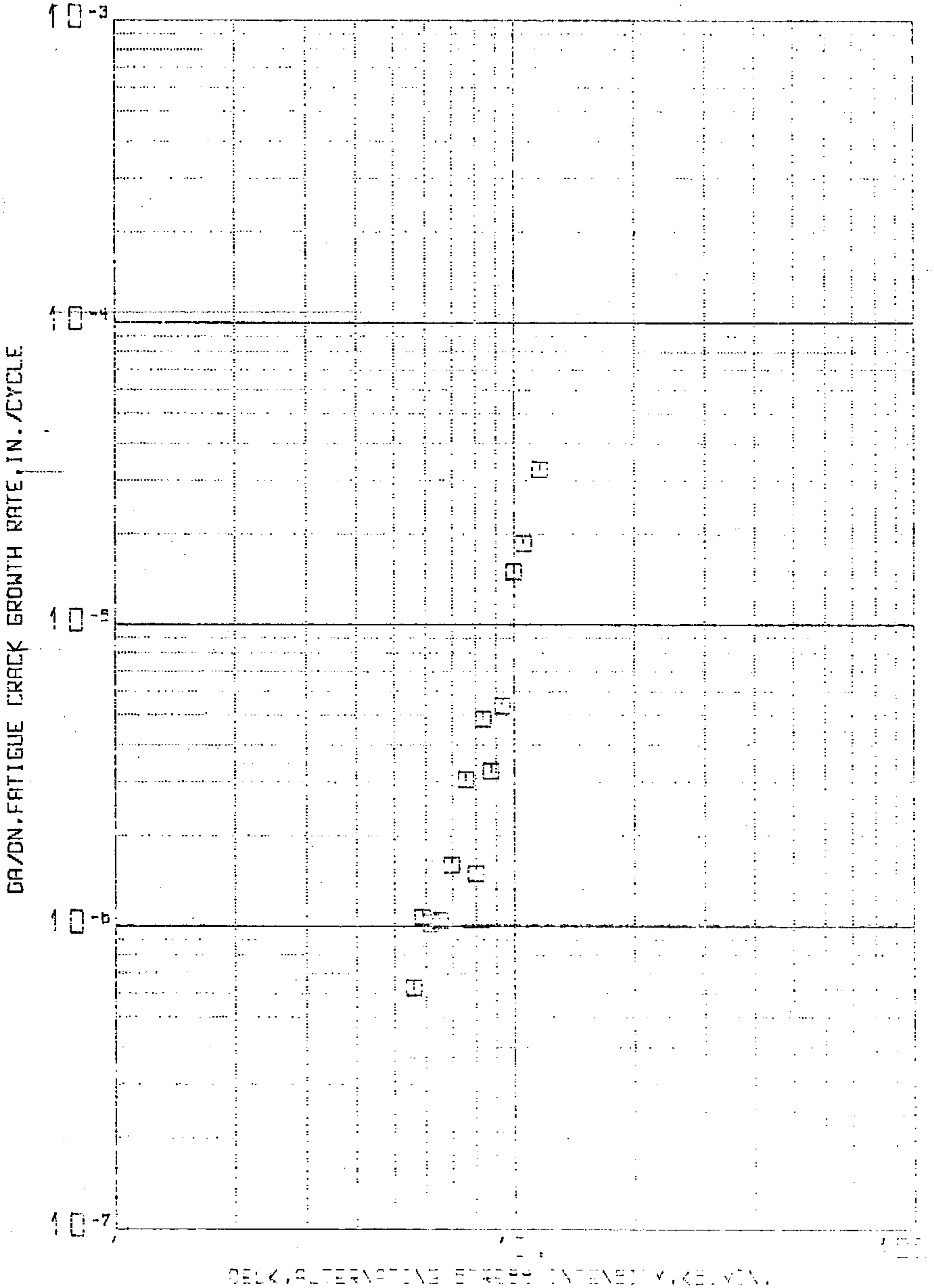


FIGURE 3.5.3.5-6 FATIGUE CRACK GROWTH RATE OF SPECIMEN 3FT-6T AT 600°F - NO SOAK, TRANSVERSE.

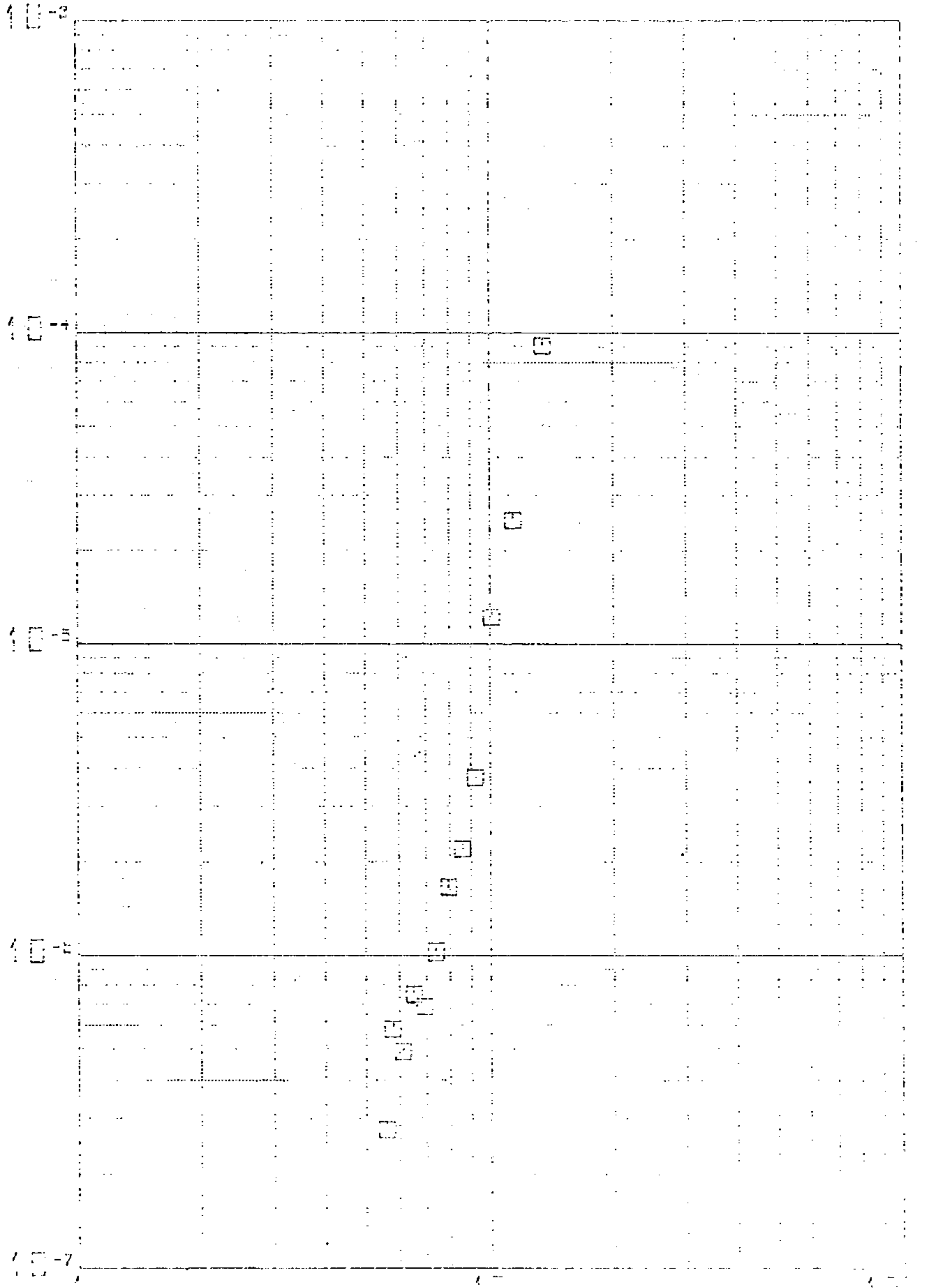


FIGURE 3.5.3.5-7 FATIGUE CRACK GROWTH RATE OF SPECIMEN 3FT-12L AT 600°F AFTER 100 HOUR SOAK AT 600°F, LONGITUDINAL.

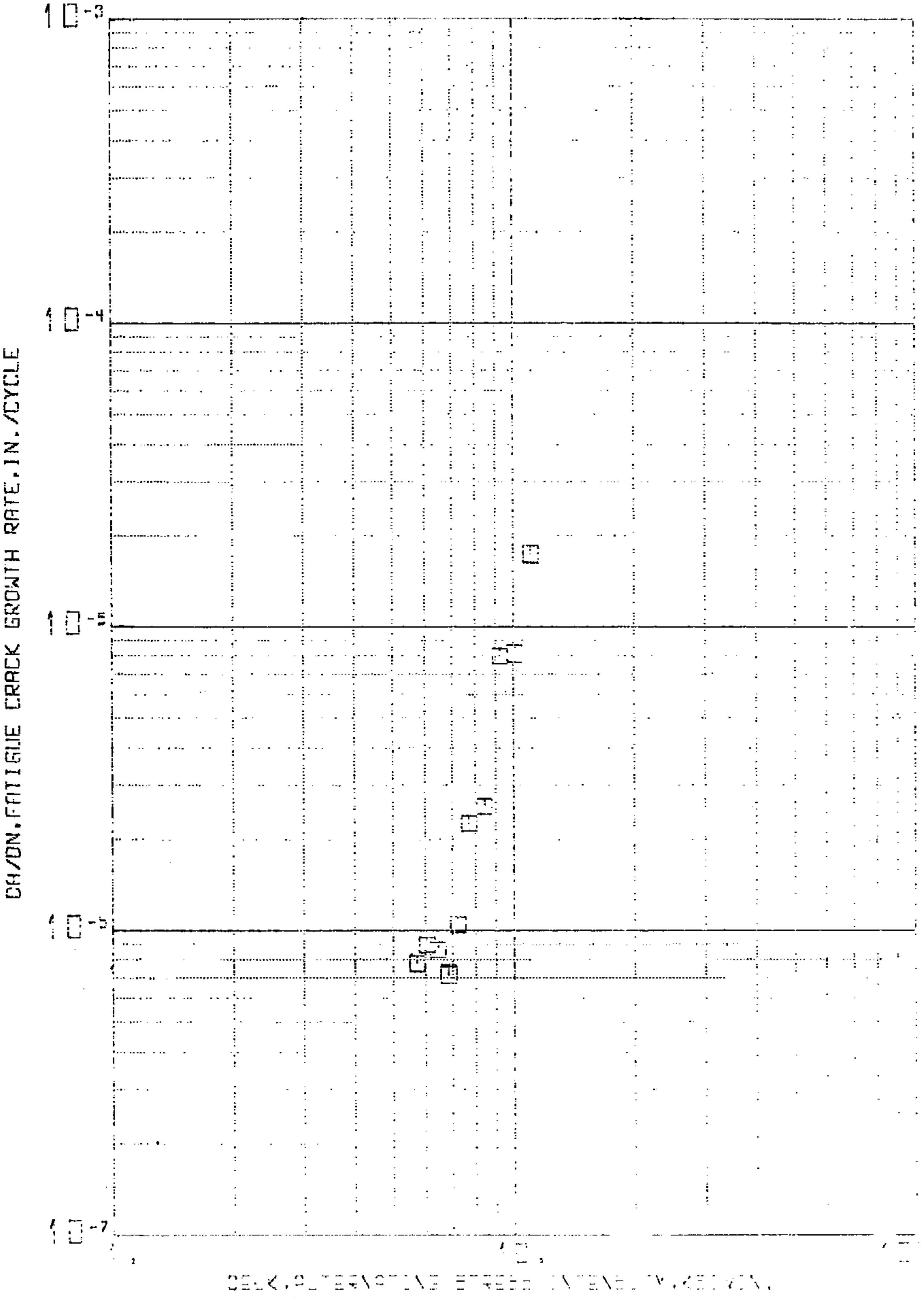


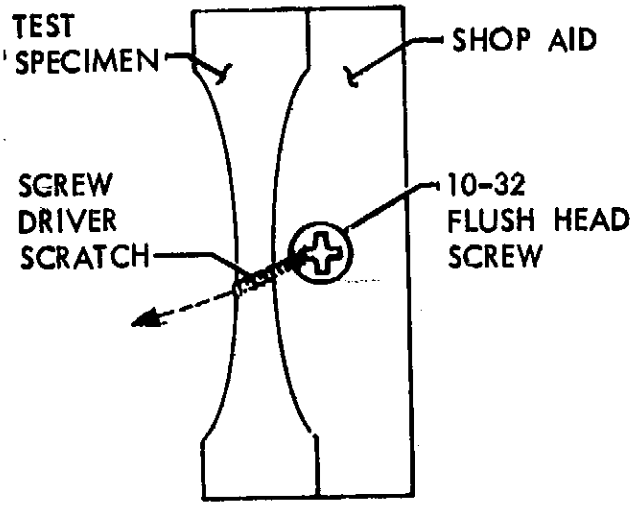
FIGURE 3.5.3.5-8 FATIGUE CRACK GROWTH RATE OF SPECIMEN 3FT-12T AT 600°F AFTER 100 HOUR SOAK AT 600°F, TRANSVERSE.

3.5.3.6 Fatigue Endurance Tests - The procedure used for testing the .150 thick material is the same as that employed for the .250 thick material. This is described in Section 3.4.2.6. Tests were also conducted in the transverse direction as well as the longitudinal.

The fatigue endurance limit test results of .150 inch Be-38Al alloy although incomplete are presented in Tables 3.5.3.6-1 thru 3.5.3.6-4.

To check the effect of scratches on the fatigue endurance limit, specimen numbers 3UF-7L, -8L, -9L, and 3UF-10L, -11L, and -12L were deliberately scratched across the test section with a torque set driver.

A form was made which matched the contour of the unnotched fatigue specimen as shown in sketch. A 10-32 flush head screw with a torque set recess was tightened in a normal manner with a torque set driver. While applying torque, the set was permitted to slip off the screw head and scratch across the specimen test section under full driving force.



Examination of the data in Tables 3.5.3.6-2 and 3.5.3.6-4 shows the scratched specimens had longer fatigue life than the notched $K_T = 3$ specimen.

SPECIMEN I.D.	CONDITION	DIRECTION	TEST TEMP. $^{\circ}$F	MAXIMUM STRESS - KSI	CYCLES TO FAILURE N
3UF-1L	AS RECEIVED	LONG.	ROOM	35.0	94,680
-2L				30.0	4,478,680
-3L				27.0	10^7 N.F.
3UF-1T		TRANS.	ROOM	35.0	109,620
-2T				30.0	2,579,060
-3T				25.0	10^7 N.F.
3UF-4L		LONG.	600	10.0	10^7 N.F.
-5L				15.0	10^7 N.F.
-6L				20.0	2,854,575
3UF-4T		TRANS.	600	20.0	203,770
-5T				15.0	680,210
-6T				10.0	10^7 N.F.

REF. - R.N. PAGE 529775

TABLE 3.5.3.6-1. FATIGUE ENDURANCE LIMIT TEST RESULTS OF .150 INCH THICK Be-38Al LOCKALLOY AT ROOM TEMPERATURE AND 600°F, IN THE AS RECEIVED CONDITION, IN BOTH THE LONGITUDINAL AND TRANSVERSE DIRECTIONS. $K_t = 1$

SPECIMEN I.D.	CONDITION	DIRECTION	TEST TEMP. °F	MAXIMUM STRESS - KSI	CYCLES TO FAILURE N
3UF-7L *	SOAKED 164 HRS** AT 600°F	LONG.	ROOM	30.0	1,356,030
-8L *				25.0	10^7 N.F.
-9L *				27.5	10^7 N.F.
3UF-7T		TRANS.	ROOM	30.0	1,230,370
-8T				25.0	1800 ***
-9T				25.0	10^7 N.F.
3UF-10L *		LONG.	600	15.0	10^7 N.F.
-11L *				20.0	100,792
-12L *				17.5	495,072
3UF-10T		TRANS.	600	15.0	10^7 N.F.
-11T				20.0	112,362
-12T				17.5	TIMER MALFUNCTIONED

N.F. - NO FAILURE

* SCRATCHED SPECIMENS WITH TORQUE SET DRIVER

** INADVERTENTLY OVERSOAKED 64 HRS

*** PREMATURE FAILURE - TO BE ANALYZED

REF. - R.N. PAGE 529775

TABLE 3.5.3.6-2. FATIGUE ENDURANCE LIMIT TEST RESULTS OF .150 INCH THICK Be-38Al LOCKALLOY AT ROOM TEMPERATURE AND 600°F, AFTER EXPOSURE TO 600°F FOR 164 HOURS, IN BOTH LONGITUDINAL AND TRANSVERSE DIRECTIONS. $K_t = 1$

SPECIMEN I.D.	CONDITION	DIRECTION	TEST TEMP. °F	MAXIMUM STRESS - KSI	CYCLES TO FAILURE N
3NF-1L	AS RECEIVED	LONG.	ROOM	20.0	619,012
-2L				17.5	10^7 N.F.
-3L					1,539,999
3NF-1T		TRANS.	ROOM	20.0	941,270
-2T				15.0	10^7 N.F.
-3T				17.5	10^7 N.F.
3NF-4L		LONG.	600	15.0	145,189
-5L				10.0	10^7 N.F.
-6L				12.5	8,930,400
3NF-4T		TRANS.	600	15.0	BUCKLED
-5T				12.5	10^7 N.F.
-6T				15.0	677,180

N.F. - NO FAILURE

REF. - R.N. PAGE 529776

TABLE 3.5.3.6-3. FATIGUE ENDURANCE LIMIT TEST RESULTS OF .150 INCH Be-38Al ALLOY AT ROOM TEMPERATURE AND 600°F, IN THE AS RECEIVED CONDITION AND IN BOTH THE LONGITUDINAL AND TRANSVERSE DIRECTIONS. $K_t = 3$

SPECIMEN I.D.	CONDITION	DIRECTION	TEST TEMP. °F	MAXIMUM STRESS - KSI	CYCLES TO FAILURE N
3NF-7L	SOAKED 164 HRS** AT 600°F	LONG.	ROOM	20.0	209,843
-8L				15.0	10^7 N.F.
-9L				17.5	4,616,520
3NF-7T		TRANS.	ROOM	20.0	10^7 N.F.
-8T				21.0	150,945
-9T				25.0	28,160
3NF-10L		LONG.	600	15.0	143,012
-11L				10.0	10^7 N.F.
-12L				12.5	8,544,538
3NF-10T		TRANS.	600	15.0	154,192
-11T				10	10^7 N.F.
-12T				12.5	5,893,095

N.F. - NO FAILURE
** INADVERTENTLY OVERSOAKED 64 HOURS
REF. - R.N. PAGES 529776 AND 529730

TABLE 3.5.3.6-4. FATIGUE ENDURANCE LIMIT TEST RESULTS OF .150 INCH THICK Be-38Al LOCKALLOY AT ROOM TEMPERATURE AND 600°F, AFTER EXPOSURE TO 600°F FOR 164 HOURS, IN BOTH THE LONGITUDINAL AND TRANSVERSE DIRECTIONS. $K_t = 3$

3.5.3.7 Stress Corrosion Tests - The procedure used for testing the .150 thick material is the same as that employed for the .250 thick material. This is described in Section 3.4.2.7 and is not repeated here.

The stress corrosion test results are presented in Table 3.5.3.7-1. No stress corrosion failures were observed. However, from an appearance standpoint, ADP high temperature aluminized paint offered the best protection.

SPECIMEN I.D.	CONDITION	TEST TEMP. °F	TEST STRESS - KSI	HOURS UNDER STRESS
3SC-1T	BARE + 3.5% SALT	ROOM	35.0	50.0 N.F.
-2T			35.0	103.5 N.F.
-3T			35.0	10.4 N.F.
3SC-4T		600	10.0	50.0 N.F.
-5T			10.0	103.2 N.F.
-6T			10.0	10.0 N.F.
3SC-7T	ALODINE COAT + 3.5% SALT	ROOM	35.0	106.4 N.F.
-8T			35.0	52.3 N.F.
-9T			35.0	10.0 N.F.
3SC-10T		600	10.0	10.0 N.F.
-11T			10.0	103.2 N.F.
-12T			10.0	50.0 N.F.
3SC-13T	PAINT + 3.5% SALT	ROOM	35.0	106.3 N.F.
-14T			35.0	50.1 N.F.
-15T			35.0	10.0 N.F.
3SC-16T		600	10.0	102.9 N.F.
-17T			10.0	50.0 N.F.
-18T			10.0	10.0 N.F.

N.F. - NO FAILURE
REF. - R.N. PAGE 529774

TABLE 3.5.3.7-1. STRESS CORROSION TEST RESULTS OF .150 INCH THICK Be-38Al LOCKALLOY AT ROOM TEMPERATURE AND 600°F IN THE TRANVERSE DIRECTION

3.5.3.8 Creep Strength Tests - The procedure used for testing the .150 inch thick Be-38Al is the same as that employed for the .250 inch thick material. This is described in Section 3.4.2.8 and is not repeated here.

A dead-weight load was applied at 600°F so as to produce a stress level in both the longitudinal and transverse directions on the specimens as follows:

Specimen I.D.	Stress ksi
3CR-1L,1T	20.0
3CR-2L,2T	12.5
3CR-3L,3T	7.5, 8.0

A plot of Creep-Rupture curves at 600°F in the longitudinal and transverse directions are presented in Figure 3.5.3.8-1 and Figure 3.5.3.8-2, respectively.

A plot of Creep curves at various total deformations at 600°F in the longitudinal and transverse directions are presented in Figure 3.5.3.8-3 and Figure 3.5.3.8-4, respectively.

3[illegible] - 2L
- 1L
- 3L

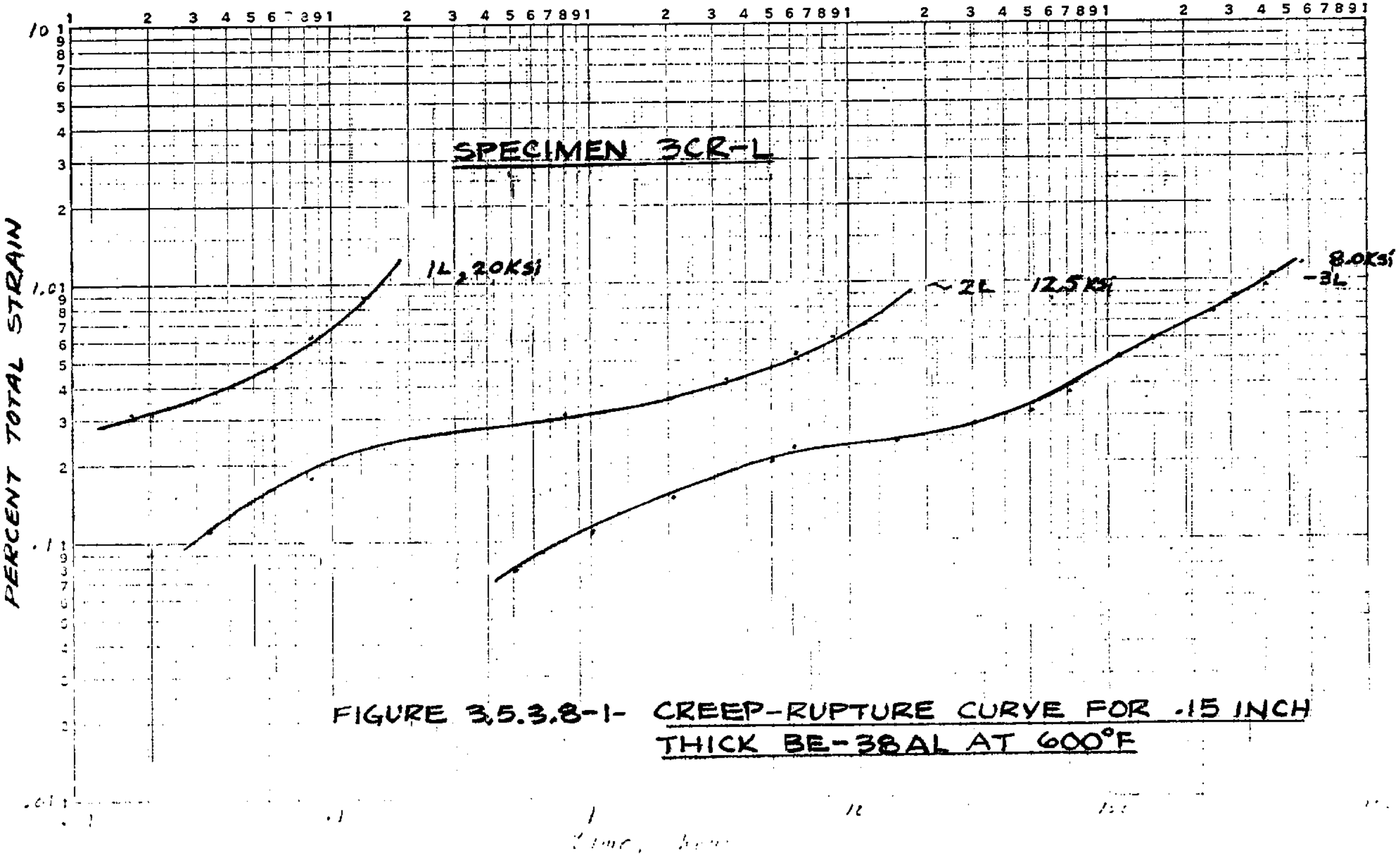


FIGURE 3.5.3.8-1- CREEP-RUPTURE CURVE FOR .15 INCH THICK BE-38AL AT 600°F

3CR - 1T
- 2T
- 3T

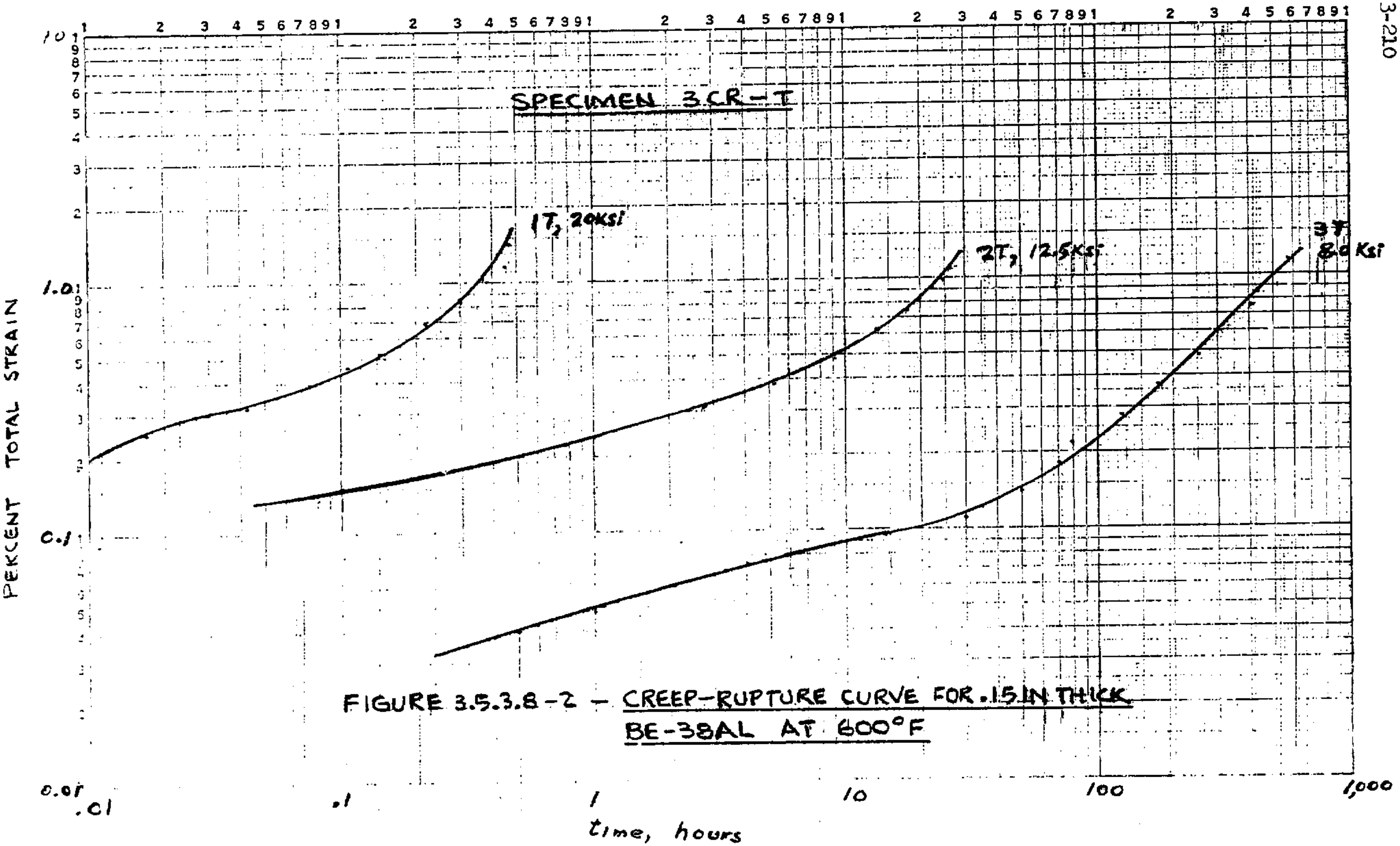


FIGURE 3.5.3.8-2 — CREEP-RUPTURE CURVE FOR .15 IN THICK BE-38AL AT 600°F

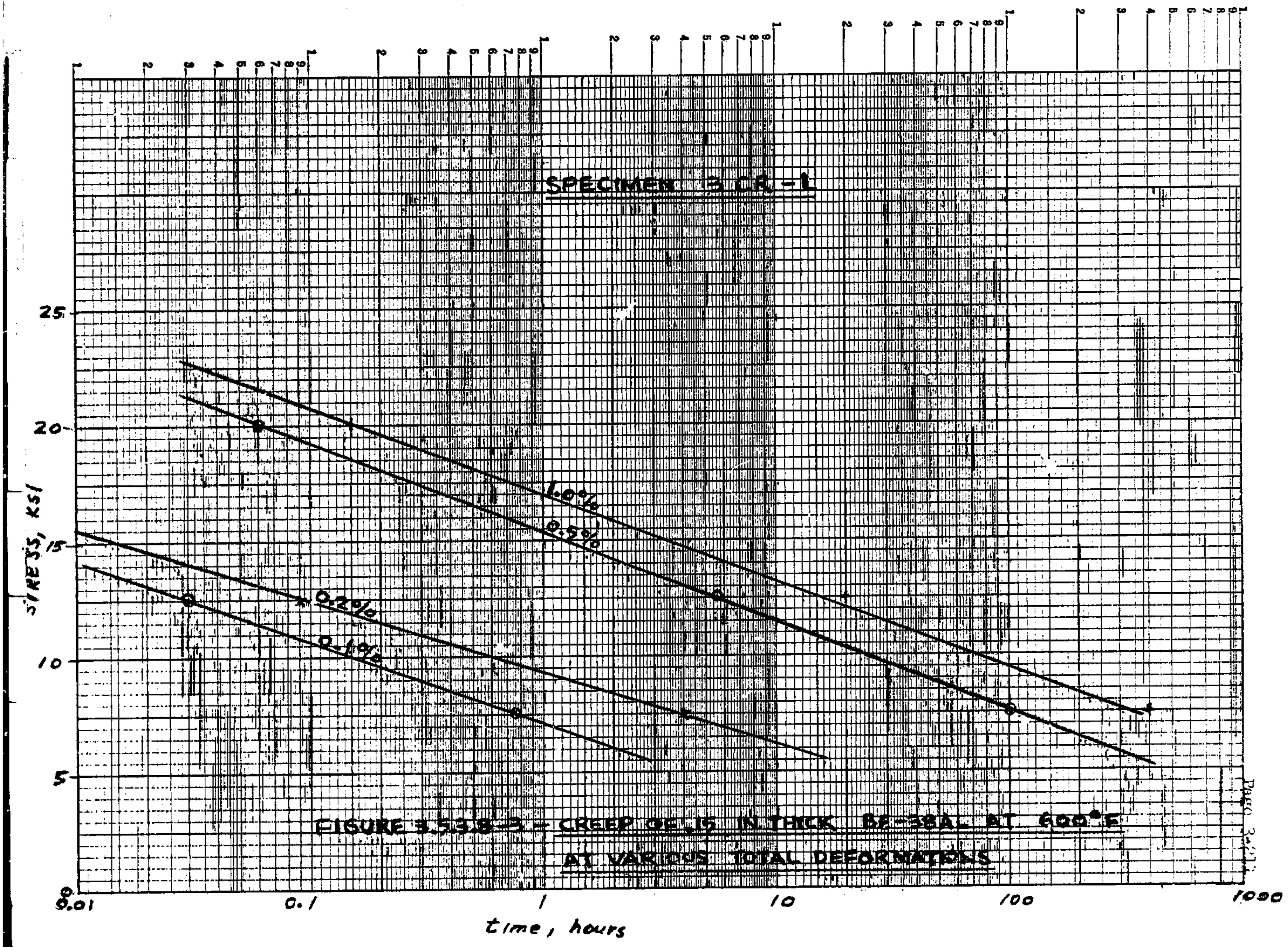


FIGURE 3.53.8-3 — CREEP OF .15 IN THICK BF-38AL AT 600°F AT VARIOUS TOTAL DEFORMATIONS

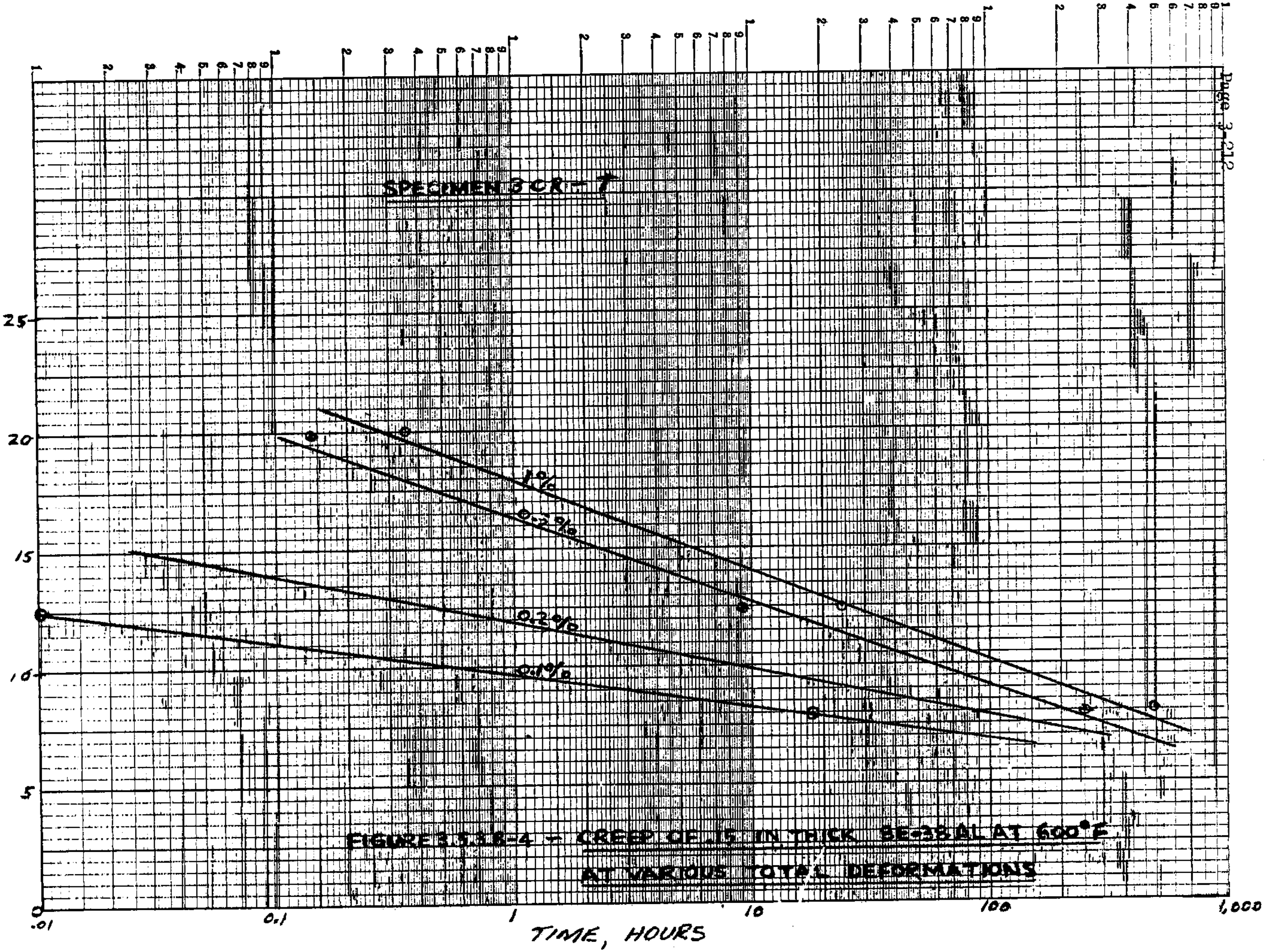


FIGURE 3.5.3.8-4 – CREEP OF .15 IN THICK BE-38AL AT 600°F AT VARIOUS TOTAL DEFORMATIONS

3.5.3.9 Poisson's Ratio Tests - The procedure used for testing the .150 thick material is the same as that employed for the .250 thick material. This is described in Section 3.4.2.9 and is not repeated here.

For the room temperature tests, the loads for the four loading runs were lowered to prevent overloading the thinner specimens (.150 inch versus .250 inch) and are as follows:

Run #1 0 to 300 lb. in 50 lb. increments.

Run #2 0 to 600 lb. in 100 lb. increments.

Run #3 0 to 2100 lb. in 300 lb. increments.

Run #4 0 to 3000 lb. in 300 lb. increments (or highest load possible at reasonable stabilization).

For elevated tests at 600°F, the following loadings were used:

Run #1 0 to 300 lb. in 50 lb. increments.

Run #2 0 to 1500 lb. in 300 lb. increments.

Run #3 0 to 1900 lb. in 300 lb. increments (or highest load possible at reasonable stabilization).

Strain readings were obtained for each gage at each increment of loading.

The results of the Poisson ratio tests for the .150 inch thick Be-38Al alloy are tabulated in Table 3.5.3.9-1 and were obtained from the graphical presentations shown in Figures 3.5.3.9-1a and 1b through Figures 3.5.3.9-12a and 12b.

An added benefit from the Poisson ratio tests was the ability to obtain modulus of elasticity values from the axial strain gages as contrasted to the conventional method of using extensometers. These results are shown in Table 3.5.3.9-1. Comparing the values obtained with the strain gage readings to those obtained with extensometers, a smaller range is realized for the strain gaged values, particularly at 600°F as shown below:

	Modulus of Elasticity - PSI x 10^{-6}	
	Room	600°F
Strain Gage	27.0 Min. - [illegible] Max.	19.0 Min. - [illegible] Max.
Extensometer	23.3 Min. - [illegible] Max.	[illegible] Min. - [illegible] Max.

SPECIMEN NO.	CONDITION	TEST TEMP	FROM GRAPHS		AVERAGE
			μ	MODULUS	
3PR-1L	NONE	ROOM TEMP	.149	28.5×10^6 PSI	μ = .158, MODULUS = 27.85×10^6 PSI
3PR-2L	NONE	ROOM TEMP	.159	27.8×10^6 PSI	
3PR-3L	NONE	ROOM TEMP	.156	28.6×10^6 PSI	
3PR-7L	100 HRS AT 600°F	ROOM TEMP	.162	27.2×10^6 PSI	
3PR-8L	100 HRS AT 600°F	ROOM TEMP	.158	27.0×10^6 PSI	
3PR-9L	100 HRS AT 600°F	ROOM TEMP	.163	28.0×10^6 PSI	
3PR-4L	NONE	600°F	.140	19.1×10^6 PSI	μ = .175, MODULUS = 20×10^6 PSI
3PR-5L	NONE	600°F	.197	20.1×10^6 PSI	
3PR-6L	NONE	600°F	.171	19.5×10^6 PSI	
3PR-10L	100 HRS AT 600°F	600°F	.198	22.6×10^6 PSI	
3PR-11L	100 HRS AT 600°F	600°F	.175	19.5×10^6 PSI	
3PR-12L	100 HRS AT 600°F	600°F	.167	19.0×10^6 PSI	

TABLE 3.5.3.9-1. POISSON'S RATIO AND YOUNG'S MODULUS TABULATION FOR .15" THICK x 1/2" WIDE Be-38Al SPECIMENS

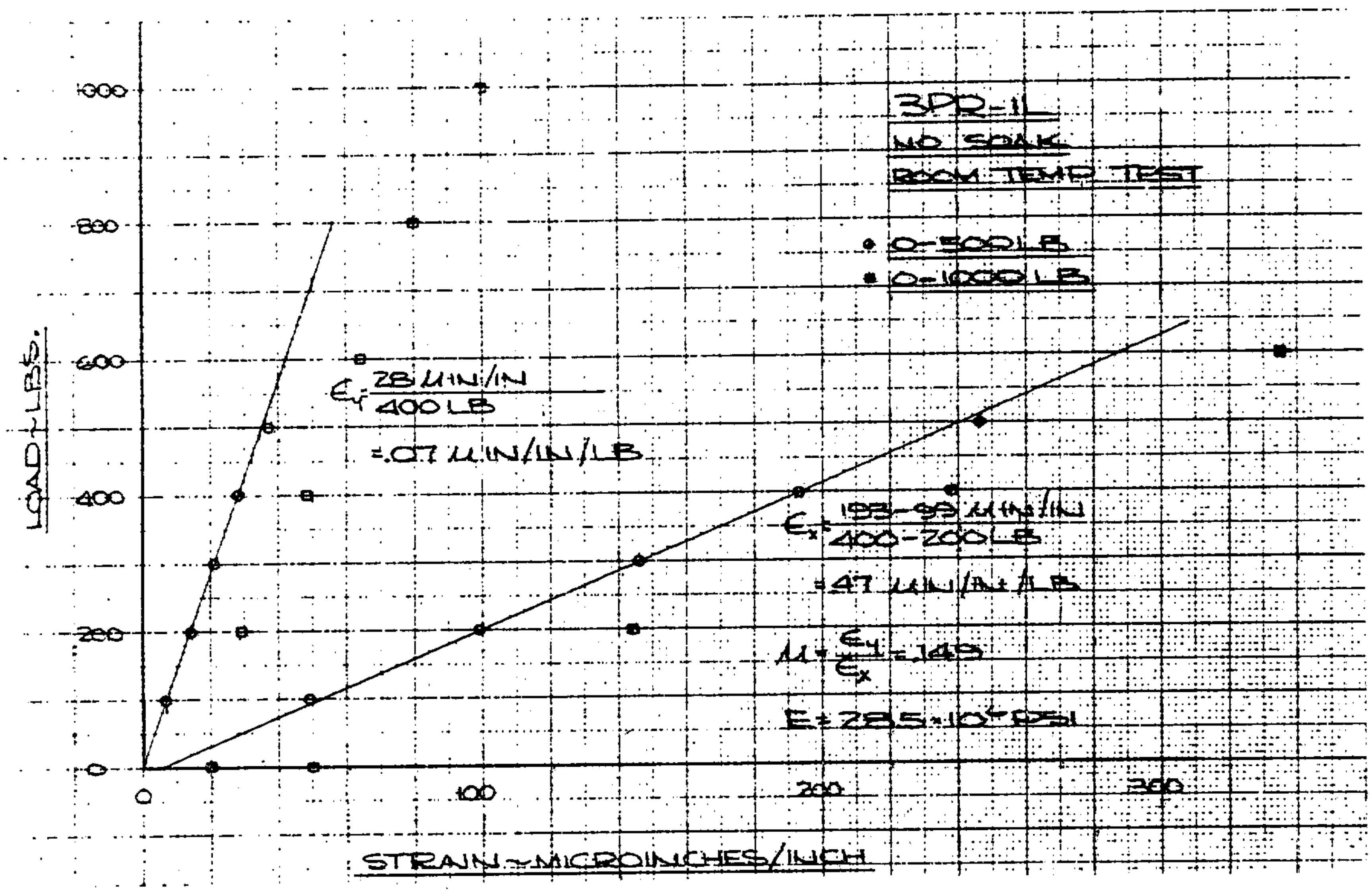


FIGURE 3.5.3.9-1a DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 3PR-1L AT ROOM TEMPERATURE - NO SOAK, LONGITUDINAL. (SHEET 1 OF 2)

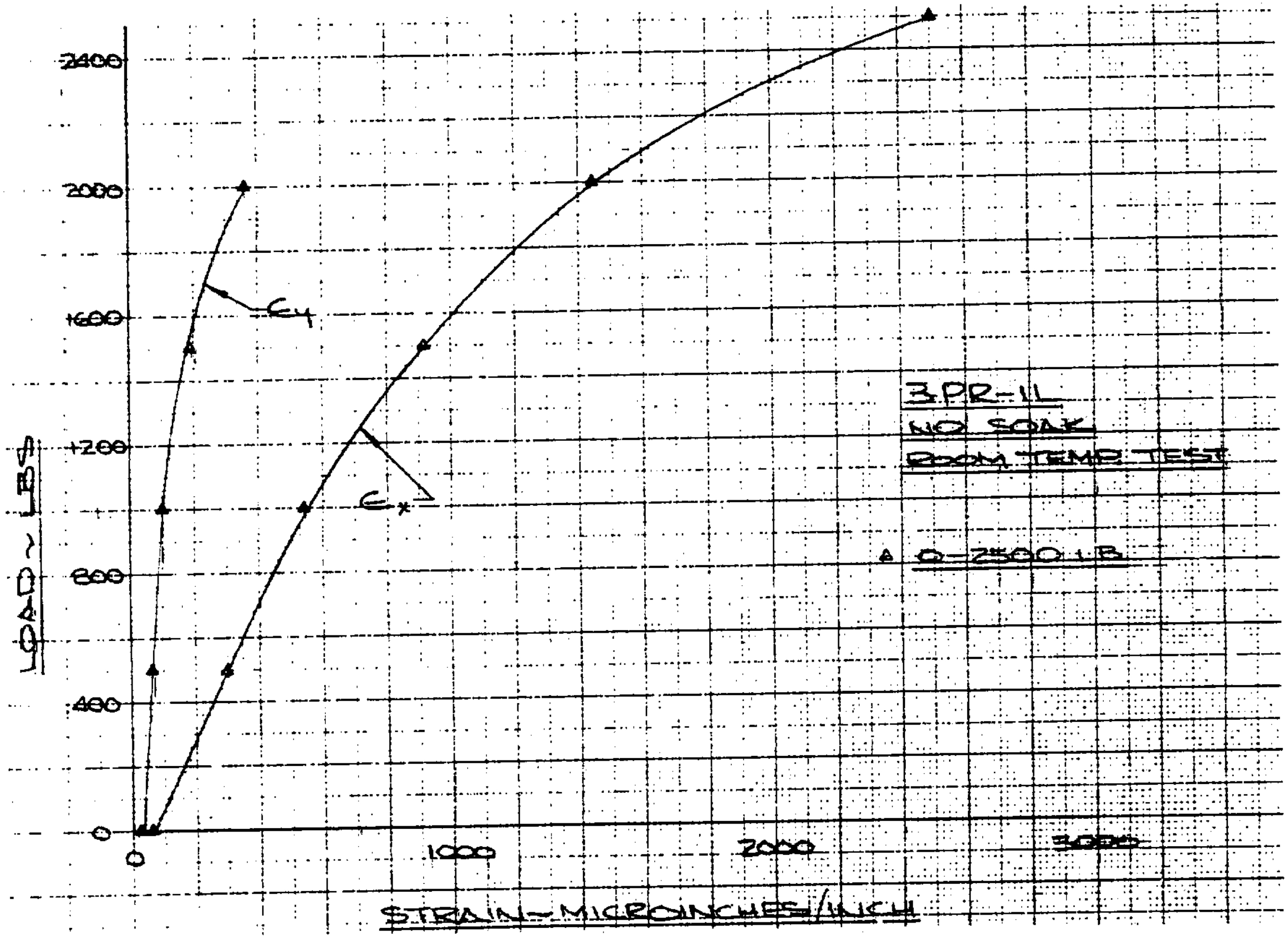


FIGURE 3.5.3.9-1b DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 3PR-1L AT ROOM TEMPERATURE - NO SOAK, LONGITUDINAL. (SHEET 2 OF 2)

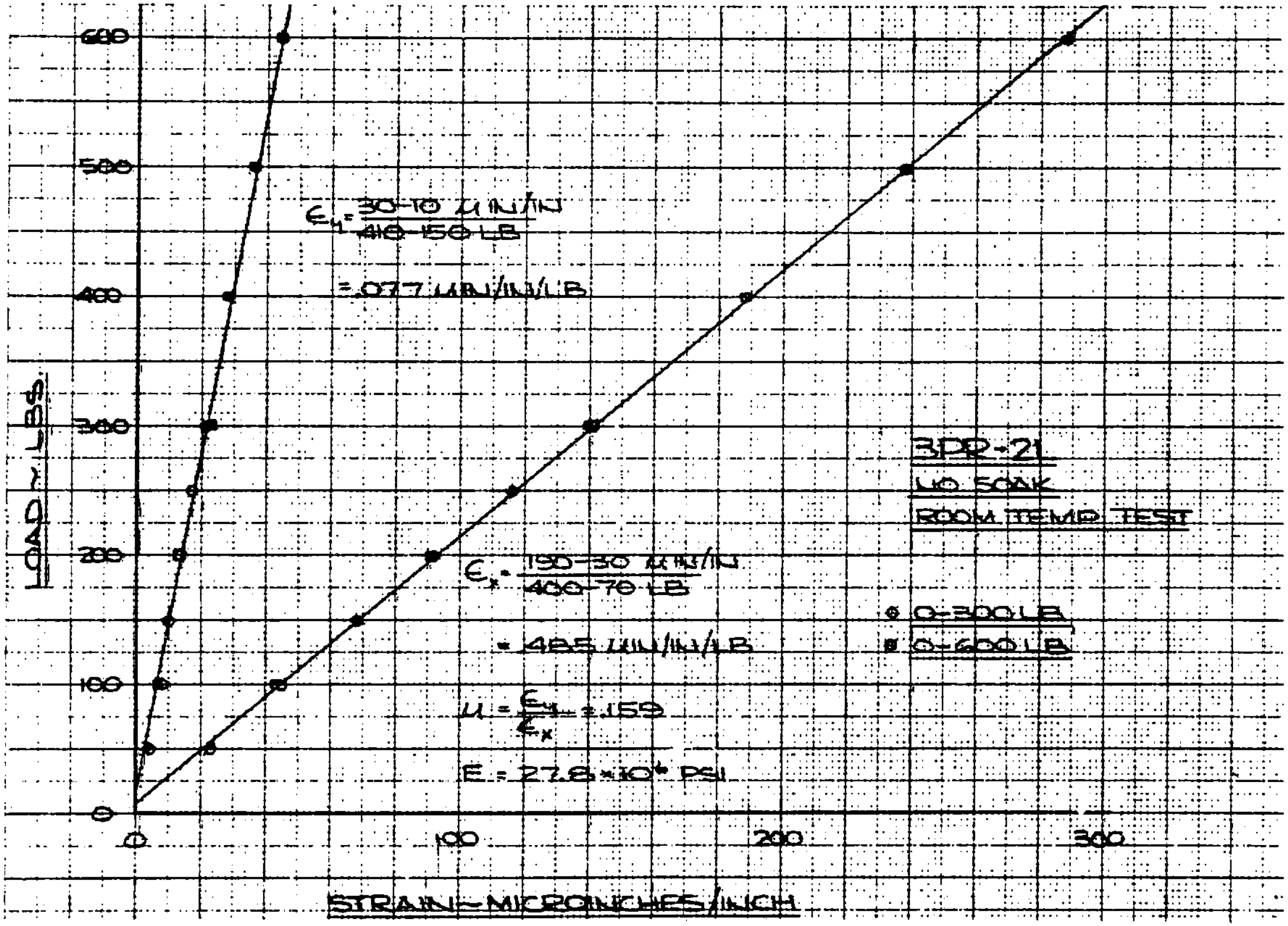


FIGURE 3.5.3.9-2a DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 3PR-2L AT ROOM TEMPERATURE - NO SOAK, LONGITUDINAL. (SHEET 1 OF 2)

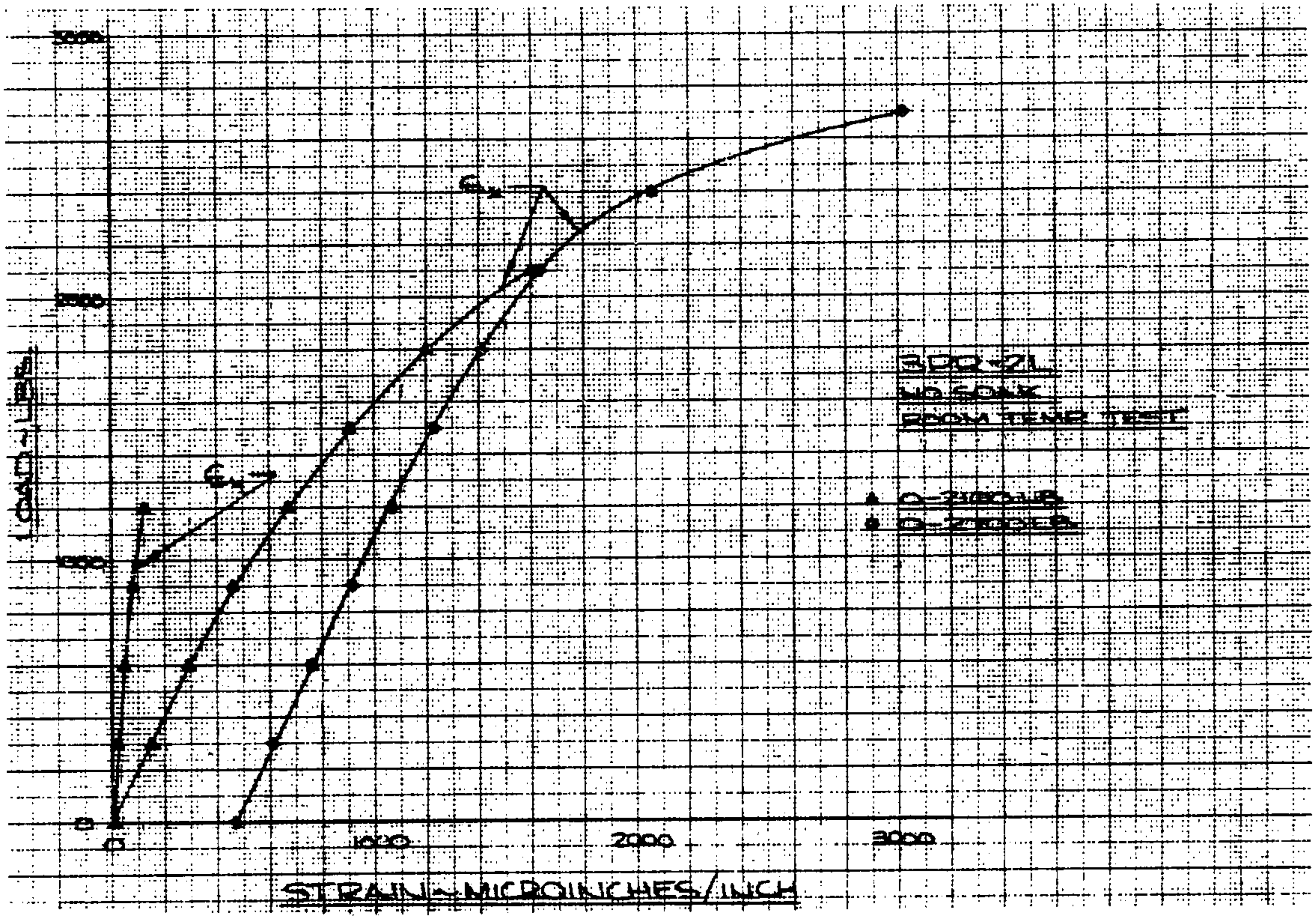


FIGURE 3.5.3.9-2b DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 3PR-2L AT ROOM TEMPERATURE - NO SOAK, LONGITUDINAL. (SHEET 2 OF 2)

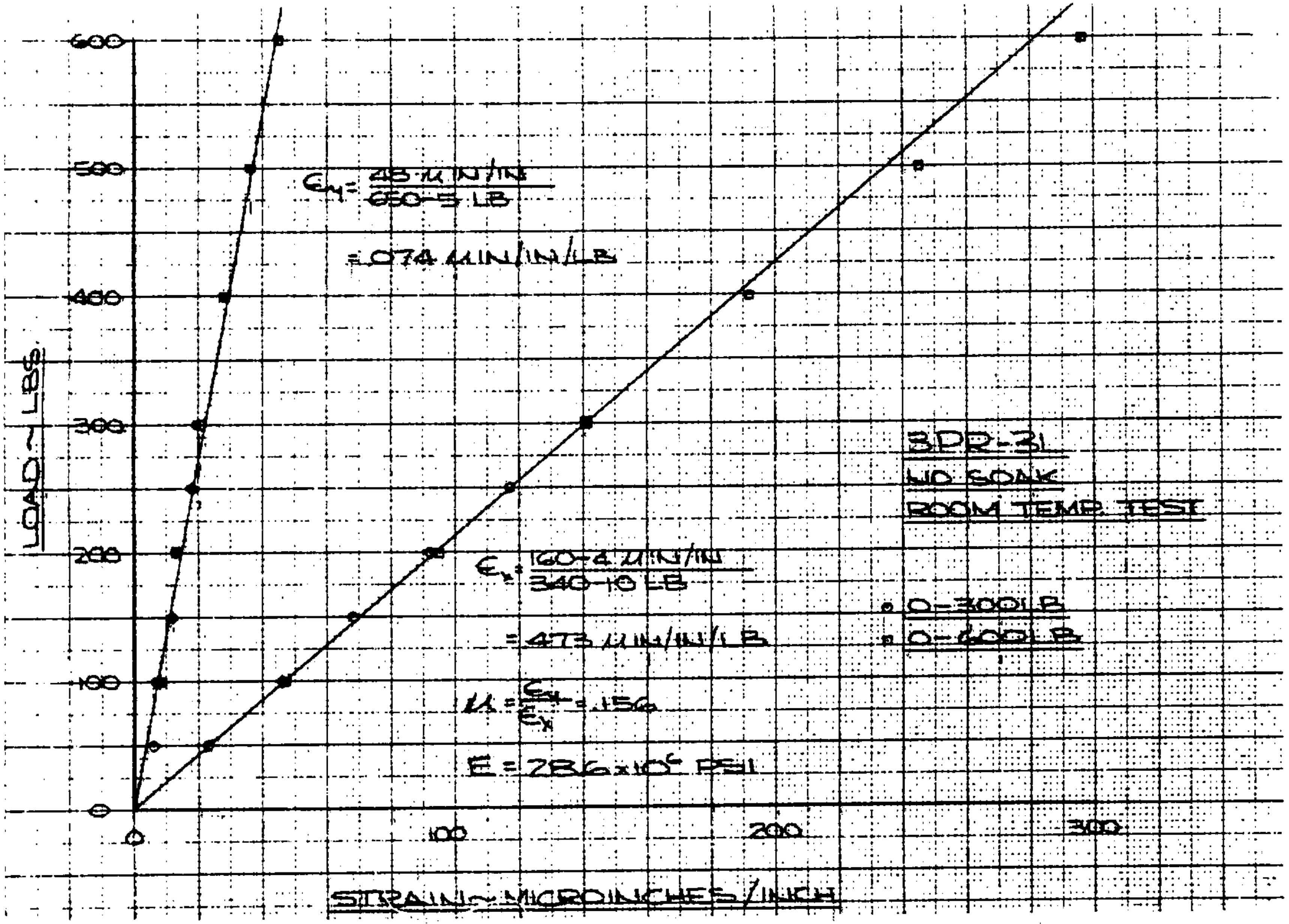


FIGURE 3.5.3.9-3a DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 3PR-3L AT ROOM TEMPERATURE - NO SOAK, LONGITUDINAL. (SHEET 1 OF 2)

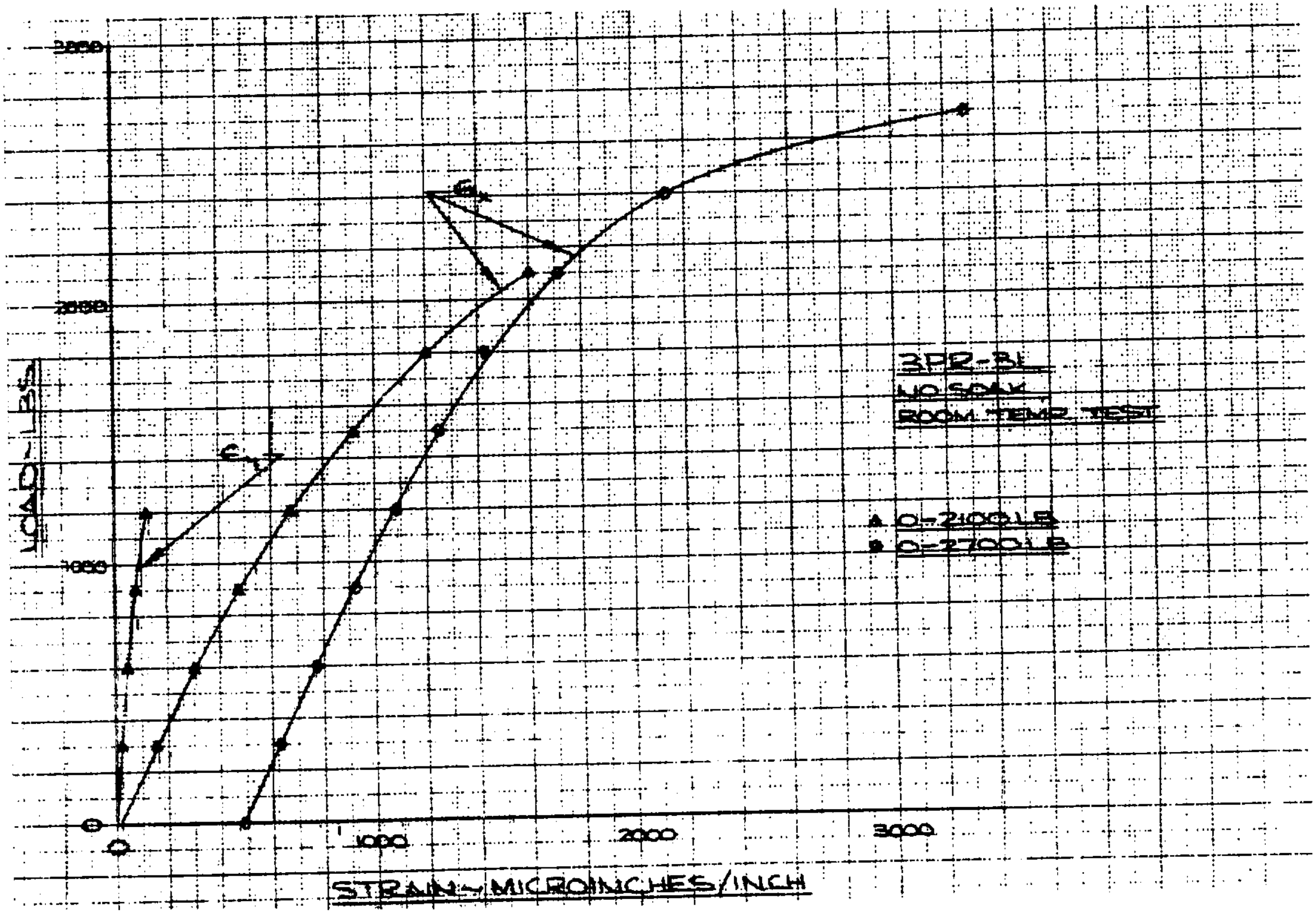


FIGURE 3.5.3.9-3b DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 3PR-3L AT ROOM TEMPERATURE - NO SOAK, LONGITUDINAL. (SHEET 2 OF 2)

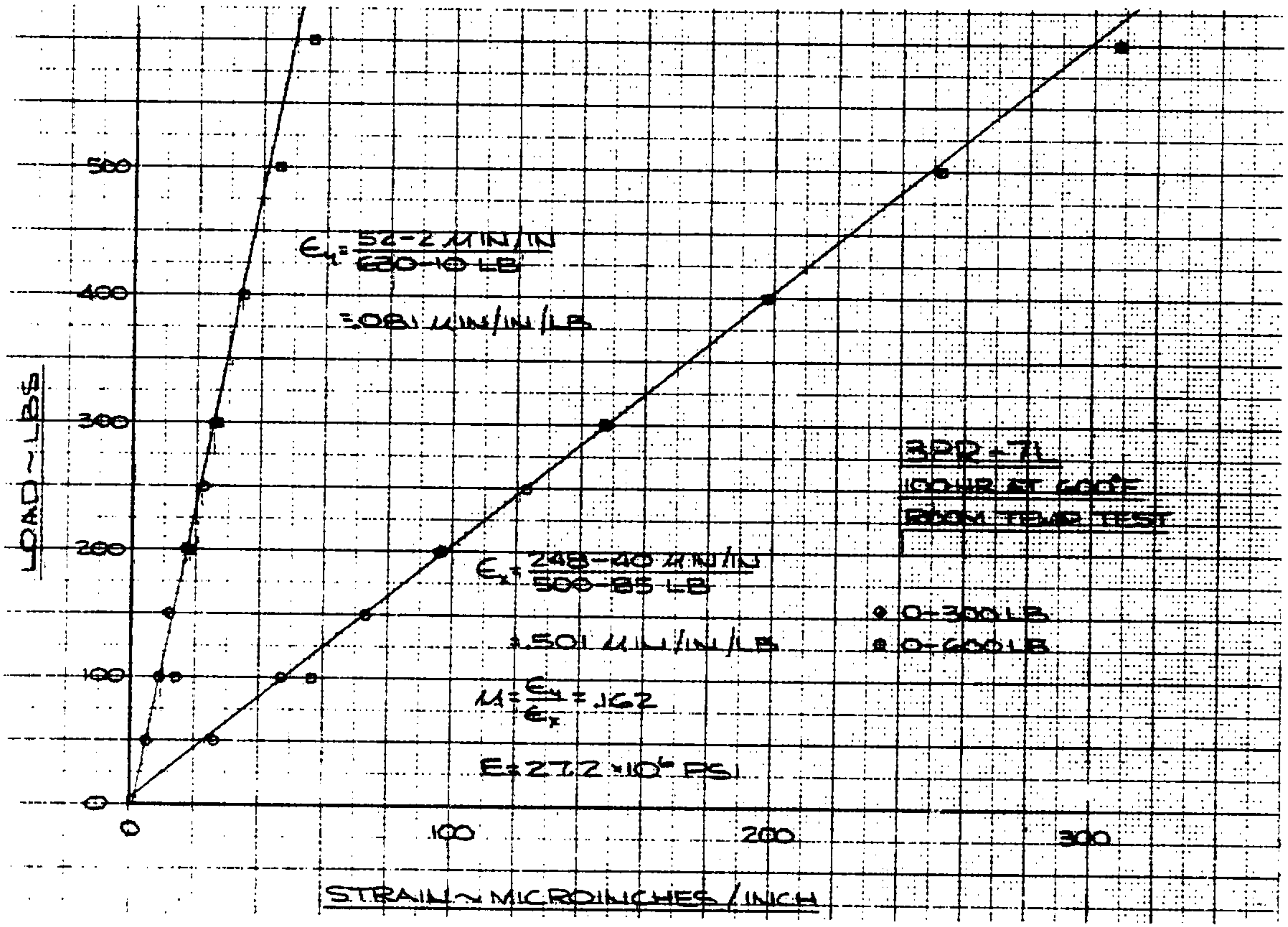


FIGURE 3.5.3.9-4a DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 3PR-7L AT ROOM TEMPERATURE AFTER 100 HOUR SOAK AT 600°F, LONGITUDINAL. (SHEET 1 OF 2)

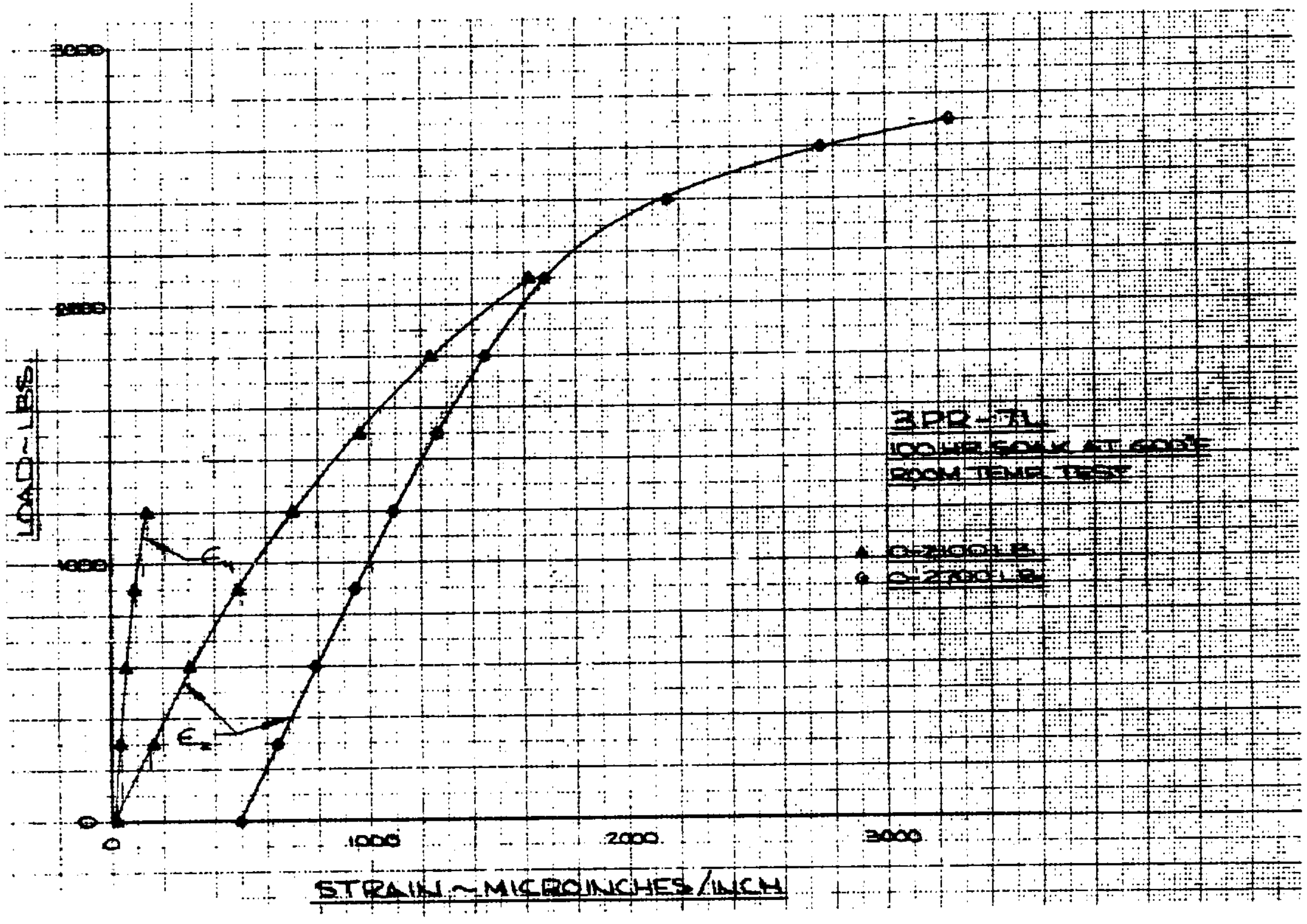


FIGURE 3.5.3.9-4b DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 3PR-7L AT ROOM TEMPERATURE AFTER 100 HOUR SOAK AT 600°F, LONGITUDINAL. (SHEET 2 OF 2)

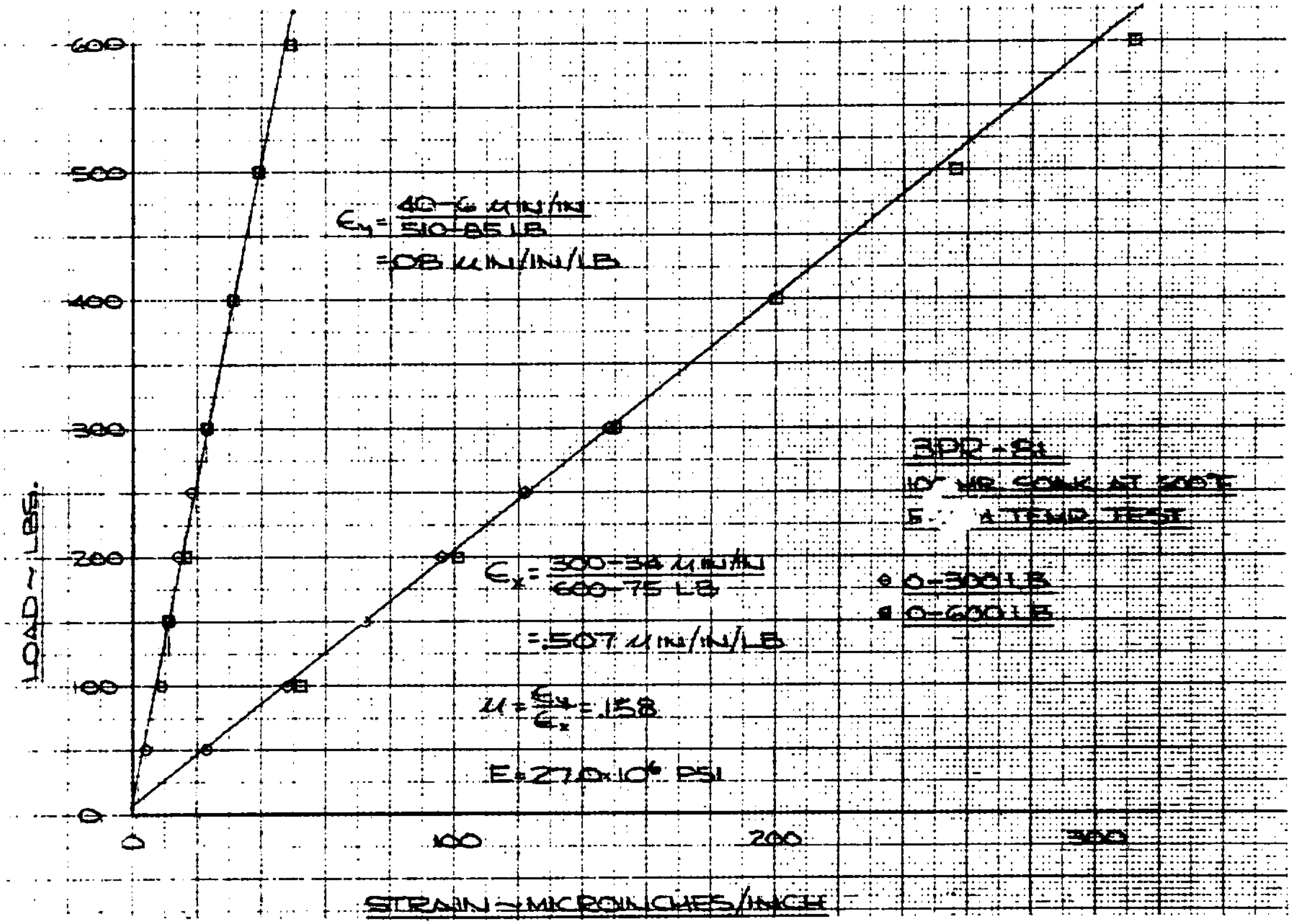


FIGURE 3.5.3.9-5a DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 3PR-8L AT ROOM TEMPERATURE AFTER 100 HOUR SOAK AT 600°F, LONGITUDINAL. (SHEET 1 OF 2)

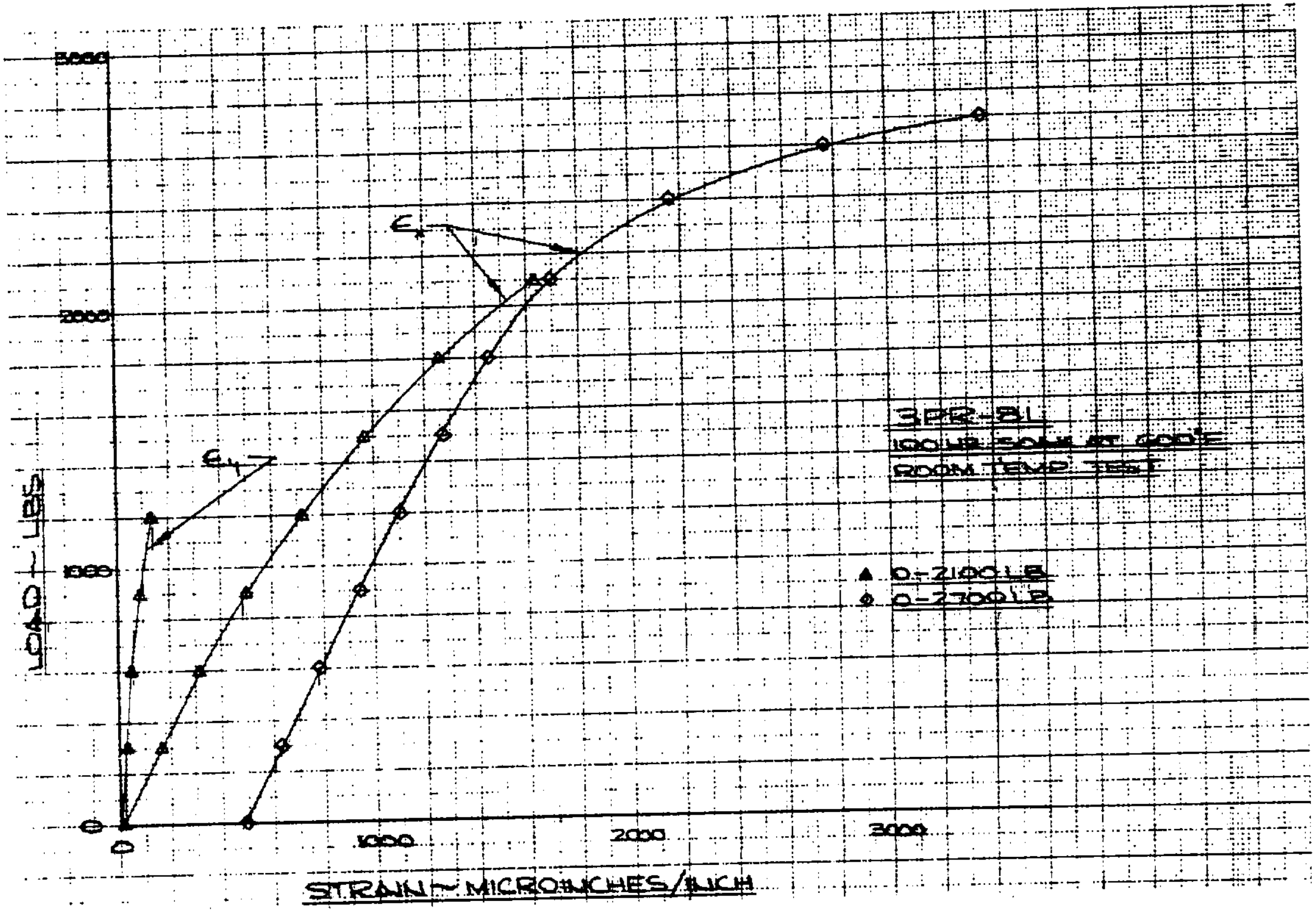


FIGURE 3.5.3.9-5b DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 3PR-8L AT ROOM TEMPERATURE AFTER 100 HOUR SOAK AT 600°F, LONGITUDINAL. (SHEET 2 OF 2)

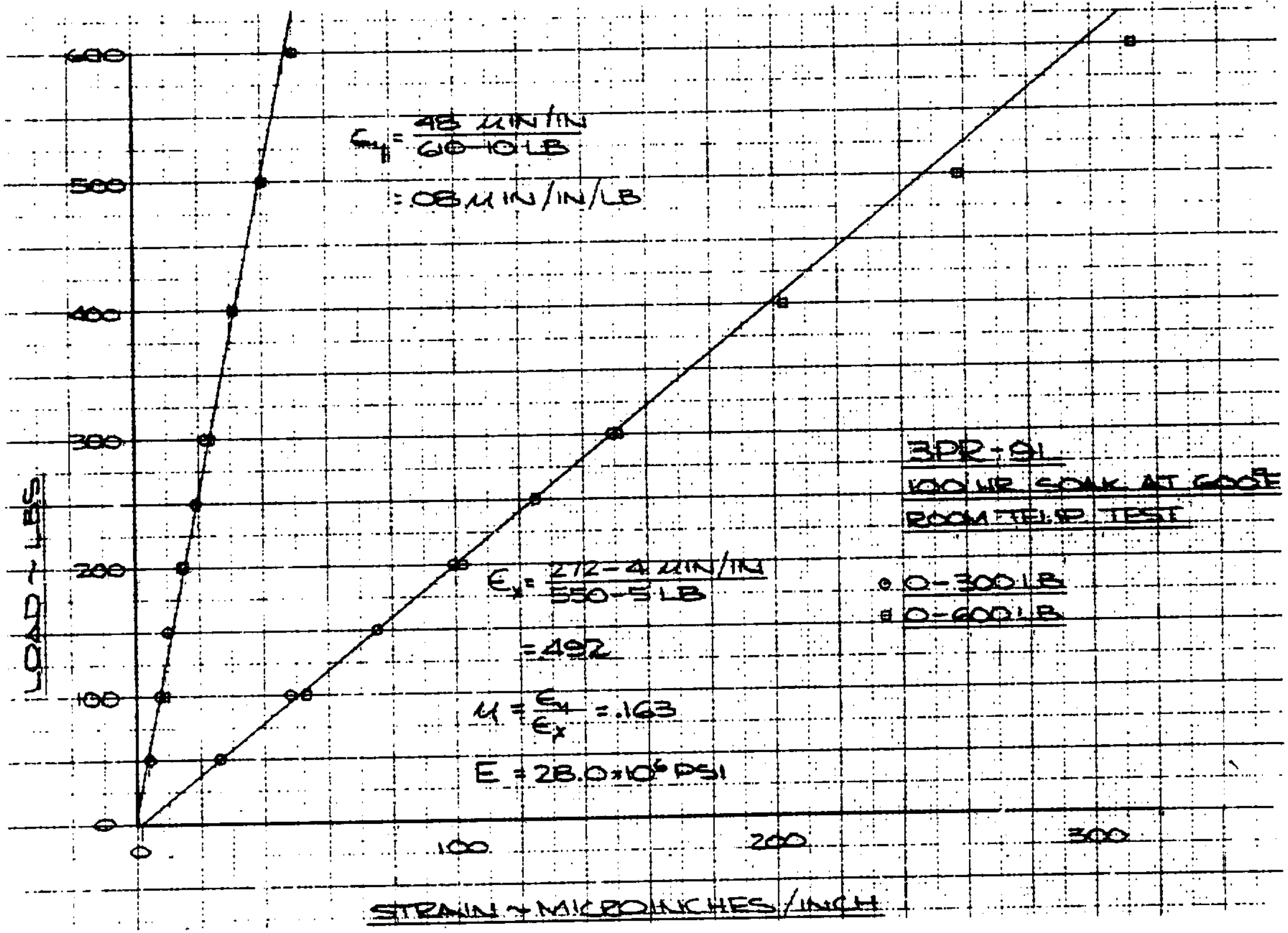


FIGURE 3.5.3.9-6a DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 3PR-9L AT ROOM TEMPERATURE AFTER 100 HOUR SOAK AT 600°F, LONGITUDINAL. (SHEET 1 OF 2)

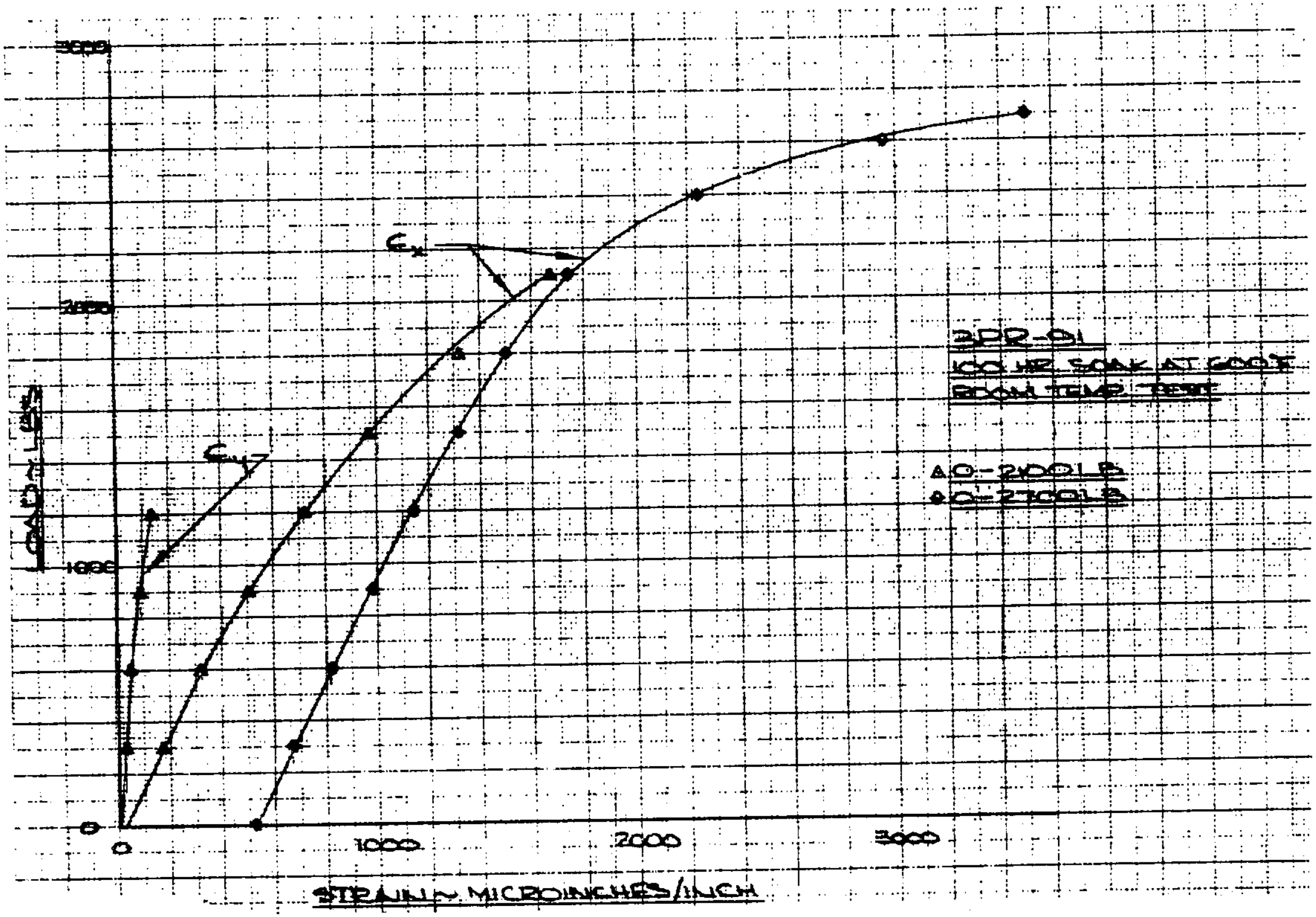


FIGURE 3.5.3.9-6b DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 3PR-9L AT ROOM TEMPERATURE AFTER 100 HOUR SOAK AT 600°F, LONGITUDINAL. (SHEET 2 OF 2)

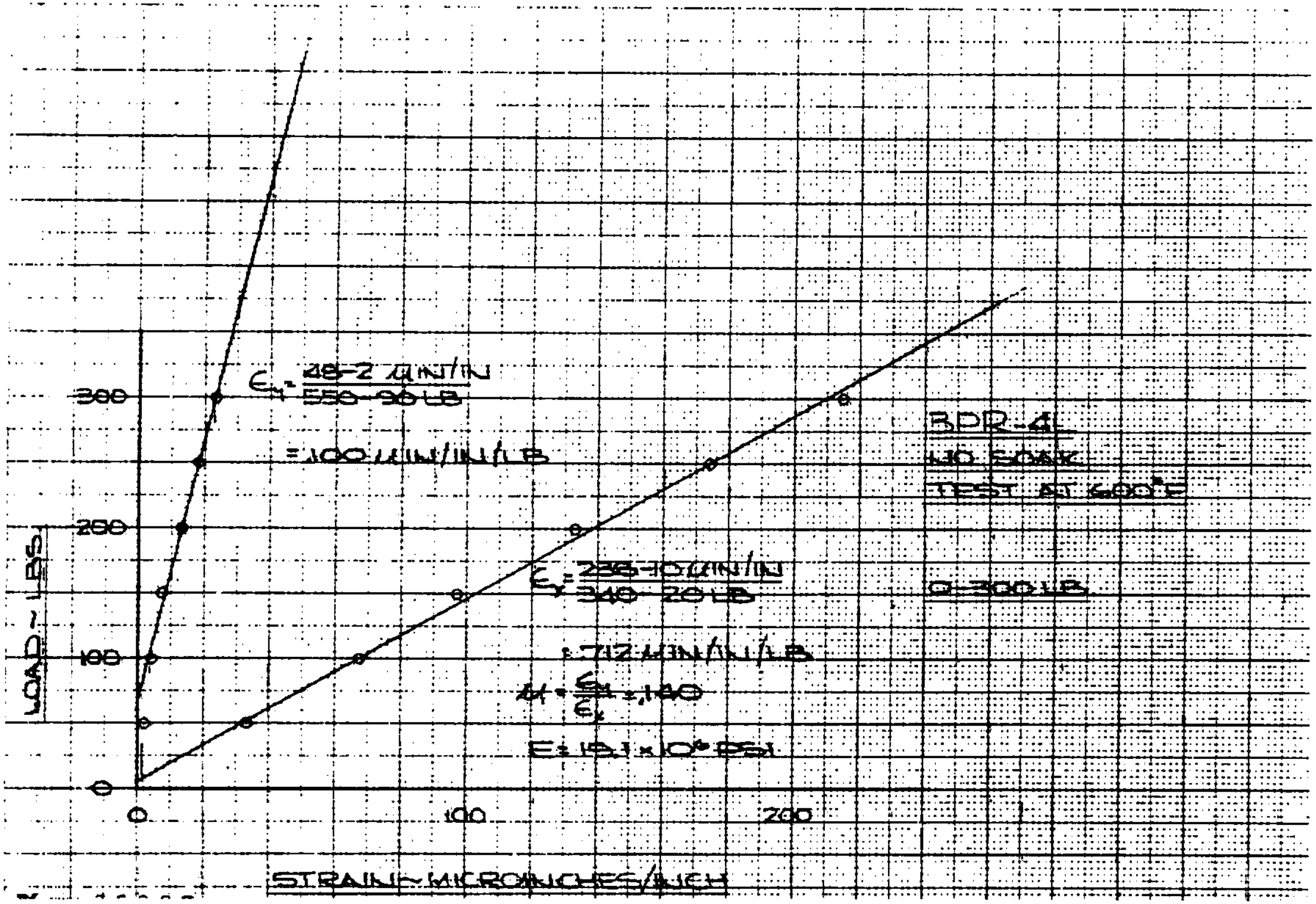


FIGURE 3.5.3.9-7a DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 3PR-4L AT 600°F - NO SOAK, LONGITUDINAL. (SHEET 1 OF 2)

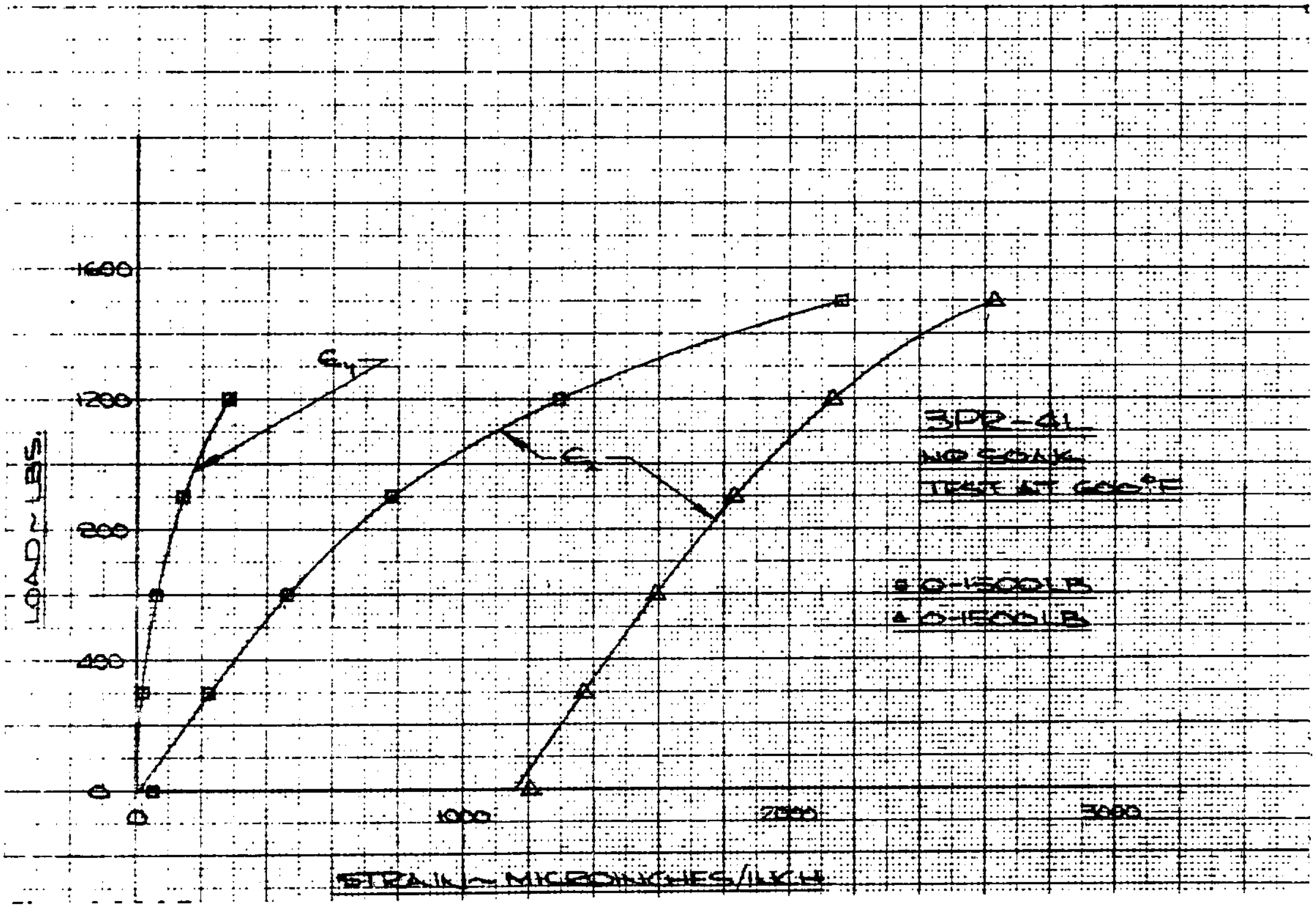


FIGURE 3.5.3.9-7b DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 3PR-4L AT 600°F - NO SOAK, LONGITUDINAL. (SHEET 2 OF 2)

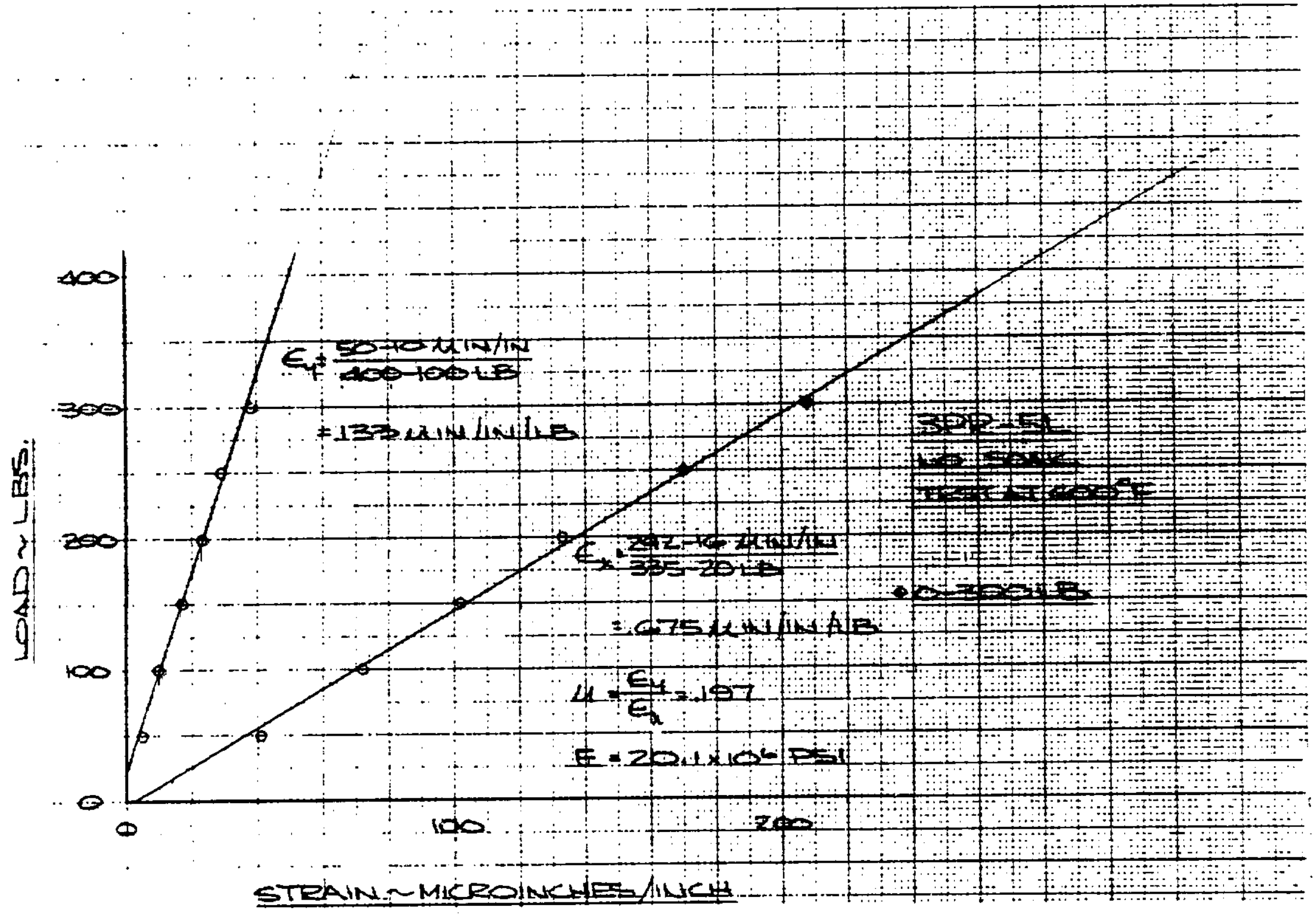


FIGURE 3.5.3.9-8a DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 3PR-5L AT 600°F - NO SOAK, LONGITUDINAL. (SHEET 1 OF 2)

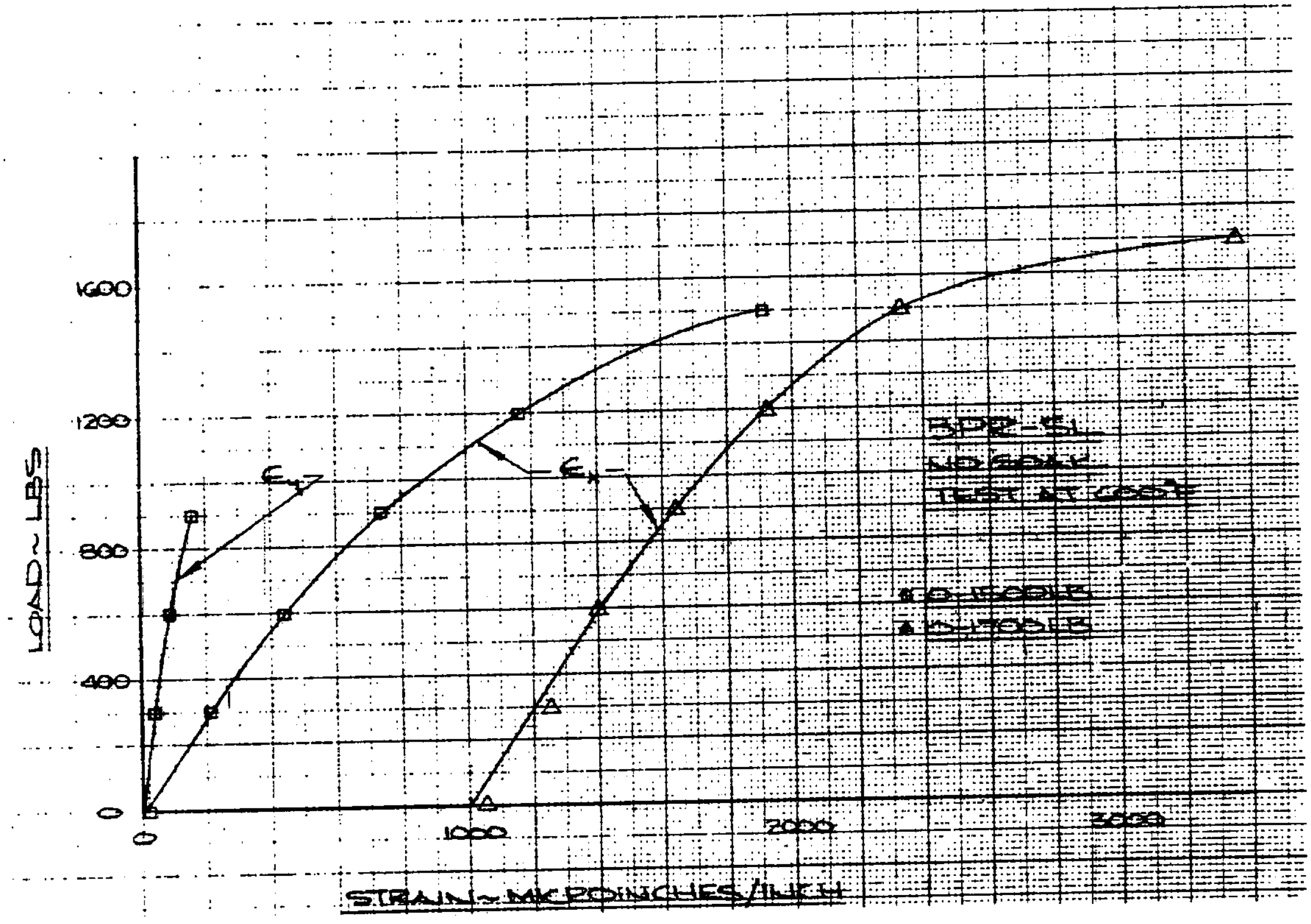


FIGURE 3.5.3.9-8b DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 3PR-5L AT 600°F - NO SOAK, LONGITUDINAL. (SHEET 2 OF 2)

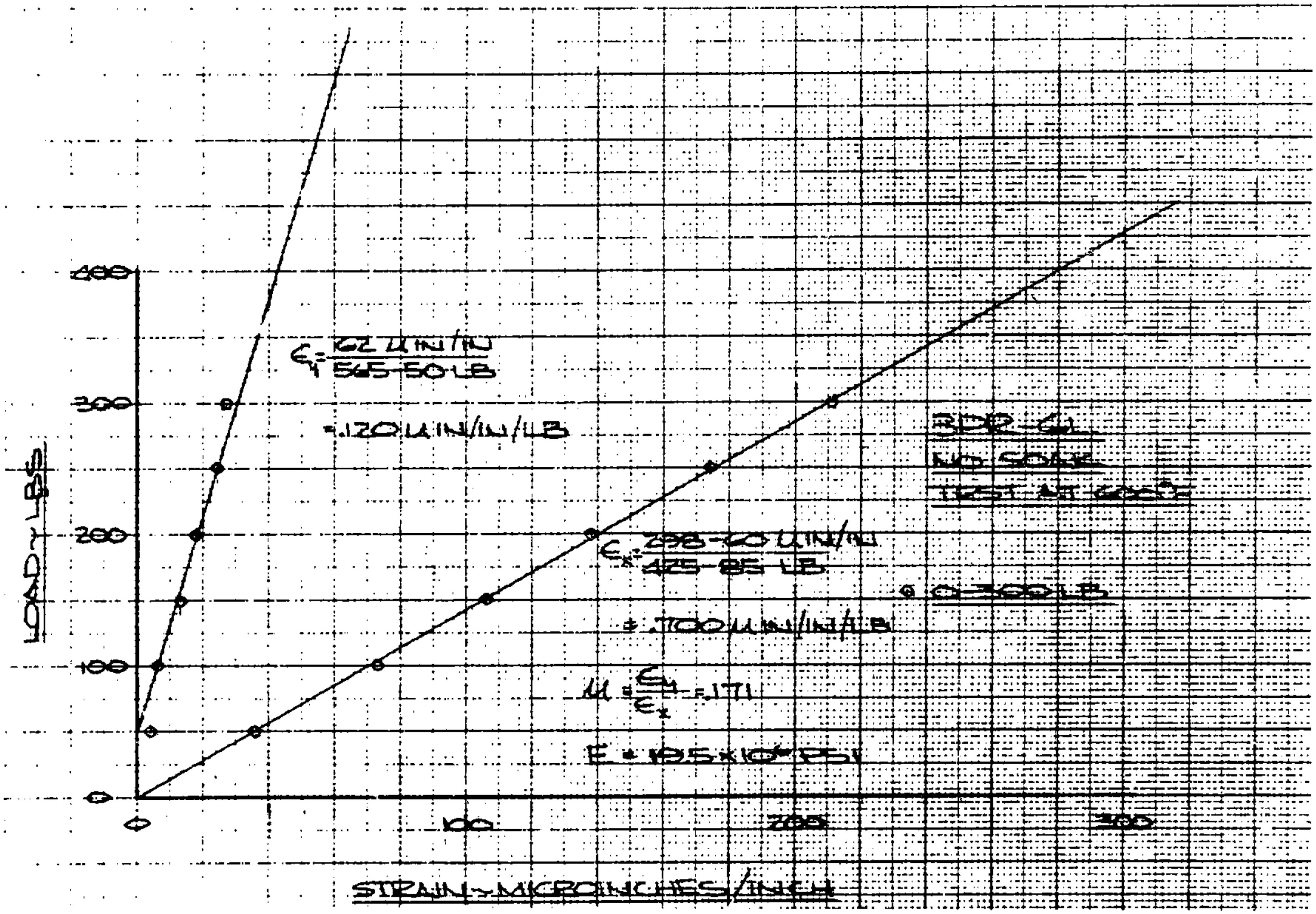


FIGURE 3.5.3.9-9a DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 3PR-6L AT 600°F - NO SOAK, LONGITUDINAL. (SHEET 1 OF 2)

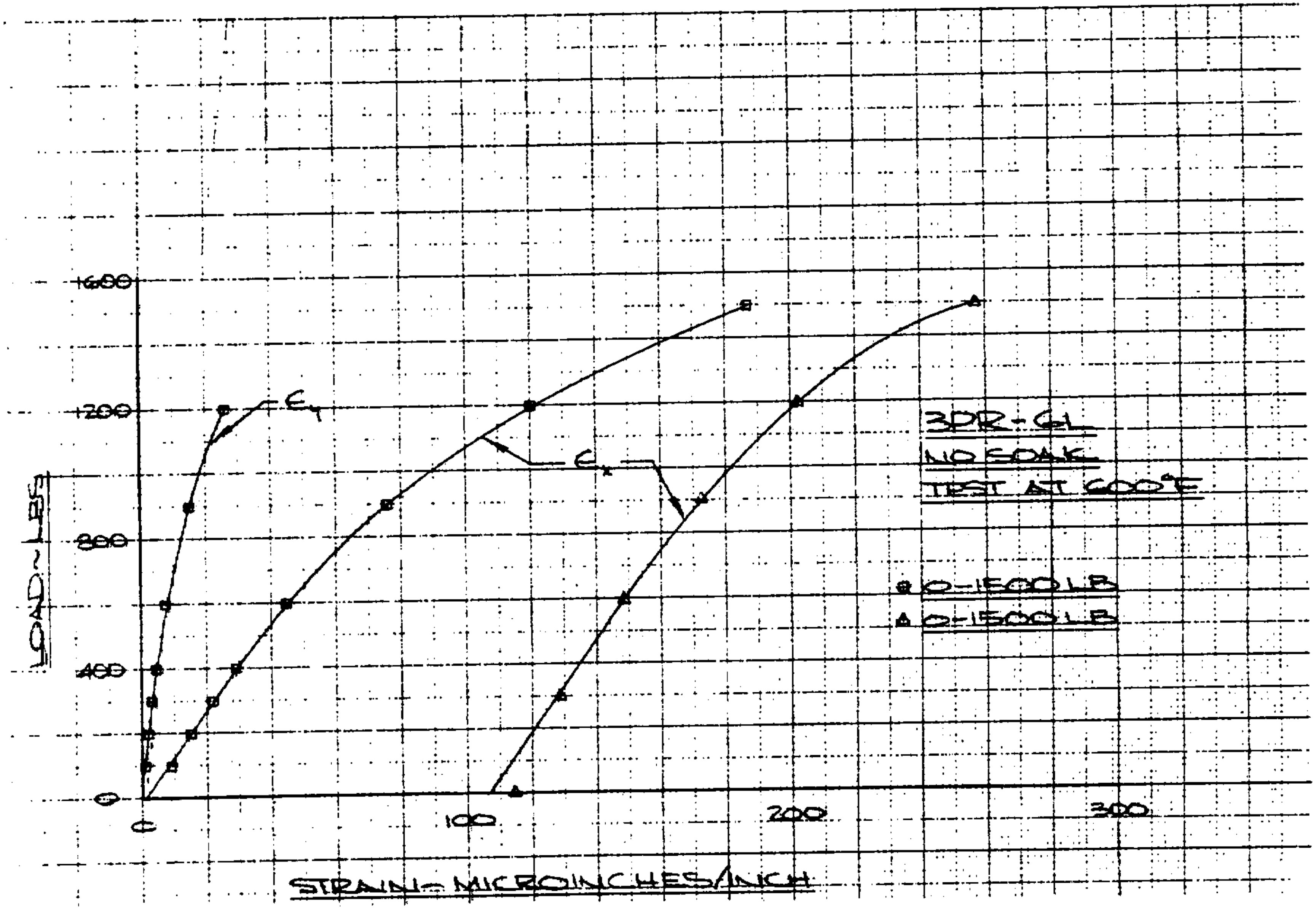


FIGURE 3.5.3.9-9b DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 3PR-6L AT 600°F - NO SOAK, LONGITUDINAL. (SHEET 2 OF 2)

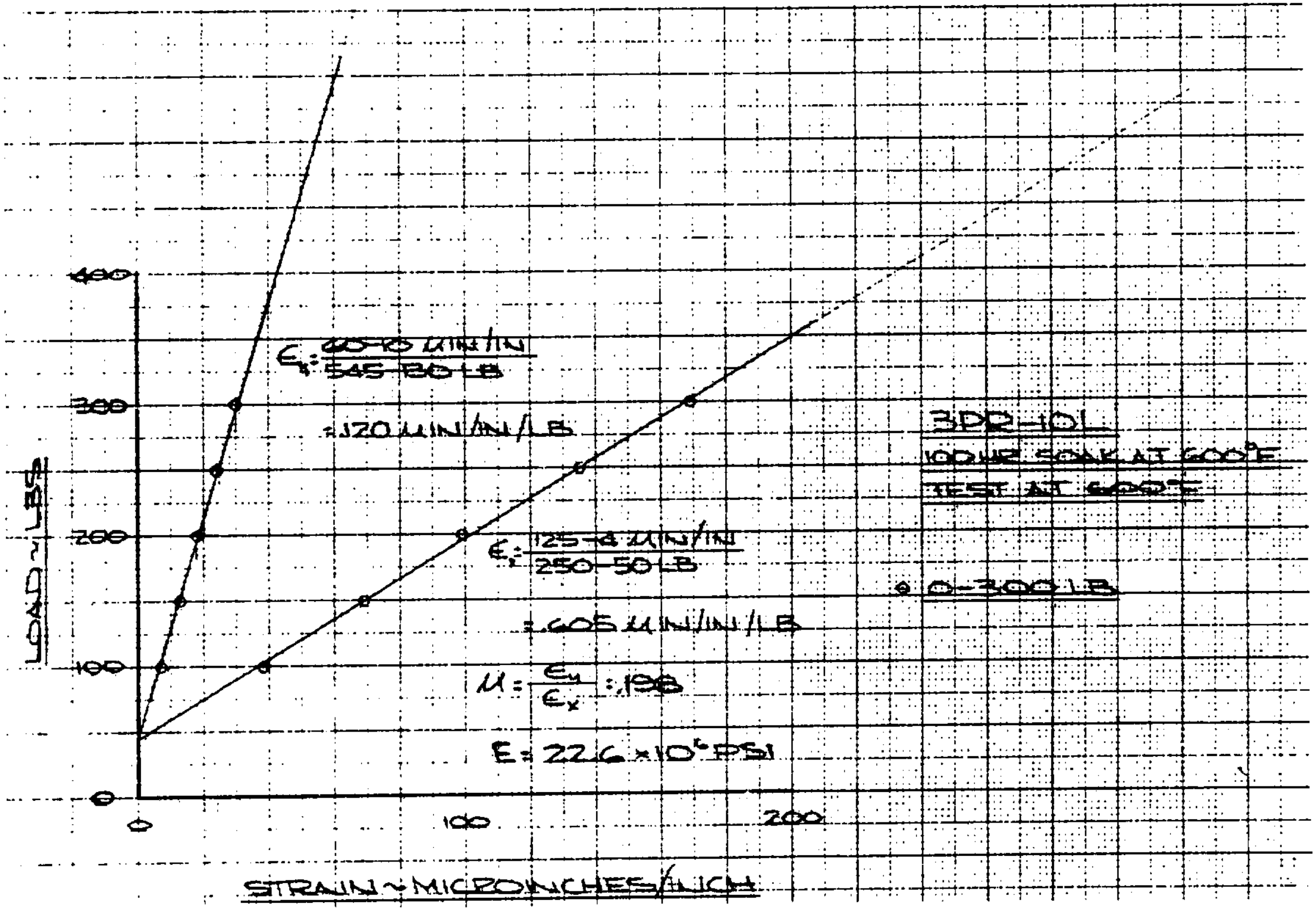


FIGURE 3.5.3.9-10a DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 3PR-10L AT 600°F AFTER 100 HOUR SOAK AT 600°F, LONGITUDINAL. (SHEET 1 OF 2)

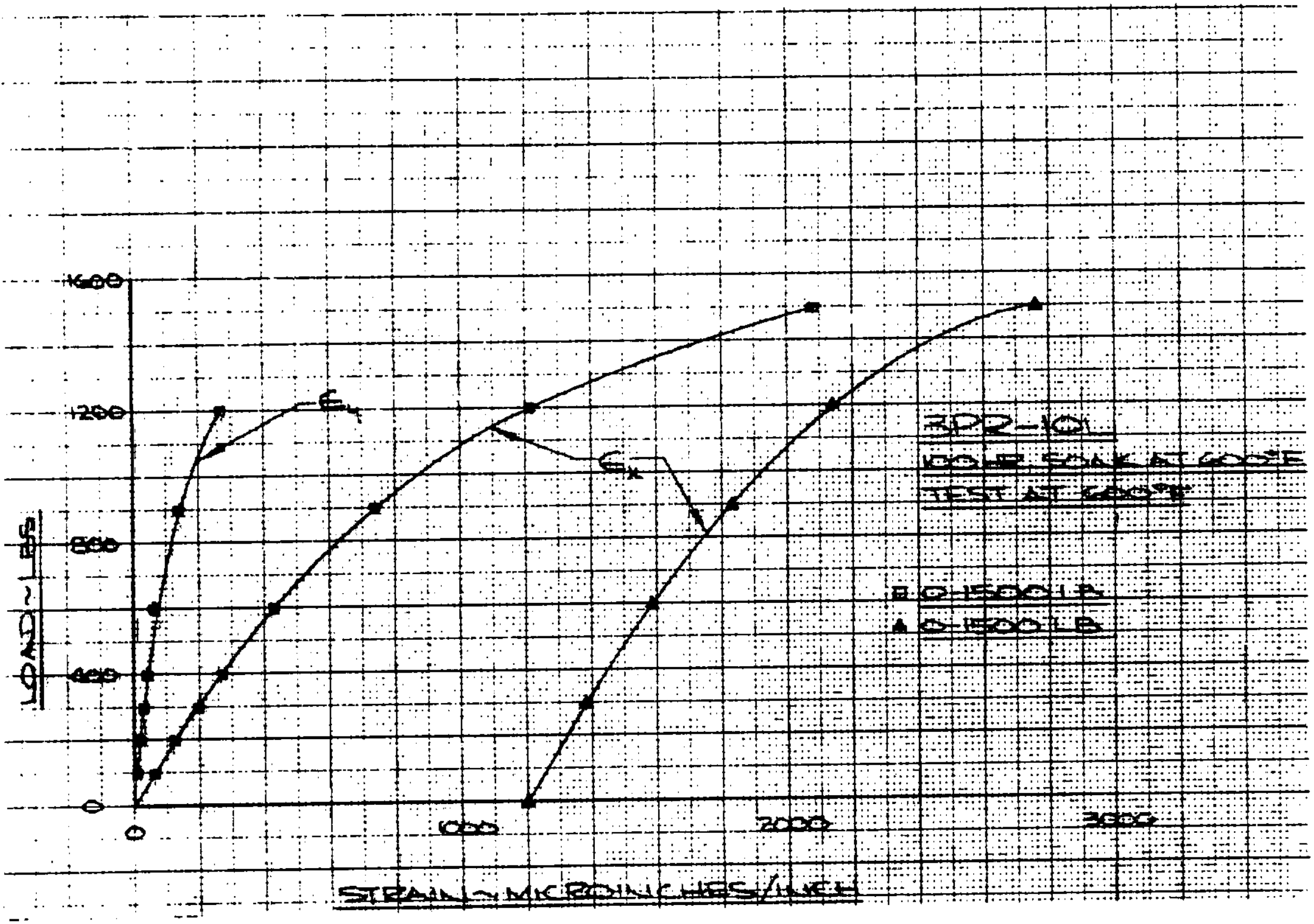


FIGURE 3.5.3.9-10b DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 3PR-10L AT 600°F AFTER 100 HOUR SOAK AT 600°F, LONGITUDINAL. (SHEET 2 OF 2)

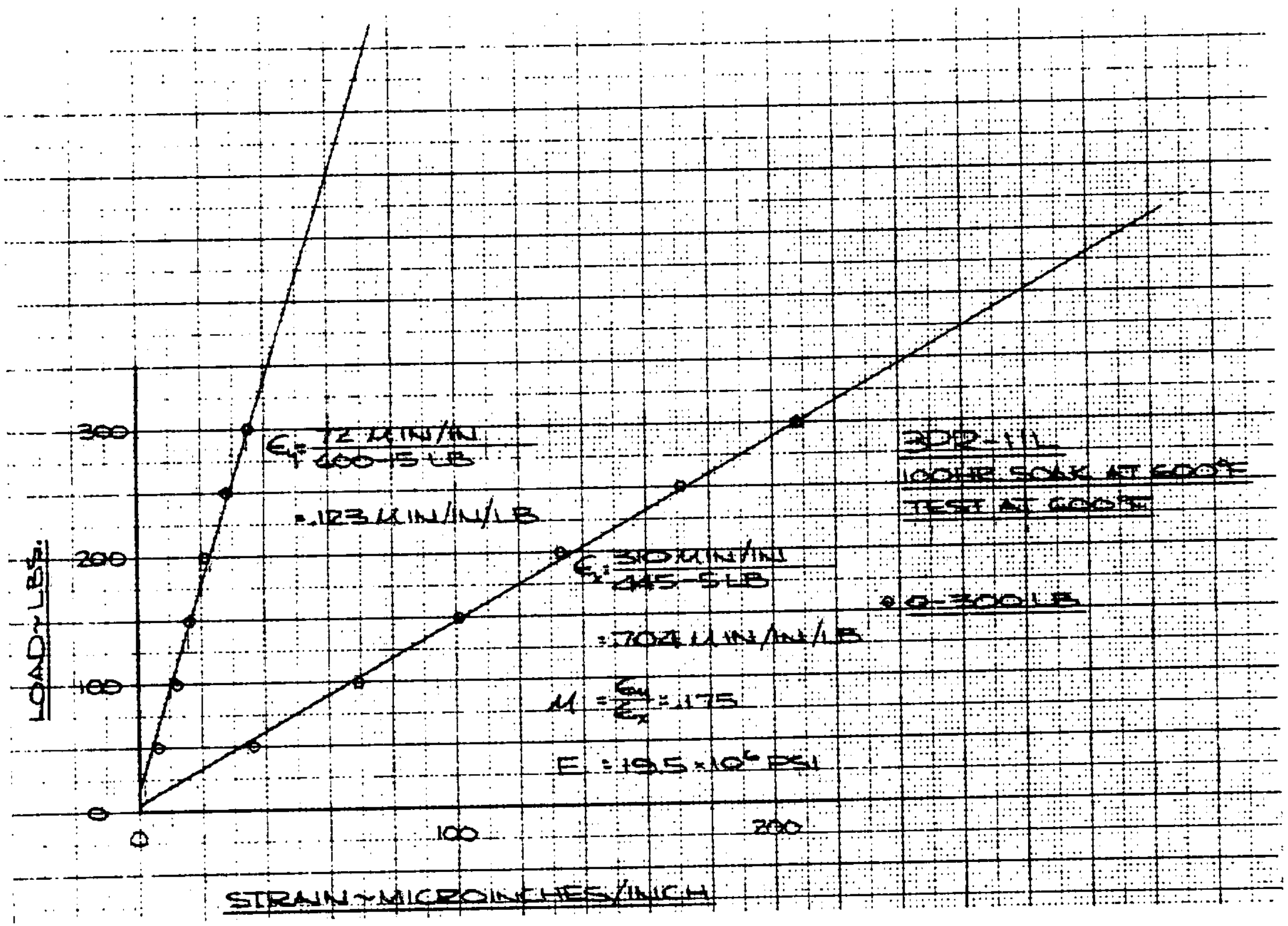


FIGURE 3.5.3.9-11a DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 3PR-11L AT 600°F AFTER 100 HOUR SOAK AT 600°F, LONGITUDINAL. (SHEET 1 OF 2)

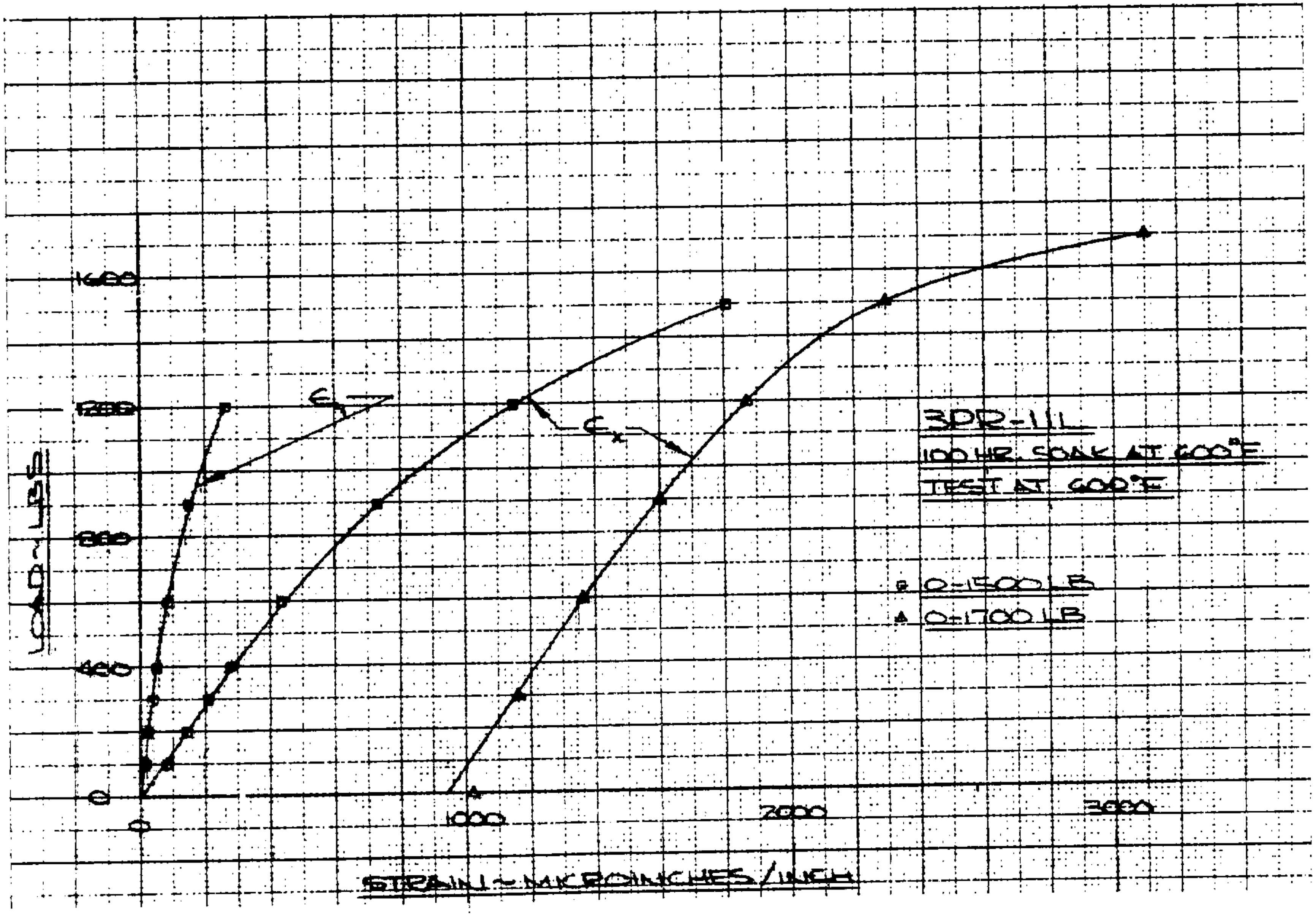


FIGURE 3.5.3.9-11b DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 3PR-11L AT 600°F AFTER 100 HOUR SOAK AT 600°F, LONGITUDINAL. (SHEET 2 OF 2)

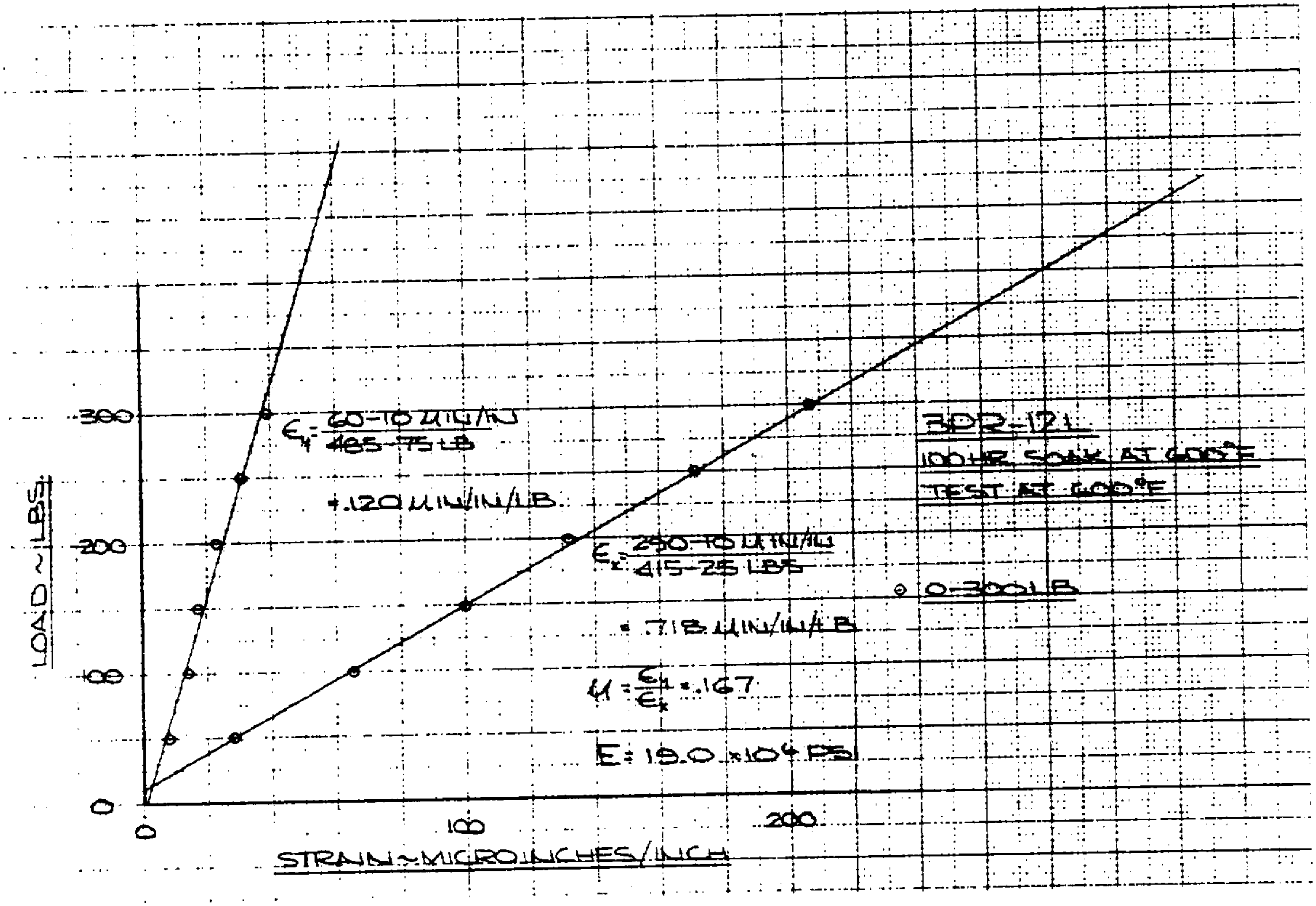


FIGURE 3.5.3.9-12a DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 3PR-12L AT 600°F AFTER 100 HOUR SOAK AT 600°F, LONGITUDINAL. (SHEET 1 OF 2)

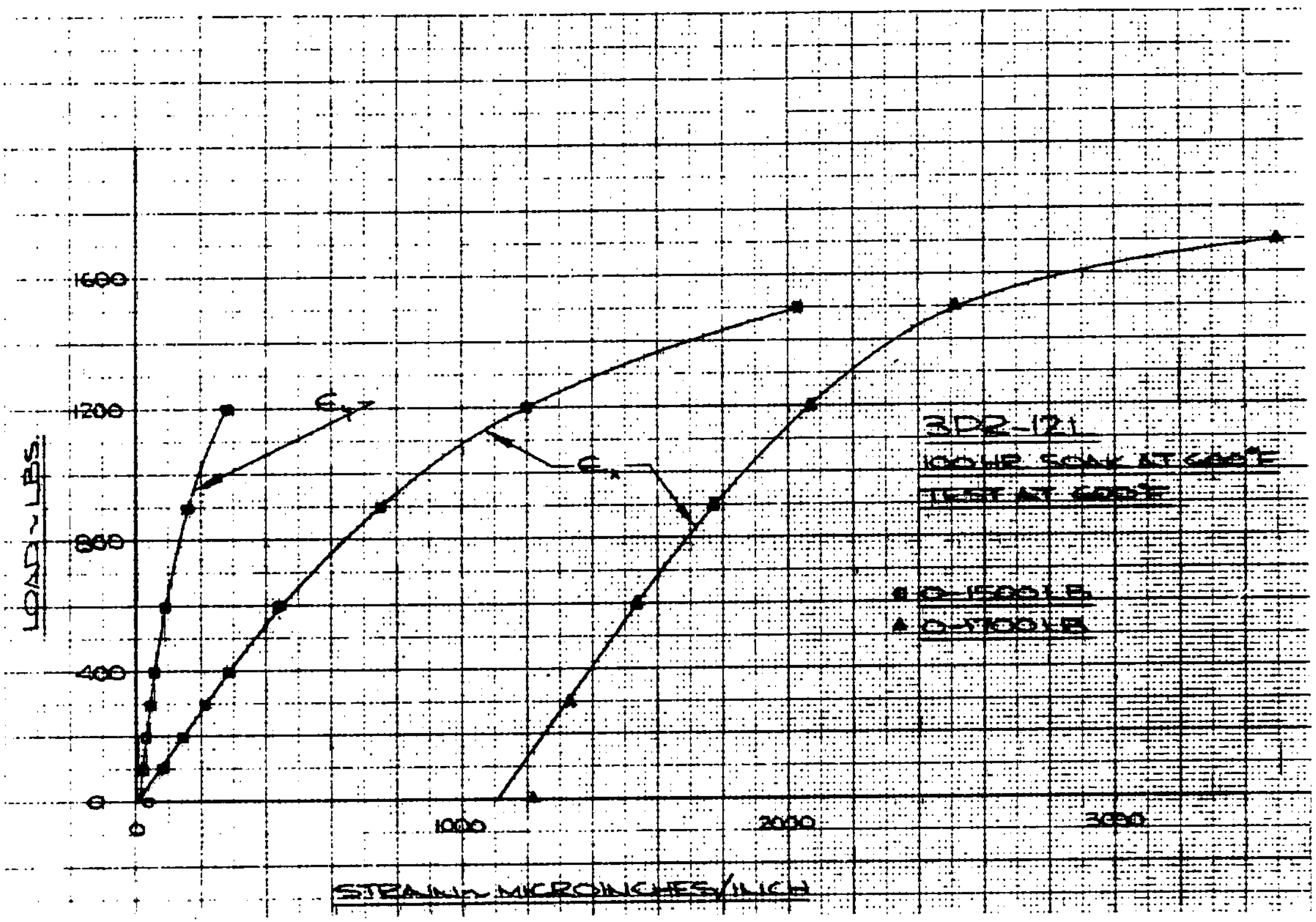


FIGURE 3.5.3.9-12b DETERMINATION OF POISSON'S RATIO AND YOUNG'S MODULUS FOR SPECIMEN 3PR-12L AT 600°F AFTER 100 HOUR SOAK AT 600°F, LONGITUDINAL. (SHEET 2 OF 2)

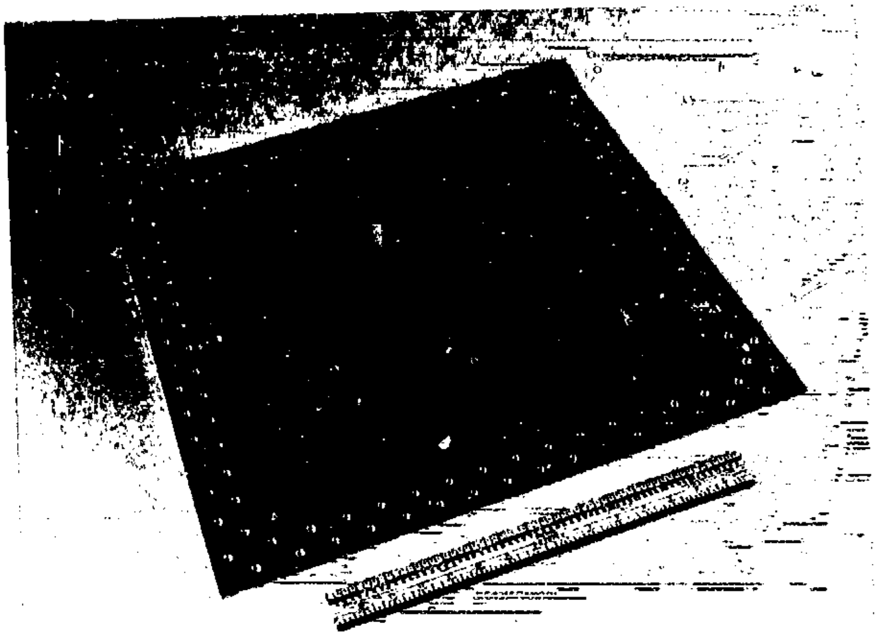
3.6 SHEAR PANEL TESTS

Shear tests were performed on two 22-inch square Be-38Al alloy panels. While not required as part of the material characterization study, these test were conducted to further demonstrate the suitability of Lockalloy for structural applications on a larger scale than had been demonstrated by coupon tests. The first panel was tested to determine its shear buckling characteristics and ultimate shear strength. This panel was prepared from a portion of the .150-inch material originally intended for use in the characterization study of this thickness of Be-38Al alloy. The results of this test provided base-line information for a similar test of a second panel which was subjected to a localized thermal shock prior to testing. This test panel was prepared from a sheet of .140-inch Be-38Al material obtained from KBI. This sheet of material had originally been rejected by KBI because of edge cracks and surface imperfections. However, the shear panel was prepared from a portion of the sheet deemed acceptable on the basis of data obtained from tensile specimens taken from the same sheet.

3.6.1 Shear Test of .150-inch Be-38Al Panel

3.6.1.1 Test Specimen - A 22.0 x 22.0 x .150 inch shear panel was machined from Be-38Al Lockalloy in the same configuration as shown by the typical aluminum panel shown in Figure 3.6.1.1-1. This panel was used as a drill jig for the Lockalloy panel. Presented in Figure 3.6.1.1-2 are the actual measured thicknesses of the Be-38Al panel. Table 3.6.1.1-1 presents a tabulation of material properties from specimens taken from the same sheet, in both the longitudinal and transverse directions, from which the shear panel was machined. Included in the tabulation are the material properties as provided by material supplier.

3.6.1.2 Test Set-Up and Procedure - The test panel was mounted in a pin-jointed, steel picture frame and this assembly in turn was mounted into a ground test fixture



76-5007-2

Fig. 3.6.1.1-1 - Aluminum Panel Used as Drill Jig for Identical Size .15 Inch Thick Be-38Al Lockalloy Panel.

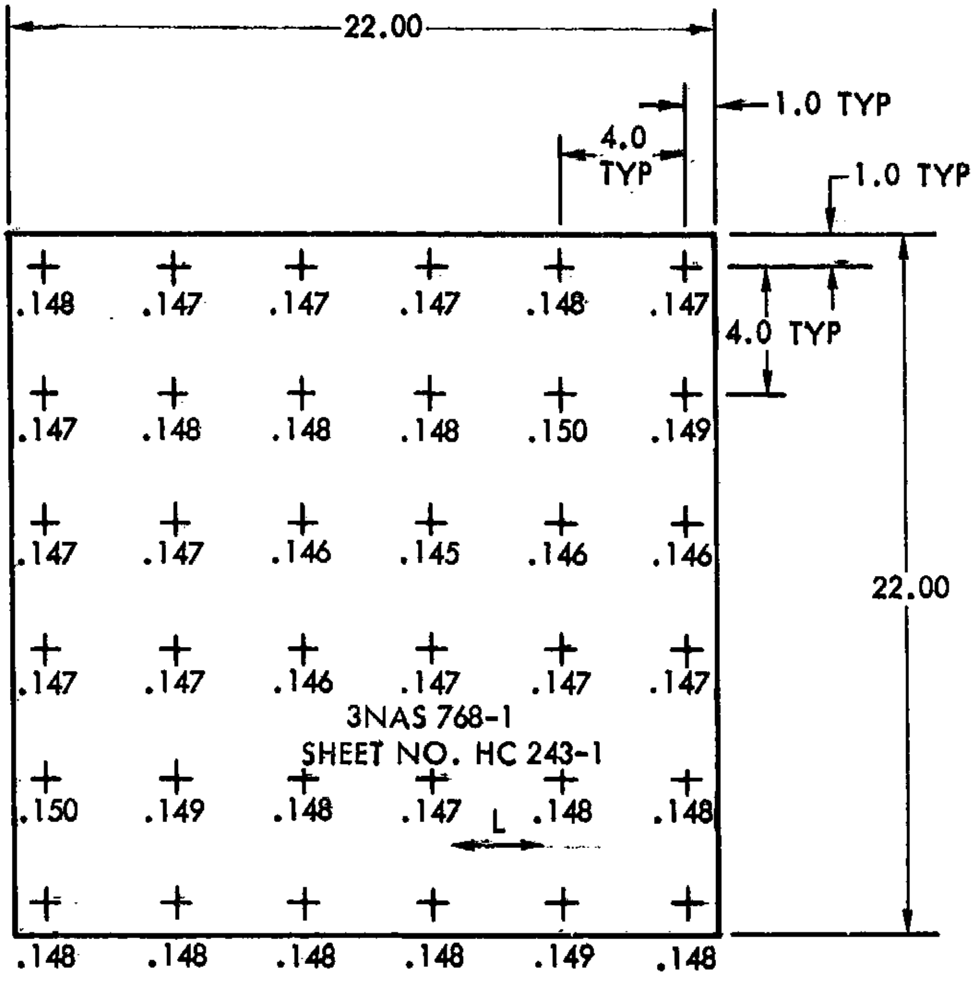


FIGURE 3.6.[illegible].1-[illegible]. ACTUAL MEASURED THICKNESSES OF .150 INCH THICK Be-38A1 PANEL.

SPECIMEN I.D.	ULTIMATE KSI	.2% YIELD KSI	% E 1.0 G.L.	E_T PSIx10^{-6}
3NAS768-1L	49.3	33.0	10	27.6
-2L	47.9	32.6	9	26.9
-3L	49.5	32.9	14	26.2
AVG.	48.9	32.8	11	26.9
3NAS768-1T	50.0	32.9	12	29.2
-2T	50.0	32.9	14	30.4
-3T	49.7	33.2	13	29.3
AVG.	49.9	33.0	13	29.6
MATERIAL SUPPLIER DATA				
L	49.2	34.0	13.6	
L	49.1	33.9	12.7	
AVG.	49.2	34.0	13.2	
T	48.4	32.5	11.5	
T	47.1	35.0	8.0	
AVG.	47.8	33.8	9.8	

NOTE: AVERAGE ULTIMATE SHEAR STRESS (F_{SU})
FOR 3NAS768-1 PANEL = 37.2 PSI
(TRIPLICATE SPECIMENS).

REF. R.N. PAGES 568954 AND 568968

TABLE [illegible] MATERIAL PROPERTIES OF SHAPE [illegible]
SHEAR PANEL (SHEET [illegible])

designed and fabricated by Lockheed-Advanced Development Projects as shown in Figure 3.6.1.2-1. Test loads were applied hydraulically and oil pressure was regulated by an Edison Load Maintainer as shown in Figure 3.6.1.2-2. Test loads do not include test fixture tare weight of 2,640 pounds. For simplicity, this load was neglected since at the failure load of the panel it represents an error of approximately 2 percent which was considered negligible.

Strain gage locations are shown on Figure 3.6.1.2-3. Readings were taken at each increment of loading by two strain indicators hooked into a switch box. One indicator was used for gage read-out of the axial gages and the other indicator for the shear gages. A photo of the set up is shown in Figure 3.6.1.2-4.

Deflections were recorded at each load increment by back-to-back dial gages installed parallel and normal to the applied load as shown in Figure 3.6.1.2-5.

3.6.1.3 <u>Test Results</u> - Test loads were applied from zero to 60,000 pounds in 20,000 pound increments, then in 10,000 pound increments to 80,000 pounds, and then returning to zero load. A buckle measuring .002 - .004 inches was observed at the 80,000 pound loading. Strain and deflection readings were recorded at each load increment and are tabulated in Table 3.6.1.3-1 and Table 3.6.1.3-2, respectively. Plots of shear strains and deflections versus loads are shown in Figure 3.6.1.3-1 and 3.6.1.3-2, respectively. The panel was then rotated 90° counter-clockwise (facing the near side) and the same loading to 80,000 pounds and back to zero repeated. Again strain and deflection readings were recorded and are tabulated in Table 3.6.1.3-3 and Table 3.6.1.3-4, respectively. Plots of shear strains and deflections versus load for this run #2 are shown in Figures 3.6.1.3 and 3.6.1.3-4, respectively.

The panel was then loaded to failure in the same increments as used on the previous run without recording any further strains or deflections other than monitering the highest reading shear gage - i.e., V003.1. The panel failed in a ductile manner while a load of 120,000 pounds was held on the panel for ten (10) minutes.

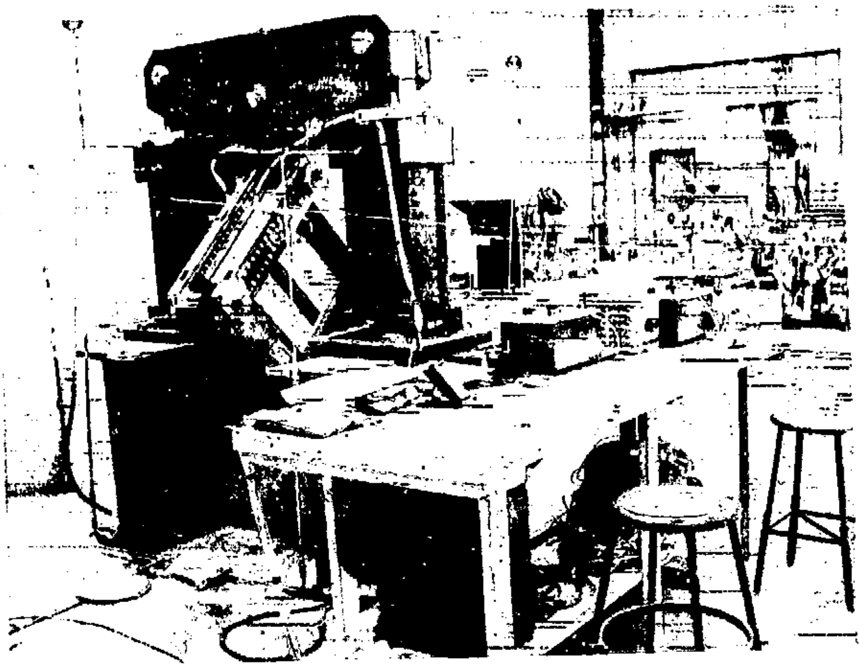


Fig. 3.6.1.2-1 - Test Set-Up Shear Panel Test.

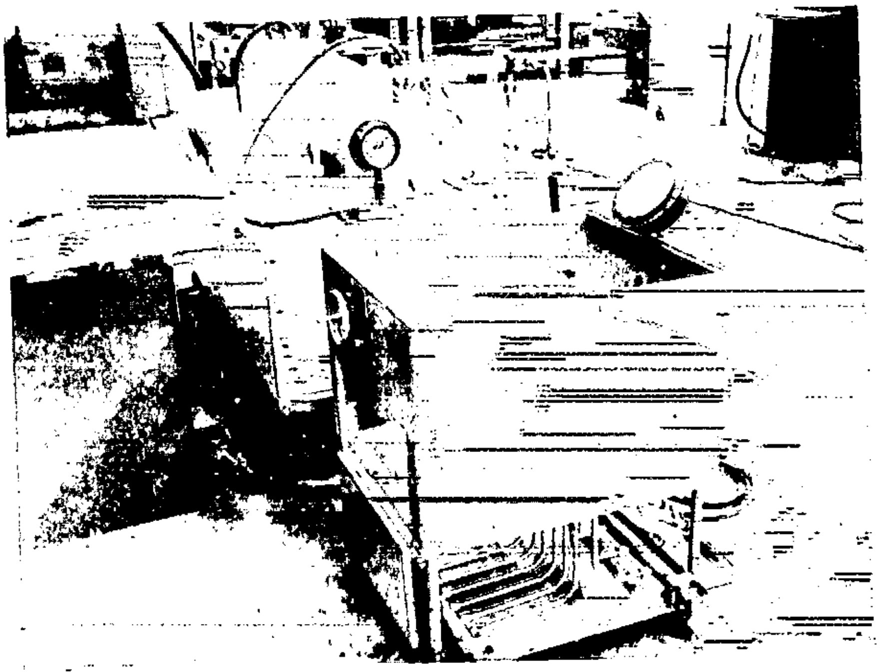


Fig. 3.6.1.2-2 - Edison Load Maintainer.

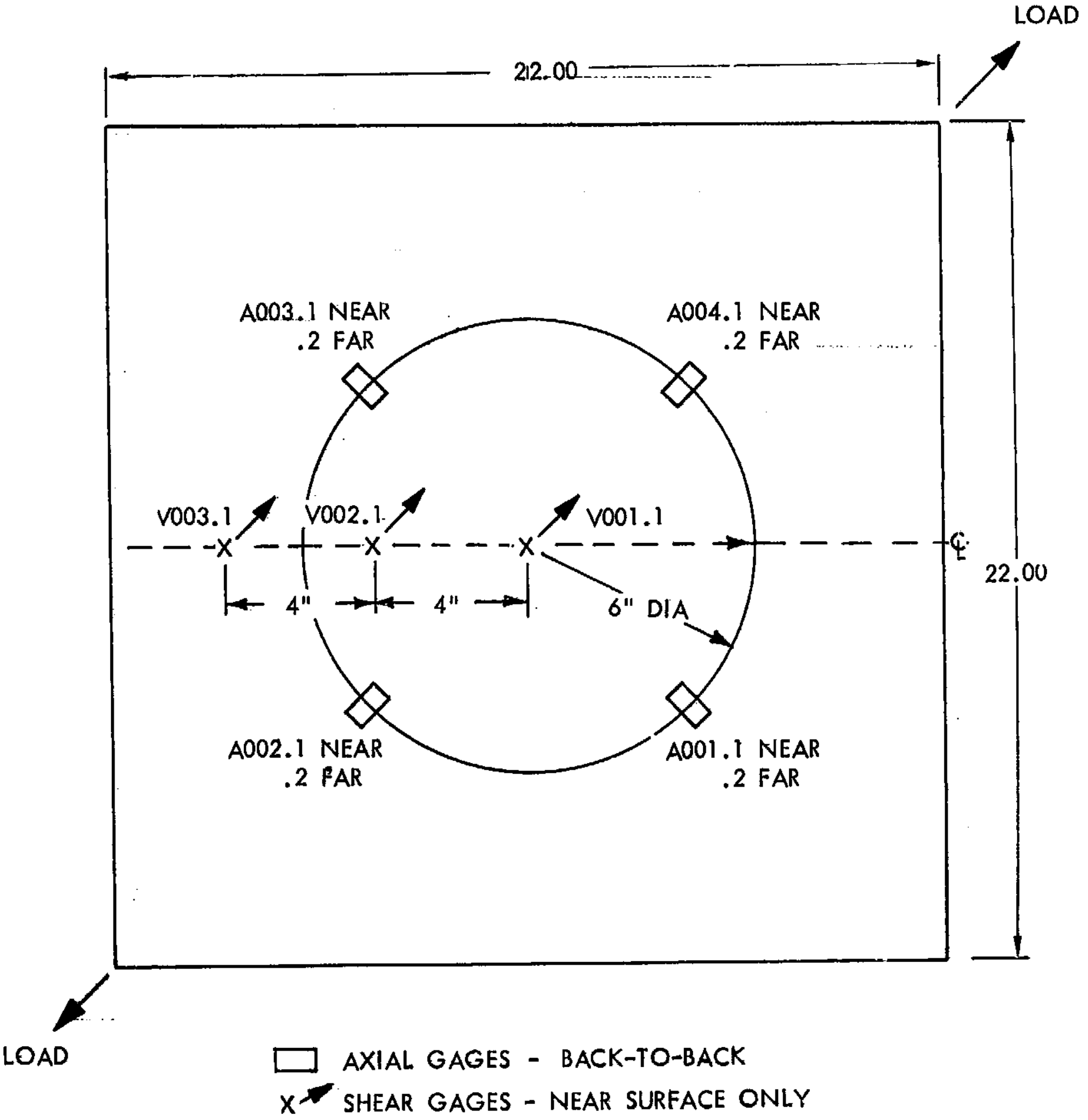
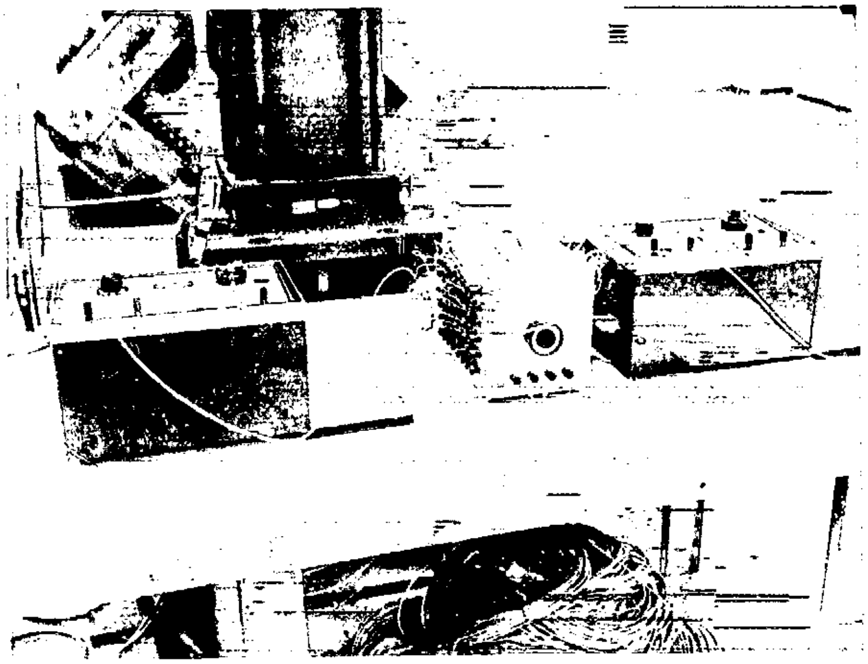


Fig. 3.6.1.2-3 - Strain Gage Locations on .150 Inch Thick Be-38Al Panel

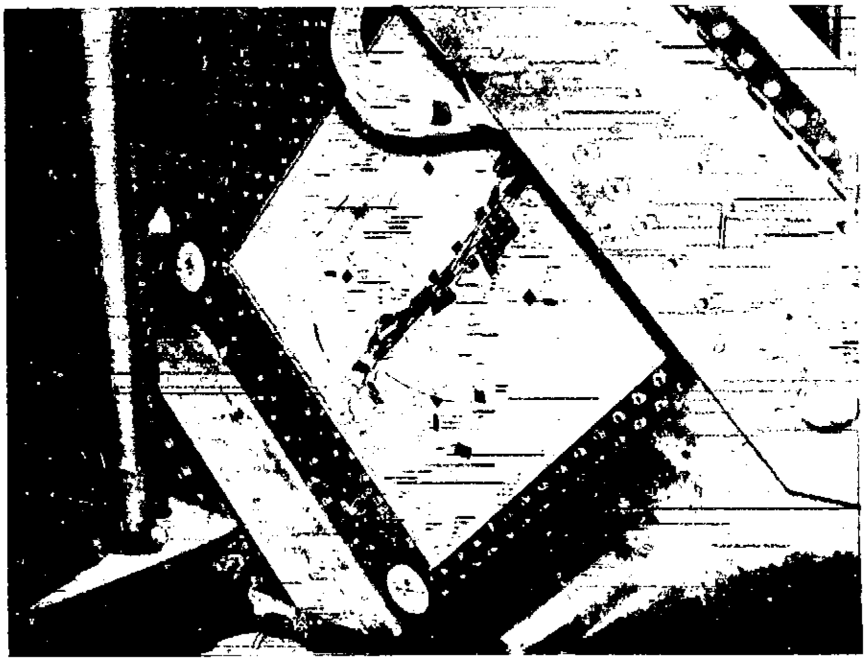


75-5413-8

Fig. 3.6.1.2-4 - Strain Indicator and Switch Box Arrangement.

75-5413-10

Near Side



75-5413-7

Far Side

Fig. 3.6.1.2-5 - Back-to-back dial gage installation, normal and parallel to load application.

GAGE NO.	CHANNEL NO.	0	20K	40K	60K	70K	80K	0
V001.1	1	28375	28537 162	28745 370	28937 562	29050 675	29177 802	29564 279
V002.1	3	30238	30400 162	20609 371	30827 589	30962 724	31110 872	30315 77
V003.1	5	29417	29594 177	29074 457	30197 780	30413 996	30704 1287	29512 145
A001.1	13	30385	30302 -83	30177 -125	30061 -324	29993 -392	29897 -488	30315 -70
A001.2	14	30151	30086 -65	29997 -89	29956 -195	29905 -246	29851 -300	30100 -51
A002.1	15	31955	32065 110	32193 128	32319 364	32410 455	32515 560	31939 34
A002.2	16	31196	31302 106	31418 116	31527 331	31596 400	31689 493	31230 34
A003.1	17	30264	30188 -76	30089 -99	29990 -274	29954 -310	29817 -447	30204 -60
A003.2	18	29957	29856 -101	29796 -60	29699 -258	29646 -311	29566 -391	29904 -53
A004.1	19	31350	31451 101	31575 124	31685 335	31762 412	31865 515	31385 35
A004.2	20	31273	31367 114	31489 122	31614 341	31682 409	31782 509	31295 22

TABLE 3.6.1.3-1. SHEAR AND AXIAL GAGE STRAIN READINGS - MICRO INCH/INCH OF .150 INCH THICK Be-38Al PANEL, RUN NO. 1

LOAD KIPS	GAGE #4	Δ	GAGE #2	Δ	AVG.	GAGE #3	Δ	GAGE #1	Δ	AVG.
0	.476		.459			.460		.548		
20	.474	-.002	.457	-.002	-.002	.460	0	.548	0	0
40	.471	-.005	.455	-.004	-.0045	.463	+.003	.551	+.003	+.003
60	.468	-.008	.452	-.007	-.0075	.467	+.007	.554	+.006	+.005
70	.466	-.010	.450	-.009	-.0095	.469	+.009	.557	+.009	+.009
80	.464	-.012	.448	-.011	-.0115	.471	+.010	.559	+.010	+.010
0	.471	-.005	.456	-.003	-.004	.462	+.002	.550	+.002	+.002

TABLE 3.6.1.3-2. DEFLECTION READINGS IN INCHES OF .15 INCH THICK Be-38Al PANEL, RUN NO. 1

FIGURE 3.6.1.5-1

LOCKALLOY SHEAR PANEL - BE-38 AL

t = .150 Run 1

SHEAR GAGE READINGS

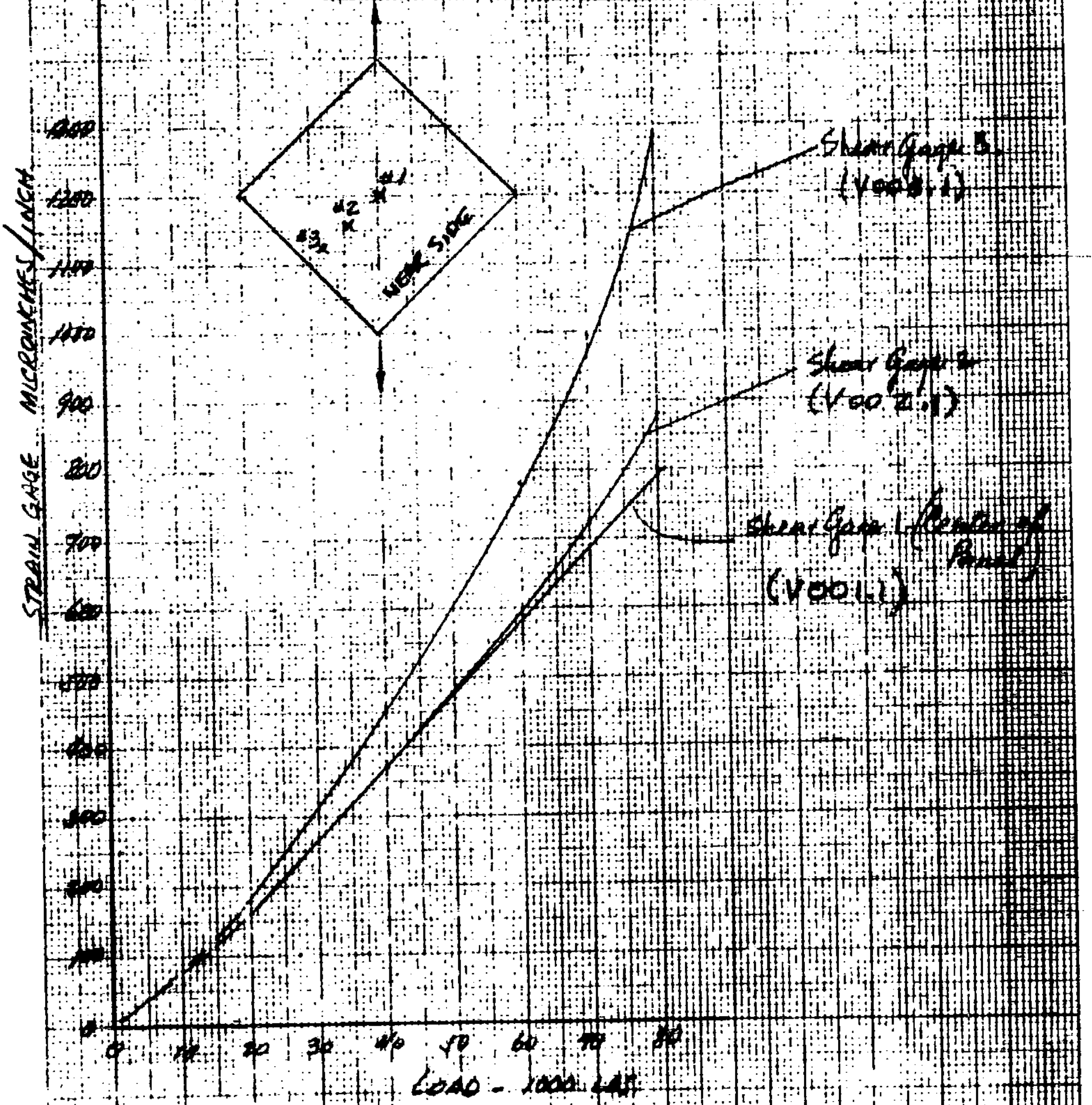
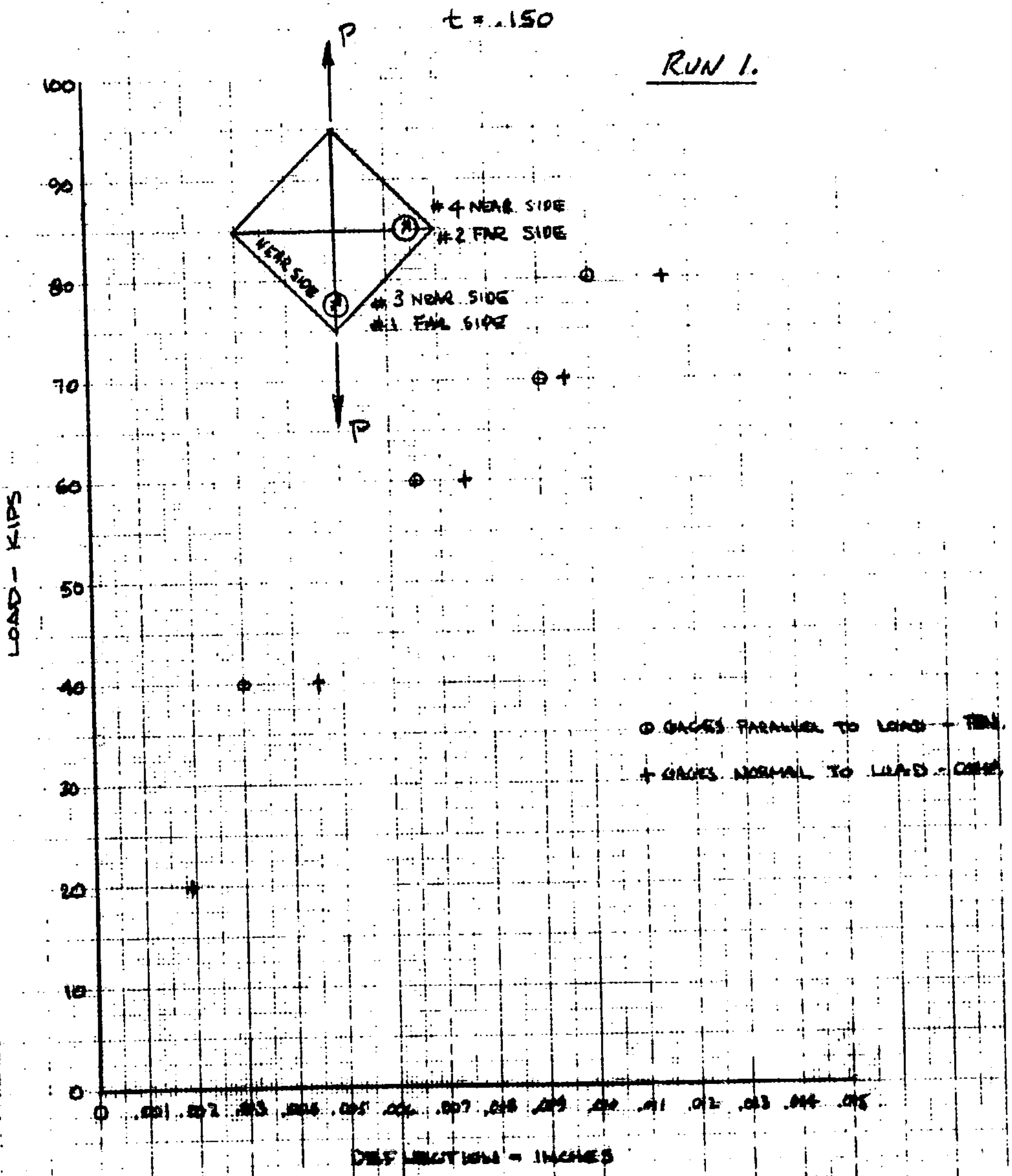


FIGURE 3.6.1.3-2

BE-38AL LOCKALLOY SHEAR PANEL DEFLECTIONS



GAGE NO.	CHANNEL NO.	0	20K	40K	60K	70K	80K	0
V001.1	1	28474	28279 -195	27888 -586	27415 -1059	27068 -1406	26438 -2036	27276
V002.1	3	30339	30132 -207	29702 -637	29185 -1154	28791 -1548	28031 -2308	29006
V003.1	5	29572	29305 -267	28772 -800	28135 -1437	27627 -1945	26621 -2951	27817
A001.1	13	30295	30419 124	30694 399	30998 703	31219 924	31476 1181	30545
A001.2	14	30094	30179 85	30381 287	30649 555	30839 745	31069 975	30610
A002.1	15	31997	31888 -109	31658 -339	31391 -606	31172 -825	30881 -1116	31324
A002.2	16	31229	31139 -90	30911 -318	30608 -549	30434 -795	30221 -1008	30556
A003.1	17	30168	30294 126	30552 384	30864 696	31011 843	31342 1174	30845
A003.2	18	29873	29961 88	30202 329	30504 631	30724 851	30968 1095	30484
A004.1	19	31382	31282 -100	31050 -332	30801 -581	30546 -836	30271 -1111	30668
A004.2	20	31309	31212 -97	30992 -317	30752 -557	30577 -732	30394 -915	30735

TABLE 3.6.1.3-3. SHEAR AND AXIAL GAGE STRAIN READINGS - MICRO INCH/INCH OF .150 INCH THICK Be-38Al PANEL, RUN NO. 2. (PANEL ROTATED 90° COUNTER-CLOCKWISE LOOKING AT NEAR SIDE)

LOAD KIPS	GAGE #4	Δ	GAGE #2	Δ	AVG.	GAGE #3	Δ	GAGE #1	Δ	AVG
0	.474		.458			.463		.524		
20	.476	+.002	.460	+.002	+.002	.460	-.003	.523	-.001	-.002
40	.484	+.010	.465	+.007	+.0085	.453	-.010	.518	-.006	-.008
60	.494	+.020	.476	+.018	+.019	.445	-.018	.512	-.012	-.015
70	.502	+.028	.486	+.028	+.028	.438	-.025	.501	-.023	-.024
80	.510	+.036	.494	+.036	+.036	.428	-.035	.491	-.033	-.034
0	.503	+.029	.484	+.026	+.0275	.435	-.028	.496	-.028	-.028

TABLE 3.6.1.3-4. DEFLECTION READINGS IN INCHES OF .150 INCH THICK Be-38Al PANEL-RUN NO. 2 (PANEL ROTATED 90° COUNTER-CLOCKWISE LOOKING AT NEAR SIDE)

FIGURE 3.6.1.3-5

BE-38AC Lockalloy Shear Panel

t = .150 RUN 2

Shear Gage Readings

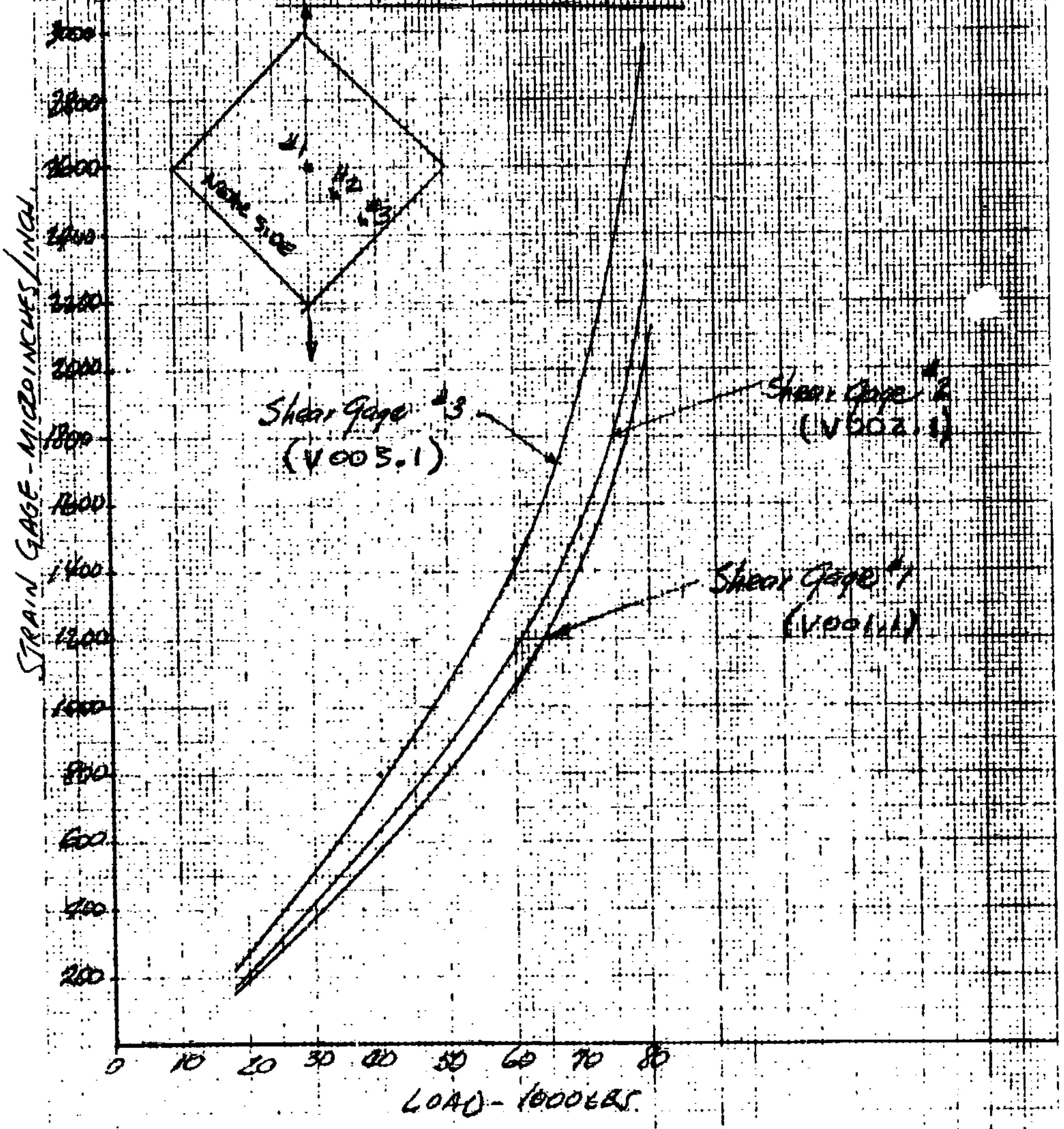
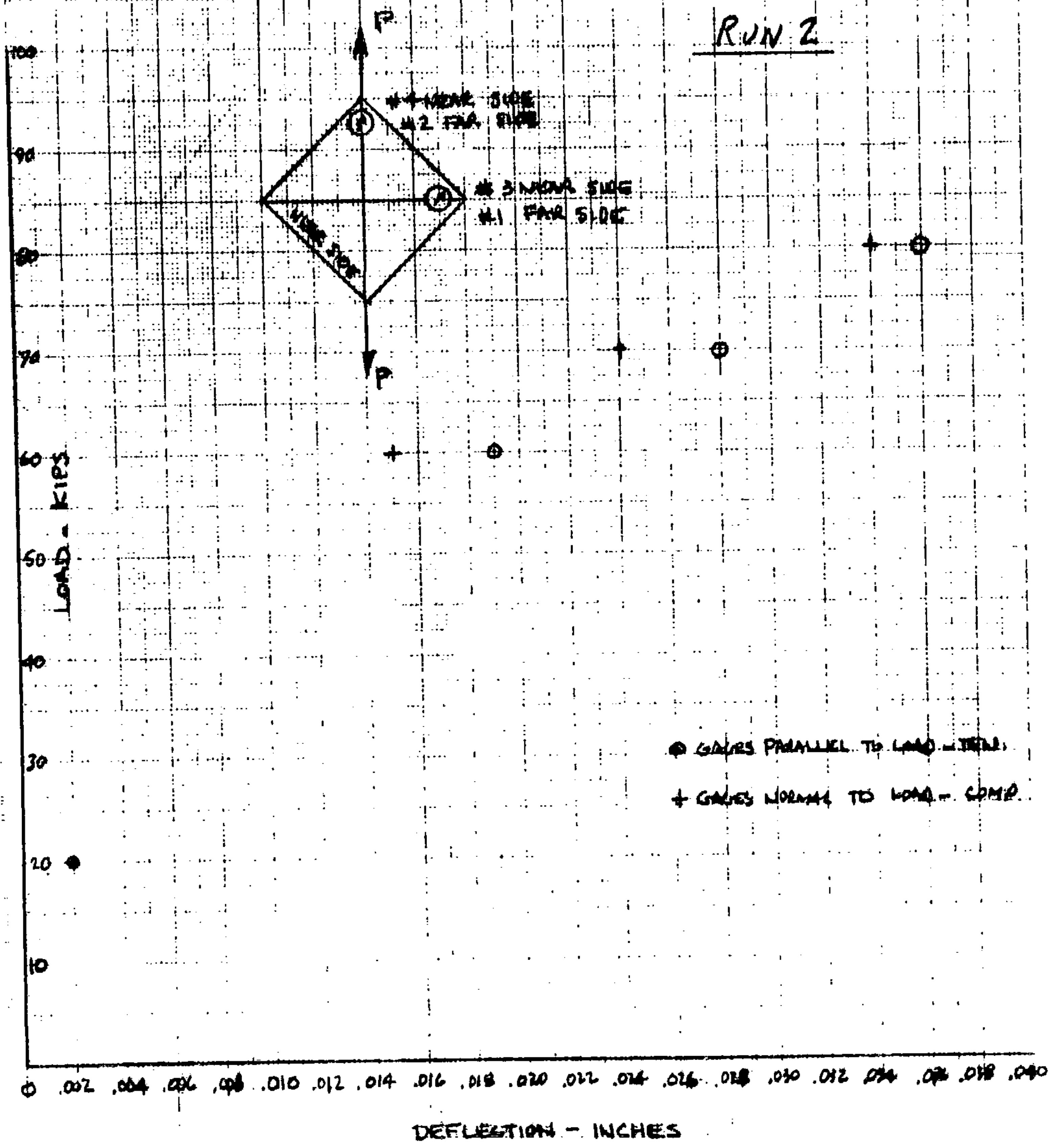


FIGURE 3.6.1.3-4

Be-BBAL LOCKALLOY SHEAR PANEL DEFLECTIONS

t = .150



The failed panel is shown in Figure 3.6.1.3-5.

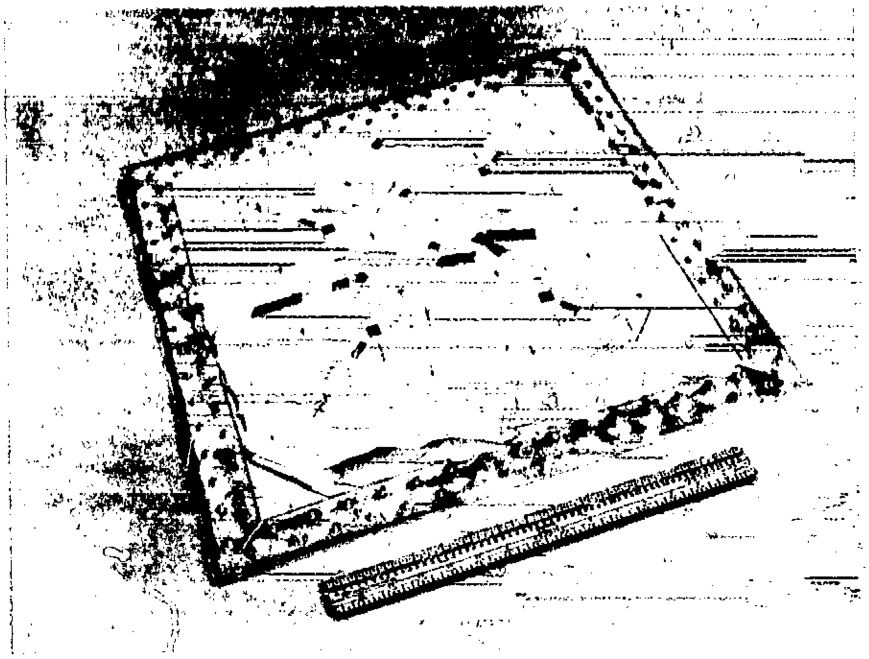
A plot of measured stresses is shown in Figure 3.6.1.3-6. (Figure 3.6.1.3-6 shows stresses below the panel buckling load. At higher load level buckles caused distortion in the strain readings). The stress reduction at the center of the panel is attributed in part to the fact that the edge attachments were "inside" the center of the load application on the "picture frame" members causing a redistribution of loads inside the panel. The results of the shear panel tests are:

$P_{FAILURE}$ = 120,000 lb. Failure Load, Failed at Net Section.

$F_{S_{FAILURE}}$ = 28,280 PSI Failure Stress on Gross Area

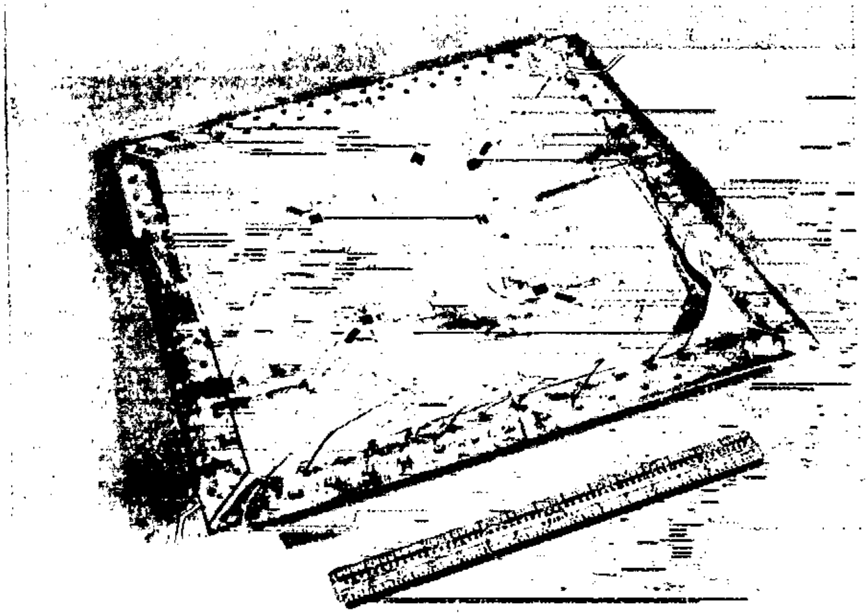
$$\left.\begin{array}{l} F_{S_{cr\,(MEASURED)}} = 18{,}850 \text{ PSI} \\ F_{S_{cr\,(CALCULATED)}} = 13{,}000 \text{ PSI} \end{array}\right\} \text{Initial Buckling Stress}$$

[To account for reduced stresses at center of panel, assume
$F_{S_{cr}} \approx .6 \times 28,850 = 11,310$ PSI $\approx$ 13,000 PSI]



76-5007-1

Near Side



76-5007-7

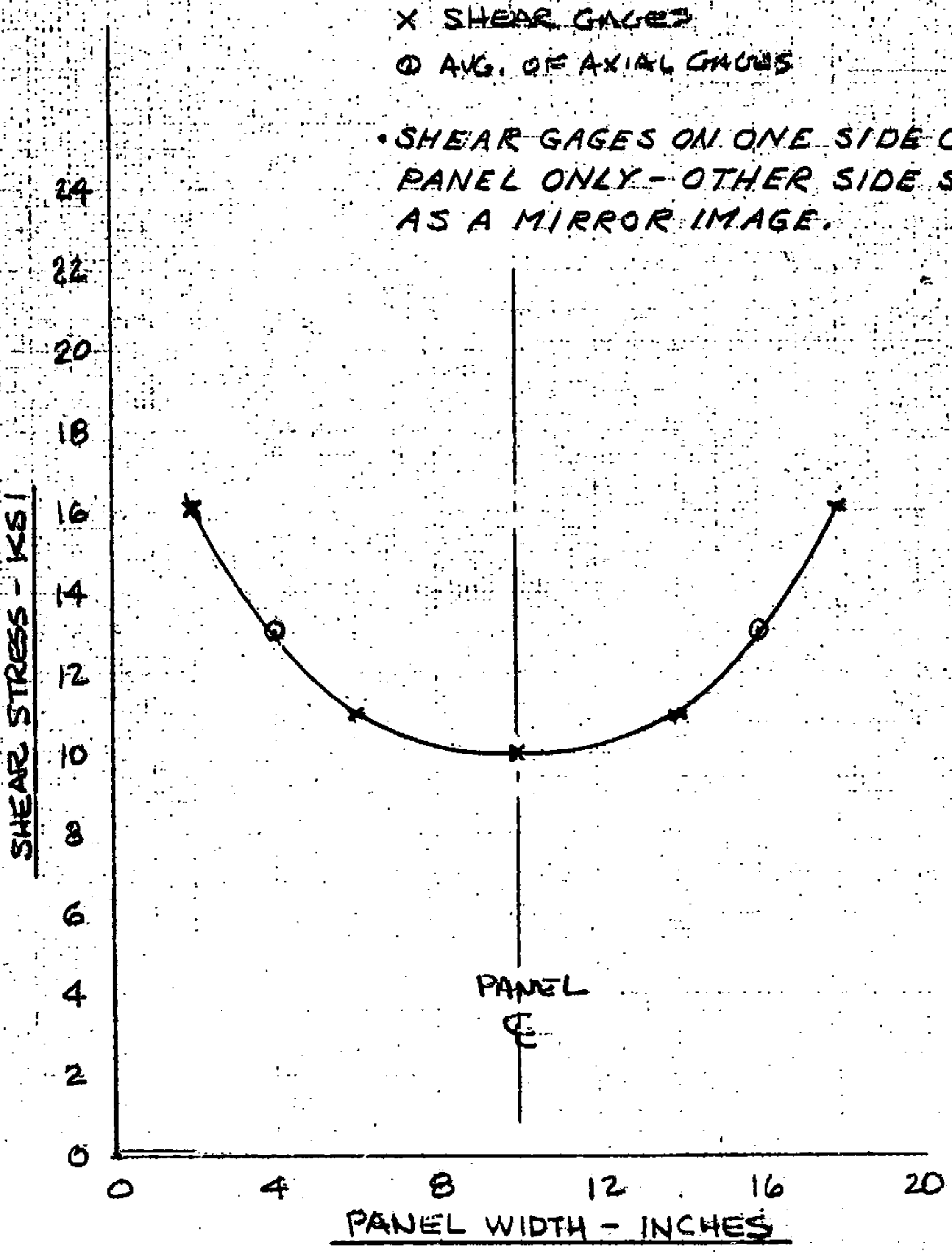
Far Side

Fig. 3.6.1.3-5 - Failed .150 inch thick Be-38Al Lockalloy shear panel. (Failure Load = 120,000 pounds)

FIGURE 3.6.1.3-6

BE-38AL LOCKALLOY SHEAR PANEL - .150 t

80,000 POUND RUN NO. 1



3.6.2 Shear Test of .140 Inch Be-38Al Panel Following Localized Thermal Shock

3.6.2.1 Test Specimen - A 22.0 x 22.0 x .140 inch shear panel was machined from Be-38Al Lockalloy in the same configuration as shown by the typical aluminum panel shown in Figure 3.6.1.1-1 which again was used as a drill jig for the .140 inch thick Lockalloy panel. Presented in Figure 3.6.2.1-1 are the actual measured thicknesses of the .140 inch panel. Table 3.6.2.1-1 presents a tabulation of material properties of specimens taken from the same sheet, in both the longitudinal and transverse directions, from which the shear panel was machined. Included in the tabulation are the material properties as provided by the material supplier.

3.6.2.2 Test Set-up and Procedure - The test panel was mounted into a pin-jointed steel "picture frame" as shown in the photo in Figure 3.6.2.2-1.

Thirteen (13) Iron-Constantan, Type J thermocouples were attached with Viton along the centerline of the panel in the locations identified by Fig. 3.6.2.2.-2.

The "picture frame" with the installed thermocoupled shear panel was moved out-doors (as a health safety precaution) and supported in a horizontal position on steel horses with the plain side up (thermocouples on under-side). The thermocouple cables were then attached to the CEC 5-119 oscillograph shown in Figure 3.6.2.2-3. A heat shock was to be applied to the center of the panel with an oxygen-acetylene. torch at a specific distance and heat torch settings with the intent to heat the panel to 1000°F in a time span of from 40 to 48 seconds. A special holder for the torch, as shown in Figure 3.6.2.2-4 positioned the torch tip at the same distance from the Lockalloy panel as the distance determined by trial and error on thermocoupled aluminum panels. Once the distance and the torch heat setting was considered acceptable, the torch was placed into the holder and timing of the heat shock test began. In the event the thermocouple on the under-side of the torch became loose, a hand held pyrometer was used as a back-up to monitor panel temperature.

SPECIMEN I.D.	ULTIMATE KSI	.2% YIELD KSI	% e 1.0" G.L.	E PSI x 10^{-6}
3NAS769-1L	49.4	33.6	12	27.8
3NAS769-2L	49.6	33.2	12	26.9
3NAS769-3L	48.5	33.5	9	25.6
AVG.	49.2	33.4	11	26.8
3NAS769-1T	50.4	33.8	10	29.4
3NAS769-2T	50.7	33.7	11	25.6
3NAS769-3T	50.5	33.9	11	27.2
AVG.	50.5	33.8	11	27.4
MATERIAL SUPPLIER PROPERTIES				
1L	45.4	31.0	9	—
2L	43.6	32.5	6.5	—
AVG.	44.5	31.8	7.8	
-1T	47.2	31.5	13.5	—
-2T	46.0	31.8	9	—
AVG.	46.6	31.6	11.2	

NOTE: THE AVERAGE ULTIMATE FLATWISE SHEAR STRESS OF TRIPLICATE SPECIMENS = 37.7 KSI

REF: R.N. PAGES 568956, 568968.

TABLE 3.6.2.3-1. MATERIAL PROPERTIES OF .140 INCH THICK Be-38Al LOCKALLOY PANEL (SHEET NO. HC 231-3)

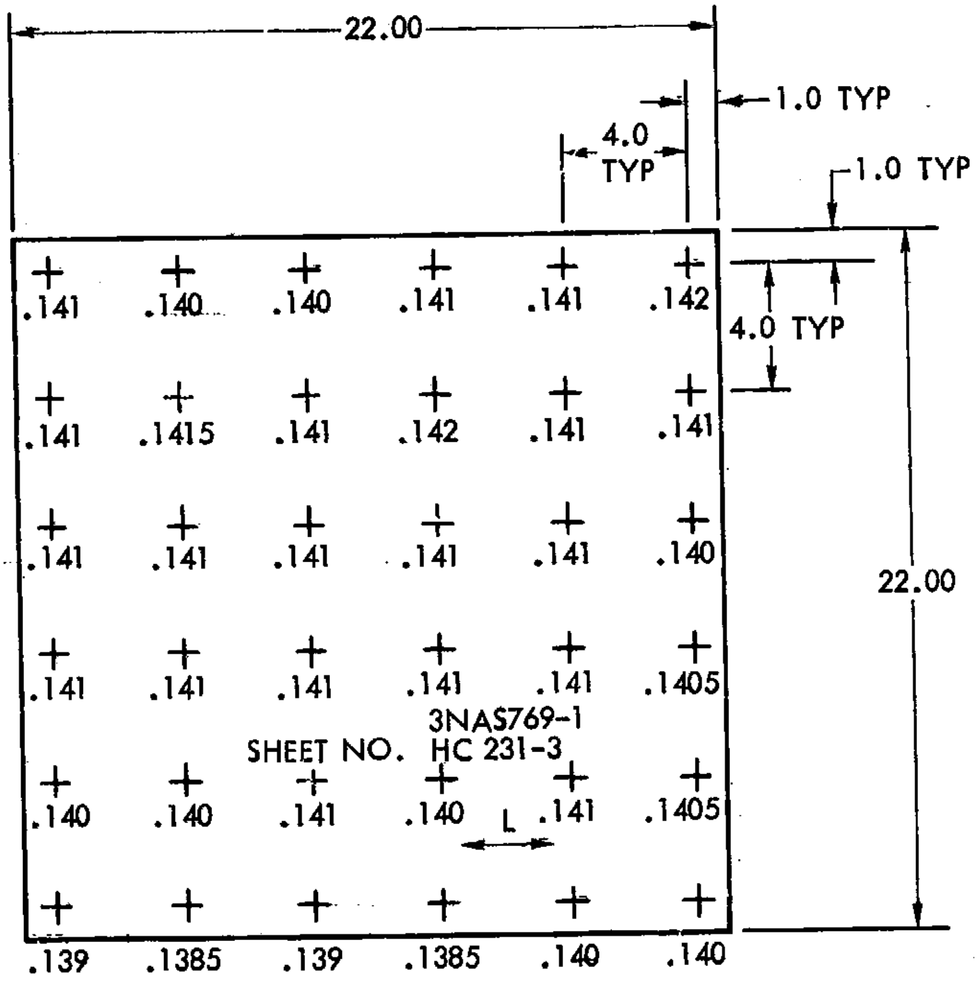


FIGURE 3.6. [illegible] ACTUAL MEASURED THICKNESSES OF THE [illegible] THICK [illegible]

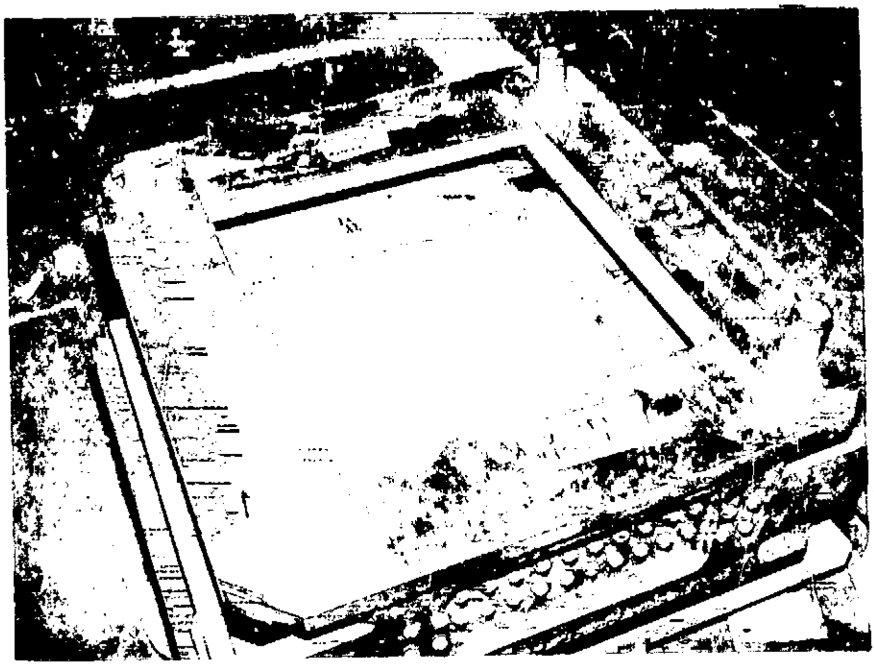


Figure 3.6.2.2-1 Lockalloy Panel Installed In Pin-Jointed, Steel "Picture Frame"

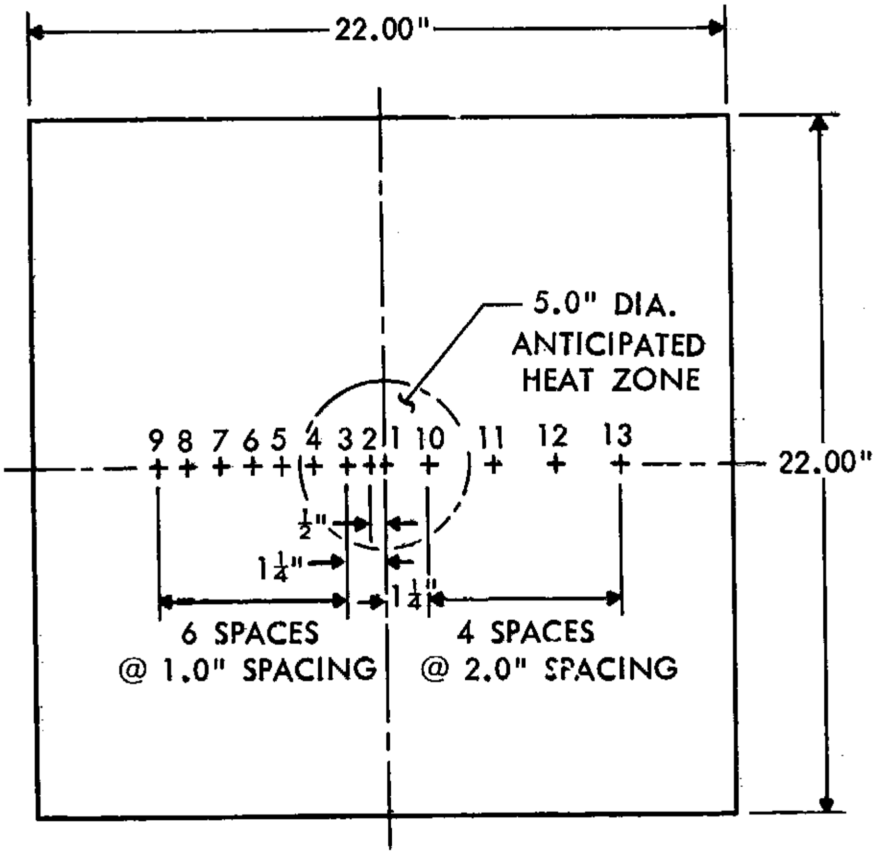
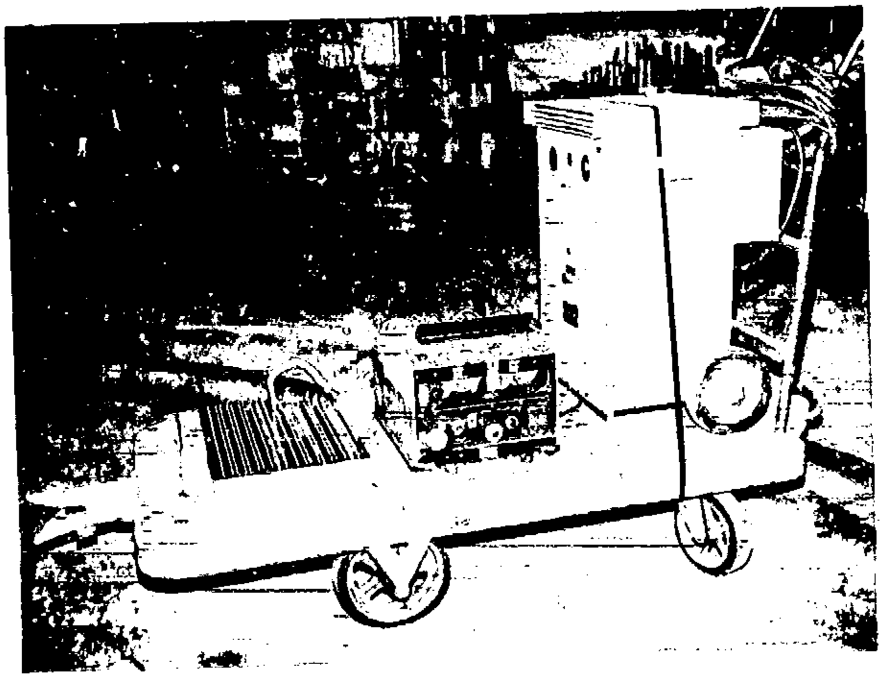
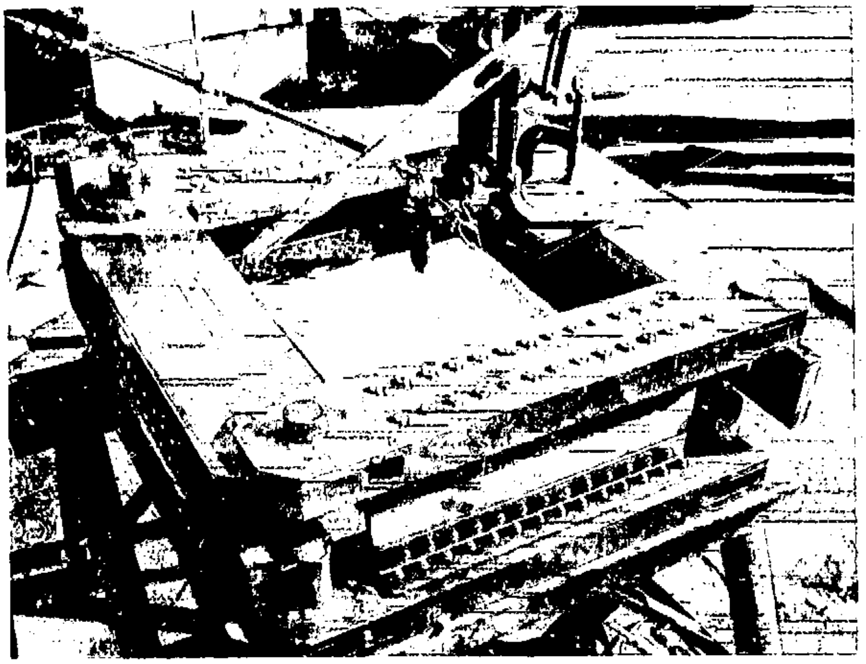


FIG. 3.6.2.[illegible]-[illegible] THERMOCOUPLE LOCATIONS WITH NUMBERED IDENTIFICATION.



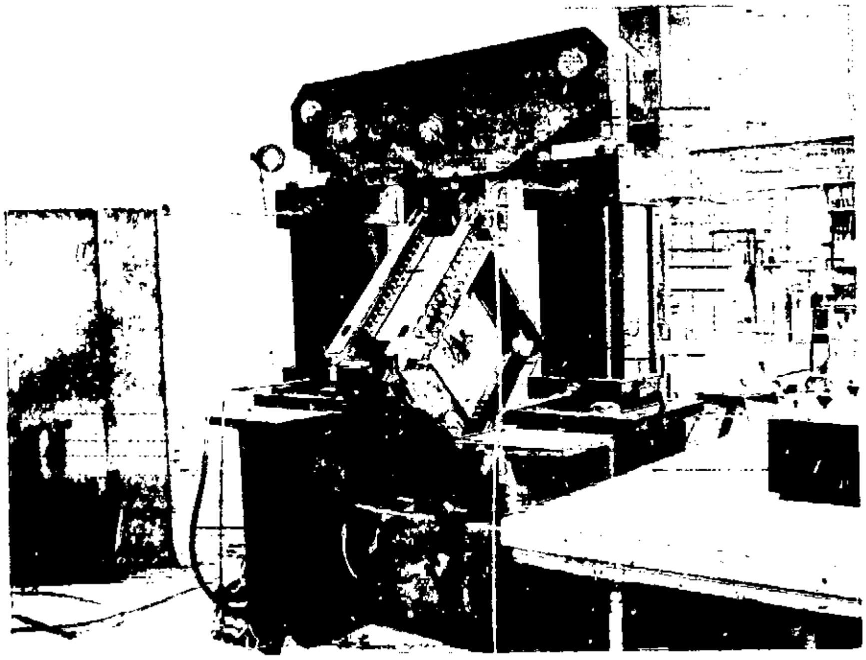
75-5433-7

Figure 3.6.2.2-3 - Photo of CEC 5-119 Oscillograph



75-5433-5

Fig. 3.6.2.2-4 - Positioning Tool and Holder for Torch Tip



75-[illegible]

Fig. 3.6.[illegible] - [illegible]

After being subjected to the thermal shock, the same test set-up and procedure as described in the first paragraph of 3.6.1.2 was repeated here. A photo of the test set-up for the .140 inch thick Be-38Al panel is shown in Figure 3.6.2.2-5.

Deflections were recorded at each load increment up to and including 100,000 pounds, by back-to-back dial gages installed parallel and normal to the applied load as shown in Figure 3.6.2.2-6. . No other instrumentation was used.

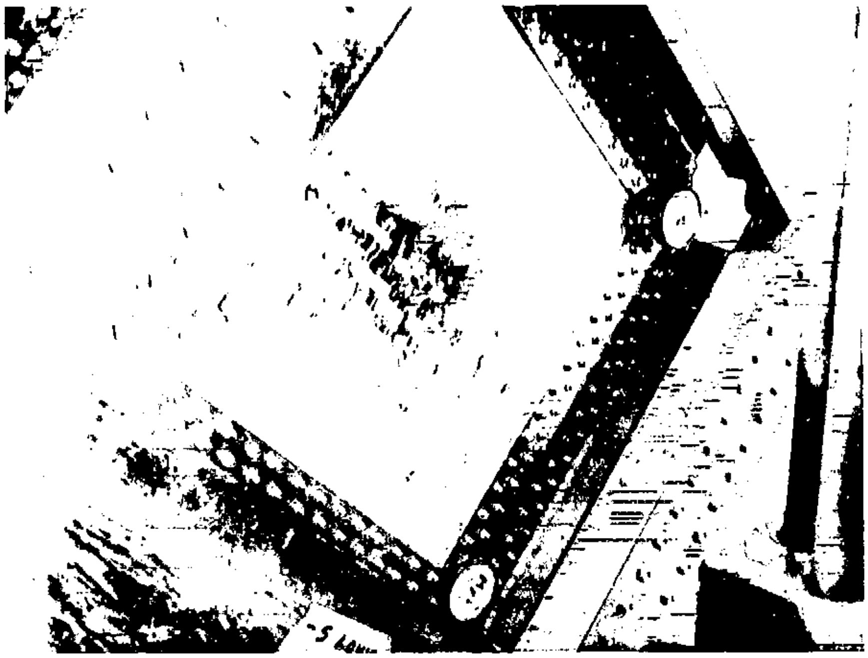
3.6.2.3 Test Results - A thermal shock of 41.9 seconds duration was applied to the center of the Lockalloy panel producing an estimated 1400°F peak temperature as determined from the oscillograph traces. The thermal shock test temperature profile is shown in Figure 3.6.2.3-1.

The heating rate to the panel during the thermal shock test was estimated as follows. An analytical thermal model was generated for the panel which includes all modes of heat transfer occurring in the actual test. The distribution of film coefficient over the plate could be approximated from standard impingement heating methods, Reference 1*, knowing the torch exit geometry and distance from the plate. Solutions were obtained from this model for various combinations of torch temperature and impingement point film coefficient until the analytical thermal response for the plate matched that of the test. The resulting heating rate to the plate was 50 Btu/ft^2-sec over a 3 inch diameter circle centered under the torch at test initiation, decreasing as the plate heated up.

An over-all photo showing the "bump" in the center of the panel which was restrained in the "picture frame" jig during the thermal shock, is shown in Figure 3.6.2.3-2. The close-up photo in Figure 3.6.2.3-3 shows that [illegible] beads were exuded and the "bump" height measures approximately 1/8 inch. Figure 3.6.2.3-4 is a color photo showing a dye-check inspection of the area after the exuded aluminum beads were removed.

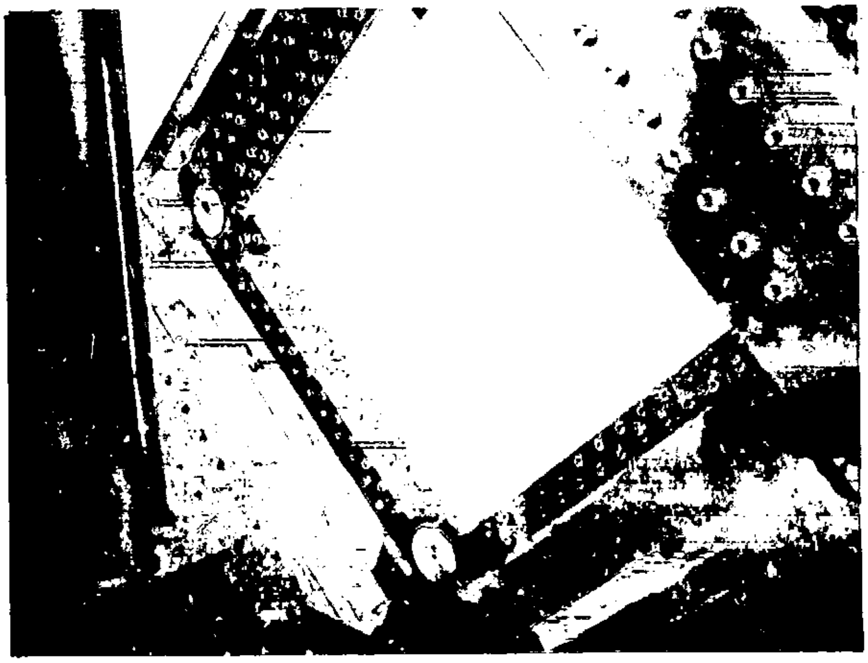
---

*Reference 1 - [illegible], Frederick F., "A Fundamental Investigation of [illegible] Heat Transfer," University of Cincinnati, Ph.D. Thesis, [illegible].



75-5433-12

Near Side



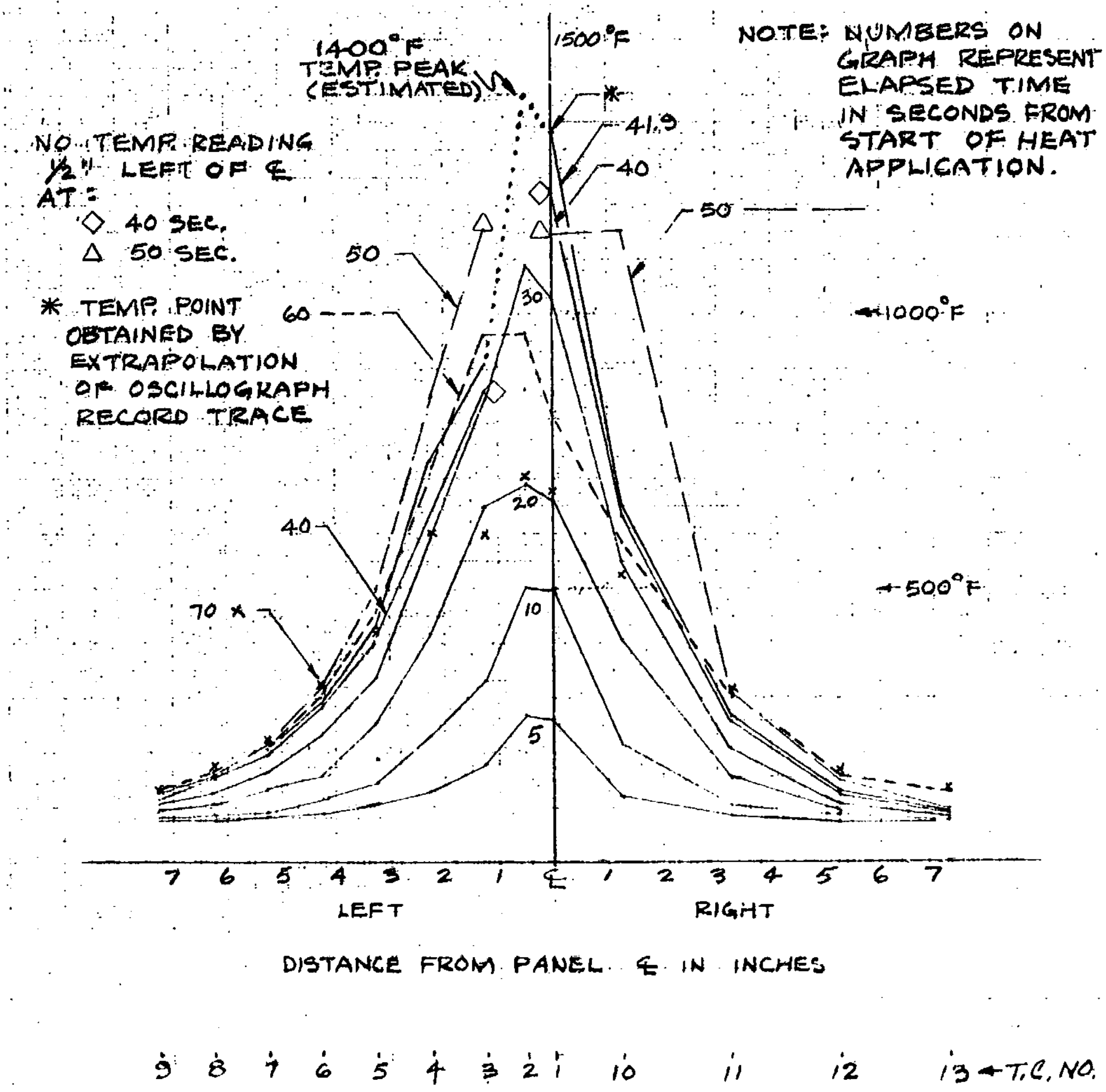
75-5433-8

Far Side

Figure [illegible] - [illegible],
[illegible].

FIGURE 3.6.2.3-1

THERMAL SHOCK PANEL
HEAT TEST
TEMPERATURE PROFILE

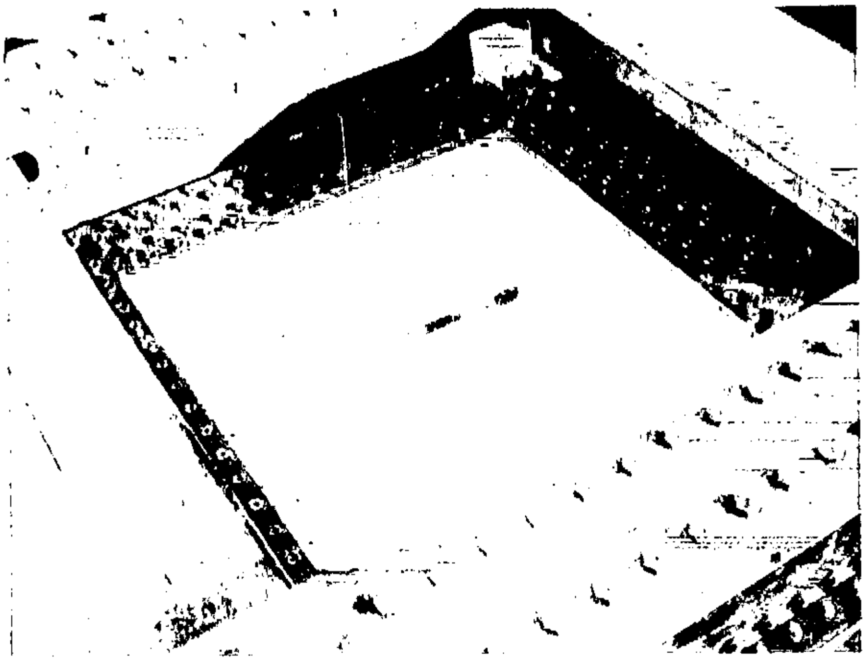


NOTE: NUMBERS ON GRAPH REPRESENT ELAPSED TIME IN SECONDS FROM START OF HEAT APPLICATION.

NO TEMP. READING ½" LEFT OF ℄ AT:
◇ 40 SEC.
△ 50 SEC.

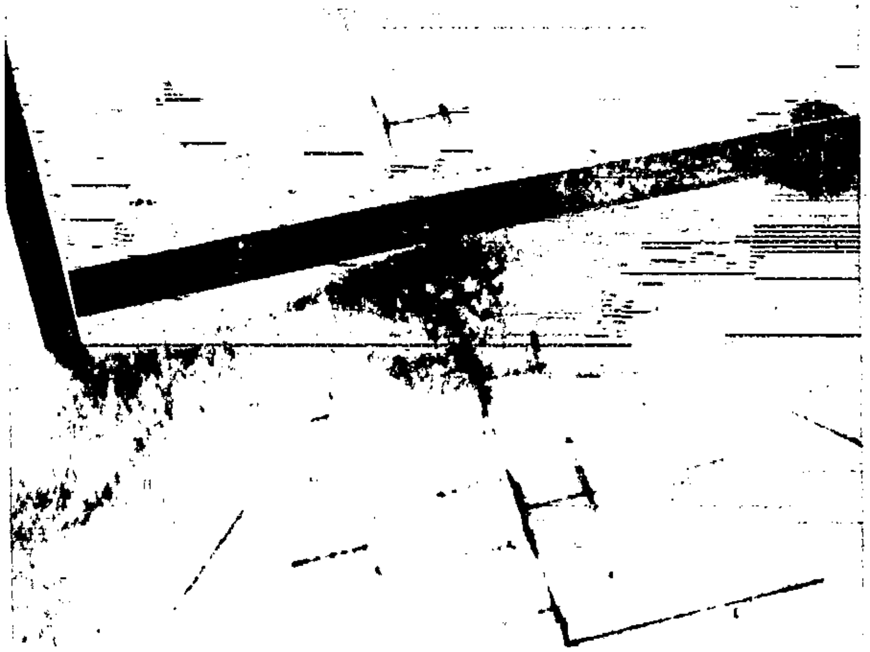
✱ TEMP. POINT OBTAINED BY EXTRAPOLATION OF OSCILLOGRAPH RECORD TRACE

1400°F TEMP. PEAK (ESTIMATED)



75-5433-9

Fig. 3.6.2.3-2 - Overall View of Restrained Panel Showing Bump in Center of Panel



75-5433-11

Fig. 3.6.2.3-3 - Close-up View Showing Aluminum Beads Exuded from Panel and Bump Height of Approximately 1/4 inch.

Test loads for the one run to failure were applied from zero to 100,000 pounds in 20,000 pound increments and then at 10,000 pounds to failure.

A plot of deflection versus loads is shown in Figure 3.6.2.3-5.

The thermal shocked panel failed at 120,000 pounds which is the same as the failure load of the first shear panel, indicating that the heated area of the thermal shocked panel, with lower stresses at the center, was still less critical than the net section through the edge attachments. The failed panel after removal from the "picture frame" jig is shown in Figure 3.6.2.3-6.

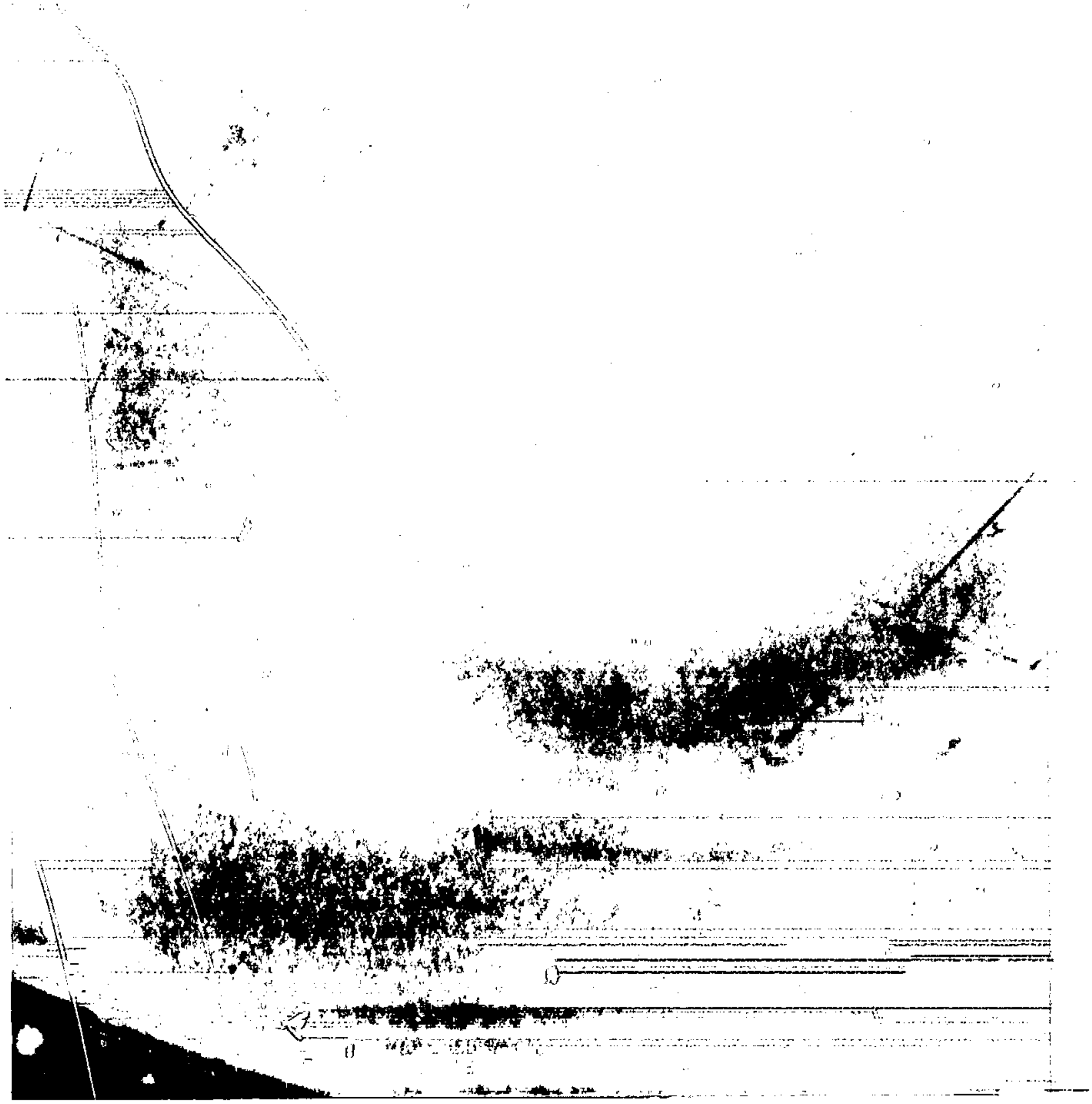


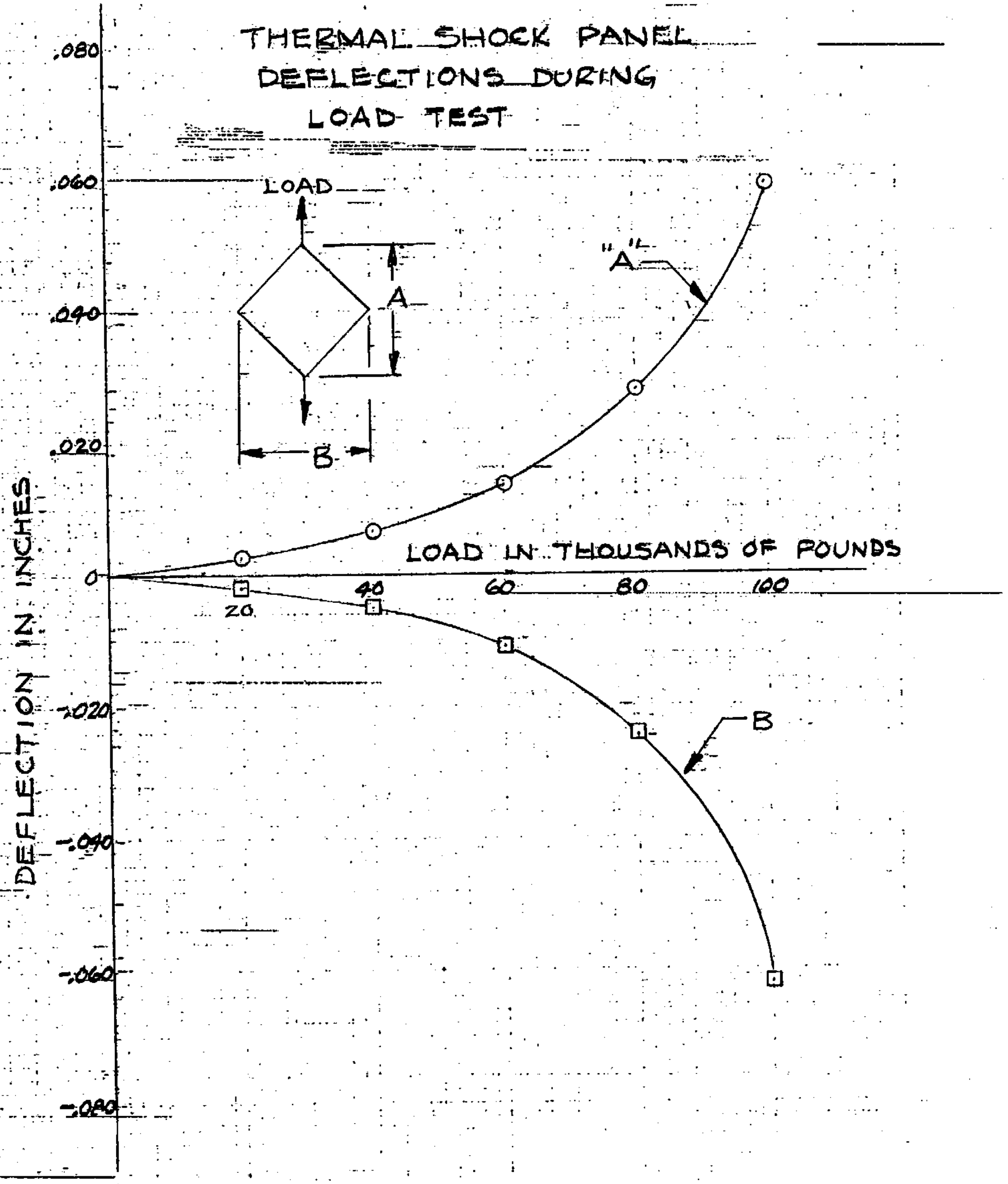
FIGURE 3.6.2.3.4 DYE-CHECK INSPECTION OF "BUMP" AFTER EXUDED BEADS OF ALUMINUM WERE REMOVED

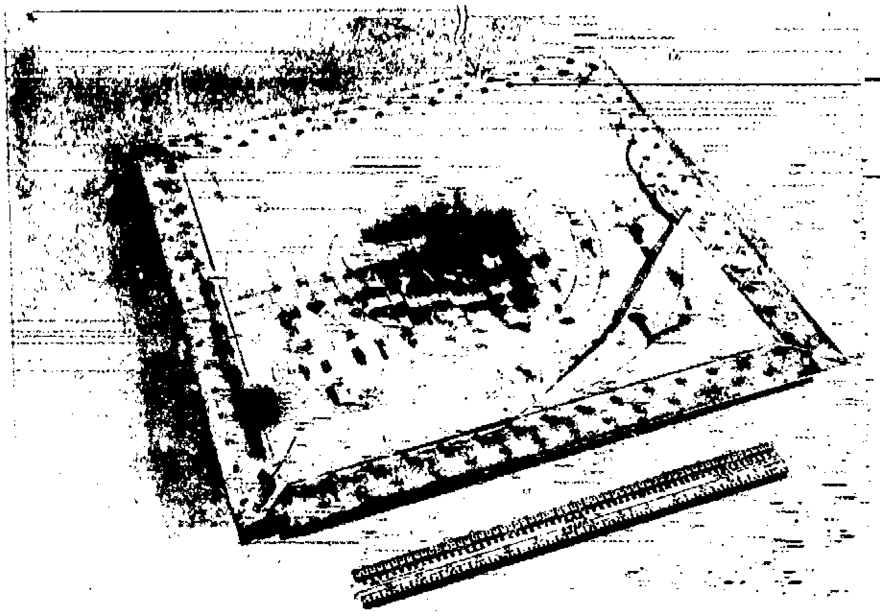
C, S

Bob Wong
1/6/76

FIGURE 3.6.2.3-5

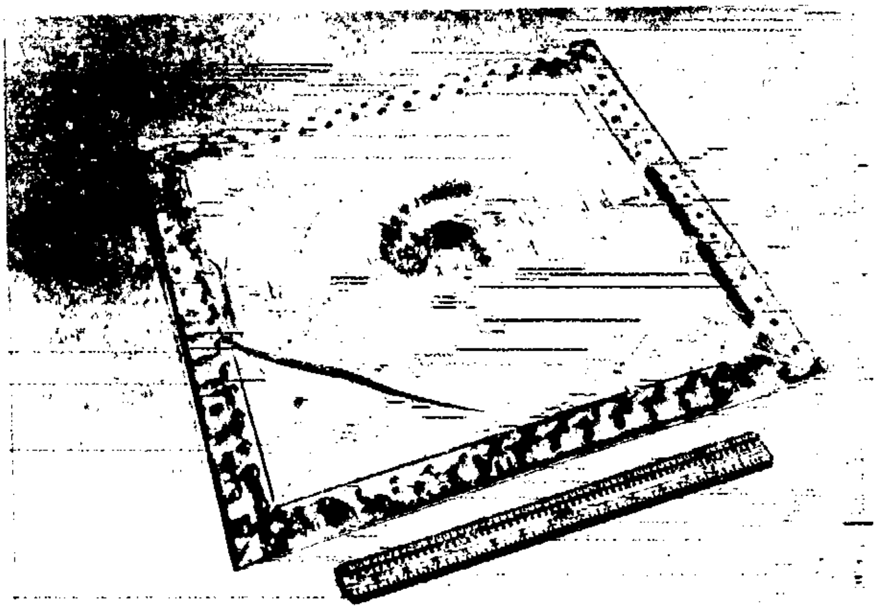
THERMAL SHOCK PANEL DEFLECTIONS DURING LOAD TEST





76-5007-3

Near Side



76-5007-5

Far Side

Fig. 3.6.2.3-6 - Failed .140 inch thick Be-38A: Thermal Shocked Lockalloy Panel (Failure Load = 120,000 pounds)

3.7 THERMAL SHOCK TESTS OF .095 INCH THICK Be-38Al ALLOY

To obtain preliminary information regarding the resistance of Lockalloy to thermal shock, two samples of .095 inch thick Be-38Al alloy sheet (supplied gratis by the Lockheed Missiles and Space Company) were instrumented and subjected to direct impingement of a localized oxygen-acetylene flame.

The first sample measured approximately $9\frac{1}{2}$ x $10\frac{1}{4}$ inches and had previously been used for a projectile impact test. A thermocouple (TC-1) was attached to the back side of this specimen, on the centerline of the $9\frac{1}{2}$ inch dimension, directly opposite the point of flame impingement. A second thermocouple (TC-2) was attached to the back side of the specimen at a distance of 3 inches from the first. The oxygen-acetylene flame was held in direct contact with the surface of the material. The temperature on the back side of the sample directly opposite the flame (TC-1) reached 1000°F in 48 seconds. At that time, the temperature 3 inches away (TC-2) was only 240°F. This temperature differential of 760°F resulted in the area under the flame being raised and permanently deformed to a height of approximately .050 inch.

On the second sample, which measured approximately 4 x 10 inches, the thermocouples were attached on the centerline of the 4 inch dimension. On this sample the temperature directly opposite the flame (TC-1) reached 1500°F in 67 seconds, while the temperature 3 inches away (TC-2) was 325°F. At this temperature the specimen, which was supported on each end, drooped approximately .125 inch of its own weight, but the local deformation directly under the flame was only .010 inch. A small bubble of what appeared to be pure aluminum exuded from the surface of the material, directly under the flame, as the temperature on the back side of the specimen approached 1500°F.

Each of these samples was subsequently Zyglo inspected. There was no evidence of cracking. The local distortions were considered minor for the rather severe thermal shock conditions which resulted in localized temperature differentials of 760°F and 1175°F.

The two samples used for these thermal shock tests are shown in Figure 3.7-1.

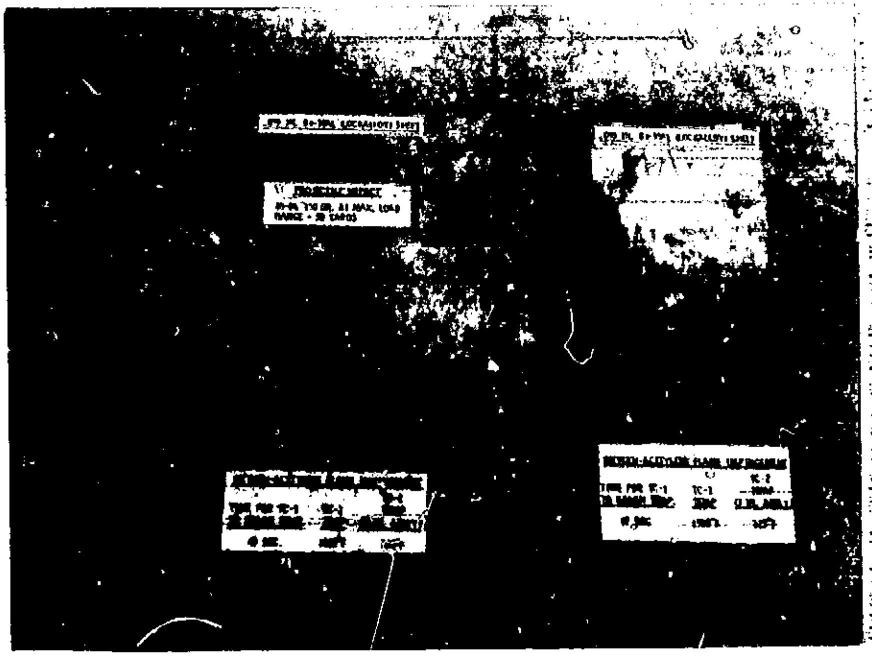


Fig. 3.7-1 - .095 Inch Thick Be-38Al Sheet Samples used for Thermal Shock Tests.

3.8 QUALIFICATION TESTING

ADP's long standing materials use policy calls for "in-plant" qualification of all materials for which statistical property data is insufficient. Tensile coupons are prepared from each piece of such materials and are tested prior to their release to production for ultimate and yield strength, percent elongation, and modulus of elasticity. These tests are in addition to the material certification tests performed and reported by the Material suppliers.

In the case of the Lockalloy sheet material, because of the delays in deliveries and the urgency to release material to production as soon as it became available, the qualification testing was done concurrently with fabrication of the panels. Coupons were made from remnants of each sheet, but because of the irregular shape of the remnants, coupon alignment with sheet grain was not attempted. The coupons, where possible, were taken in two mutually perpendicular directions indicated as A & B. Table 3.8-1 presents the results of ADP's qualification testing. KBI tensile values, in the longitudinal and long transverse grain direction, as available, are listed for comparison. The rolling history of each sheet (number of rollings in the transverse direction) is also indicated.

MATERIAL QUALIFICATION - TABLE

Sheet I.D.	t	ADP TESTING Coupon Direction	F_{tu} KSI	F_{ty} KSI	% e	E x 10^3 KSI	KBF TESTING Grain	F_{tu} KSI	F_{ty} KSI	% e	No. of Rollings
127-3	.150	A	50.6 49.9	38.3 38.4	6 6$^{(1)}$	27.6 29.4	L	54.1 54.3	39.9 39.7	11.5 11.5	3
		B	52.3 53.5	40.7 39.9	4$^{(1)}$ 9	26.8 28.7	T	50.0 50.0	38.2 38.1	7.6 8.3	
137-4	.125	A	54.7 53.7	39.1 38.0	9 8$^{(2)}$	28.6 30.0	L	50.6 51.2	34.8 35.2	10.1 11.7	4
		B	51.9 51.8	37.1 36.4	7 8	26.2 30.7	T	49.1 46.9	33.7 34.1	9.2 6.2	
137-5	.125	A	54.6 52.5	39.4 38.5	9 8	27.8 26.5	L	50.6 51.8	37.7 38.9	13.3 11.2	4
		B	51.9 55.4	38.2 39.5	7 10	26.4 31.7	T	54.3 53.4	39.2 38.2	13.2 12.9	
146-2	.125	A	55.0 54.5	40.1 39.8	9.5 8.5$^{(2)}$	29.6 25.9	L	53.8 52.2	38.1 36.2	18.2 13.8	4
		B	N.A.				T	51.1 50.7	35.6 35.5	15.8 15.7	
146-3	.125	A	54.1 53.4	39.8 40.5	8 7	30.2 28.2	L	52.2 51.6	39.0 37.4	12.5 10.2	4
		B	53.0 53.5	39.3 39.2	7.5 8	31.1 30.4	T	50.9 47.9	36.3 35.7	10.8 7.2	
160-3	.150	A	53.7 52.7	38.9 38.6	11 9.5	26.8 25.5	L	52.0 52.2	37.4 38.3	14.3 15.4	3
		B	51.2 51.5	37.5 37.3	9 8	24.3 26.9	T	52.6 52.0	39.6 39.2	13.5 15.3	
160-4	.150	A	52.9 51.9	37.0 36.3	12.5 11	27.7 27.4	L	N.A. N.A.	N.A. N.A.	N.A. N.A.	3
		B	51.5 51.6	36.5 36.4	8.5$^{(2)}$ 9.5	27.8 34.4	T	51.7 51.6	39.2 38.0	12.5 13.7	
161-1	.125	A	52.4 52.7	39.4 39.9	8 10	25.1 34.4	L	50.7 51.3	34.6 36.3	10.7 15.6	3
		B	52.6 51.9	39.4 39.5	9 8	34.8 25.9	T	51.0 51.4	37.3 35.4	11.7 12.7	
161-2	.150	A	54.0 53.1	38.8 38.0	11 10	25.3 25.8	L	53.1 50.3	39.1 36.0	10.7 11.9	3
		B	52.4 52.5	37.9 38.4	11 11	27.9 28.5	T	50.2 52.8	36.6 37.5	13.5 14.4	

TABLE 3.8-1. MATERIAL QUALIFICATION

MATERIAL QUALIFICATION - TABLE (Continued)											
		ADR TESTING					KBI TESTING				
Sheet I.D.	t	Coupon Direction	F_{tu} KSI	F_{ty} KSI	% e	$E \times 10^3$ KSI	Grain	F_{tu} KSI	F_{ty} KSI	% e	No. of Rollings
161-4	.150	A	(3) 53.7	(3) 39.4	(3) 12	26.4	L	50.9 50.0	35.3 36.0	13.8 8.8	3
		B	53.0 52.7	38.9 39.2	8.5 7.5	29.3 27.8	T	51.2 51.0	38.5 38.2	15.8 13.1	
161-5	.125	A	52.4 52.3	33.9 33.7	11 11	29.6 26.6	L	53.1 54.3	38.4 39.7	11.6 11.5	4
		B	49.7 51.1	32.0 34.8	9 10	29.7 29.4	T	52.3 52.7	39.8 38.8	10.6 9.8	
197-2	.150	A	51.5 52.2	34.3 34.8	11 11	32.7 27.4	L	53.3 53.4	37.4 36.9	10.3 10.5	4
		B	N.A.	N.A.	N.A.		T	53.4 51.4	36.9 36.3	14.2 7.2	
197-3	.150	A	52.3 53.6	36.9 37.9	9 11	29.2 31.4	L	51.9 50.7	36.9 36.9	11.8 14.5	3
		B	53.6 52.1	37.0 36.8	10 9	40.8 27.1	T	51.6 50.9	36.7 36.1	11.2 8.2	3
197-4	.125	A	52.0 52.3	32.2 31.6	11 13	29.0 31.6	L	54.6 54.8	40.2 40.0	14.2 9.4	3
		B	N.A. N.A.	N.A. N.A.	N.A. N.A.		T	52.0 52.2	36.2 36.6	11.5 12.2	
227-1	.150	A	51.5 51.7	36.4 37.3	9 10	30.8 28.0	L	53.2 50.3	38.0 39.0	10.7 5.4	3
		B	50.6 49.9	35.3 35.6	10 8	27.6 27.7	T	52.8 52.6	36.5 37.0	13.7 8.8	
227-2	.125	A	51.7 51.6	35.4 35.8	10 10	28.6 28.2	L	53.0 54.6	36.6 37.3	13.0 13.2	3
		B	51.7 51.1	35.2 35.4	10 8	33.5 34.6	T	51.3 55.0	37.8 38.2	6.0 11.7	
227-3	.150	A	51.6 50.8	35.0 34.5	9 9	28.5 26.8	L	53.9 55	39.2 39.2	11.1 11.6	3
		B	52.1 51.7	33.9 34.3	12 13	31.7 24.6	T	52.8 54.2	38.4 38.4	12.1 11.5	

TABLE 3.8-1. MATERIAL QUALIFICATION (Continued)

MATERIAL QUALIFICATION - TABLE (Continued)											
		ADP TESTING					KBI TESTING				
Sheet I.D.	t	Coupon Direction	F_{tu} KSI	F_{ty} KSI	% e	$E \times 10^3$ KSI	Grain	F_{tu} KSI	F_{ty} KSI	% e	No. of Rollings
227-4	.125	A	52.2	37.3	10	34.7	L	50.6	35.3	9.0	3
			38.2	37.9	11	38.1		52.0	35.4	12.8	
		B	53.6	38.9	10	30.1	T	52.2	37.1	13.8	
			53.4	38.1	10	34.7		52.4	36.7	13.4	
231-2	.150	A	52.2	37.8	8	24.5	L	47.9	33.6	7.3	3
			52.6	37.8	9	26.5		47.8	33.5	7.6	
		B	53.3	37.4	10	28.1	T	49.0	33.2	12.0	
			53.4	37.6	11	27.8		47.9	33.4	8.0	
243-2	.150	A	52.4	36.7	9	24.3	L	50.3	34.9	11.2	N.A.
			51.9	36.0	9	25.0		49.9	34.7	11.4	
							T	51.6	33.7	10.0	
								51.3	34.8	11.2	

(1) FAILED NEAR GAGE POINT

(2) FAILED OUTSIDE GAGE LENGTH

(3) FAILED AT SCRIBE MARK

(4) R.N. PAGES 568560 AND 568563 THRU 568566

TABLE 3.8-1. MATERIAL QUALIFICATION (Concluded)

3.9 MISCELLANEOUS TESTS

Miscellaneous tests performed as part of the material characterization study included special tensile tests to evaluate the short transverse strength of Lockalloy plate, and cyclic reversed bend tests to determine whether cold bending could be employed to correct minor discrepancies on formed Lockalloy parts. These tests are described in the following paragraphs.

3.9.1 Short Transverse Strength - Special tensile tests were conducted to evaluate the short transverse strength of Lockalloy plate. Three non-standard specimens were made from a .250 inch thick Be-38Al plate (Heat: HC161-3) which was used in the material characterization program. The coupons were machined per drawing TH-100 as shown on page B-16 in the Appendix with the exception of the fillet radius which was considerably smaller than the .03 radius specified. The radius was estimated to be .003 to .006 inch. Reinforcing steel plates were bonded to the coupon flanges to prevent flange failures. Figure 3.9.1-2 shows the three Lockalloy coupons prior to testing. Figure 3.9.1-1 shows the coupons with the loading fixture in place.

Because of the geometry of the specimens and the manner of loading bending stresses and high stress concentrations are present at the vicinity of the fillet radius. The calculated failure stress, therefore, cannot be considered as establishing the tensile strength level in the short transverse direction for this material. Rather, it represents a qualitative measure of its strength in this direction. The average failure stress of the plate tested was approximately 32% of the ultimate stress in the longitudinal and long transverse grain direction for this plate. By way of comparison, a 7075-T6 bare plate of the same thickness, tested identically, failed at 22% of its longitudinal or long transverse ultimate strength. Examination of the fractured surface shows that failure, in two of the three specimens tested, started in two parallel planes as evidenced by loose platelets shown in Figure 3.9.1-3.

The relatively high short transverse to longitudinal strength ratio, however, does not suggest any in-plane weakness due to delamination.

Table 3.9.1-1 shows the test results for the Lockalloy and the 7075-T6 Aluminum alloy. Table 3.9.1-2 shows typical longitudinal and long transverse properties for comparison.

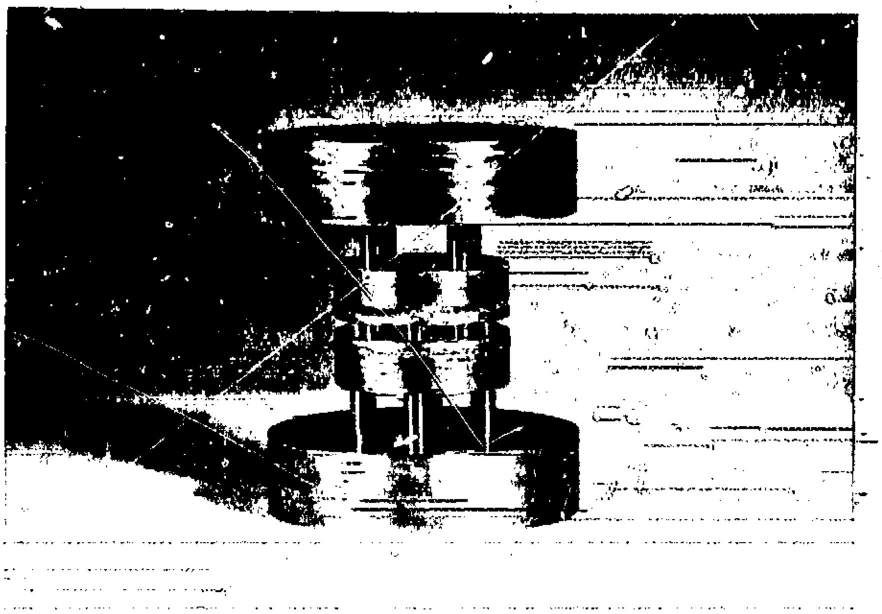


Fig. 3.9.1-1 - Loading Fixture and Coupon

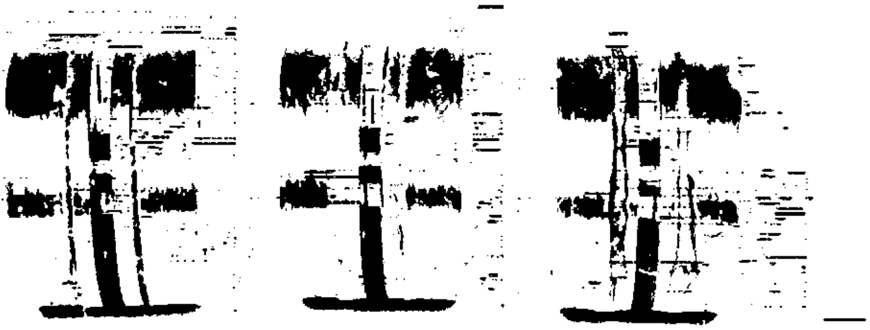


Fig. 3.9.1-2 - Short Transverse Tensile Coupons - [illegible]

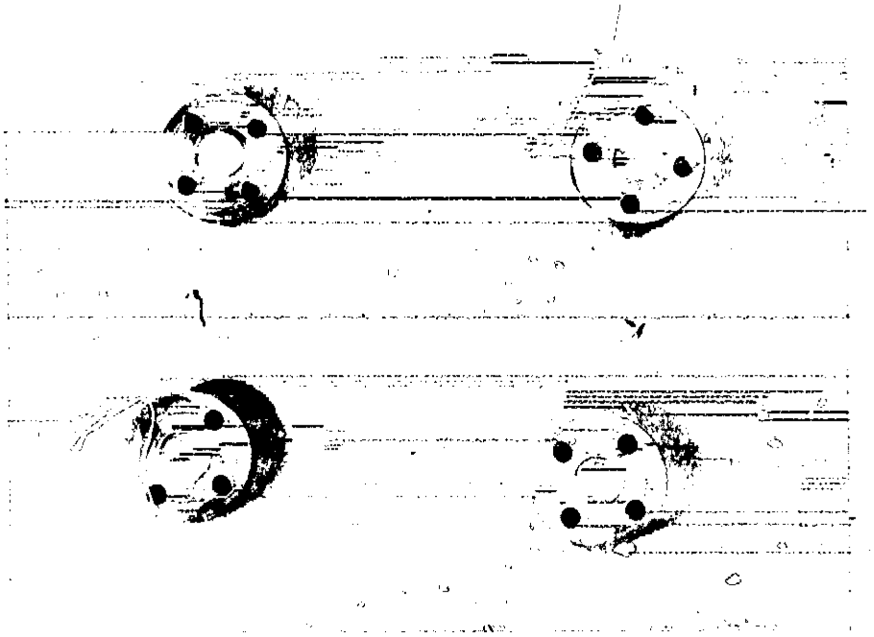


Fig. 3.9.1-3 - Failed Coupons-Lockalloy

LOCKALLOY SHEET: HC-161-3				ALUMINUM ALLOY 7075-T6 - BARE PLATE		
SPEC. NO.	AREA -IN^2	LOAD AT FAILURE-LBS	FAILURE STRESS-PSI	AREA -IN^2	LOAD AT FAILURE-LBS	FAILURE STRESS-PSI
1	.1098	1880	17120	1110	2080	18740
2	.1098	1500	13660	1098	2040	18580
3	.1098	1890	17210	1110	2200	19820
		AVG:	16000 PSI		AVG:	19050 PSI

TABLE 3.9.1-1. TENSILE STRENGTH-SHORT TRANSVERSE GRAIN DIRECTION

LONGITUDINAL				LONG TRANSVERSE			
SPEC. NO.	F_{tu} -KSI	F_{ty} -KSI	% e	SPEC. NO.	F_{tu} -KSI	F_{ty} -KSI	% e
5T-1L	51630	36400	9	5T-1T	49680	36050	8
5T-2L	51450	36580	9	5T-2T	50240	36170	9
5T-3L	50890	36470	9	5T-2T	49600	36200	9
AVG:	51350	36480	9	AVG:	49840	36140	8.66

TABLE 3.9.1-2. TENSILE STRENGTH PROPERTIES-LONGITUDINAL AND TRANSVERSE GRAIN DIRECTION-LOCKALLOY SHEET 161-3

LONGITUDINAL				LONG TRANSVERSE			
SPEC. NO.	F_{tu} -PSI	F_{ty} -PSI	% e	SPEC. NO.	F_{tu} -PSI	F_{ty} -PSI	% e
1	85300	80100	12.0	1	86800	76800	11
2	84900	80080	11.5	2	87100	77600	10.5
AVE:	85100	80000	11.7	AVE:	87000	77200	10.7

LOCKALLOY STRENGTH RATIOS:

$$\frac{\text{SHORT TRANSVERSE}}{\text{ULTIMATE-LONG.}} = \frac{F_{S.T.}}{F_{L}} = \frac{16000}{51350} = 31\%$$

$$\frac{\text{SHORT TRANSVERSE}}{\text{ULTIMATE-L.T.}} = \frac{F_{S.T.}}{F_{L.T.}} = \frac{16000}{49840} = 32\%$$

ALUMINUM ALLOY PLATE - 7075-T6 - STRENGTH RATIOS:

$$\frac{\text{SHORT TRANSVERSE}}{\text{ULTIMATE-LONG.}} = \frac{F_{S.T.}}{F_{L}} = \frac{19050}{85100} = 22\%$$

$$\frac{\text{SHORT TRANSVERSE}}{\text{ULTIMATE-L.T.}} = \frac{F_{S.T.}}{F_{L.T.}} = \frac{19050}{87000} = 22\%$$

TABLE 3.9.1-3. ALUMINUM ALLOY - 7075-T6 (SAME PLATE USED FOR SHORT TRANSVERSE TESTING) - TENSILE STRENGTH, L & LT GRAIN DIRECTION

3.9.2 Cyclic Reversed Bend Test - The following non-standard test was performed to ascertain whether a mild cold "Check and Straightening" operation could be used as a corrective fabrication process on Lockalloy parts without affecting the integrity of the material.

The test consisted of cycling a strip of Lockalloy through a reversed bend loading while periodically monitoring the modulus of elasticity in both loading directions. The specimen was a remnant piece of Be-38Al, .125 thick by 1.28 inch wide and approximately 10.0 inches long. It was loaded as a simple beam over a span of 5.0 inches with the load applied at midspan by means of a Wiedemann-Baldwin testing machine. A deflectometer periodically recorded the deflection at midspan versus load. The test set-up is shown in Figures 3.9.2-1 and 3.9.2-2. The applied load was 91.2 lb. resulting in a bending stress of 29,800 PSI.

For the first and every tenth loading cycle thereafter the specimen was loaded twice on the same side before reversing it and repeating the procedure on the other side. During these cycles, load-deflection curves were recorded. The test was discontinued after 101 loading cycles. The strip was then inspected by Zygloing and was found to be free of cracks.

The test data was reduced to modulus of elasticity and the values are presented separately for the first and second loading in Tables 3.9.2-1 and 3.9.2-2, respectively.

The increase in stiffness found on all of the second load applications is evidently a characteristic of this material, and it was observed on other similar tests. The fact, however, that the modulus of elasticity, for each loading, did not show any significant change through the 100 cycles of load reversal indicates that the material remains structurally sound.

On the basis of these test results and since the anticipated straightening operation was not expected to impose any more severe conditions, "Check and

Straightening" was in this case approved and used successfully to correct forming deficiencies in one of the surface panels.

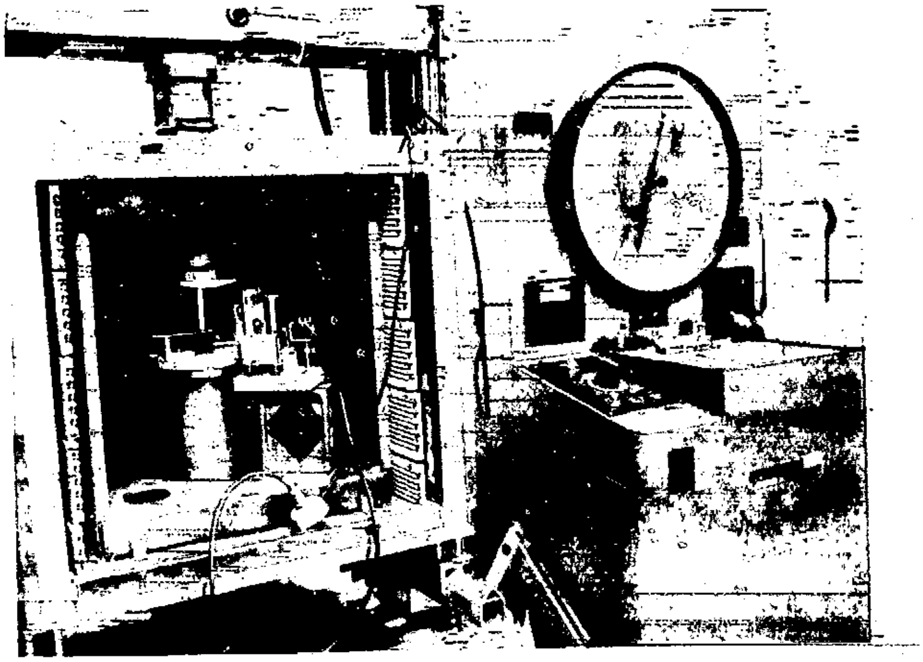


Fig. 3.9.2-1 - Overall view of Test Machine and Set-up for Reverse Bending Test.

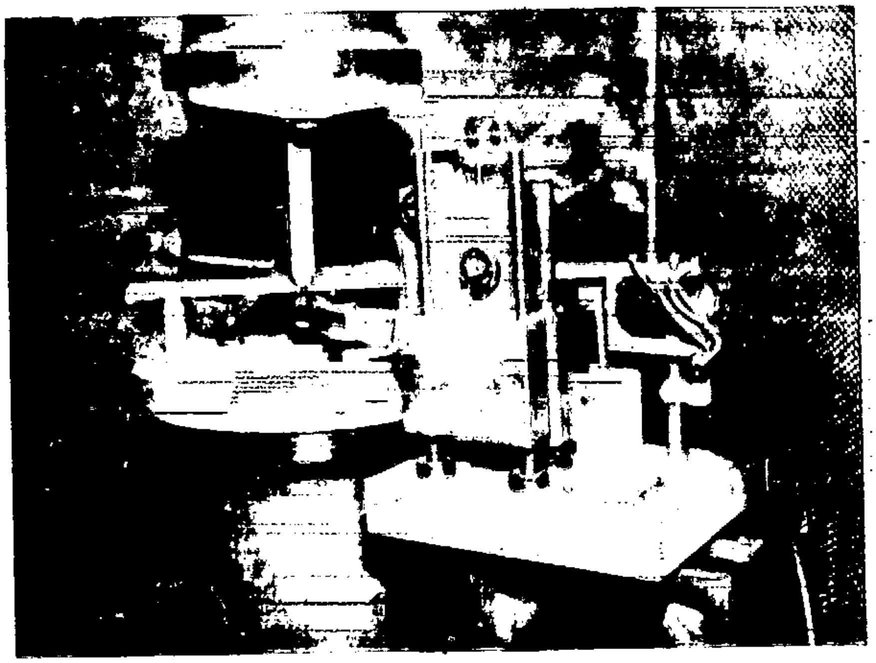


Fig. 3.9.2-2 - Close-up View of Specimen and Loading Arrangement

CYCLE	SIDE	DEFLECTION	LOAD #	E - PSI X 10^6
1	1	.04115	91.25	22.5
	2	.0457		20.2
11	1	.04175		22.2
	2	.0428		22.6
21	1	.0416		22.2
	2	.0430		21.5
31	1	.0420		22.0
	2	.0427		21.7
41	1	.0423		21.9
	2	.04225		21.9
51	1	.0416		22.2
	2	.0430		21.5
61	1	.0417		22.2
	2	.04275		21.6
71	1	.0415		22.3
	2	.04275		21.6
81	1	.0425		21.8
	2	.0430		21.5
91	1	.0424		21.8
	2	.04255		21.7
101	1	.0421		22.0
	2	.0434	91.25	21.3

TABLE 3.9.2-1 CYCLIC REVERSE BENDING MODULUS OF ELASTICITY - FIRST LOADING

CYCLE	SIDE	DEFLECTION	LOAD #	E - PSI
1	1	.03545	91.25	26.1×10^6
	2	.03545		26.1×10^6
11	1	.0351		26.4×10^6
	2	.03545		26.1×10^6
21	1	.0347		26.7×10^6
	2	.03525		26.3×10^6
31	1	.0348		26.6×10^6
	2	.0347		26.7×10^6
41	1	.0345		26.8×10^6
	2	.0349		26.5×10^6
51	1	.03425		27.0×10^6
	2	.0349		26.5×10^6
61	1	.0345		26.8×10^6
	2	.03485		26.6×10^6
71	1	.0338		27.4×10^6
	2	.03475		26.6×10^6
81	1	.0348		26.6×10^6
	2	.035		26.4×10^6
91	1	.0348		26.6×10^6
	2	.0343		27.0×10^6
101	1	.0344		26.9×10^6
	2	.0343	91.25	27.0×10^6

TABLE 3.9.2-2. CYCLIC REVERSE BENDING MODULUS OF ELASTICITY-SECOND LOADING

3.10 SUMMARY

The material characterization program for the Be-43Al and Be-38Al Lockalloy material is summarized as follows:

The supposedly reported better bending characteristics of the Be-43Al Lockalloy over the Be-38Al Lockalloy were found to be essentially equivalent in this test program. Therefore, Lockalloy Be-38Al would be recommended for any future major application of Lockalloy.

On the basis of the formability tests performed on the Lockalloy Be-38Al, it appears that additional effort is desirable to better define formability and determine appropriate annealing and heat treating cycles for the material.

Considerable test scatter was exhibited in the tensile and compressive modulii of elasticity of the Lockalloy material. This can be explained, in part, by the difficulty experienced in establishing a tangent to the small straight-line portion of a basically non-linear load-deflection curve characteristic for the Lockalloy material. A contractor funded test program (not part of the Statement of Work for this contract) has been initiated to determine a modulus of elasticity from coupon data, such that it will be consistent with measured stability allowables on plate or column specimens at room temperature. It is probable that some limited testing will also be accomplished at 600°F.

Modulus of elasticity values as obtained from the axial strain gages used on the Poisson's ratio tests, exhibited less scatter as contrasted to the conventional method of data obtained using extensometers, at both room temperature and at 600°F. The strain gage approach may be the most reliable method to determine the modulus of elasticity of Lockalloy material.

Exposure of the Lockalloy material to 600°F for 100 hours was either equivalent to or better than any of the material properties of non-exposed material when tested at room temperature or at 600°F.

The fatigue life of a K_t 1 specimen, deliberately scratched across its test section with a torque set recess driver, is better than a K_t 3 specimen either at room temperature or at 600°F.

The fracture toughness of Lockalloy, sheet and plate is equivalent to or better than 2024-T3 aluminum based on the residual strength ratio, R_{sc}, as defined in ASTM E-399. Valid K_{IC} values were not obtained, since specimen minimum thickness of ~~more than~~ one inch ~~would be~~ required in order to obtain valid K_{IC} ~~values~~. For extruded Lockalloy material, such as used in the ventral fin leading and trailing edges, the R_{sc} in the ext~~rusion dire~~ction was much better than Lockalloy sheet or plate, but in the transverse direction no valid value could be obtained on the one specimen tested as defined by ASTM E-399. This implies the material may have poorer fracture toughness in the transverse direction than exhibited by sheet or plate.

Crack growth rate characteristics of Lockalloy on a normalized basis (alternating stress intensity/density) is approximately 3×10^{-6} inches per cycle as compared to a typical crack growth rate in titanium or aluminum or approximately 2×10^{-5} inches per cycle for an assumed crack size of .2 inch long in the center of a wide panel operating at a structural efficiency (strength to density ratio) of 200,000 inches.

No evidence of stress corrosion cracking was encountered of bare and protected (Alodine 1200 or ADP high temp. aluminized paint) specimens coated with 3.5 percent salt. The specimens were stressed at 35 ksi at room temperature and 10 ksi at 600°F for 100 hour exposure. At the conclusion of the test, from all appearances, the ADP high temp. aluminized paint system offered the best protection.

Lockalloy is subject to galvanic and general corrosion attack if not protected, similar to aluminum alloys. ADP high temperature aluminized paint provides excellent protection against galvanic and general corrosion as substantiated by the 1300 hour galvanic test and 400 hour general corrosion test in a salt environment.

The two Lockalloy shear panels tested at room temperature, one with thermal shock and the other without any prior heating, failed at the same load of 120,000 pounds through the net section of the edge attachments. This indicates that the heated area of the thermal shock panel, with the lower stresses at the center of the panel, was still less critical than the net section through the edge attachments.

The special tests conducted to evaluate the strength in the short transverse direction of Lockalloy plate showed a ratio of 32% (average S.T. strength/Long. ultimate strength) as compared to a ratio of 22% for an identical specimen in 7075-T6 material. The relatively high short transverse to longitudinal strength ratio does not suggest any in-plane weakness due to delamination for the Lockalloy material.

On the basis of the test results of the cyclic reversed bend tests, since the modulus of elasticity did not show any change through 100 cycles of load reversals, indicates that the material remained structurally sound. Mild cold "check and straightening" was therefore approved and was used successfully to correct a forming deficiency on one of the ventral fin surface panels.

Test results of deliberately scratched lap-shear joint specimens with a torque set recess driver showed no effect when scratched normal to the applied load. Scratching the specimens parallel to the applied load showed a decrease in the failing load. However, it was still considered to be within the normal test scatter encountered when testing lap-shear joint specimens.

SECTION 4

DESIGN CRITERIA

4.1 DESIGN CONCEPT

The two underlying objectives in the ventral fin design were simplicity of construction and increased stiffness. To obtain the required stiffness, Be-38Al Lockalloy, an alloy consisting of 62 percent beryllium and 38 percent aluminum, was selected as the principal structural material. Lockalloy is an extremely lightweight alloy that has a modulus of elasticity which approaches that of steel. It is ideally suited to applications where compression loading is a factor. In order to exploit these characteristics, a semimonocoque design was chosen. In this type of structure, relatively thick surface panels absorb the primary internal loads and the substructure merely serves to support the panels and provide a stabilizing effect. Two main characteristics of the ventral fin design thus are a light titanium rib and beam skeleton and Lockalloy surface panels. For simplicity, a symmetrical hexagon airfoil was chosen since this section consists mainly of flat surfaces, and panel bends are needed only to form the leading and trailing edge wedges.

4.2 STRUCTURAL ANALYSIS

A structural analysis was accomplished early in the program to verify the structural integrity of the ventral fin design. A mathematical model of the ventral fin was set up and the NASTRAN structural analysis computer program was utilized for calculating and distributing internal loads and stresses. External loadings, critical internal loads, and stress calculations resulting therefrom were published previously in Lockheed-ADP Report No. SP-4400, dated 17 July 1975.

4.3 SUBSTRUCTURE DESIGN

The substructure (Figure 4.3-1) is a riveted network of titanium ribs and beams fabricated primarily from annealed .050-inch Ti-13V-11Cr-3Al material. The beams are joggled to provide a smooth intersection with the ribs. The root rib is of constant thickness between the front and rear principal beams. The ventral fin contour tapers uniformly from the root rib to the tip rib. The design emphasizes simplicity and ease of fabrication and allows the bulk of the sheet metal to be sheared in the flat; only a minor amount of profiling is required. The design further specifies that all sheet metal forming is to be done cold on a brake or a Verson press. The joggles are standardized to reduce tooling costs and are done on one joggle block using shims to control joggle depth. Detail parts are designed for fabrication using standard machining operations. No patterns are required. Screw holes are provided throughout the substructure for attaching the Lockalloy surface plates. Fittings for attaching the ventral fin to the airplane are installed at the two points where the root rib intersects with the front and rear principal beams.

4.4 SURFACE DESIGN

The surface contour of the ventral fin is essentially flat, except at the front and rear sections where a slight taper is introduced. The skin-like surface is provided by 32 Lockalloy panels plus Lockalloy leading and trailing edge members. The panels are fabricated from Lockalloy sheet material of .125-inch and .150-inch thicknesses. Twelve of the panels required forming to produce the required curvatures (approximately 3-degree, 2.5-inch radius bends) in the vicinity of the front and rear beams. All panels were designed for screw installation for two reasons: Rivets would have to be squeezed instead of bucked, and access, at least from one side, is required to install and service instrumentation. The left-hand panels are installed using hex nuts and the right-hand panels using plate nuts. The design thus

Fig. 4.3-1 - Ventral Fin Substructure Installed in Assembly Jig 75-5297-5

provides for access from the right side only. The leading and trailing edge members (Figure 4.4-1) are machined from extruded Lockalloy bar stock to provide a designated taper and a recess for installation of the surface panels. Figure 4.4-2 shows the partially completed ventral fin as it appeared during installation of surface panels, and Figures 4.4-3 and 4.4-4 show the completed fin with and without panels installed.

4.5 FLIGHT TEST INSTRUMENTATION

One of the requirements of the ventral fin design was that it contain provisions for installation of flight test instrumentation. (Ground test instrumentation, i.e., strain gages and deflection gages, were temporarily attached to the surface panels of the fin externally at specified locations during the tests but did not influence the design.) The flight test instrumentation specified by NASA included 20 dynamic pressure transducers, 2 scannivalves, 19 strain gages, 10 thermocouples, 3 accelerometers, and a probe for measuring angle of attack and yaw. To accommodate these instruments, 80 pressure ports (type NA3718) are provided at specified locations for ultimate connection (by NASA) to the dynamic pressure transducers; mounting provisions are incorporated for the dynamic pressure transducers, the accelerometers, and the probe; and clamps and routing holes are provided for installation of the NASA-supplied wiring harness (see Figure 4.4-4). The design also specifies the locations of the strain gages and thermocouples which were installed by Lockheed-ADP. In addition, appropriate space is provided at specified locations for installation (by NASA) of a "patch panel" and an "electrical connection panel."

4.6 DESIGN SUPPORT COMPONENT TESTS

Various tests were performed whenever required to validate certain aspects of the overall design. These included compression splice tests, compression stability tests, and panel stiffness tests. These tests are described in the following paragraphs. (Note: Additional details concerning the compression splice tests and

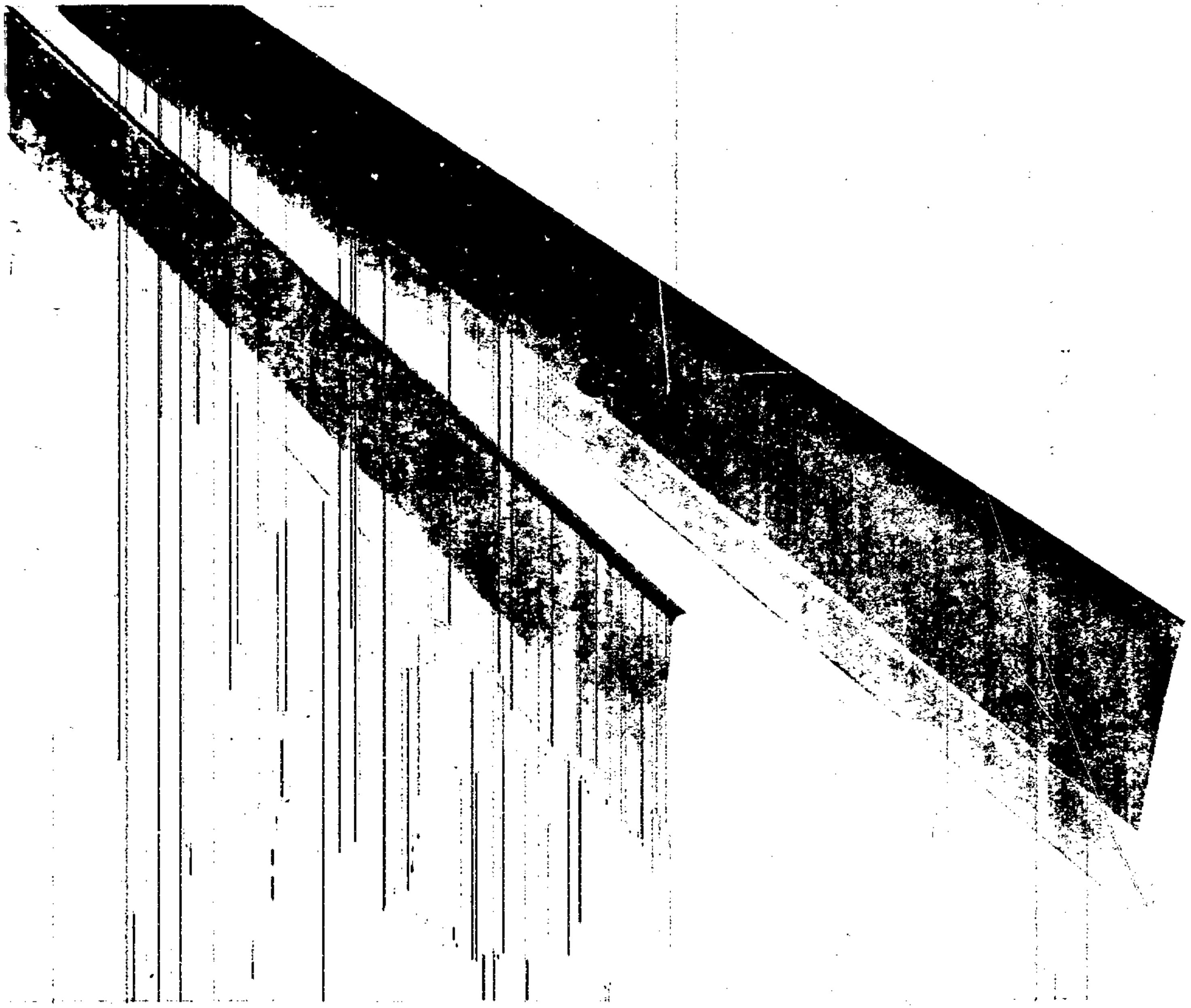
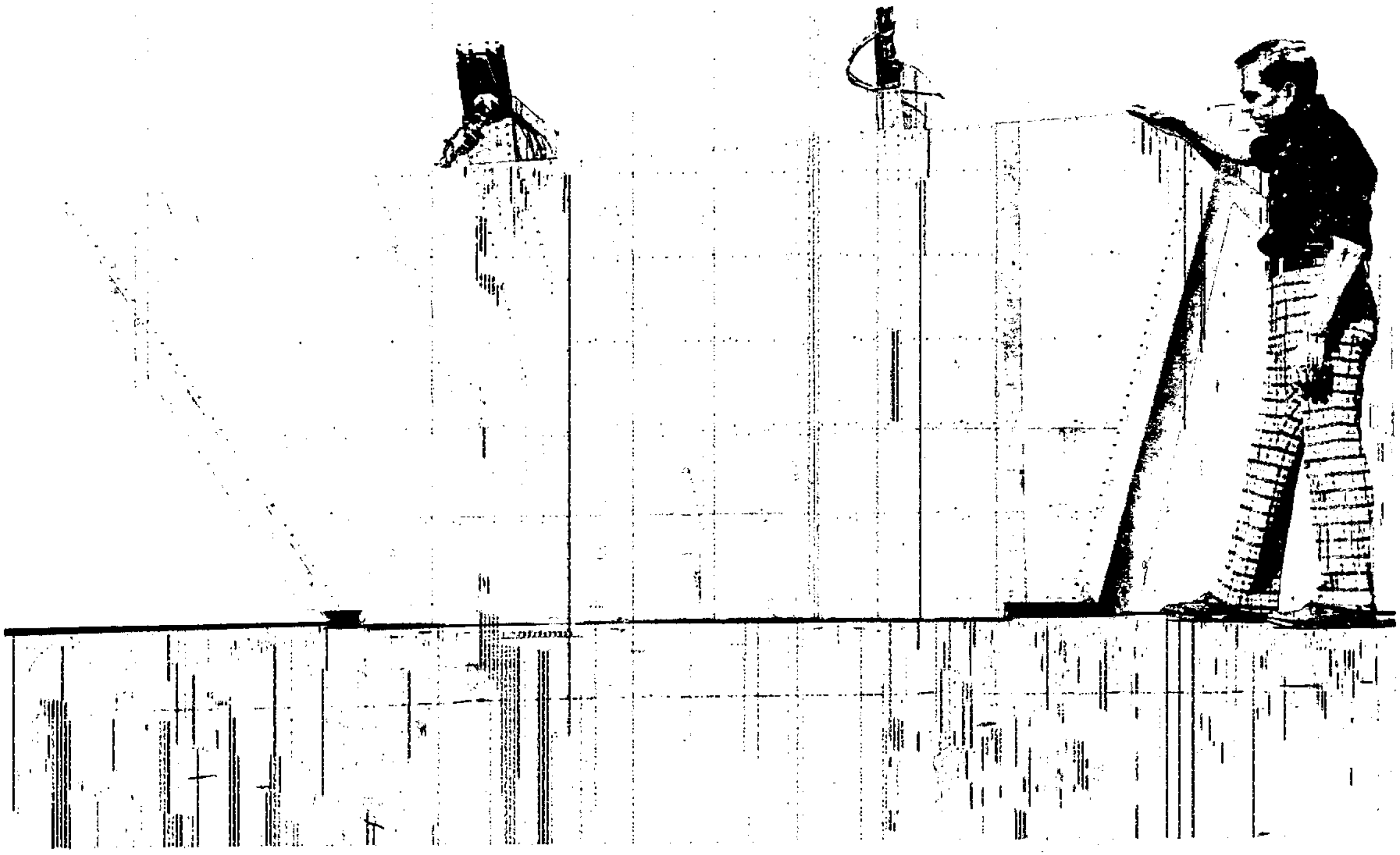


Fig. [illegible]-1 - Leading and Trailing Edge Members of Ventral Fin 75-5-5--1

75-5297-1

Fig. 4-2 - Ventral Fin with Surface Panels Partially Installed



[illegible] - Completed Ventral Fin with All Panels and Fittings Installed [illegible]

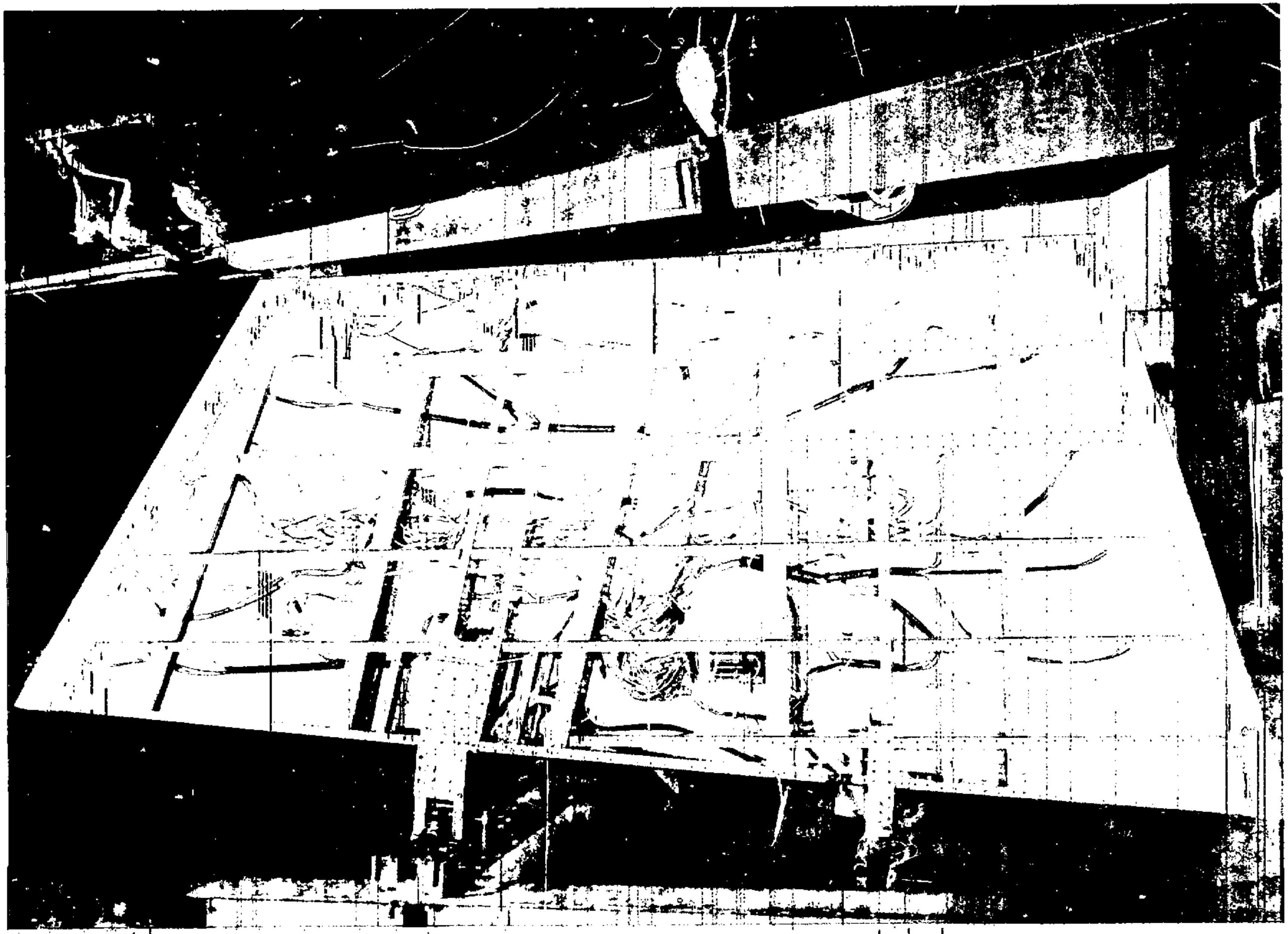


Fig. [illegible] - Completed Ventral Fin with Right-Hand Panels Removed for Access to Instrumentation

75-5370-1

31 x 31 x 4 inches, is shown in its test fixture in Figure 4.6.2-1. For economy, annealed 321 stainless steel was used on this specimen to simulate the Lockalloy surfaces. (Annealed 321 has nearly the same modulus of elasticity and compression yield strength as Be-38Al alloy and also has a compression stress-strain curve which closely approximates that of Lockalloy.) The titanium substructure in this specimen was thus representative of the ventral fin substructure. The specimen was loaded in bending to produce compression in the upper surface. Test results, which are presented in Volume 2, Appendix D of this report, confirmed that the titanium substructure would provide adequate support for stability of the Lockalloy surfaces to compression stresses considerably in excess of the design ultimate stress for the fin.

4.6.3 Panel Stiffness Tests - Modulus of elasticity is the most important material property in a stability critical structure such as the ventral fin. Modulus of elasticity values for Lockalloy, determined from tensile testing, have exhibited considerable scatter. This can be explained, in part, by the difficulty experienced in establishing a tangent to the small straight line portion of the load-deflection curve that is associated with the low proportional limit of this material.

Actual ventral fin panels which, by virtue of their rectangular configuration, could be subjected to bending loads, were tested to determine bending stiffness. Six panels were tested, all of which were formed and therefore subjected to the thermal stress relieve treatment at 1050°F. Data for a seventh panel was obtained by testing a remnant from the Lockalloy sheet used for that panel.

The test consisted of loading the panels as a simple beam incrementally to a total load of 100.24 pounds, while monitoring panel deflection at the midpoint. The loading cycle was repeated twice. The loading arrangement is shown in Figure 4.6.3-1.

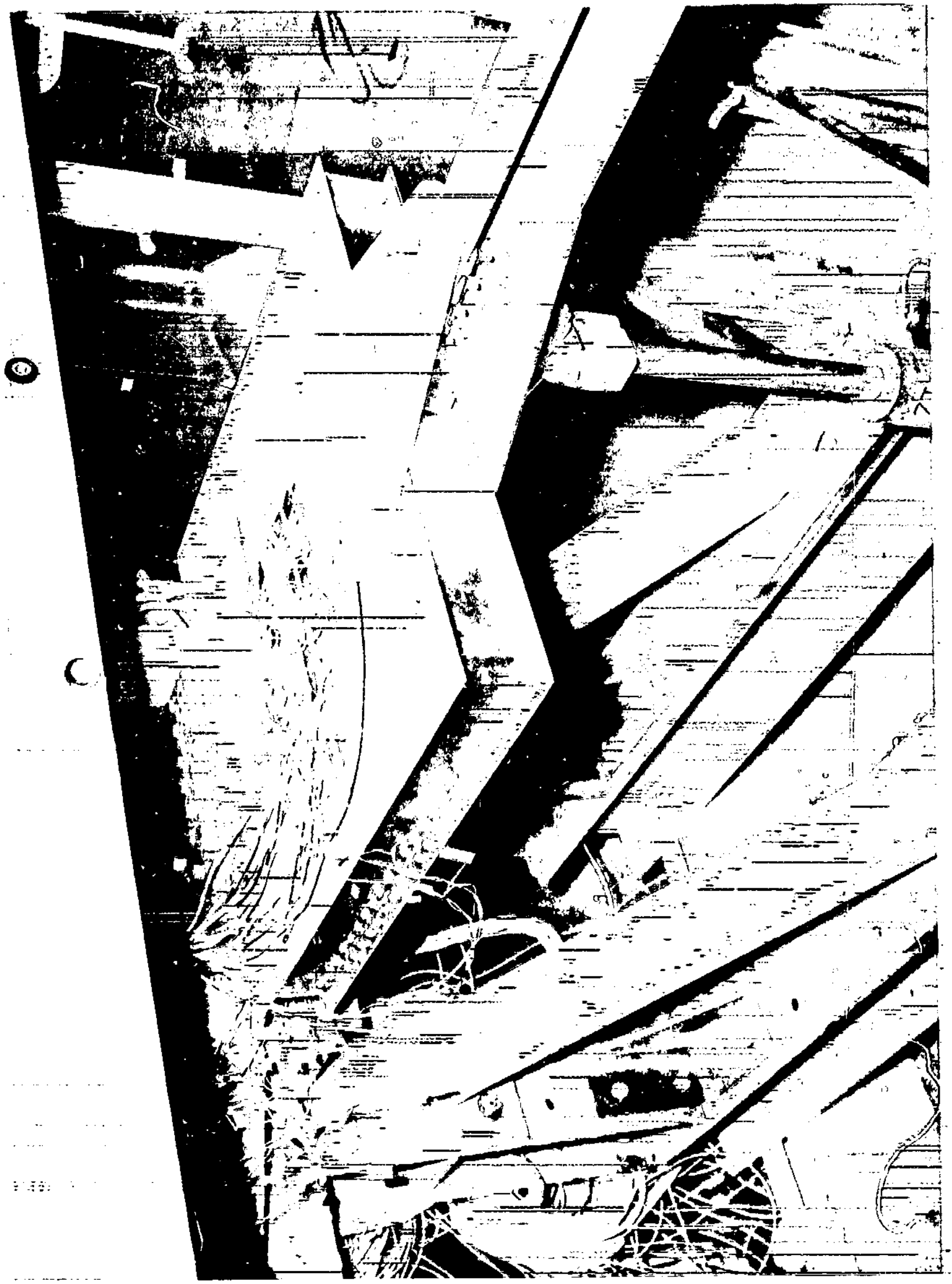


Fig. [illegible]-1 - Three-Ply Box Beam Installed in Test Fixture

75-[illegible]-09-

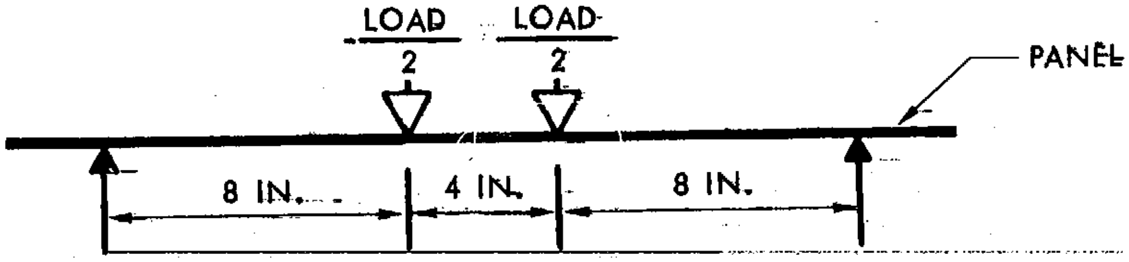


Fig. 4.6.3-1 - Panel Stiffness Test Loading Arrangement

The effective modulus of elasticity for each panel at the test stress level was determined from the cross-section and test data by means of the beam deflection theory. Table 4.6.3-1 presents the test data and the calculated effective modulus of elasticity for each of the panels tested.

4.7 DESIGN CHANGES

A number of design changes were made after initial release of the engineering drawings. As a result of the joint strength tests described in Paragraph 4.6.1, titanium splice straps were added on the exterior surface wherever spanwise joints occurred. This was done to reduce the eccentricity caused by the thick skin and the thin substructure. The strap was made in two pieces between each rib to prevent the thermal expansion of the strap from loading the screw heads. Design changes were also made to accommodate smaller surface panels which were required as a result of accepting 40-inch Lockalloy sheet material from KBI. The initial design, which called for 20 surface panels, was revised to incorporate an additional chordwise splice in the surface panels and thereby allow use of 32 smaller-size panels. The splice was made on the inner side of the skin in the vicinity of a rib. The panels were undercut to accommodate the splice plate and stiffener angles were added.

In addition, several design changes were made as a result of the ground tests of the completed ventral fin. A review of the strain gage data obtained during the

PANEL NO.	SHEET I.D.	t	MOMENT OF INERTIA -IN^4	1ST LOADING			2ND LOADING		
				δ -IN AVE.	STRESS -KSI	EX10^3 KS	δ -IN AVE.	STRESS -KSI	EX10^3 KSI
3NAS692-3	HC161-1	.1214	.001363	.463	17.8	25.0	.412	17.8	28.1
3NAS692-4	HC137-5	.1385	.001809	.335	15.4	26.0	.317	15.4	27.5
3NAS695-3	HC146-2	.1285	.001839	.309	14.0	27.7	.289	14.0	29.7
3NAS695-4	HC146-2	.130	.001904	.318	13.7	26.0	.298	13.7	27.8
3NAS688-3	HC-161-5	.127	.0017752	.345	14.3	25.7	.318	14.3	27.9
3NAS688-4	HC-161-5	.132	.001997	.325	13.2	24.3	.306	13.2	25.8
3NAS694-2 (REMNANT PIECE)	HC160-3	.128	.001407	.426	18.2	26.3	.392	18.2	28.5

$E_{AVE.} = 25.6 \times 10^3$ KSI

27.9×10^3 KSI

$$\text{STRESS} = \frac{Mt}{2I} = \frac{400.96 \times t}{2I}$$

$$E = \frac{M}{24I\delta}(3l^2 - 4a^2) = \frac{15771.09}{I\delta}$$

TABLE 4.6.3-1. MODULUS OF ELASTICITY TEST DATA FOR SURFACE PANELS proof load tests indicated that stresses in the Lockalloy surface panels, near the root of the rear beam, were higher than had been predicted earlier. The titanium substructure was subsequently reinforced to provide increased edge support and preclude possible instability failure of the surface panels in this area between limit and ultimate loadings. Several formed titanium angles were installed inside the existing spanwise titanium splice channels to increase the support capability of the substructure at the panel joints.

SECTION 5

TOOLING REQUIREMENTS

One of the guiding philosophies in the design of the ventral fin was to hold tooling requirements to a minimum. This was accomplished by eliminating hot sizing of the titanium substructure detail parts, by minimizing bends in the surface panels, and also by using multipurpose flat templates and Verson dies. The tooling that was used for the fabrication and assembly of the fin is described in terms of substructure tooling, surface panel tooling, and assembly tooling.

5.1 SUBSTRUCTURE TOOLING

Substructure tooling consisted of flat templates, Verson dies, one joggle die, drill templates, and drill bushings. The flat templates were made from aluminum sheet material using standard shop practices. Whenever possible, flat templates were designed for multipurpose applications (fabrication of more than one part). Verson dies were used for fabricating the sheet metal ribs and beams. Owing to the common taper of the leading and trailing edges of the ventral fin, some of these dies had multiple applications.

As an economy measure, the substructure was designed so that only one joggle die would be needed. This concept was based upon using a common joggle length and varying the joggle depth during the fabrication process by adding shims to the joggle block.

The predrilled Lockalloy surface panels were used as drill templates for drilling panel-mounting holes in the substructure. This served to ensure accurate location of the holes. During the drilling process, a drill bushing of appropriate size was inserted in the holes to isolate the drill bit from the Lockalloy, thereby preventing beryllium contamination. Drill templates made of aluminum plate were used for drilling the attachment holes for the hinge fittings, except in certain instances where holes had to be drilled using the actual fittings as drill templates. Drill bushings were provided for this purpose.

5.2 SURFACE PANEL TOOLING

Surface panel tooling consisted of ceramic forming dies, flat templates, and drill fixtures. Two male ceramic dies were used to bend the 12 Lockalloy surface panels that required forming, one for the forward panels and one for the aft panels. Left-hand and right-hand panels were formed on the same die.

Flat templates were used to fabricate the surface panels. These templates were made out of aluminum sheet material. Each template was cut to the same size as its associated panel and had finish-size holes. The templates were used for locating and drilling all mounting holes in the panels and for profiling edges.

Two special drill fixtures were used to facilitate drilling the mating holes in the leading and trailing edge members and their attaching panels. Separate fixtures were employed for the leading and trailing edges. The fixtures held the leading (or trailing) edge member and the six adjacent panels in place as an assembly prior to in-line drilling; they also served as drill guides when locating and drilling the holes in the panels and the leading (trailing) edge members.

5.3 ASSEMBLY TOOLING

Assembly tooling for the ventral fin consisted of a single assembly jig. As an economy measure, the assembly jig that was used for the original all-titanium ventral fin was adapted for this application. Considerable modification was required, however, except for certain areas in the vicinity of the root rib, the tip rib, and the front and rear hinge fittings. This was necessary since the planform of the new fin differs somewhat from that of its predecessor.

A minimum number of locators for substructure ribs and beams and for the leading and trailing edge members were added as required. This kind of tooling was held to a minimum by installing the panels in a given sequence, starting with the leading and trailing edges and the tip panels. The panels were located, one to the other, using spacers in between to provide for thermal expansion gaps.

SECTION 6

FABRICATION AND ASSEMBLY

Fabrication and assembly of the ventral fin involved fabrication of the principal members and detail parts of the titanium substructure, fabrication of the Lockalloy surface panels and leading/trailing edges, assembly of the substructure, installation of flight test instrumentation and associated wiring, and finally, installation of surface plates and hinge fittings. This section covers all of the above operations. However, since this was the first significant application of Lockalloy as a structural material for aircraft, added emphasis is given to the operations entailing machining and forming of the Lockalloy components of the ventral fin and the safety precautions and safety tests associated therewith. All fabrication and assembly operations were accomplished at Lockheed-ADP's production facilities, with the exception of Lockalloy machining operations. These were accomplished out of plant by selected vendors that had the special equipment needed to collect the beryllium particles produced by the machining operations.

6.1 PANEL FABRICATION

The ventral fin surface structure consists of 32 Lockalloy panels of varying shapes and sizes, plus Lockalloy leading and trailing edge members. Twenty of the panels and the leading and trailing edge members required only machining. However, the twelve panels located over the front and rear beams of the ventral fin required both machining and forming. The forming mold lines of these panels define the forward and aft wedges of the ventral fin's cross-sectional configuration. The machining and forming operations are described in the following subparagraphs.

6.1.1 Machining Operations - The surface panels were made either from .125 or .150-inch Lockalloy sheet material. The flat panels were first cut to approximate size by bandsaw, leaving about 1/8 inch for peripheral trim. They were then machined to finish size and mounting holes were drilled. Surface panels that attach to the leading and trailing edge members were drilled on three sides only, for reasons described in the next paragraph. On the panels that required forming, two elongated indexing holes were incorporated in tabs extending along the bend line of the panels. The bend edges of these panels were trimmed to finish size prior to forming; however, the remaining edges were not trimmed and the mounting holes were not drilled until after forming. All machining operations were accomplished in accordance with templates supplied by Lockheed-ADP.

Leading and trailing edge members were machined from extruded Lockalloy bar stock to provide the required tapered cross-section and the recesses on either side which are needed to permit flush installation of the overlapping surface plates. Holes were then drilled simultaneously in the individual leading (or trailing) edge member and the surface panels that attach thereto. Special drill fixtures were supplied by Lockheed-ADP to serve as drill guides and also to hold the leading and trailing edge members and their associated panels in place during the drilling operations.

6.1.2 Forming Operations - Forming operations were accomplished at Lockheed-ADP after the panels had been machined as described earlier. The forming was relatively simple, consisting of a single element constant bend of approximately 3 degrees. Preliminary tests, performed hot on narrow coupons, suggested that an R/t ratio of 16 would be a comfortable minimum value to use in the design. A bend radius of 2.5 inches was selected, based on the thicker gauge (.150-inch) panels. A forming temperature of 1050°F for a period of 1 hour was selected as a combination forming and stress-relieving cycle. This cycle was selected because it appeared to involve the least risk of failure. Since limited time was available for development work on this program, no attempt was made to optimize the forming and stress-relieving cycle.

Single, male, cast ceramic (glassrock) dies were used. Because of the difference in bend angle between the front and the rear beam panels, two dies were made. Each die incorporated two sets of indexing holes to accommodate the different size panels. The eight smaller panels with an approximate bend line of 11 inches were formed first in accordance with the following procedure:

a. The blank was first washed in an alkaline soap solution.

b. The die was then preheated to 1050°F and lubricated by spraying it with a graphite lubricant (Everlube T-50).

c. The blank was loaded on the preheated die and indexed by means of drop pins.

d. The blank was then covered with slip sheets in preparation for loading with weights. (Slip sheets were .016-inch thick commercially pure titanium. Two slip sheets were used, one on either side of the bend.)

e. Preheated dead weights were then placed on the slip sheets. Stainless steel bars and plates were used for this purpose.

f. The die assembly was then placed in the furnace and heated to 1050°F. This temperature was maintained for one hour. External thermocouples were placed against the die face to monitor temperature.

g. The loaded die was then removed from the furnace and allowed to cool overnight to room temperature. After cooling, the weights were unloaded and the formed parts were removed.

h. After being washed and Zyglo-inspected, the formed part was sent to the outside machine shop for finish machining.

The above procedure proved to be highly successful in forming all of the small panels. Bend definition and angularity were good and all of these panels were formed at the first attempt. The same procedure was therefore used for the four larger panels. Two of these panels had 36-inch bend lines.

The initial effort to form one of these panels using the above procedure did not meet with the same success, however. The panel, upon removal of the dead weights, lifted off the die along its periphery, resulting in an anticlastic, saddle-back-shaped surface. The bow at the bend line measured approximately 3/8 inch, with the edges being higher than the middle. The bowing was thought to be the result of an incomplete stress relief. To compensate, the heating cycle was extended to 12 hours and the dead weights were rearranged to apply greater pressure around the edges. This, too, however, was unsuccessful, suggesting that the bowing could possibly be due to residual stresses induced during cool down.

Various methods were employed to maintain an even temperature during cool down on this and subsequent panels. Panels were covered with insulating blankets and allowed to slowly cool in the oven, and weights were judiciously removed to compensate for uneven cool down. A set of shaped ceramic blocks was also made to separate the panel from the steel weights. All of these methods met with partial success and none were repeatable. In addition, cold-forming on a power brake followed by a die anneal was tried, but this too did not appreciably improve panel definition. As a result of the above forming trials, two panels with a slight bow of approximately .09 and .10, respectively, were deemed acceptable for assembly. On the remaining two panels the bowing persisted to a magnitude of approximately 1/4 inch.

A check and straightening operation in a power brake was then tried. This standard shop practice, which is often employed to correct minor distortions in aluminum and titanium parts, is normally governed by process specifications. However, since no previous experience existed with Lockalloy, a simple cold bend test was devised and performed on a Lockalloy remnant to verify that the panel would suffer no damage or degradation. This test is described in Section 3, Paragraph 3.9. One of the cold-straightened panels was successfully brought to the desired configuration and after Zyglo-inspection was released to production. The second panel, however, was distorted by the introduction of a slight oil can buckle. To remove this distortion, the panel was subjected to an additional stress-relieving cycle on the ceramic die. The original forming procedure was used but a different cooling cycle was tried. This time the panel was removed from the hot die rapidly and suspended in still air to allow natural cooling to room temperature. The panel produced by this method proved to be one of the better ones. The natural air-cool cycle evidently provided uniform cooling with attendant results. This method of cooling is much more economical than the initial method, since the duration of the cycle is greatly reduced and the die is available sooner for further production. Further verification tests are needed, however, to demonstrate the reliability and repeatability of this forming technique before it can be fully accredited.

6.2 SUBSTRUCTURE ASSEMBLY

Fabrication of the ventral fin substructure was accomplished in the assembly jig by first clamping the Lockalloy leading and trailing edge members, the titanium ribs, beams, and associated fillers, angles, and internal splice straps in positions determined by locators. The above structural members were then tack riveted together using standard shop practices. Panel mounting holes were drilled in the substructure after assembly was complete, using the actual panels as templates. Pilot holes were drilled initially. These holes were later punched and reamed to final size, unless accessibility dictated drilling. Drill bushings were used to protect the holes in the panels and also to prevent the assembly area from being contaminated by beryllium particles. Panels were clamped in place one at a time and the holes were then drilled. Mounting holes for the next adjacent panel were then drilled in a similar manner. Mounting holes for each horizontal row of panels were drilled in an orderly predetermined sequence, working from the leading and trailing edges towards the center and establishing proper thermal expansion gaps between panels in the process.

The final step in the assembly of the substructure involved installation of the front and rear hinge fittings at the intersection of the root rib and the principal front and rear beams. Most of the holes needed for installation of the fittings were drilled using drill templates made directly from the fittings. The remaining holes were drilled using the actual fittings with drill bushings installed in the holes to prevent damage.

6.3 FINAL ASSEMBLY

Final assembly of the ventral fin primarily involved installation of the flight test instrumentation and installation of surface panels. The inner surfaces of the panels and the exterior titanium splice straps were painted with a high temperature aluminized paint prior to assembly to isolate the dissimilar metals that would otherwise be in direct contact following final assembly. This was done to prevent future galvanic action.

The left-hand panels were installed first, using screws and hex nuts. These panels are permanently installed and are not supposed to be removed in the field. Next, the flight test instrumentation and its associated wire harnesses and cabling were installed indesignated locations. The final step in the assembly sequence involved installation of the right-hand surface panels. These panels are secured through close tolerance mounting holes by fixed plate nuts and screws and are designed for easy removal to provide access to internal flight test instrumentation. During final assembly, however, it became apparent that these panels could not be removed and replaced as easily as had been desired. Small inaccuracies, accumulated in the transfer drilling of holes from the panels to the substructure, combined with minimum diameter holes in the panels and the fixed locations of the plate nuts, made it difficult to install and remove the fasteners. This situation was corrected by carefully reaming the holes in the Lockalloy panels to increase their diameter to the high side of acceptable tolerances.

The completed ventral fin was then subjected to proof-load tests. A review of the strain gage data obtained during these tests indicated that stresses in the surface panels, near the root rib and rear beam, were considerably higher than had been predicted. The substructure was reinforced as a result to provide increased edge support and preclude possible instability failure of the surface panels in this area between limit and ultimate loadings. Several formed titanium angles were installed inside the existing spanwise titanium splice channels to increase the support capability of the substructure at the panel joints.

6.4 SAFETY PROVISIONS AND TESTS

Safety tests were performed periodically throughout the program by Lockheed-ADP personnel in association with the Lockheed-California Company Industrial Safety Department. These tests were needed to assure the safety of personnel that would be fabricating the Lockalloy components of the ventral fin or conducting the concurrent material characterization studies. Since the toxic effects that accrue from inhalation of beryllium powder are well known, it was reasonable to assume that the machining or hot forming of Lockalloy could be hazardous to the personnel so engaged. For this reason, the machining of most of the Lockalloy components was left to outside vendors that had special hooded enclosures equipped with vacuum devices to prevent contamination of the air. However, since all forming operations and material characterization studies were to be accomplished in-plant by Lockheed-ADP personnel, special tests were performed in advance to confirm that heating Lockalloy to temperatures of 1050°F did not present a health hazard. In addition, tests were performed to detect Lockalloy surface contamination and also to determine the hazards associated with simple machining operations that might have to be done in-plant.

6.4.1 Lockalloy Heating Safety Tests - To verify the safety of working with Lockalloy at typical forming temperatures, several specimens were heated in a small furnace and air samples obtained periodically by opening the furnace door. The air samples were collected using equipment provided by, and under the direct supervision of, a representative from the Lockheed-California Company Industrial Safety Department.

Two types of equipment were used which collected air samples at two different rates of airflow. Filters from both samplers were submitted for analysis to determine the total quantity of beryllium collected. In each case, the total weight of beryllium was extremely small compared to allowable levels. For a given volume of air, however, there was a large difference in the quantity collected using the two samplers. These results were considered inconclusive, since the total weights of beryllium reported approached the minimum that could be measured using the accepted analysis method.

A second set of air samples was obtained, over a longer period of time, using the equipment with the highest rate of airflow. This was done in an attempt to collect a larger total quantity of beryllium, if any was present.

Filters used during this second set of sampling tests were submitted for analysis, along with new, uncontaminated filters. These filters were analyzed using two different analysis methods. In both cases, the total quantity of beryllium reported on the unexposed filters was higher than that found on the filters used during actual air sampling of Lockalloy specimens heated to 1050°F. In all cases, the total weight reported was less than the minimum that can be accurately measured by the particular analysis method used.

As a result of the above tests, the Industrial Safety Department concluded that heating Lockalloy specimens to 1050°F does not liberate any beryllium to the atmosphere. Lockheed-ADP was then authorized to process and test Lockalloy at this temperature without any special precautionary measures.

6.4.2 Lockalloy Surface Contamination Safety Tests - Special tests were performed to measure surface contamination of Lockalloy under various conditions. The Lockalloy surface panels were tested for surface contamination by wiping the panels with filter papers. Panels were tested in as-received condition, after machining, and after thorough washing. Analysis of the filters indicated that the surface beryllium is detectable but considerably below the limits considered acceptable.

Similar tests performed on Lockalloy specimens exposed to 3.5 percent salt spray solution for seven days indicated high levels of beryllium oxides attached to the surface. It was therefore concluded that paint or other appropriate surface coatings should be used to protect Lockalloy material intended for use in corrosive environments, and thereby protect personnel from possible contamination.

6.4.3 Lockalloy Machining Safety Tests - During final assembly of the ventral fin it became necessary to enlarge the holes in the Lockalloy panels (See Paragraph 6.3). Since this operation was performed at Lockheed-ADP, it afforded an opportunity to determine whether or not it posed any hazards to the personnel involved. During the reaming operation, portable vacuum equipment was used to collect the Lockalloy chips. Air samples were also collected at the work and in the surrounding area by a representative from the Lockheed-California Company Industrial Safety Department. Analysis of these samples indicated that the quantity of beryllium in the atmosphere was well below acceptable limits and confirmed that this operation could be accomplished safely.

6.4.4 Physical Examinations for Personnel - In addition to the above safety tests, all Lockheed-ADP personnel involved in Lockalloy fabrication and testing were given thorough physical examinations at the outset of the program and will be re-examined at its conclusion to determine whether any deleterious effects on the health of personnel occurred as a result of their participation on this program.

6.5 EXPERIENCE SUMMARY

During fabrication of the Lockalloy surface panels, valuable experience was gained relative to the machining and forming of Be-38Al Lockalloy. Although the formed parts were relatively simple, the formability of Lockalloy was confirmed and the ease with which it can be machined was amply demonstrated. Specific conclusions resulting from the various fabrication processes utilized during the program and from the accompanying safety tests are listed below:

a. Lockalloy can be machined almost as easily as structural aluminum alloys. (The cutting life of the cutters is approximately one-half that of cutters used on aluminum alloys.)

b. Standard cutting tools can be used for Lockalloy - no special carbide-type cutting tools are necessary.

c. Unlike beryllium, no postmachining etching of Lockalloy is required to eliminate microcracking.

d. Extensive Lockalloy machining operations require special equipment to prevent random dispersion of beryllium particles; however, simple machining operations such as reaming, countersinking, corrective drilling, etc., can be accomplished using portable vacuum equipment to prevent contamination of the work area.

e. Small Lockalloy panels can be formed with relative ease at temperatures of 1050°F using inexpensive open-face ceramic dies; larger Lockalloy panels are subject to distortions introduced by non-uniform cooling. Although this problem appeared to have been overcome by the simple expedient of natural air-cooling following forming, additional tests are needed to confirm the repeatability of this process.

f. Lockalloy does not require cleaning to remove oxidation after prolonged exposure to forming temperatures.

g. No safety precautions are necessary to protect personnel during Lockalloy forming operations.

h. Fabrication costs associated with Lockalloy forming operations appear to be reasonable since relatively simple open-face ceramic dies can be used for most anticipated applications. Moreover, forming can be accomplished in the furnace without the use of a hot press.

i. Handling of Lockalloy material or parts fabricated therefrom is not hazardous to personnel; however, handling of Lockalloy material that has had prolonged exposure to a corrosive environment may be hazardous to personnel if products of corrosion are present. To prevent corrosion and also safeguard personnel, Lockalloy material intended for use in such an environment should be protected by painting or other surface treatments.

SECTION 7

GROUND TESTS

Ground tests were performed to proof test the ventral fin prior to delivery to NASA Flight Research Center and to calibrate the flight test instrumentation. These tests were performed with the ventral fin mounted in a loading fixture by means of its forward and aft hinge fittings as it is in the airplane. Instrumentation consisted of axial strain gages, shear gages, and deflection gages (Figure 7-1). Test loads were applied to the fin through strategically located compression pads by means of hydraulic jacks (Figure 7-2). The fin was first proof-loaded to design limit load for each of three different critical flight loading conditions (15, 47, and 71 percent of mean aerodynamic chord, representing anticipated flight maximums). Strain gage and deflection readings were recorded at each load increment.

Data for calibration of flight test instrumentation was obtained by separately loading each of 20 compression pads with arbitrary loads. Deflection and strain gage readings were taken at 20 percent load increments as the load was increased and as it was decreased. This data was subsequently transferred to punched cards for eventual use in a flight test correlation program.

Additional information concerning the ground tests is provided in a special report, titled "Proof and Calibration Tests - Lockalloy Ventral Fin," Lockheed-ADP Report No. SP-4401.

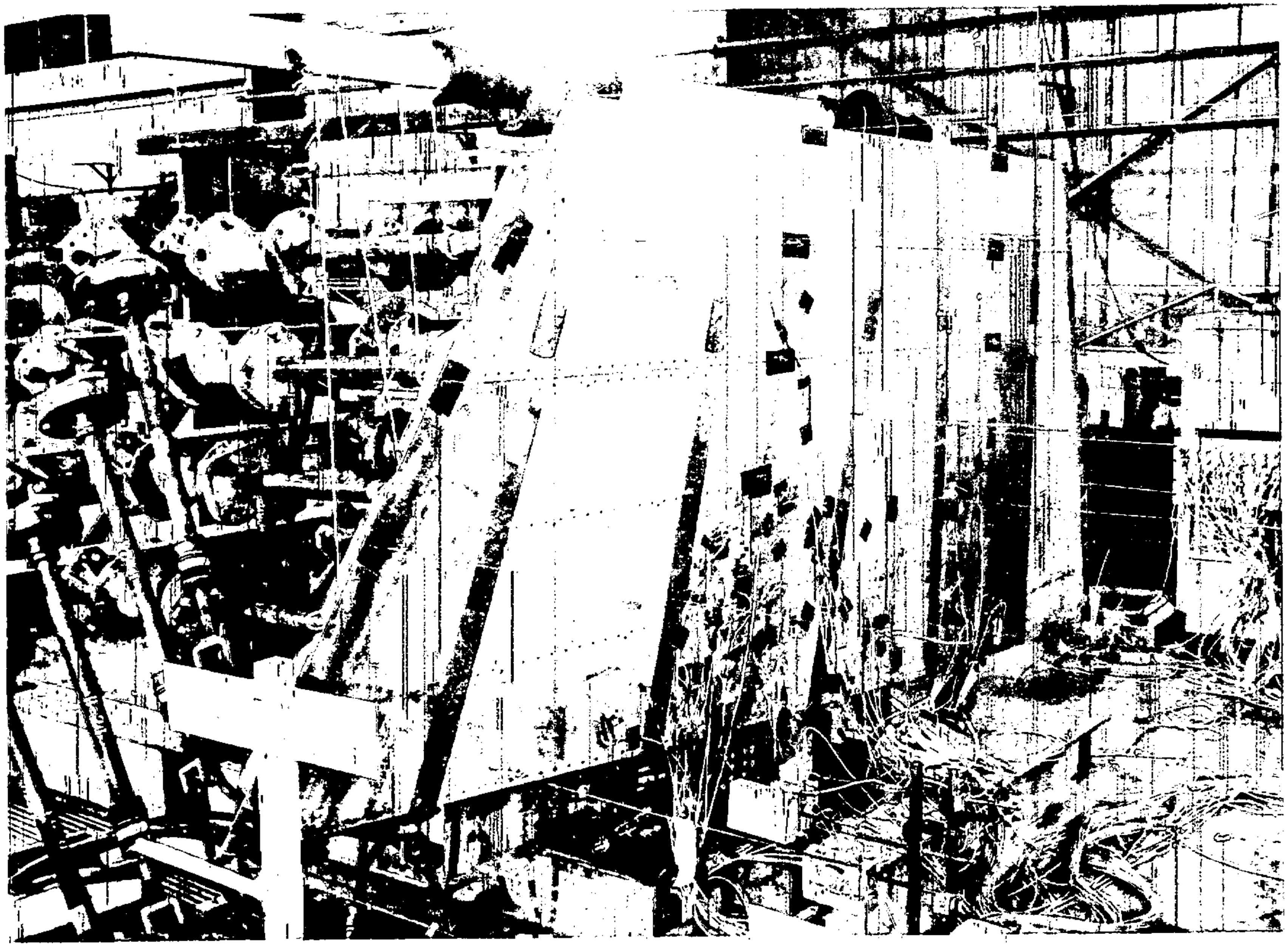


Fig. 7-2 - Vertical Fin Mounted in Loading Fixture
With Test Instrumentation Installed

75-5227-1

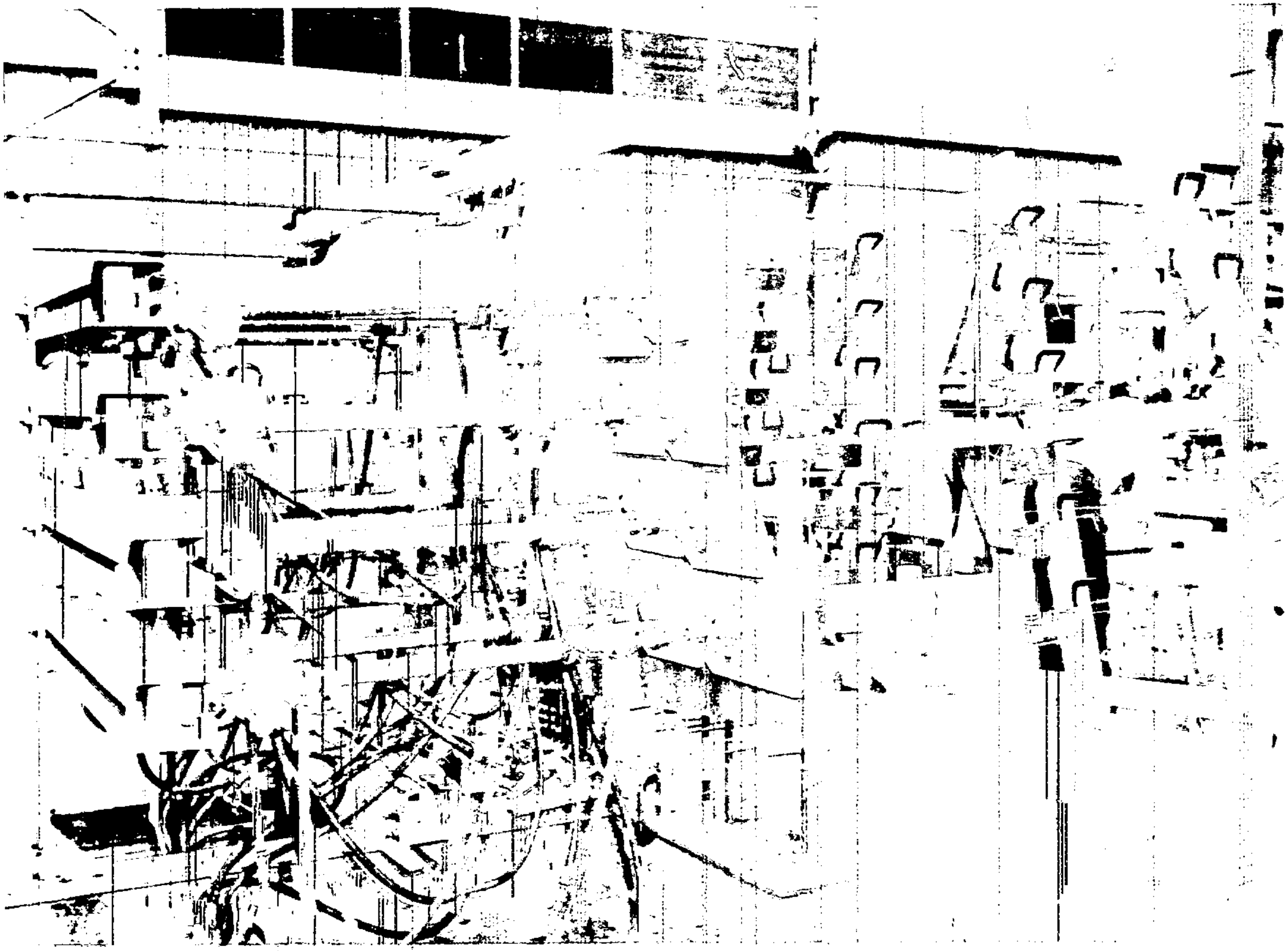


Fig. 7-2 - Hydraulic Jacks Applying Test Loads to Ventral Fin in Loading Fixture

75-5317-1

SUBJECT INDEX