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HUGHES TOOL COMPANY · AIRCRAFT DIVISION

Culver City, California

Report 285-16 (62-16)

CONTRACT AF 33(600)-30271

HOT CYCLE ROTOR SYSTEM WHIRL TESTS

March 1962

HUGHES TOOL COMPANY -- AIRCRAFT DIVISION
Culver City, California

For

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Hot Cycle Rotor During Whirl Test

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SECTION 1

SUMMARY

This report has been prepared by Hughes Tool Company -- Aircraft Division to present the results of a 60 hour whirl test program conducted under Item 7a of USAF Contract AF 33(600)-30271 "Hot Cycle Pressure Jet Rotor System, "D/A Project Number 9-38-01-000, Subtask 616. It is submitted in fulfillment of Item 7c of the contract. The whirl test program was conducted primarily to establish the structural feasibility of the Hot Cycle Rotor System. Shown in the frontispiece is the 55 foot diameter Hot Cycle Rotor during whirl test.

The Hot Cycle Pressure Jet Rotor System is based on a principle wherein the exhaust gases from high pressure ratio turbojet engine(s) located in the fuselage are ducted through the rotor hub and blades and are exhausted through a nozzle at the blade tips. Forces thus produced drive the rotor.

The structural feasibility of the Hot Cycle Propulsion System has been more than demonstrated by 60 hours of whirl testing accomplished with no significant problems. The final 25 hours of the whirl test program have been conducted with no substitution or alteration of any components. The spectrum of test conditions agrees very closely with the conditions called for in the military specifications for rotor and engine preflight tests. No dynamic problems have evidenced themselves, in confirmation of the prediction of no resonances in the operating rotor speed range. The measured temperatures for all components have been within design limits. The measured loads have generally been within design limits. At the completion of the test the total leakage has been measured at a very small level (about 0.2%). A post-test inspection has revealed no basic mechanical or structural difficulties.

The two primary parameters required to predict Hot Cycle performance, duct friction coefficient and nozzle velocity coefficient, have been verified. The duct friction coefficient has been shown to be less than the conservative value of 0.004 used for performance predictions. The nozzle velocity coefficient has been shown to be 0.98; thus showing greater efficiency than the conservative value of 0.955 used for performance predictions. As a result, the maximum measured thrust of over 20,000 pounds compares very well with predicted thrust.

Based on this favorable performance comparison, it is estimated that the T-64 gas generators, which will ultimately power the present hot cycle rotor and which has a much higher pressure ratio than the J-57 used for the whirl test, will produce a maximum thrust of about 28,000 pounds.

SECTION 2

INTRODUCTION

The helicopter industry is continuously striving to advance the rotary wing state of the art in order to improve the efficiency of the helicopter. One area in which a great deal of effort has been expended is that of the propulsion system. The gear boxes and drive shafting normally used to transmit engine power to the rotor have been a major source of cost, weight, and maintenance. While significant advances have been made, a major improvement is still required. The Hot Cycle Propulsion System promises such a major advance.

Figure 2.1 illustrates schematically the Hot Cycle Rotor System in which a turbine gas generator mounted in the fuselage exhausts through ducts to the rotor tips where the jets propel the rotor. In this way, the power of the engine drives the rotor without requiring mechanical components such as the power turbine, gear boxes, shafting etc. of the conventional propulsion system. As a result, there is a substantial saving in weight and complexity.

Although the Hot Cycle Rotor System has long been recognized as a potential means of accomplishing substantial improvements in rotor propulsion systems, several developments were required for its realization; these are:

1. Small high pressure ratio turbojets to minimize the volume of flow through the blade ducts.

2. High temperature duct material to contain the full turbojet temperature with acceptable weight.

3. Unique blade structure design to eliminate fatigue in hot parts, to provide for thermal expansion, and to be dynamically suitable.

4. Demonstration of structural feasibility by means of actual whirl test of a full scale rotor system.

The T64 engine gas generator has fulfilled the first requirement. This engine has completed its Preliminary Flight Rating Test and is currently undergoing a Flight Qualification Test. Thus, unlike other novel propulsion systems which have been proposed, <u>no</u> special engine development program is required.

The material Rene' 41 has fulfilled the second requirement. This material is suitable for operation up to temperatures of over 1200°F.

The blade structure to satisfy the third requirement is illustrated in Figure 2.2, and was developed under the present contract. The hot gases pass through the two central ducts which are attached to the skin by closely placed ribs. The skin-duct structure is divided into spanwise segments by chordwise flexures which makes this structure flexible in a spanwise direction and also causes the axial and bending loads to be carried in the two spars. This eliminates the fatigue loading from the hot parts while the spars, which carry the fatigue loads, are kept cool by the insulating air chamber and by a flow of ambient air which is pumped spanwise by centrifugal force. This flexibility also permits relative thermal expansion of the hot parts. Another important factor is that the dynamic characteristics in bending are determined entirely by the two spars. This permits tuning the blade by varying the spar dimensions so as to obtain the optimum natural frequencies.

This report presents the results of the final portion of the contracted work program -- the Whirl Test Program. As spelled out in the Contract, a total of 60 hours of whirl testing were to be conducted. The first 25 hours were specified to prove the structural feasibility of the concept. Maneuver and transient conditions were investigated in the following 10 hours. The last 25 hours consisted of an endurance-type test with no changes or modifications of components.

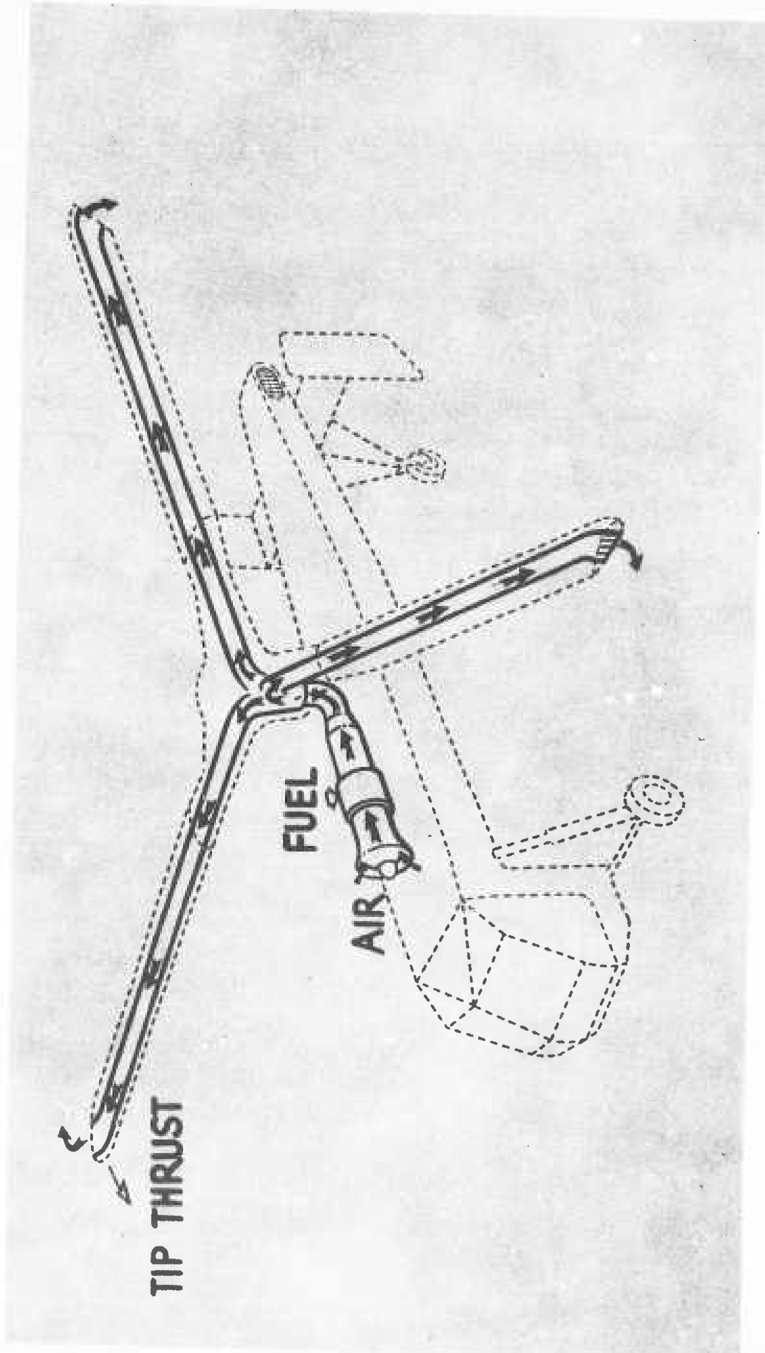


Figure 2.1 Schematic - Hot Cycle System

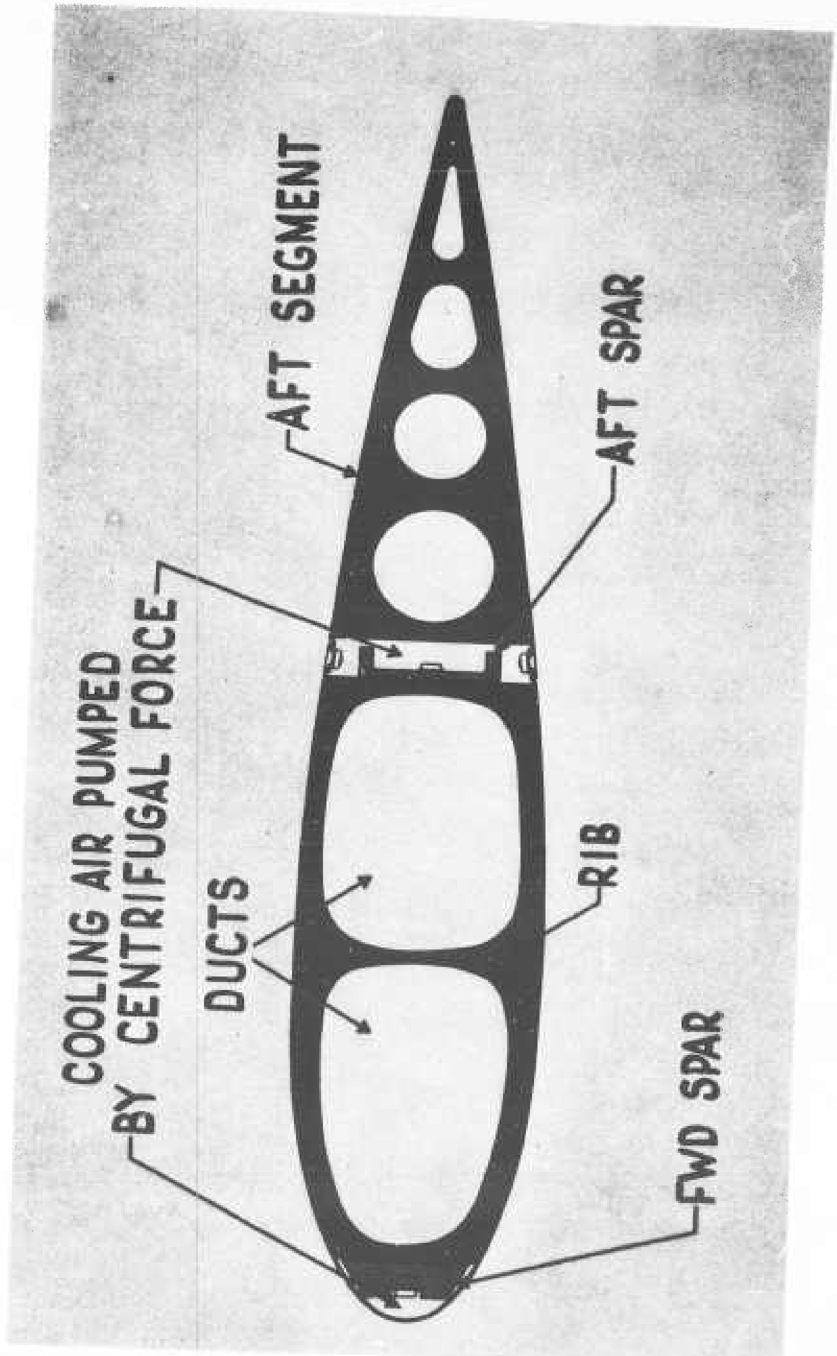


Figure 2.2 Blade Cross Section

SECTION 3

TEST EQUIPMENT

3.1 GENERAL TEST SETUP AND TEST ROTOR

3.1.1 General Arrangement of Test Site

The Hot Cycle Rotor Test Site is located in an open area, adjoining the HTC-AD runway, approximately 800 feet from the nearest building or public road. See Figure 3.1-1 and 3.1-2. Two major installations on the site are the tower, complete with rotor, and the control van.

The tower is approximately thirty feet high, is built of large diameter steel tubes and is secured at its base to a reinforced concrete pad. A hydraulically operated permanent work platform long enough to service an entire blade, is attached to the whirl tower.

A Pratt & Whitney J-57 engine is located at the base of the tower with the exhaust directed toward the landing strip. Intake and exhaust suppressors are used to minimize the engine intake and the excess output noises of the engine. (See Section 5.5) Accessories such as engine starter, power generator, fuel trailer, lubrication oil pump, and air compressor are grouped around the tower as close to their point of application as practicable, as shown in Figure 3.1-2.

The control van is located seventy-two feet south of the tower in such a manner as to give a clear view of the tower and surrounding area. Housed within the van are rotor controls, engine controls, and instrumentation equipment. An interior view of the van showing the power plant engineers station and the instrumentation is given on Figure 3.1-3.

Because of the experimental nature of the program, considerable attention was given to the provision of barriers and safety equipment to protect test personnel in case of rotor or test equipment failure.

3.1.2 Test Rotor

Figures 3.1-4 and 3.1-5 show a schematic and photograph of the Hot Cycle Rotor Structure as fabricated for this test.

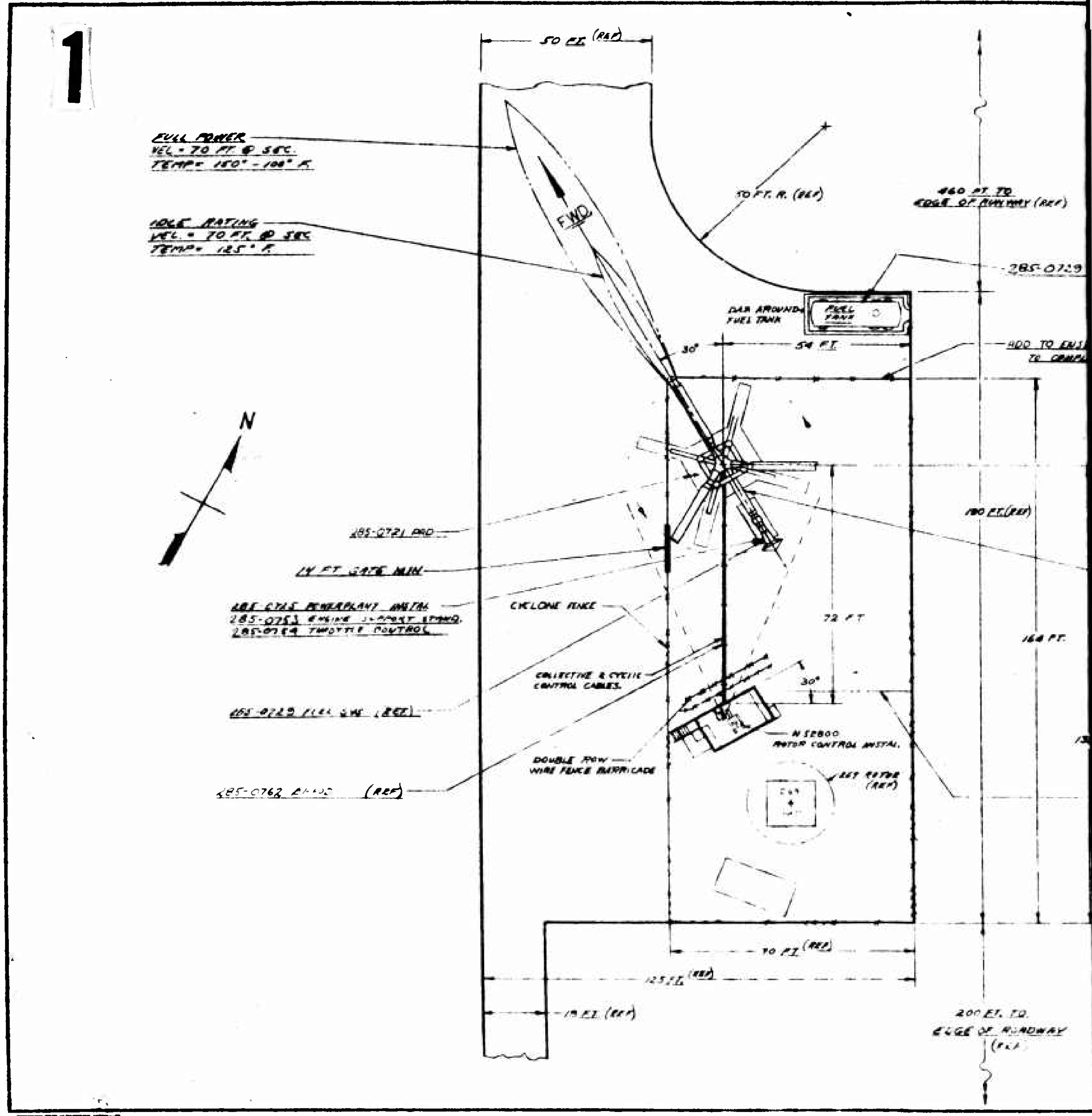
The blade design incorporates two machined titanium alloy spars that comprise the only continuous member running from the blade root to the tip. The spars are separated fifteen inches chordwise by eighteen identical sheet-metal segments 12.50 inches long, made up of two ducts contained within nine ribs and an outer cover. The segments are bolted to the spars and are jointed together by bellows-type flexible couplings riveted to the outer cover. The ducts and skins of adjacent segments are slip-jointed. In this arrangement the spars are the only members that react normal blade bending loads and centrifugal loads. Torsional and chordwise shear loads are carried by the assembly of segments. For convenience, the blades were color coded blue (instrumented blade), red and yellow.

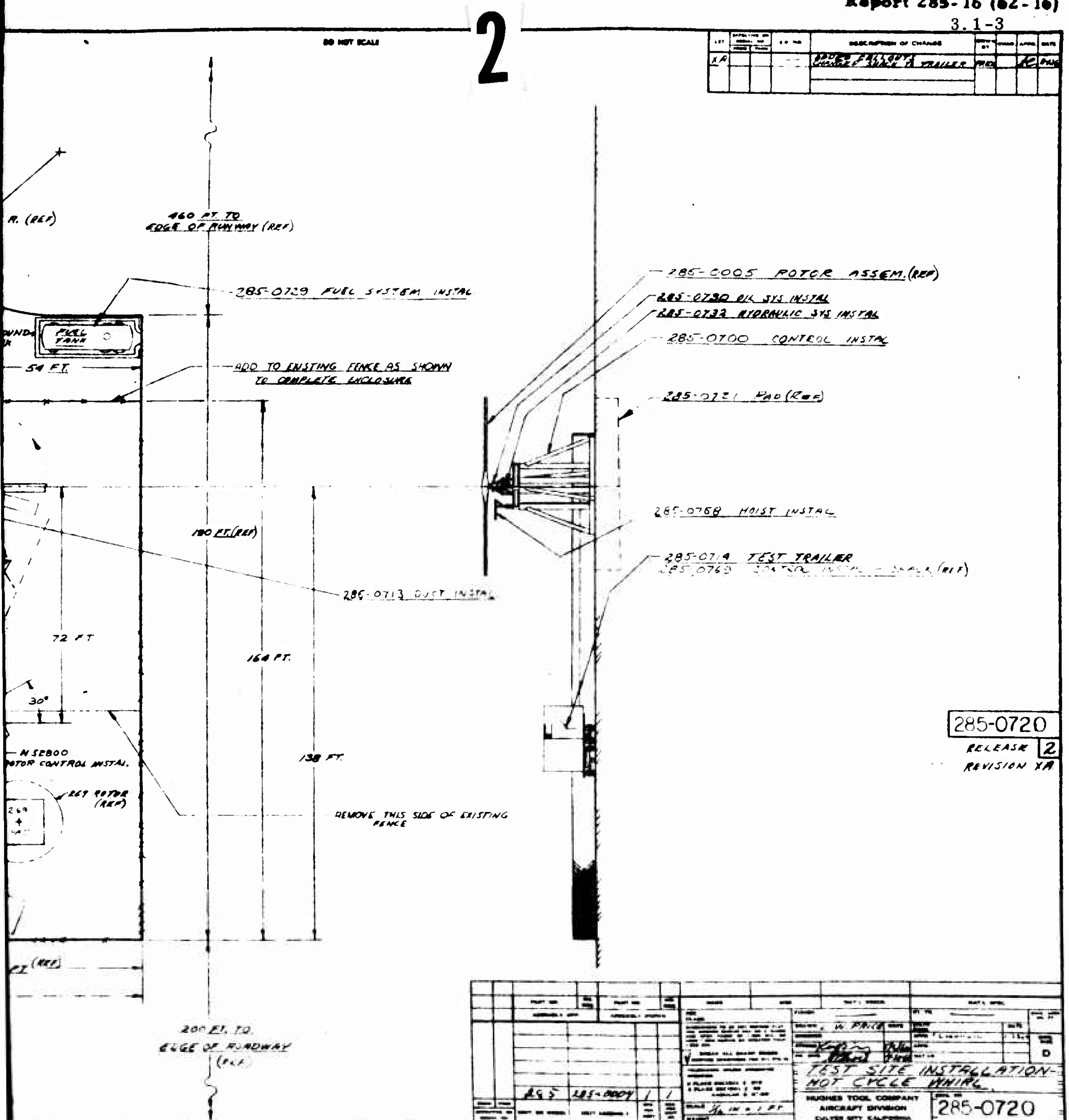
The rotor blade retention and hub structure consists of a free-floating hub supporting three coning blades by means of converging tension straps and a monoball-type bearing. The free-floating hub transfers the loads to the mast and then through two bearing systems to the supporting trusses. This hub must also provide clearance for the ducts which transfer gases used in propulsion from below the hub to the three blades. The over-all hub structure provides support for the control system.

The control system is intended to be as conventional and troublefree as possible. The various components were located so as to keep them small in size, relatively cool and readily accessible.

A complete discussion of the design and fabrication of the rotor is contained in References 3.1-1, 3.1-2, and 3.1-3.

1


50 FT. (REF)
FULL POWER
VEL = 70 FT. @ SEC.
TEMP = 150° - 100° F.
IDLE RATING
VEL = 70 FT. @ SEC
TEMP = 125° F.
FWD
N
50 FT. R. (REF)
460 FT. TO EDGE OF RUNWAY (REF)
DAM AROUND FUEL TANK
FUEL TANK
30°
54 FT.
180 FT. (REF)
285-0721 PAD
14 FT. GATE MIN
285-0725 POWERPLANT INSTAL
285-0753 ENGINE SUPPORT STAND
285-0754 THROTTLE CONTROL
CYCLONE FENCE
72 FT.
164 FT.
COLLECTIVE & CYCLIC CONTROL CABLES
30°
285-0729 FUEL SYS (REF)
N 52800 MOTOR CONTROL INSTAL.
DOUBLE ROW WIRE FENCE BARRICADE
285-0762 (REF)
70 FT. (REF)
125 FT. (REF)
15 FT. (REF)
200 FT. TO EDGE OF ROADWAY (REF)



FED. CODE 02731 FIGURE 3.1-1

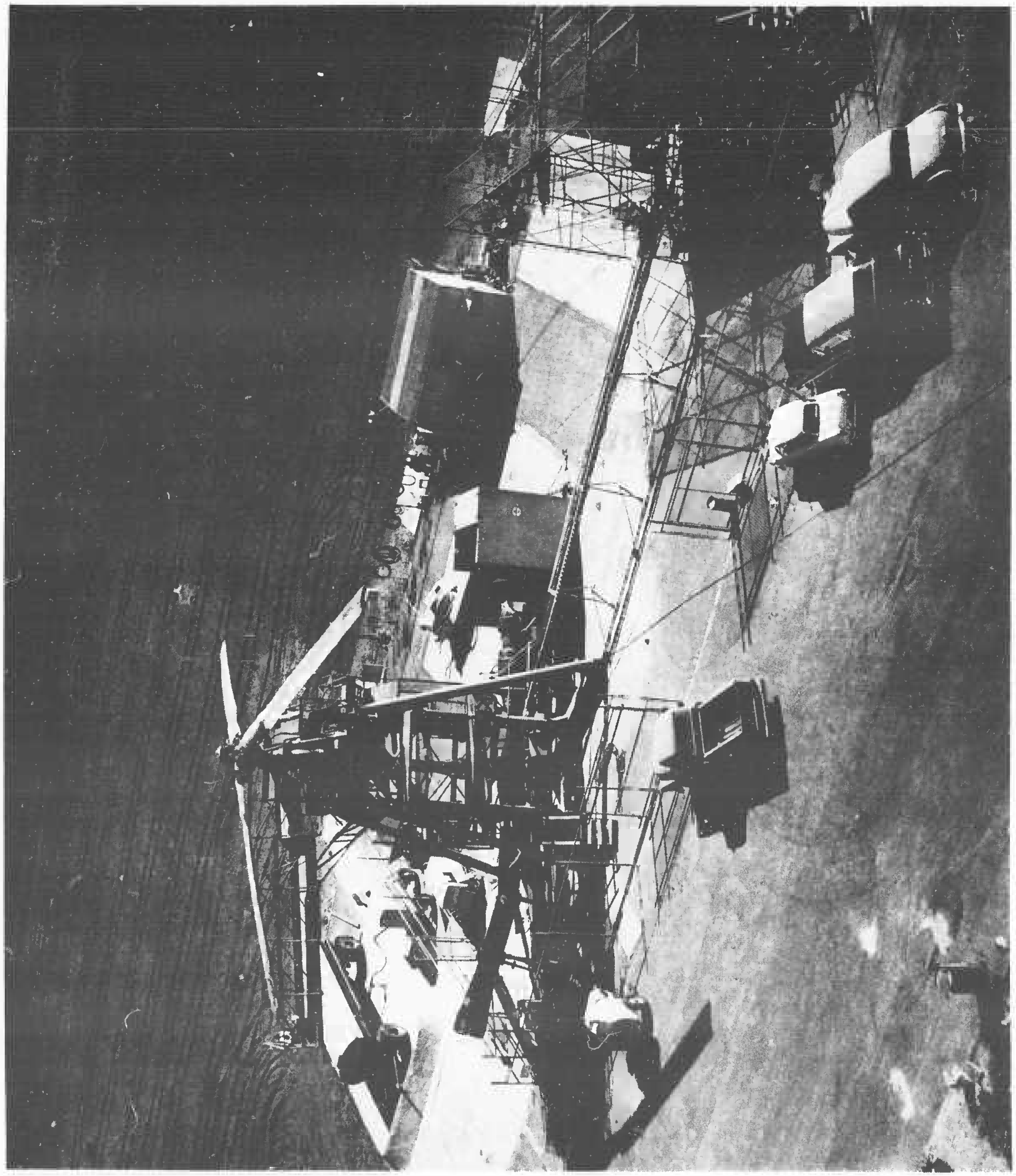


Figure 3.1-2 Test Site Area

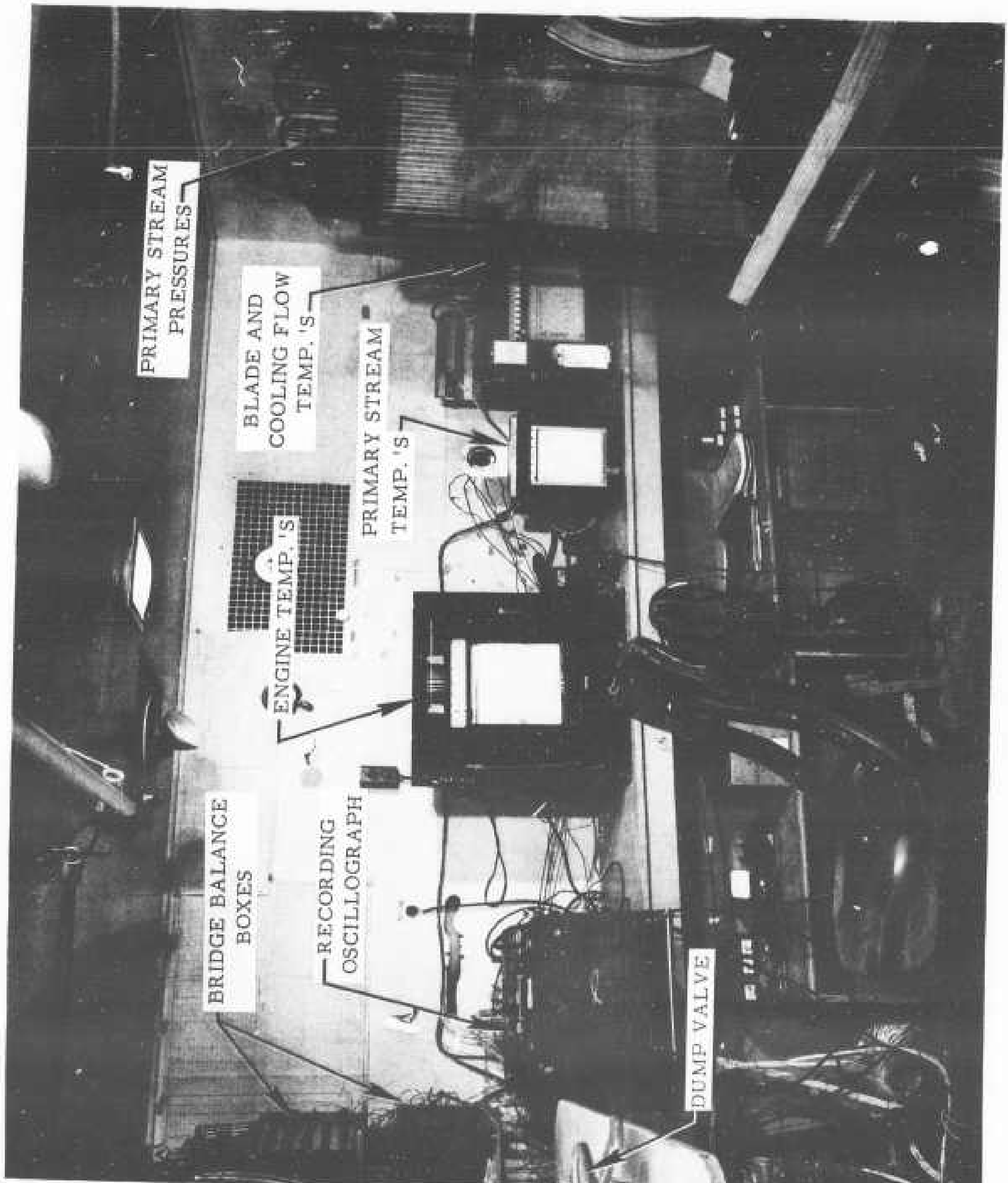


Figure 3.1-3 Internal View of Control Van; Temperature, Pressure and Strain Recording Instruments

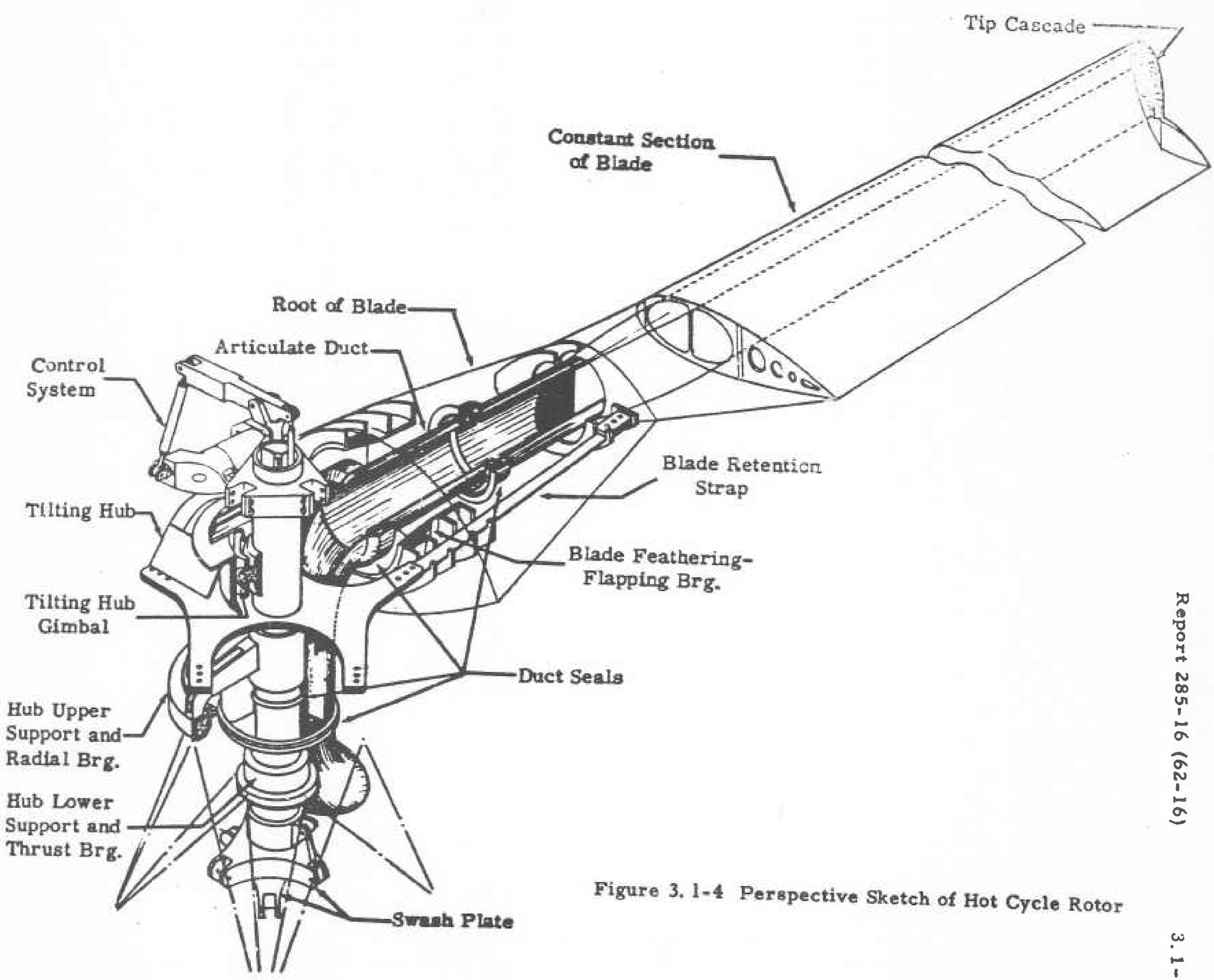


Figure 3.1-4 Perspective Sketch of Hot Cycle Rotor

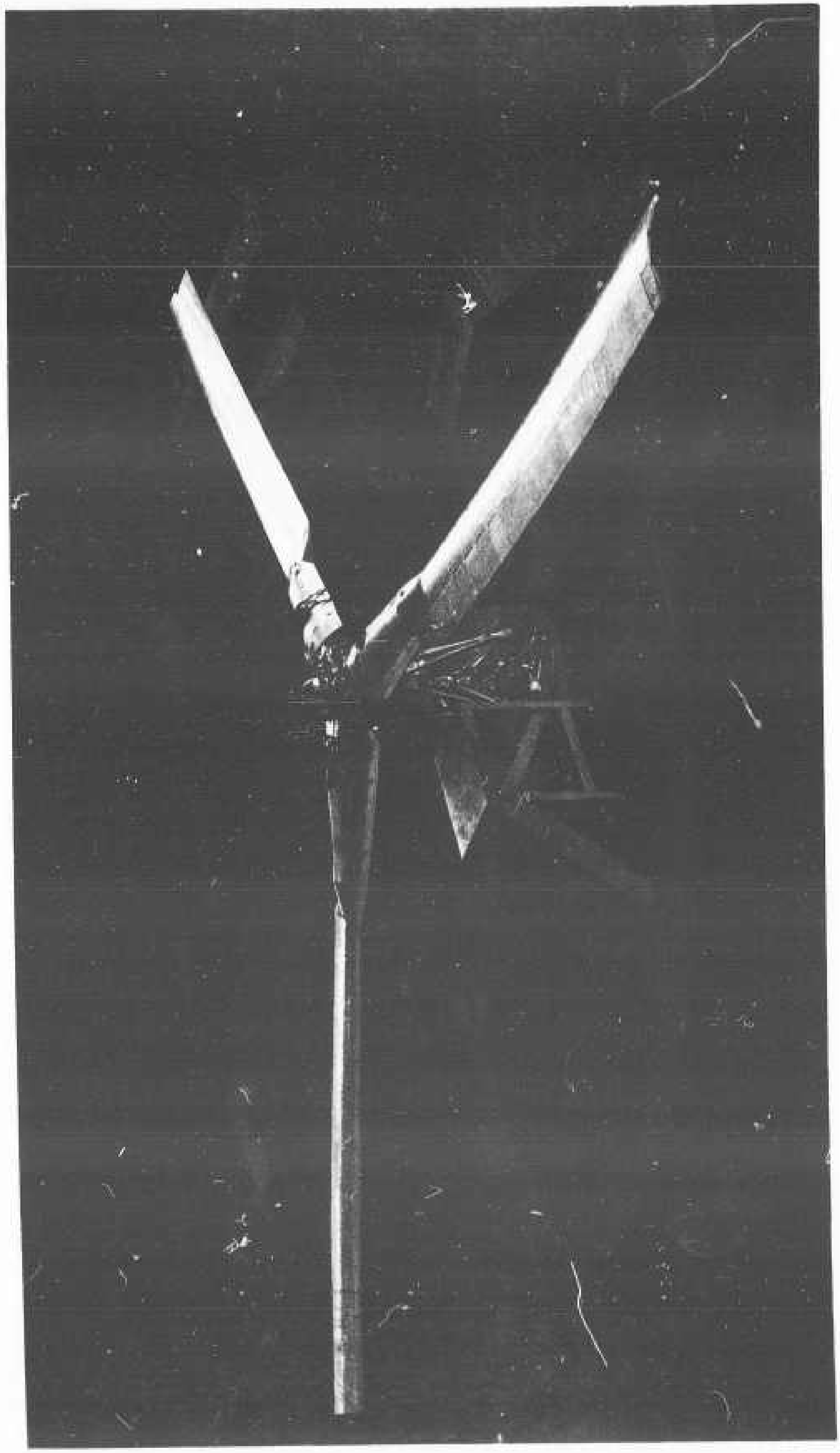


Figure 3.1-5 Hot Cycle Rotor Assembly

3.2 WHIRL TOWER

The support tower is composed of three main structural components; the upper rotor mounting truss (285-0523), the center structure (285-0703) and the lower support structure (285-0701) which attaches to the reinforced concrete base. These may be seen in the photographs of the Frontispiece and Figure 3.1-2. The upper mounting truss is a welded steel tube structure which provides support for the main rotor shaft bearings. Side loads are applied at the upper bearing and side and thrust load are taken at the lower bearing. The truss base is attached to the 285-0703 structure assembly with four 5/8 and eight 3/8 high strength bolts (180-200 KSI). The 285-0703 structure assembly acts as a spacer for transferring rotor imposed loads from the mounting truss to the main tower (285-0701). In addition it houses and supports the control system actuating cylinders. It is a welded structure composed of 5.0 inch heavy steel tubes. The lower and main tower structure (285-0701) is a welded structure consisting of large I-beams and steel tubes. The base of the tower is attached to a 2 foot thick reinforced concrete pad by 68 one-inch bolts. In general the tower is designed from rigidity considerations and is not critical for imposed loads.

The whirl test duct system is composed of two parts; the vertical ducts for carrying the hot gas to the rotor system and the horizontal ducts for exhaust overflow. Valves are located in each path to provide adjustment for operating requirements. Potential rust and subsequent spalling of the vertical ducts (test stand items only) represented a source of potential damage to the hub and blade ducts and seals. For this reason, the vertical ducts are made from corrosion resistant steel. The duct system is supported from the tower at appropriate points. Bellows are provided in the duct system to allow for differential expansion.

Structural analysis of the tower and ducting is contained in the Appendix A.

Engine throttle control was initially maintained from the mobile control van by a hydraulic servomechanism actuated by the twist grip on the collective pitch stick. This was later changed by the addition of a separate throttle control lever operating in series with the stick grip. Emergency throttle cut-off was instantly available through the use of a hydraulic accumulator which discharges high pressure fluid into the throttle servo when electrically actuated.

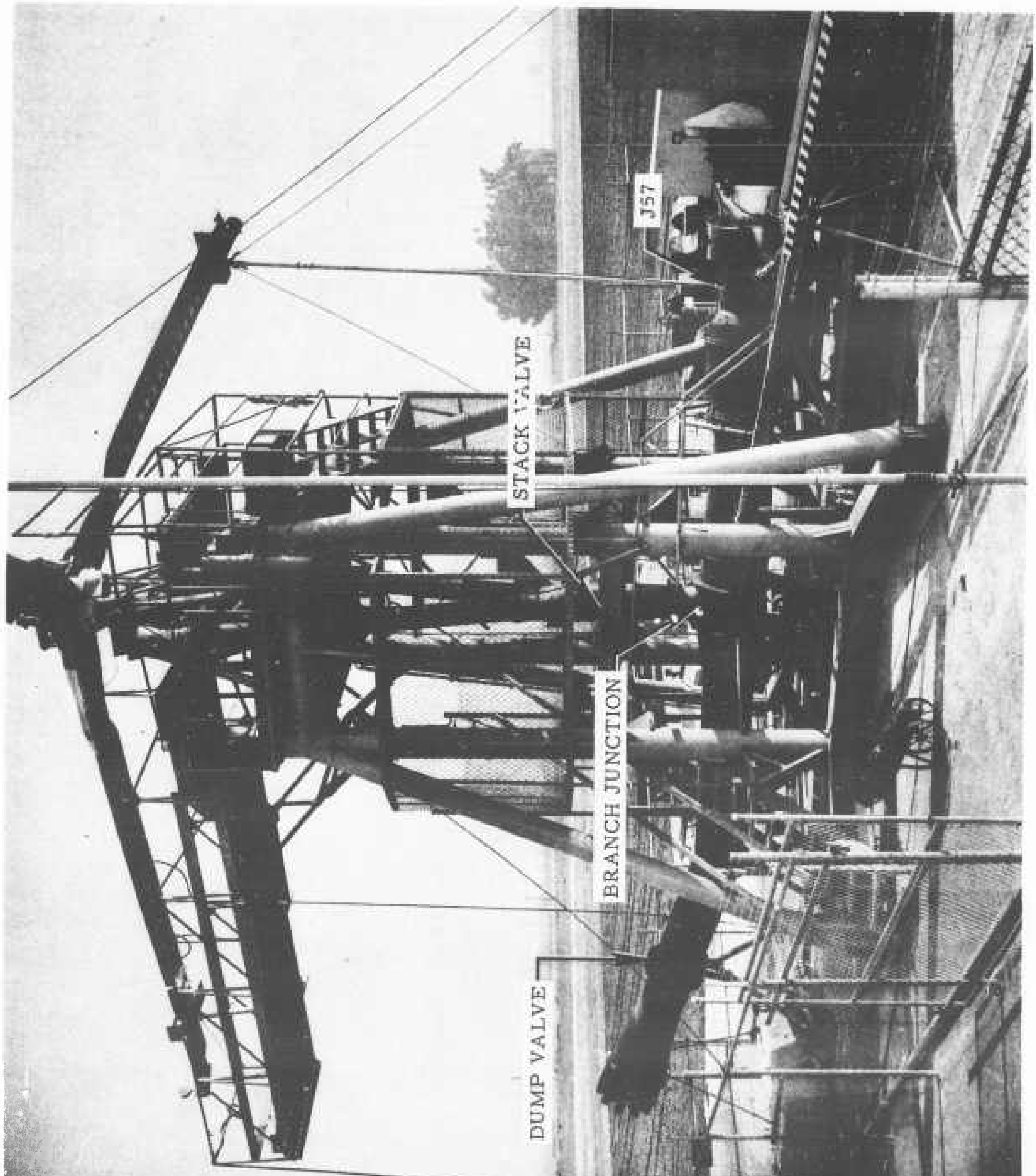


Figure 3.3-1 Powerplant and Duct Installation

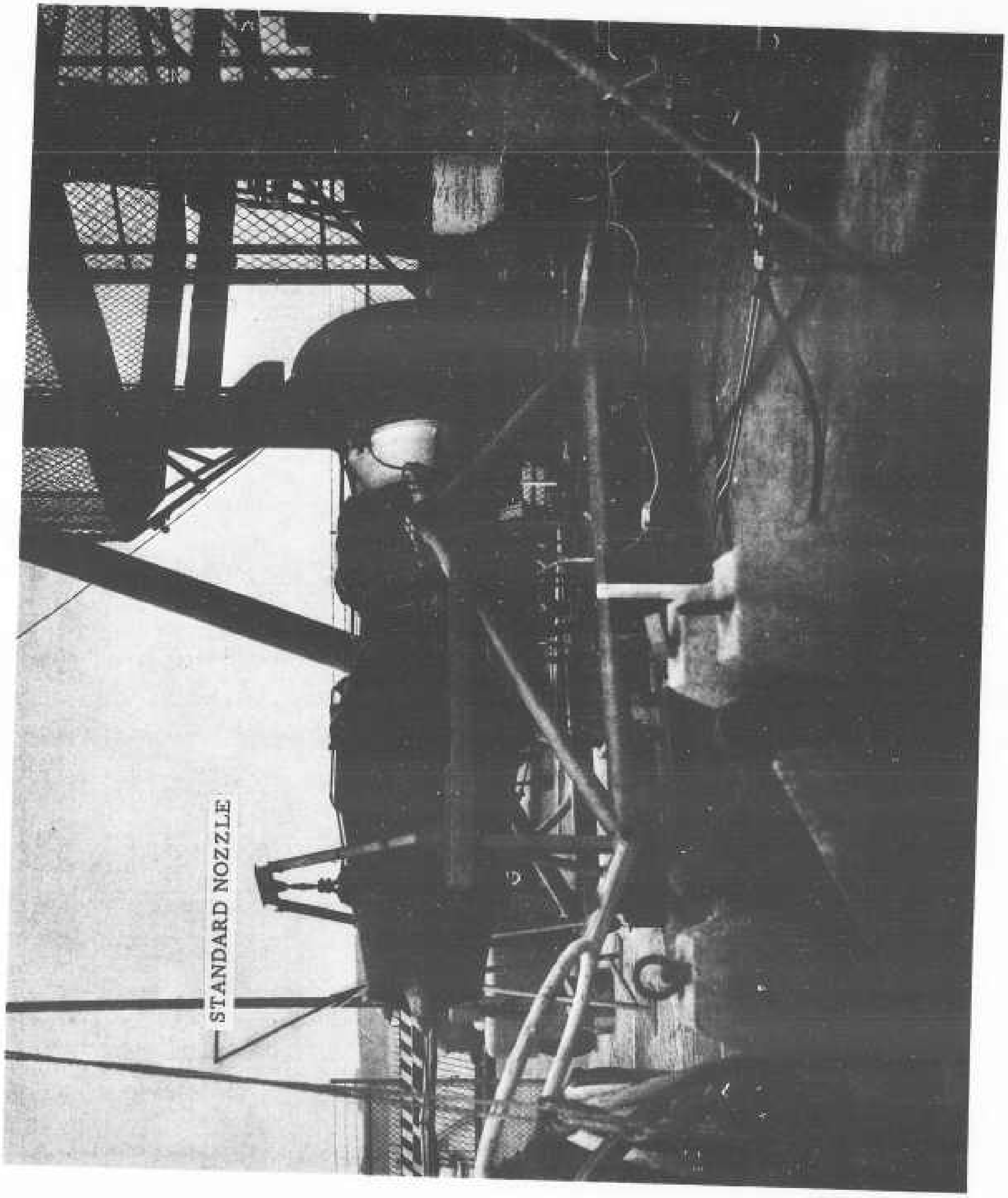


Figure 3.3-2 Engine Rotated 180° for Calibration with Standard Nozzle

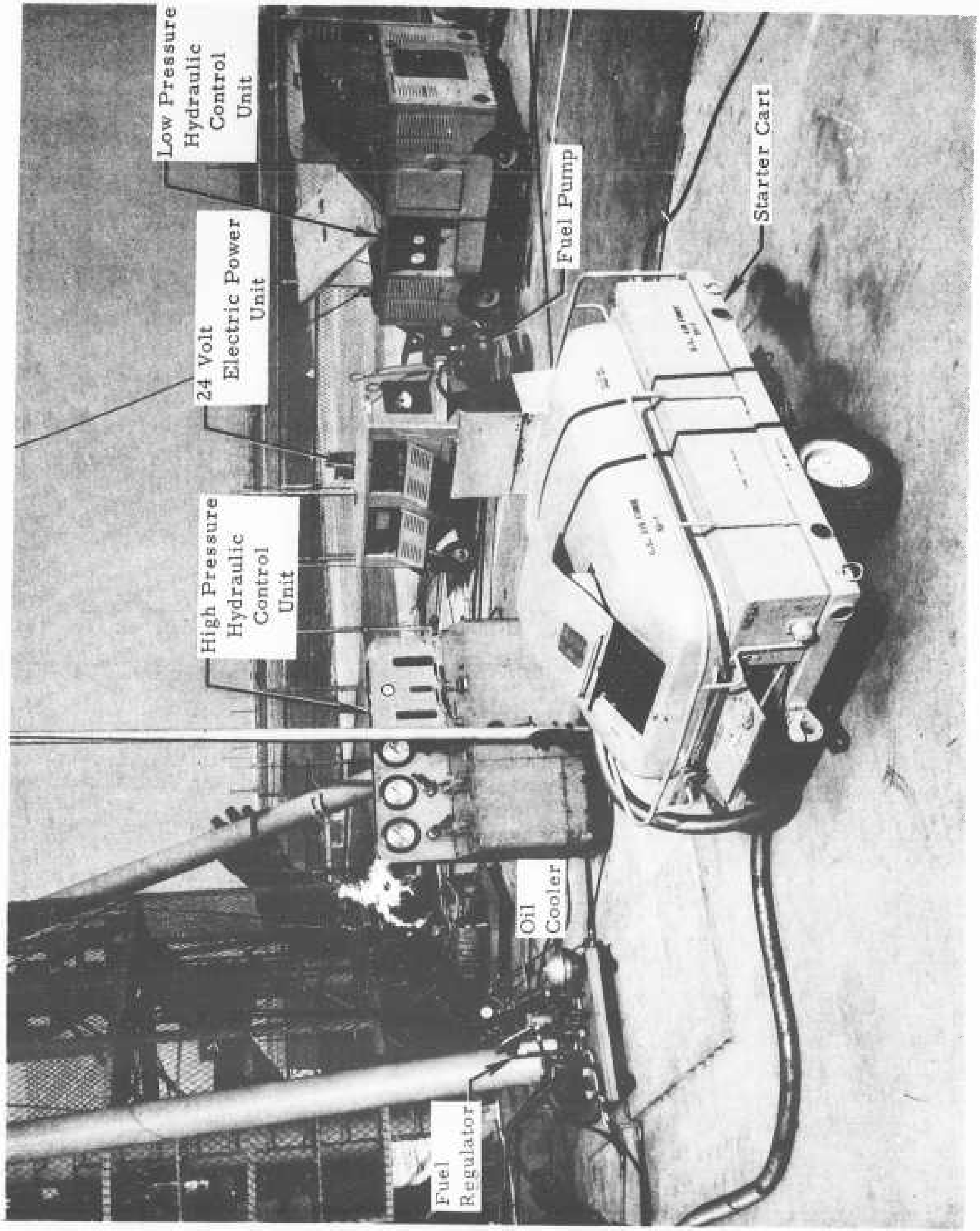


Figure 3.3-3 Whirl Site Support Equipment

3.4 POWER PLANT PERFORMANCE AND OPERATIONAL CHARACTERISTICS

During most of the operation of the whirl test installation, the engine is operated in complete accordance with the recommendations of the applicable technical orders and operating instructions for the J-57 (References 3.3-1 and 3.4-1). When operated in this manner, however the engine is incapable of exhaust gas temperatures equivalent to the maximum rated temperature of the T-64 gas generator: i.e., J-57 - 1148°F, T-64 - 1180°F to 1225°F. Further, the 1148° F is the maximum observed sea level value thereby indicating a probable lower value for the particular engine used. (It should be noted that Reference 3.4-1 shows 30 minute temperatures of 1200°F at 55,000 feet altitude and two minute acceleration limit values of 1220°F for the J-57.)

A method of operation of the J-57 was established and coordinated with Pratt & Whitney Aircraft to achieve the necessary elevated temperatures without distress to the engine. The operating procedure is as follows:

a. Trim and calibrate the engine with the standard exhaust nozzle prior to connection to the test rig ducting. This trim setting remains unchanged throughout the test operation of the engine.

b. For all operation simulating T-64 power settings of maximum continuous or below, the operation of the J-57 is maintained on the operating line (${}^{P}T_7$ vs. N_2)* established during the standard calibration run.

c. Military rated power of the T-64 is simulated by reducing the effective exhaust nozzle area of the J-57 through manipulation of the exhaust dump valve. This procedure allows an ample increase in ${}^{T}T_7$* although the increase in ${}^{P}T_7$ is only slight, i.e., the T-64 simulated exhaust temperatures are reached without exceeding the J-57's ${}^{P}T_7$ limitation.

The T-64's exhaust pressure values are not simulated exactly. This latter deviation is of little consequence as sufficient exhaust pressure is generated to choke the rotor tip nozzles, thereby permitting accurate extrapolation to T-64 conditions. However, meeting the T-64's exhaust temperature is important to demonstrate the mechanical integrity of the rotor blade and seals at prototype temperature. The calibration is discussed completely in Reference 3.4-2.

*See Nomenclature in **Appendix F**.

Although operation of the J-57 in this manner decreases the surge margin, no difficulty was incurred during steady state or transient runs.

During operation at maximum N_2, it was found that as the exhaust dump valve position was moved to regulate the system's pressure, several peaks in P_{T7} were observed subsequent to installation of inlet and exhaust noise suppressors. The first peak was at N_1 = 97 to 100%, second at N_1 = 92 to 94%, and the third at N_1 = 88 to 90%. These peaks were generally 1 to 1.5 psi above the general level of P_{T7} and always below values corresponding to the engine pressure ratio limit of the J-57. In order to achieve maximum power from the engine near a T_{T7} of 1200°F, it was necessary to operate at an N_2 of approximately 89%. This generally resulted in a T_{T7} operation at 1220 to 1240°F depending on ambient conditions and is comparable to the 1225°F take off rating of the advanced T-64. These peaks were slightly shifted depending on the particular inlet and exhaust noise suppressors in use at the time.

3.5 TEST SITE ROTOR CONTROLS

All of the whirl tower control items were originally designed for and successfully used on the Hughes developed U. S. Air Force XH-17 Helicopter under contract AF 33(038)-8907. They are considerably oversize, but for economy were adapted to the requirements of this program.

The whirl tower rotor controls are actuated by conventional cyclic and collective pitch sticks in the control van, shown in Figure 3.5-1. Stick motions are transmitted through a mixing linkage, shown in Figure 3.5-2, to the three quadrants that drive cables running 75 feet horizontally to the rotor tower. Relative locations of the tower, van, and run of control cables were shown previously in Figures 3.1-1 and 3.1-2.

On the tower the cables control three servo-cylinders connected to the rotor swashplate. The cylinders were designed for 3000 psi. hydraulic pressure, but were operated in this test at 625 psi..

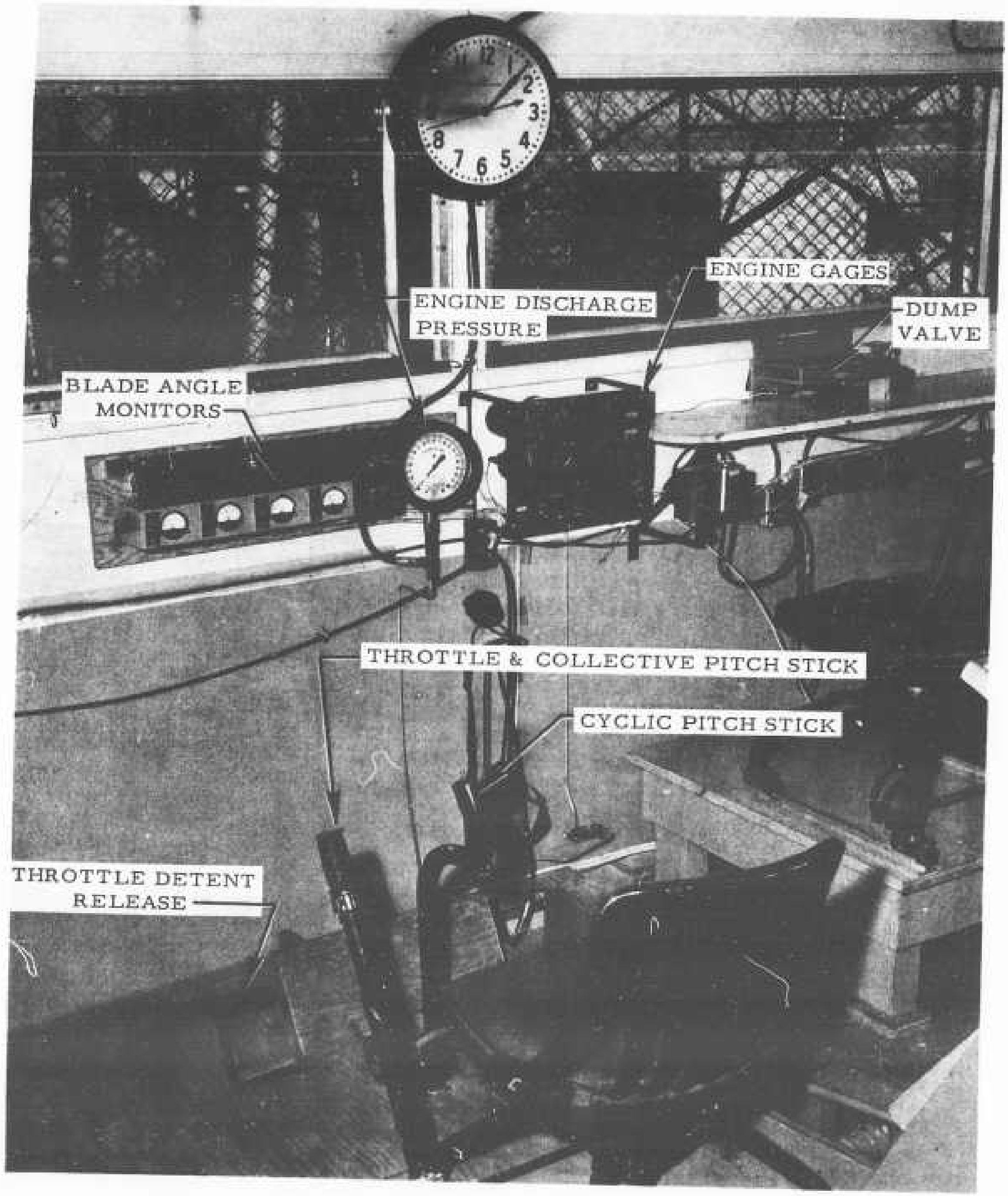
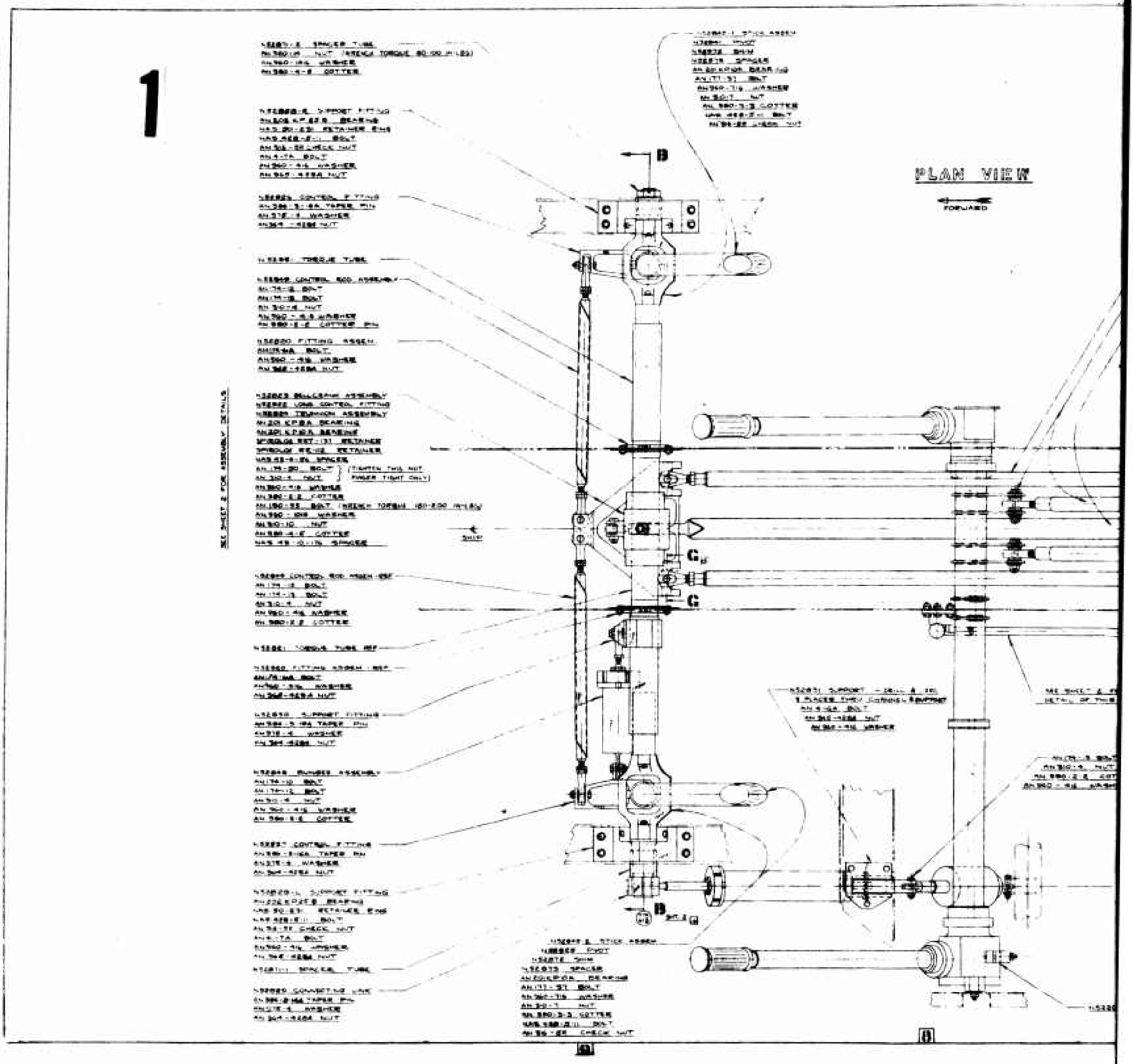
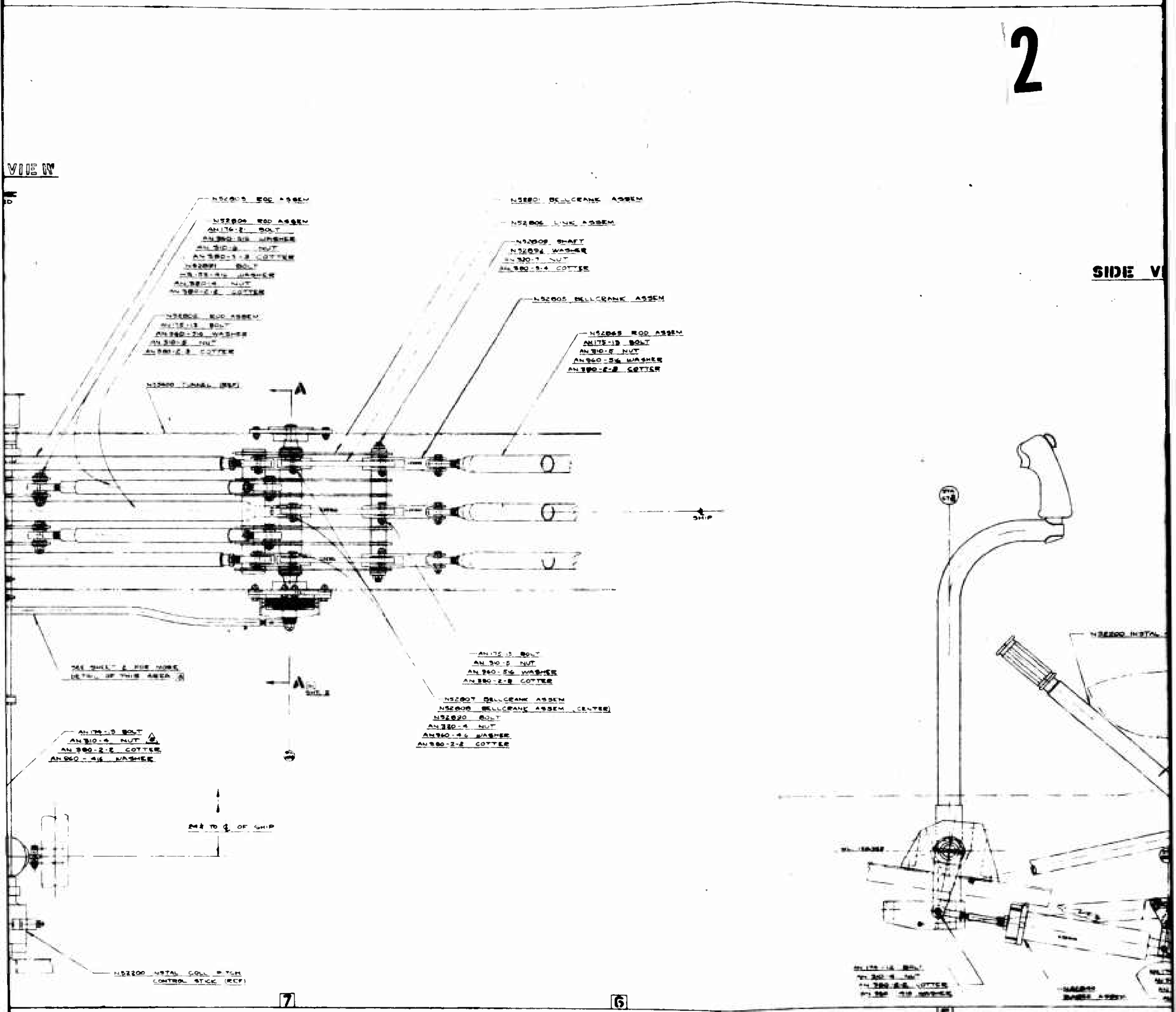
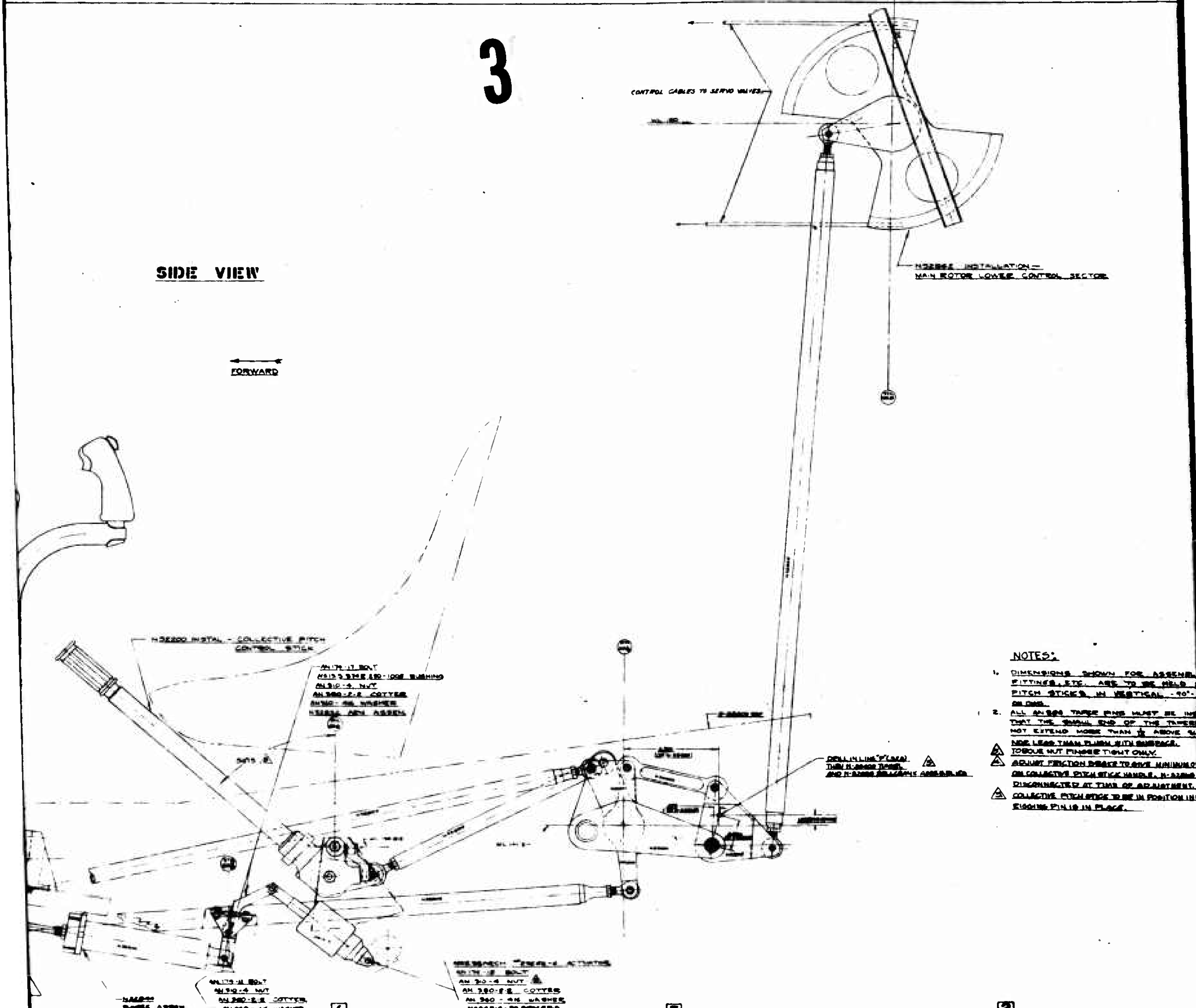


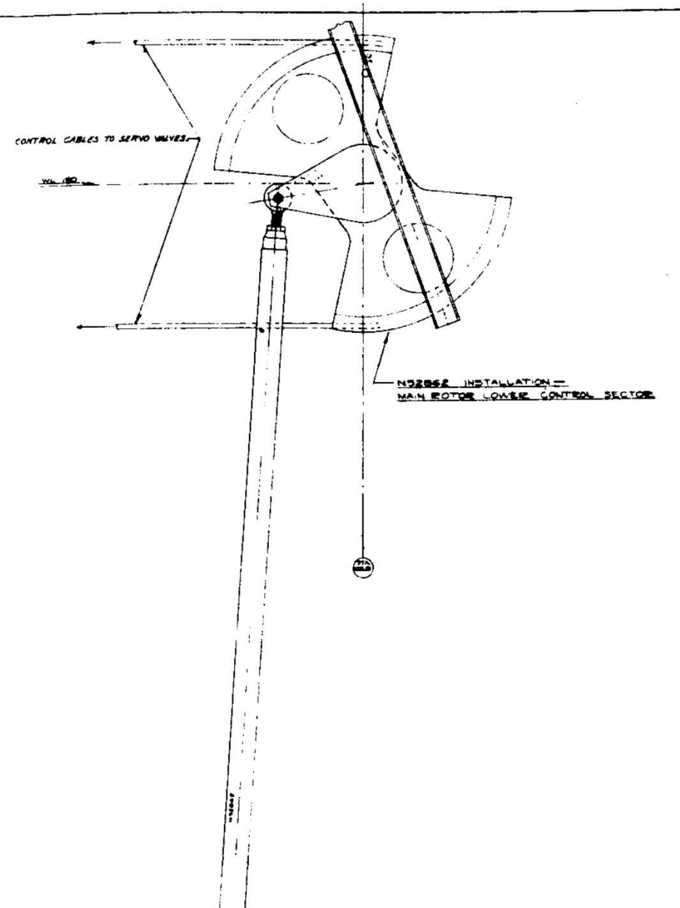
Figure 3.5-1 Internal View of Control Van; Engine and Rotor Controls

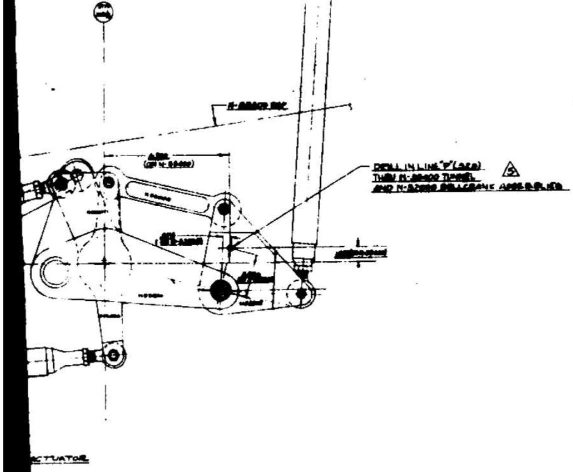

1
PLAN VIEW
FORWARD
B
G


2
VIEW
SIDE V
N52803 ROD ASSEM
N52804 ROD ASSEM
AN176-21 BOLT
AN960-516 WASHER
AN310-6 NUT
AN380-3-3 COTTER
N52801 BELLCRANK ASSEM
N52806 LINK ASSEM
N52809 SHAFT
N52894 WASHER
AN320-7 NUT
AN380-3-4 COTTER
N52805 BELLCRANK ASSEM
N52865 ROD ASSEM
AN175-13 BOLT
AN310-5 NUT
AN960-516 WASHER
AN380-2-2 COTTER
N52600 TUNNEL (REF)
A
AN175-13 BOLT
AN310-5 NUT
AN960-516 WASHER
AN380-2-2 COTTER
N52807 BELLCRANK ASSEM
N52808 BELLCRANK ASSEM (CENTER)
N52890 BOLT
AN320-4 NUT
AN960-416 WASHER
AN380-2-2 COTTER
AN310-4 NUT
AN380-2-2 COTTER
AN960-416 WASHER
OF SHIP
N52200 INSTAL COLL PITCH CONTROL STICK (REF)
7
6
5

3


SIDE VIEW
FORWARD
CONTROL CABLES TO SERVO VALVES
MAIN ROTOR LOWER CONTROL SECTOR
NOTES:
1. DIMENSIONS SHOWN FOR
FITTINGS, ETC. ARE TO BE HELD
PITCH STICKS IN VERTICAL
2. ALL
THAT THE
NOT EXTEND MORE THAN
TORQUE NUT FINGER TIGHT ONLY.
DISCONNECTED AT TIME OF ADJUSTMENT.
4
3
2





NOTES:

1. DIMENSIONS SHOWN FOR ASSEMBLY OF LEVERS, FITTINGS, ETC. ARE TO BE HELD WITH CYCLIC PITCH STICKS IN VERTICAL -90°- POSITION AS SHOWN ON DWG.
2. ALL AN 386 TAPER PINS MUST BE INSTALLED SUCH THAT THE SMALL END OF THE TAPERED SHANK SHALL NOT EXTEND MORE THAN 1/8 ABOVE SURFACE OF WORK NOR LESS THAN FLUSH WITH SURFACE.

3 TORQUE NUT FINGER TIGHT ONLY.

4 ADJUST FRICTION BRAKE TO GIVE MINIMUM OF 5# ± 1# FRICTION LOAD ON COLLECTIVE PITCH STICK HANDLE. N-52848 ROD ASSEMBLIES TO BE DISCONNECTED AT TIME OF ADJUSTMENT.

5 COLLECTIVE PITCH STICK TO BE IN POSITION INDICATED WHEN RIGGING PIN IS IN PLACE.

9	AN4-6A	BOLT				
11	AN4-7A	BOLT				
1	AN4-8A	BOLT				
16	AN174-7A	BOLT				
5	AN174-10	BOLT				
4	AN174-10A	BOLT				
1	AN174-11	BOLT				
4	AN174-12	BOLT				
5	AN174-13	BOLT				
1	AN174-15	BOLT				
1	AN174-17	BOLT				
2	AN174-20	BOLT				
8	AN176-6A					
2	AN24-14	BOLT				
11	AN175-5	BOLT				
2	AN176-21	BOLT				
2	AN177-37	BOLT				
1	AN180-25	BOLT				
4	AN201KP8A	BEARING				
6	AN201KP10A	BEARING				
2	AN201KP25B	BEARING				
13	AN310-4	NUT				
11	AN310-5	NUT				
2	AN310-6	NUT				
7	AN310-7	NUT				
1	AN310-10	NUT				
4	AN315-5R	NUT				
4	AN316-5R	NUT				
1	AN320-4	NUT				
	AN320-14	NUT				
2	AN320-7	NUT				
17	AN364-428A	NUT				
47	AN364-624A	NUT				
1	AN365-624A	NUT				
27	AN380-2-2	COTTER				
11	AN380-2-3	COTTER				
4	AN380-3-3	COTTER				
8	AN380-3-4	COTTER				
8	AN380-4-5	COTTER				
2	NAS43-4-20	SPACER				
1	AN386-3-14A	PIN				
4	AN386-3-15A	PIN				
6	AN386-3-16A	PIN				
2	AN386-3-19A	PIN				
4	AN386-3-21A	PIN				
1	AN386-3-28	PIN				
3	AN960-416	WASHER				
61	AN960-416	WASHER				
11	AN960-516	WASHER				
6	AN960-616	WASHER				
4	AN960-716	WASHER				
1	AN960-1016	WASHER				
1	AN960-1416	WASHER				
17	AN975-4	WASHER				
2	AN935F416	LOCK WASH				
4	NAS43-4-56	SPACER				
1	NAS43-10-136	SPACER				
2	NAS50-251	RETAINER				
2	NAS51-62	RETAINER				
2	NAS51-131	RETAINER				
1	NS153-616	WASHER				
6	NAS[illegible]-3-11	BOLT				
1	29685-6	ACTUATOR		AIRESEARCH	CORP. L.A.	4
2	NS153-416	WASHER				
1	NS153-516	250-1058	BUSHING			5
1	RET-137	RETAINER	SHAFER	CORP.	ST. LOUIS	10
2	RR-42	RETAINER	-	-	-	10
1	ARAES-080-125-1080		ROLLPIN	(ELASTIC	STOP NUT)	10
2	N52892	WASHER				7
2	N52891	BOLT				8
2	N52890	BOLT				2
1	N52884	SUPPORT				16
1	N52883	HANDLE ASSEM				16
1	N52882	ROD ASSEM				16
4-2, 2(-1)	N52881	DISC				17
6	N52880	BRAKE DISC				17
1	N52879	ARM				17
1	N52878	SPRING				17
1	N52877	SCREW				17
1	N52876	HOUSING				17
4	N52875	SPACER				2
2	N52872	SHIM				2
6-1, 1(-2)	N52871	SPACER				10
2	N52868	ROD ASSEM				7
1	N52862	INSTAL-LOWER	CONTROLS	SECTOR		2
1	N52849	ROD ASSEM				10
1(-1), 1(-2)	N52848	STICK ASSEM				3
1	N52844	FRAME ASSEM				3
1	N52843	BUNGEE ASSEM				16
1	N52841	FITTING				9
1	N52832	BELLCRANK				5
1	N52831	SUPPORT				9
1	N52830	SUPPORT				16
1	N52829	ARM				10
1L, 1R	N52828	FITTING				10
1	N52827	FITTING				10
1	N52826	FITTING				10
1	N52825	PIVOT				9
2	N52824	TRUNNION				10
1	N52823	BELLCRANK		-		10
1	N52822	FITTING				10
2	N52821	TUBE				10
2	N52820	FITTING				10

N52800
SHEET 1 OF 2

1	N52817	FITTING ASSEMBLY				16
1	N52816	FITTING ASSEMBLY				17
3	N52814	DISC				17
2	N52811	BOLT				16
	N52810	SHAFT				16
	N52809	SHAFT				7
1	N52808	BELLCRANK				7
1	N52807	BELLCRANK				7
1	N52806	LINK ASSEM				7
1	N52805	BELLCRANK				7
1	N52804	ROD ASSEM				8
2	N52803	ROD ASSEM				8
	N52802	ROD ASSEM				8
1	N52801	BELLCRANK				7
1	N52200	INSTAL-COLLECTIVE	PITCH	STICK		6
N52800						
NO. REQ	PART NO	NAME				

N52708

FIGURE 3.5-2 CONTROLS INSTALLATION--CABIN FLIGHT

3.6 INSTRUMENTATION

3.6.1 Strain Gage Installation

The high temperatures at which the Hot Cycle Rotor Blade operates present numerous difficulties in attachment and operation of the strain gages. The strain gages chosen, Baldwin[1] ABD-13 and Tatnall[2] C6-142-350B, are designed for use at 350°F and higher. The gages are considered fatigue resistant and stable at the temperatures indicated The ABD-13 gages and some of the C6-142-350B gages were bonded to the various components with Baldwin EPY 400 Cement, capable of service at 600°F with proper cure, with very good results. The remainder of the C6-142-350B gages were bonded to the components using Tatnall GA-50 cement. All strain gages were cured at 350°F except those on aluminum components

In addition, the problems of bridge configuration had to be considered. Most bridge locations are such that a temperature gradient could exist across the bridge. Such a condition causes an apparent strain when the normal bridge configurations are used. As a result it was necessary to use an eight gage bridge, as in the case of the spars where there are four strain gages on the top, and four strain gages on the bottom of the spar. Each four gages are wired in such a fashion as to be completely temperature compensated. The two four gage bridges were then wired in parallel to give the desired sensitivity, either to bending moments or to axial loads.

All strain gage installations were waterproofed and potted by using Dow-Corning[3] RTV 601 silastic rubber compound. The RTV 601 maintains its properties at elevated temperatures and showed fair resistance to abrasion. It was satisfactory in all respects. A typical strain gage installation on the aft spar of the blue blade, the only strain gaged blade, is shown in Figure 3.6-1. The strain gaged rotor shaft is shown in Figure 3.6-2 The strain gage wiring on the spars and other fatigue loaded parts was attached with RTV 601 which proved to be highly satisfactory throughout the test.

1 Baldwin-Lima-Hamilton Corporation, Waltham 54, Massachusetts
2 Budd Company, Instruments Division, Phoenixville, Pennsylvania
3 Dow-Corning Corporation, Midland, Michigan

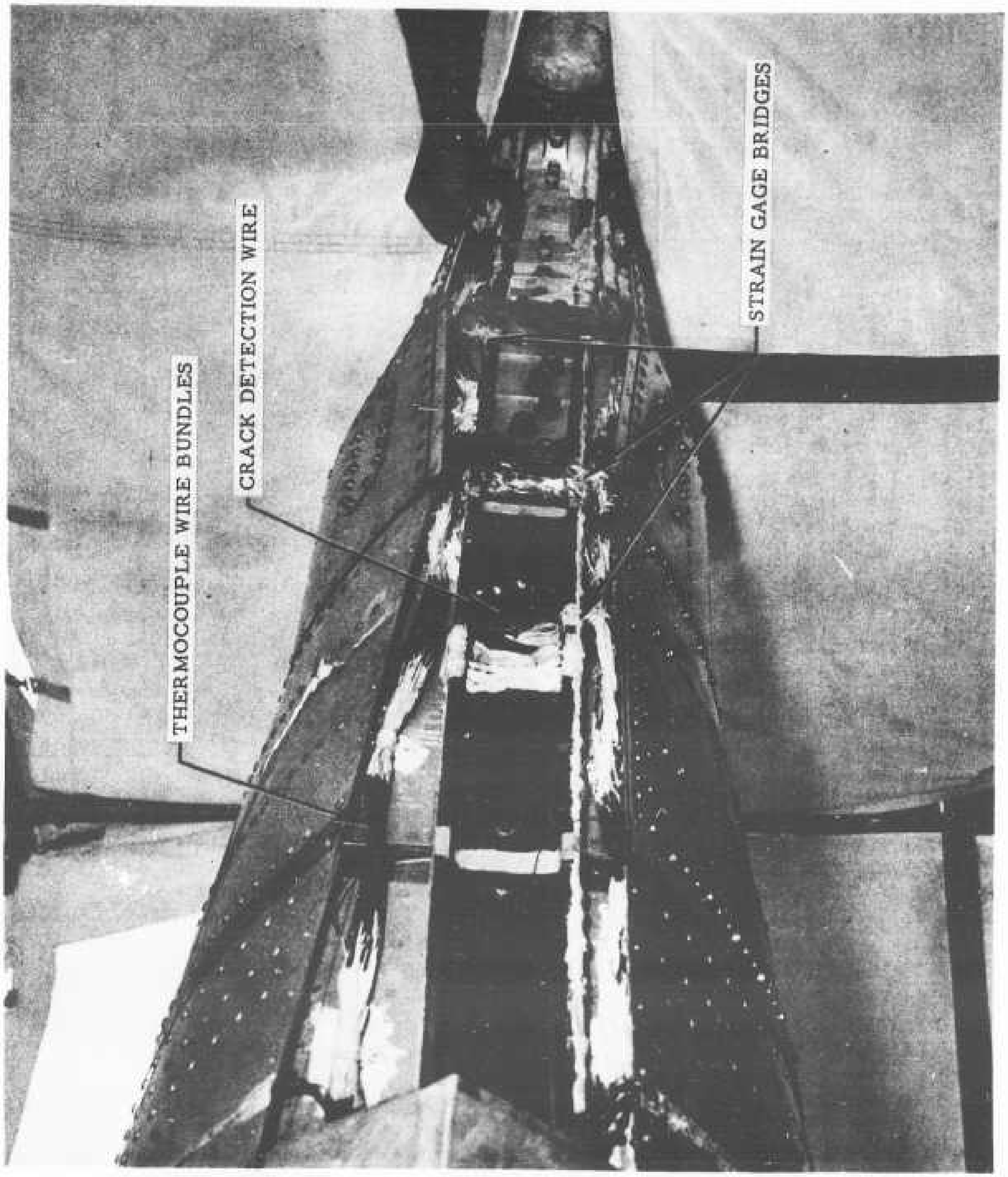


Figure 3.6-1 Instrumentation Installation at Blade Aft Spar

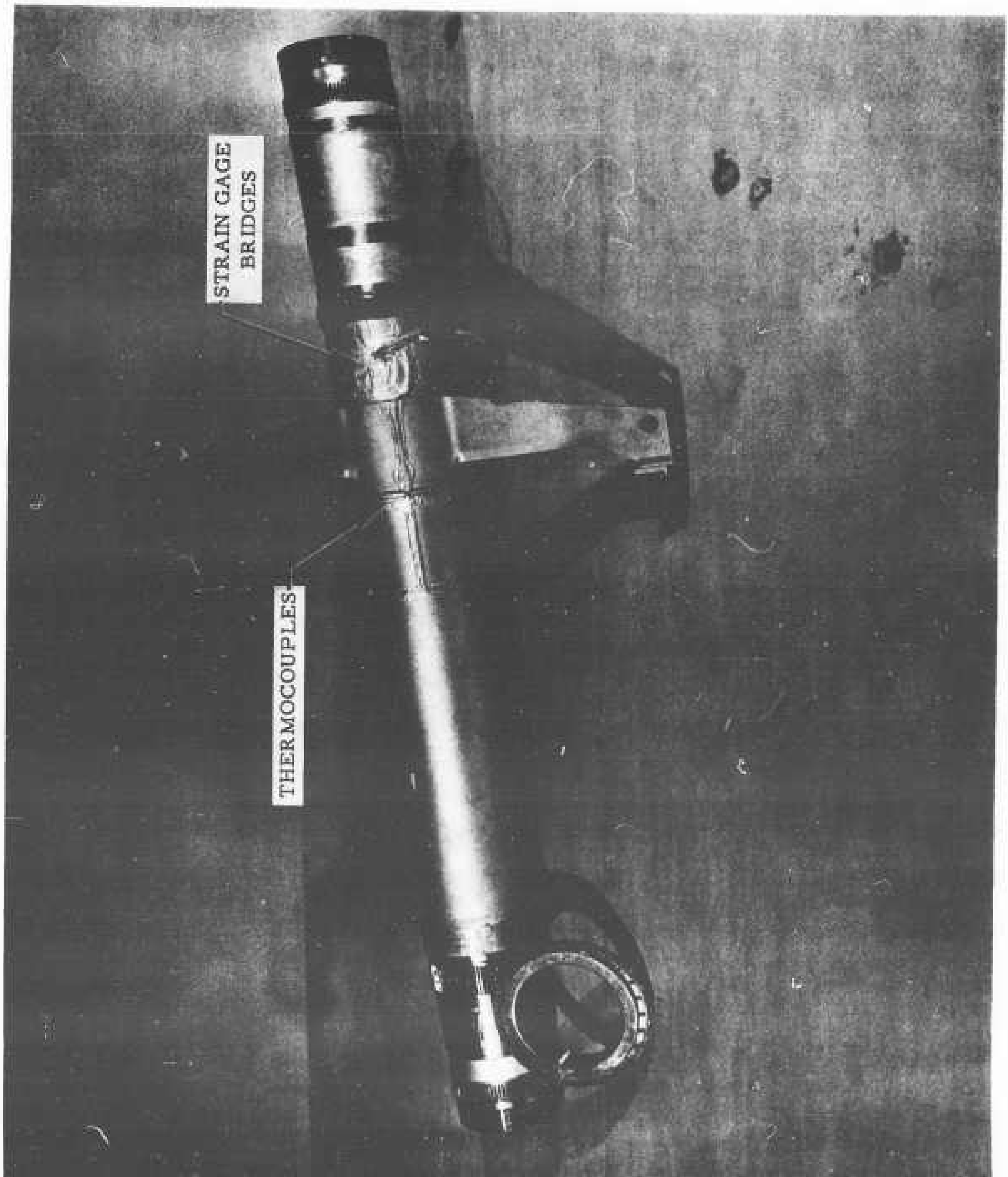


Figure 3.6-2 Instrumentation on Main Rotor Shaft

Strain gage bridges located on the structural components of the blade and hub are shown on Figures 3.6-3. Information pertaining to all of the individual strain gage bridges used is given in Table E.2-1, Appendix E.

3.6.2 Thermocouple Installation

Chrome-alumel thermocouples were used throughout on the whirl test rotor. The thermocouple wires, which were 30 gage wire (AWG), were double insulated with fiberglas. The particular type wire used was Thermoelectric Company[1] GG 30CT.

The thermocouples used on the duct walls, flexures, blade skins, and other areas which were not fatigue loaded, were attached by spot welding the ends of the wire to the part directly. These spot welds formed the junction at which the temperature was measured.

The installation of thermocouples on fatigue loaded parts such as the spars, rotor shaft, and hub gimbal lugs presented the same difficulty in attachment as encountered with the strain gages, i.e., high temperature bonding problems. The thermocouple was formed by fusing the two wires into a bead with a submerged mercury arc. This thermocouple was then installed using EPY-400[2] cement with a fiberglas retainer pad. These installations were then cured at temperatures in excess of 350°F.

All thermocouple lead wires on the blades were tied into bundles and attached to the blade structure with either spot welded sheet metal retaining clips or screw-on clamps. At least 3 clips were used for each standard blade segment. Slack was allowed at the flexure to prevent breaking of the wire due to blade deflection. To prevent centrifugal force from causing the wire bundles to slip and break, RTV 601 was used to anchor the thermocouple lead wires in the retention clips. This installation can be seen in Figure 3.6-1. The location of the individual thermocouples is shown in Figure 3.6-4 and listed in Table E.2-2, Appendix E.

3.6 3 Miscellaneous Instrumentation Installation

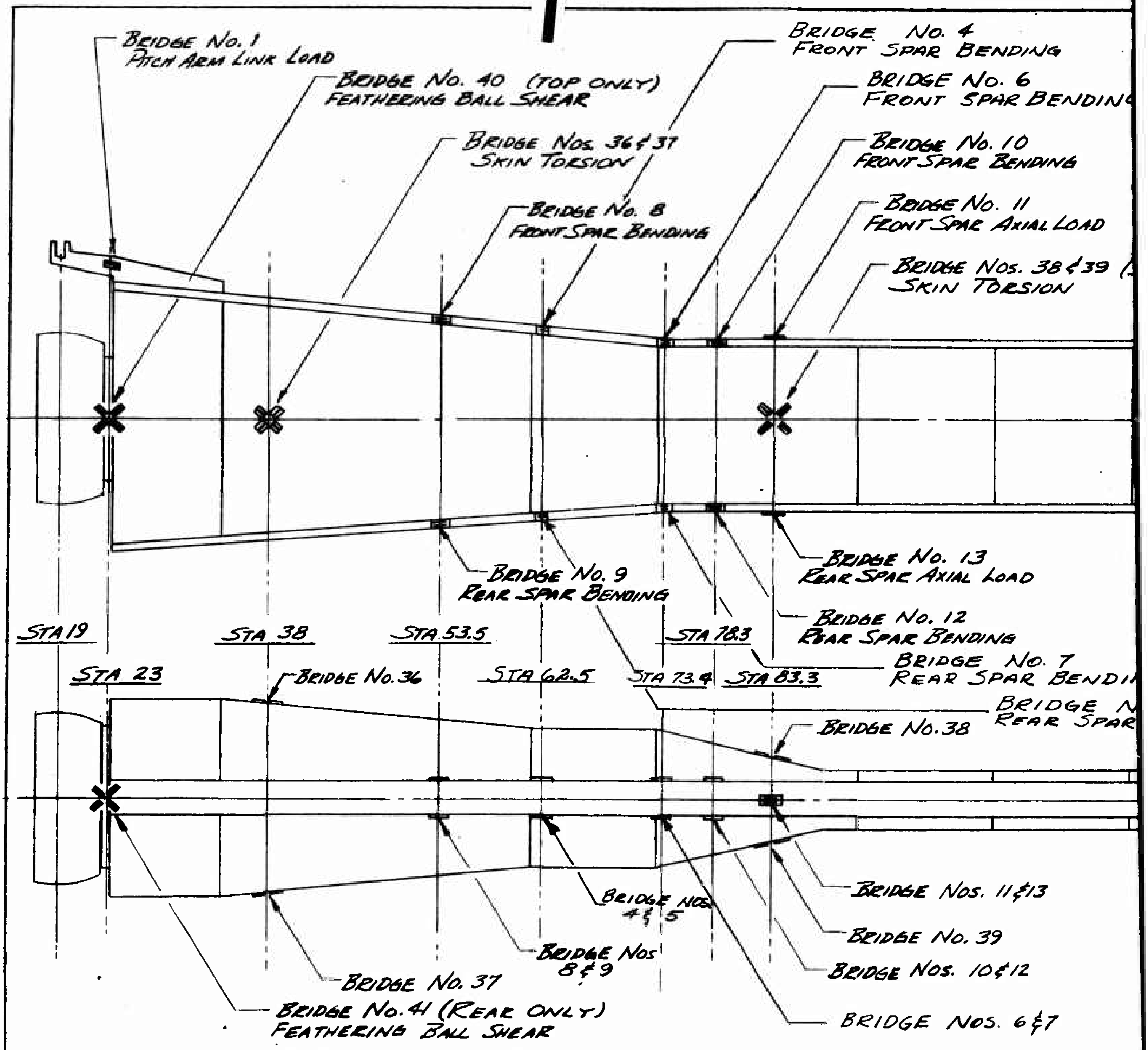
3.6.3.1 Crack Detection Wire

A crack detection wire was installed on all spars as a precautionary measure. 40 gage heavy Formvar copper wire was cemented to the spars with G.A.-50 cement between stations 55 and 90. The cement

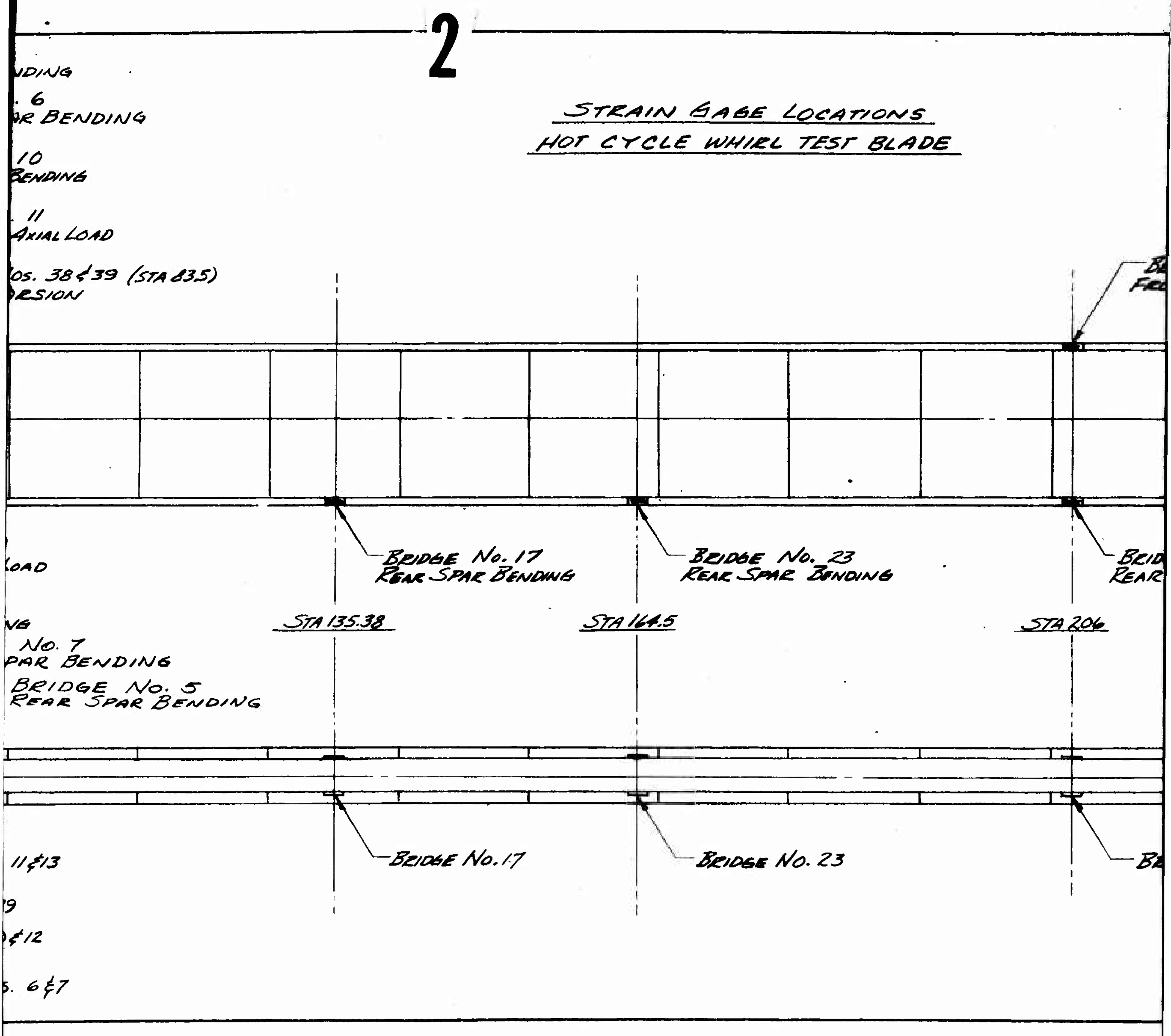
1 Thermoelectric Company, Saddle Brook, New Jersey

2 Baldwin-Lima-Hamilton Corporation, Waltham 54, Massachusetts

1

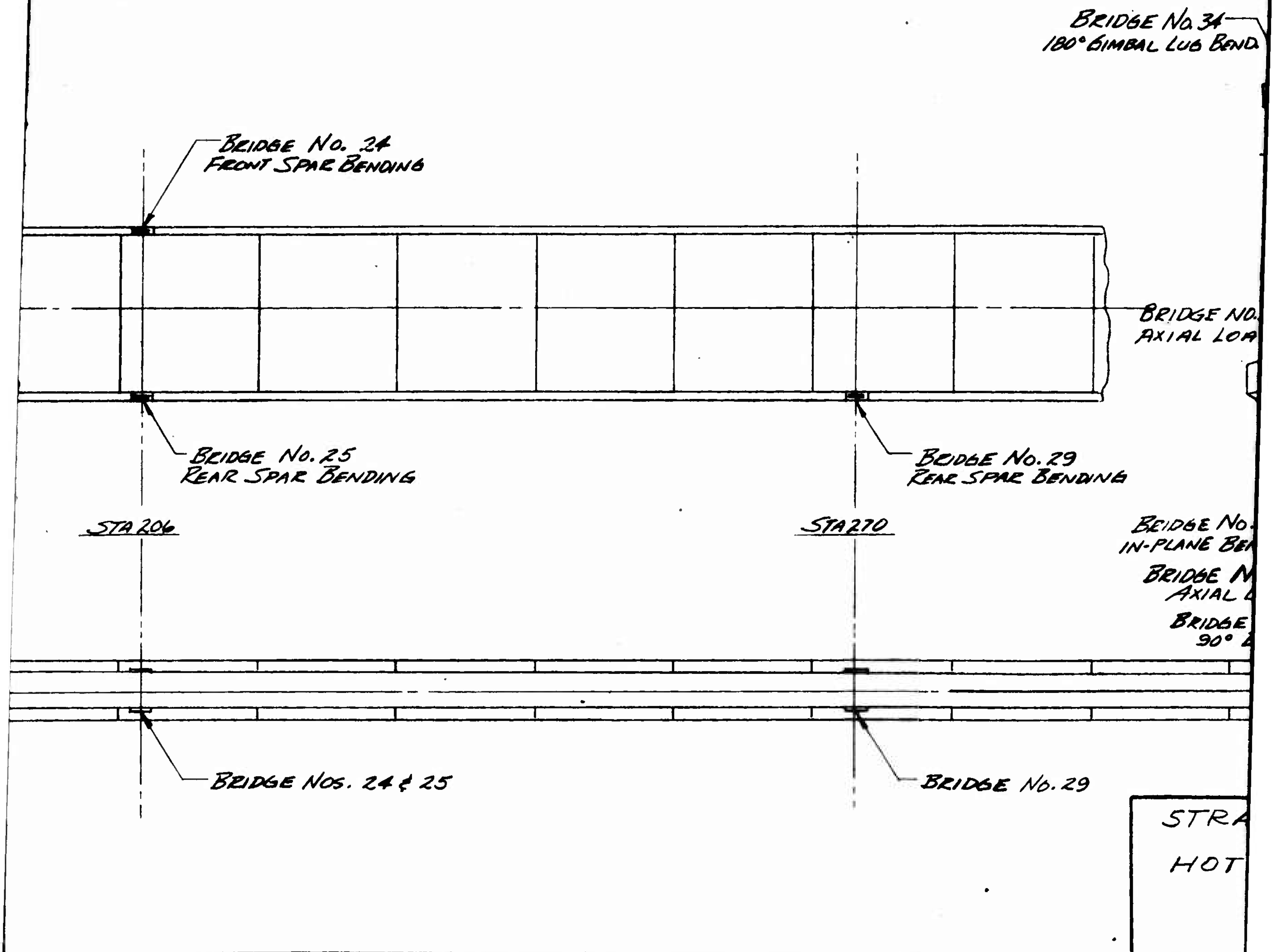


BRIDGE No. 1
PITCH ARM LINK LOAD
BRIDGE No. 40 (TOP ONLY)
FEATHERING BALL SHEAR
BRIDGE Nos. 36 & 37
SKIN TORSION
BRIDGE No. 8
FRONT SPAR BENDING
BRIDGE No. 4
FRONT SPAR BENDING
BRIDGE No. 6
FRONT SPAR
BRIDGE No. 10
FRONT SPAR BENDING
BRIDGE No. 11
FRONT SPAR AXIAL LOAD
BRIDGE Nos. 38 & 39
SKIN TORSION
BRIDGE No. 9
REAR SPAR BENDING
BRIDGE No. 13
REAR SPAR AXIAL LOAD
BRIDGE No. 12
REAR SPAR BENDING
BRIDGE No. 7
REAR SPAR
STA 19
STA 38
STA 53.5
STA 78.3
STA 23
STA 62.5
STA 73.4
STA 83.3
BRIDGE No. 36
BRIDGE
REAR SPAR
BRIDGE No. 38
BRIDGE Nos. 11 & 13
BRIDGE Nos 4 & 5
BRIDGE No. 39
BRIDGE Nos 8 & 9
BRIDGE Nos. 10 & 12
BRIDGE No. 37
BRIDGE No. 41 (REAR ONLY)
FEATHERING BALL SHEAR
BRIDGE Nos. 6 & 7



2
STRAIN GAGE LOCATIONS
HOT CYCLE WHIRL TEST BLADE
AXIAL LOAD
BRIDGE NO. 17
REAR SPAR BENDING
BRIDGE NO. 23
REAR SPAR BENDING
STA 135.38
STA 164.5
STA 206
NO. 7
BRIDGE NO. 5
REAR SPAR BENDING
BRIDGE NO. 17
BRIDGE NO. 23

3


BRIDGE No. 34
180° GIMBAL LUG BEND.
BRIDGE No. 24
FRONT SPAR BENDING
BRIDGE NO.
AXIAL LOA
BRIDGE No. 25
REAR SPAR BENDING
BRIDGE No. 29
REAR SPAR BENDING
STA 206
STA 270
BRIDGE No.
IN-PLANE BE
BRIDGE N
AXIAL
BRIDGE
90°
BRIDGE NOS. 24 & 25
BRIDGE No. 29
STRA
HOT

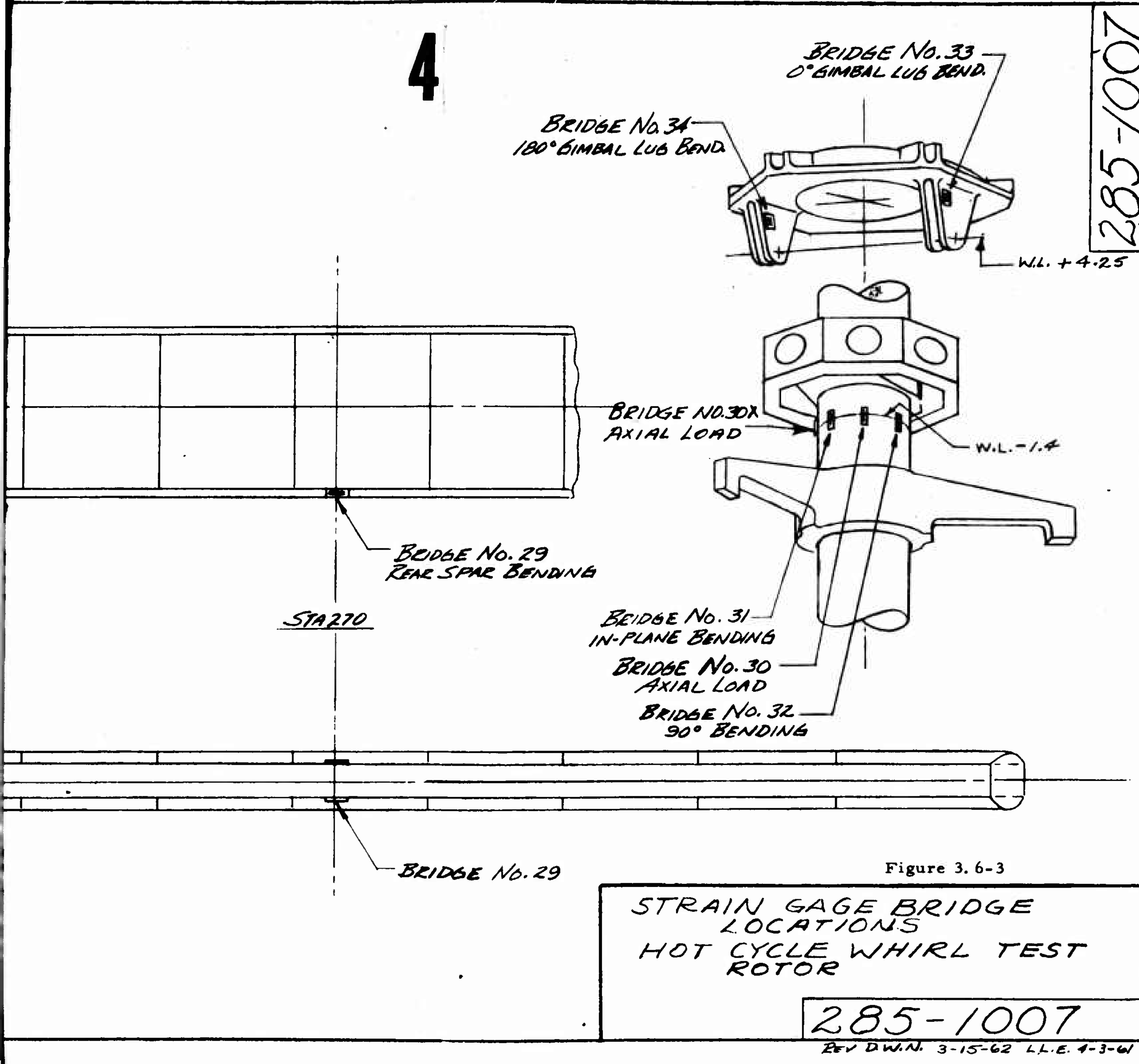
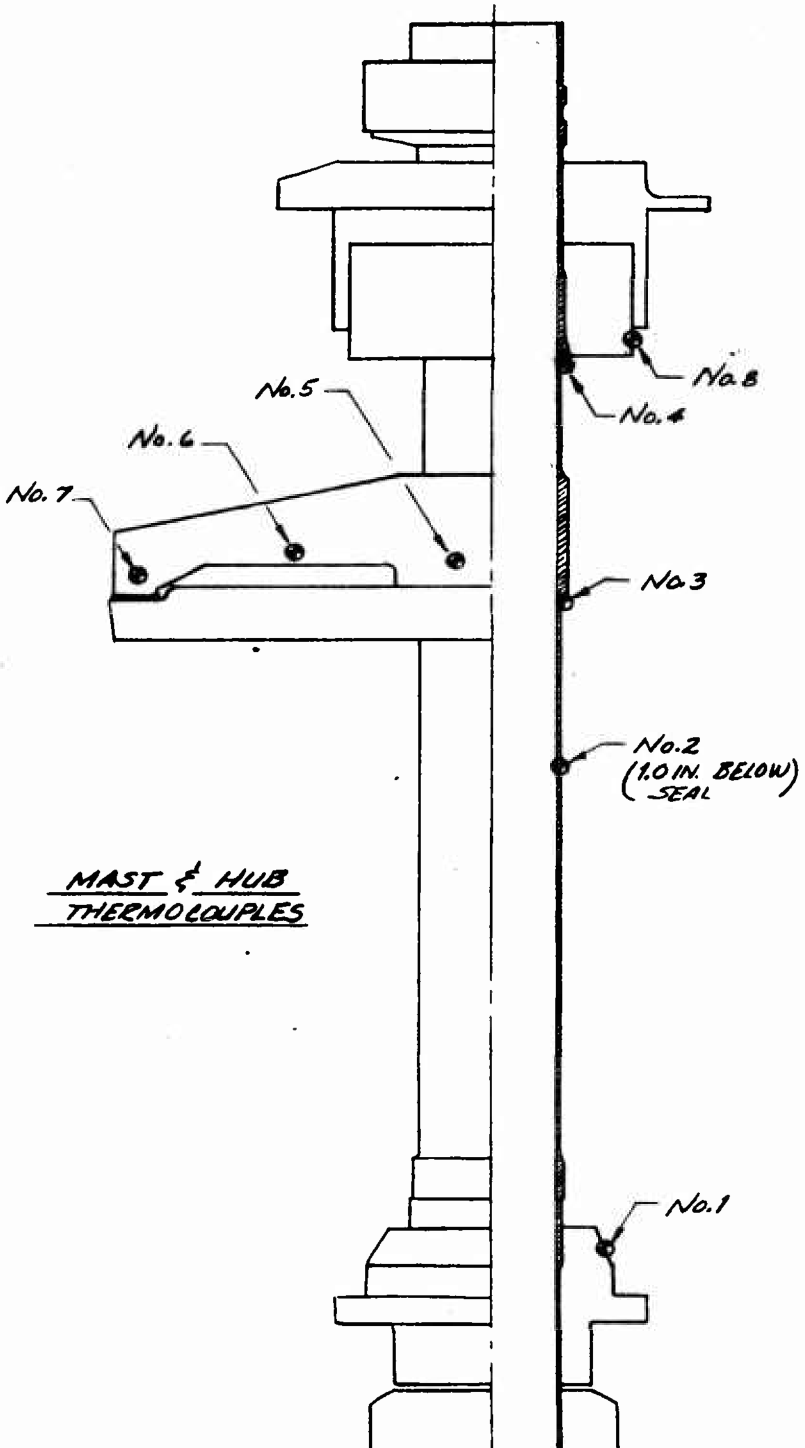

4
285-1007
BRIDGE No. 33
0° GIMBAL LUG BEND.
BRIDGE No. 34
180° GIMBAL LUG BEND.
W.L. +4.25
BRIDGE NO. 30X
AXIAL LOAD
W.L. -1.4
BRIDGE No. 29
REAR SPAR BENDING
STA 270
BRIDGE No. 31
IN-PLANE BENDING
BRIDGE No. 30
AXIAL LOAD
BRIDGE No. 32
90° BENDING
BRIDGE No. 29
STRAIN GAGE BRIDGE LOCATIONS
HOT CYCLE WHIRL TEST ROTOR
285-1007
REV D.W.N. 3-15-62 L.L.E. 4-3-61

Figure 3.6-3

1



MAST & HUB THERMOCOUPLES

FLEXURE INSTRUMENT

CODE: BC-2-3 = BLUE BLA
RC-2-3 = RED BLA
YC-2-3 = YELLOW

INSTR. FLEXURES:

BLUE BLADE – Nos
RED BLADE – Nos.
YELLOW BLADE – N

NOTES:

1. ALL THERMOCOUPLES CHROMEL ALUME
2. REF. DWGS: 285-0937, -0949, -0950, -0
3. INSTRUMENTATION INB'D OF STA 91 ON BLU
4. THE COUNTERPART OF BCD- OTHER BLADES IS: RED RCD
5. THE COUNTERPART OF BCD- OTHER BLADES IS: RED RCD
6. THE COUNTERPART OF BCD- OTHER BLADES IS: COOLING

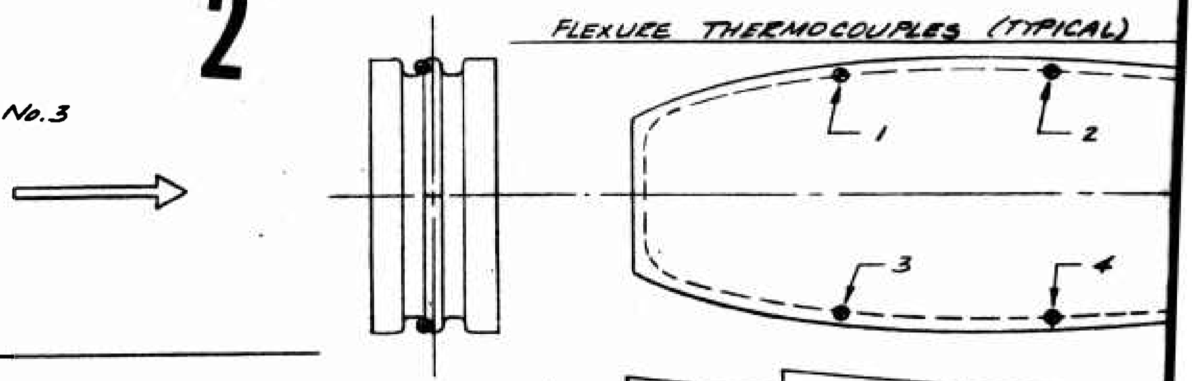
2

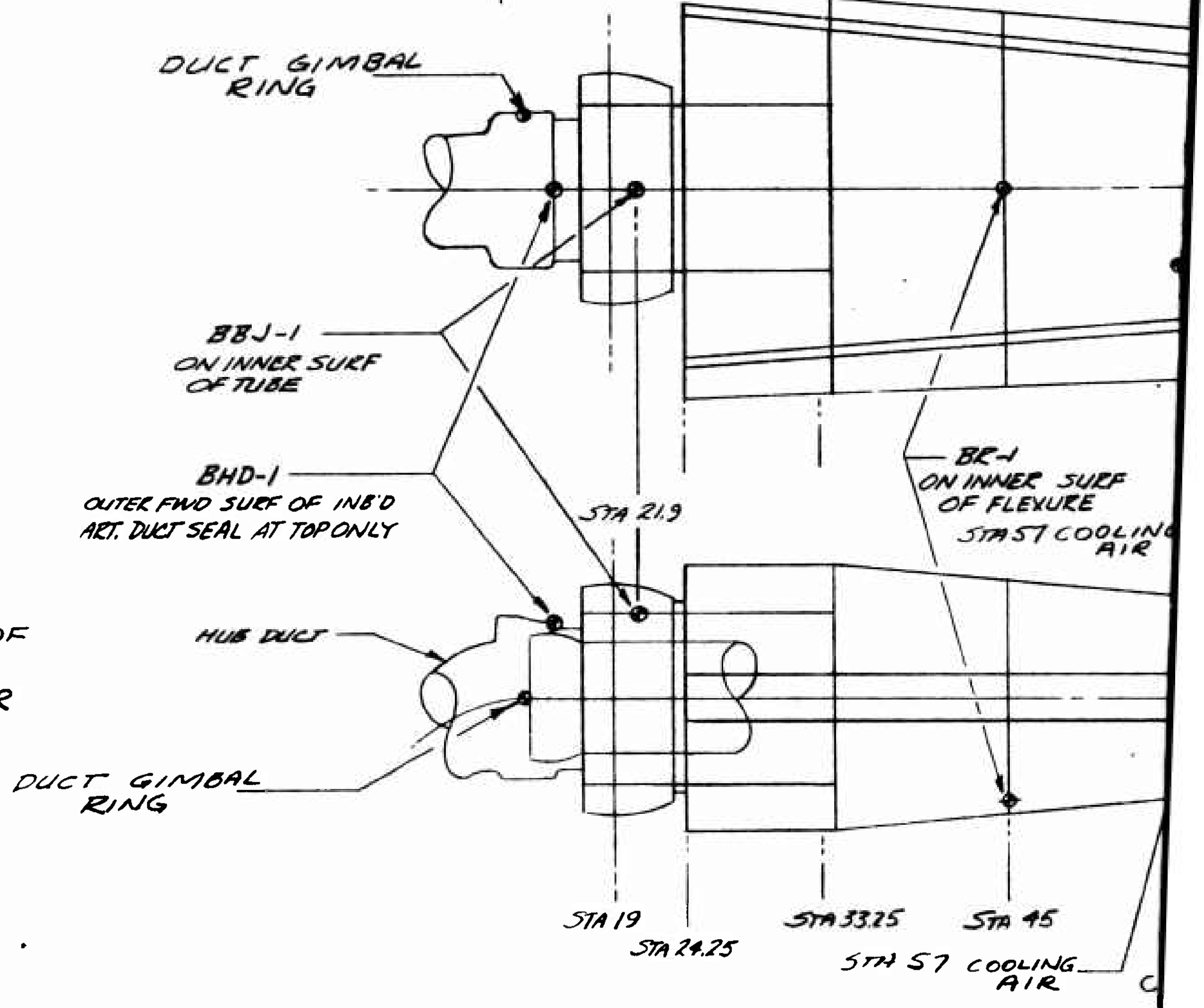
INSTRUMENTATION

2-3 = BLUE BLADE, FLEX. 2 FROM ROOT, TC No. 3
2-3 = RED BLADE, ETC.
2-3 = YELLOW BLADE, ETC.

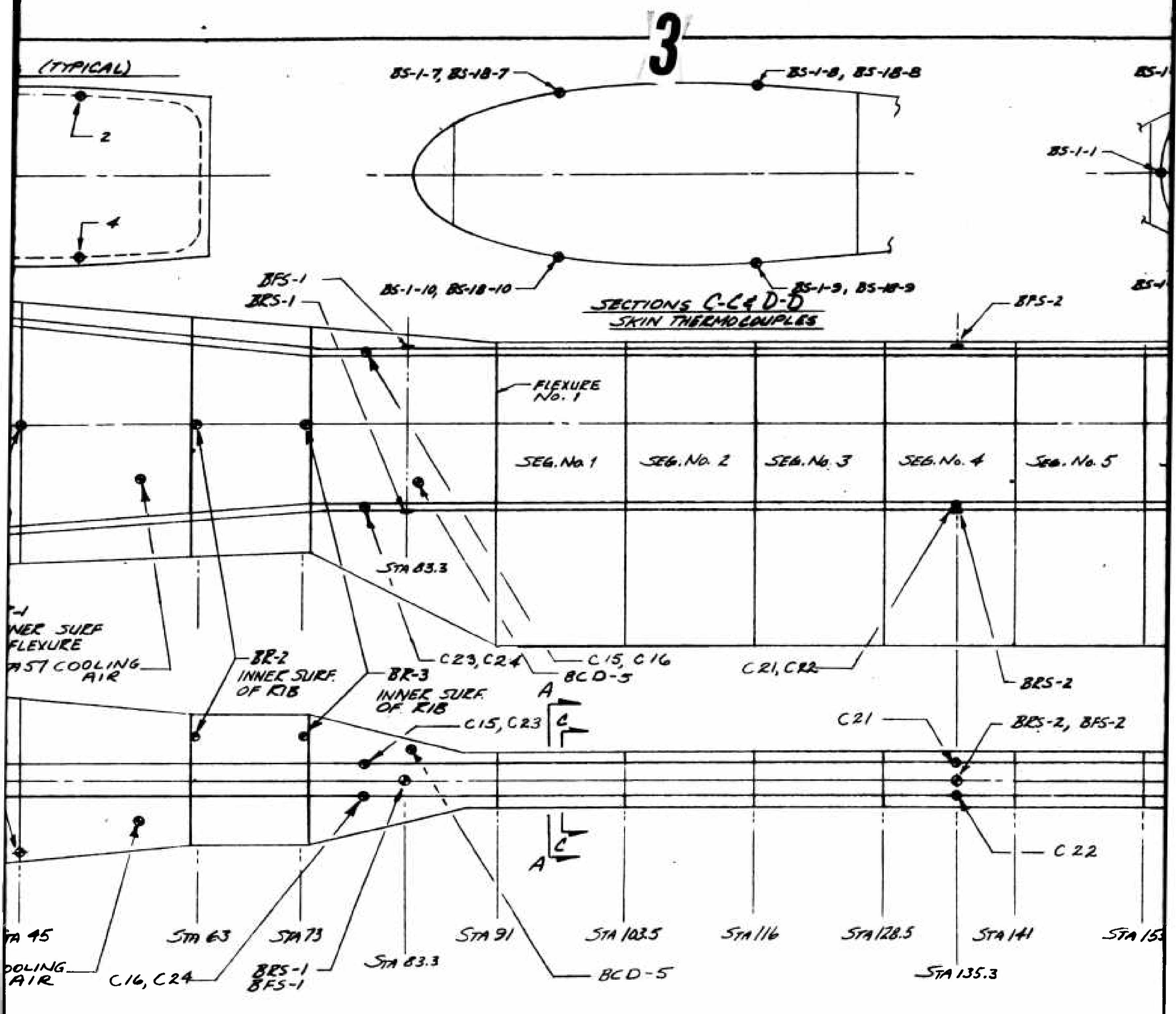
EXURES:

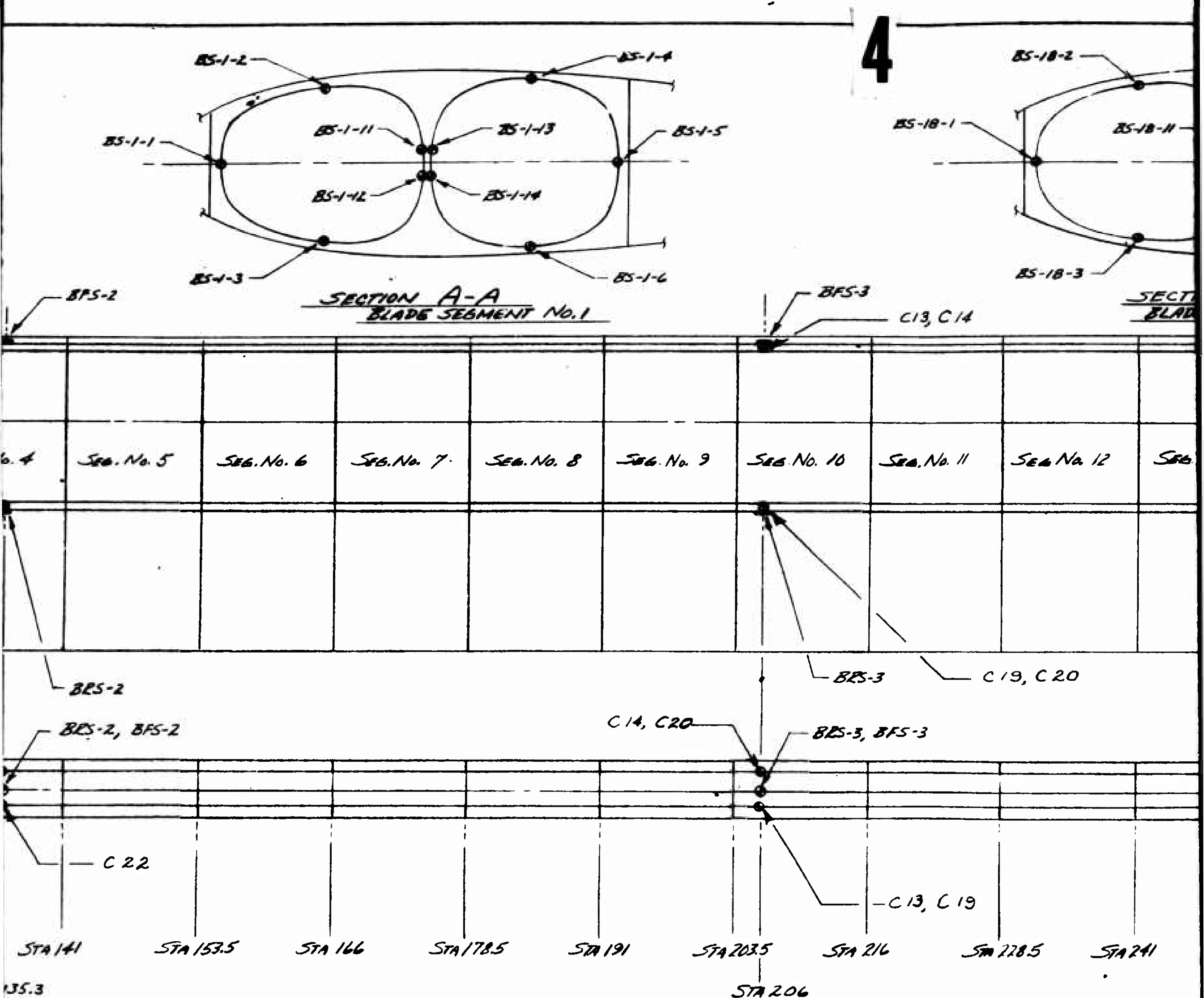
UE BLADE — Nos. 2, 4, 6, 8, 10, 12, 14, 16 & 18
D BLADE — Nos. 2 & 18
LOW BLADE — Nos. 2 & 18





CHROMEL ALUMEL
-0949, -0950, -0951, -1002
D OF STA 91 ON BLUE BLADE ONLY
ART OF BCD-1 ON THE
S: RED RCDF, YELLOW YCDF
ART OF BCD-2 ON THE
IS: RED RCDR, YELLOW YCDR
ART OF BCD-5 ON THE
IS: COOLING AIR, STA 78


3
(TYPICAL)
2
4
BS-1-7, BS-18-7
BS-1-8, BS-18-8
BS-1-1
BS-1-10, BS-18-10
BS-1-9, BS-18-9
SECTIONS C-C & D-D
SKIN THERMOCOUPLES
BFS-1
BRS-1
BFS-2
FLEXURE No. 1
SEG. No. 1
SEG. No. 2
SEG. No. 3
SEG. No. 4
SEG. No. 5
STA 83.3
INNER SURF FLEXURE
STA 57 COOLING AIR
BR-2
INNER SURF. OF RIB
BR-3
INNER SURF. OF RIB
C23, C24
C15, C16
BCD-5
C21, C22
BRS-2
A
C15, C23
C
C21
BRS-2, BFS-2
C 22
STA 45
STA 63
STA 73
STA 91
STA 103.5
STA 116
STA 128.5
STA 141
STA 135.3
COOLING AIR
C16, C24
BRS-1
BFS-1
STA 83.3
BCD-5


4
BS-1-2
BS-1-4
BS-1-1
BS-1-11
BS-1-13
BS-1-5
BS-1-12
BS-1-14
BS-1-3
BS-1-6
BS-18-2
BS-18-1
BS-18-11
BS-18-3
SECTION A-A
BLADE SEGMENT No. 1
BFS-2
BFS-3
C13, C14
Seg. No. 5
Seg. No. 6
Seg. No. 7
Seg. No. 8
Seg. No. 9
Seg. No. 10
Seg. No. 11
Seg. No. 12
BRS-2
BRS-3
C19, C20
BRS-2, BFS-2
C14, C20
BRS-3, BFS-3
C 22
C13, C19
STA 141
STA 153.5
STA 166
STA 178.5
STA 191
STA 203.5
STA 216
STA 228.5
STA 241
STA 206

5

THERMOCOUPLE LOCATIONS
HOT CYCLE WHIRL TEST BLADES

285-1008

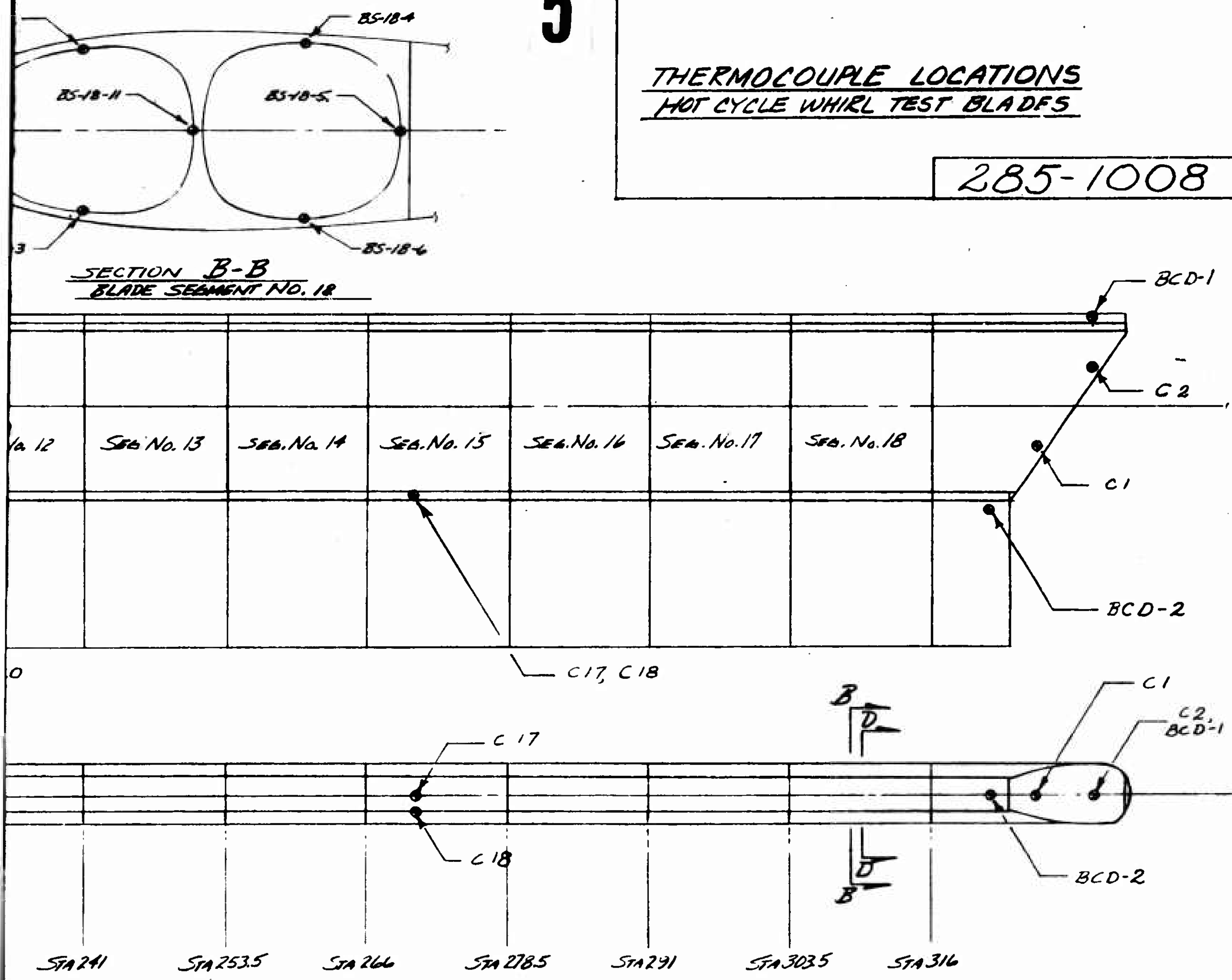


Figure 3.6-4

REV D.W.N. 3-15-62 LLE 5-3-61

was cured at 350°F. All spars were hooked up in a series circuit so that a crack in any spar would break the wire and extinguish a light bulb mounted on top of the hub. The light bulb and batteries are shown in Figure 3.6-5. The crack detection wire on the aft spar of the blue blade can be seen in Figure 3.6-1.

3.6.3.2 Hub Tilt Stop Position Indicator

A hub tilt stop indicating system was used to determine when the 2° tilt stops were disengaged. This system consisted of three microswitches hooked in series with a light and battery. When all three microswitches were closed, indicating every 2° tilt stop was disengaged, a red light mounted on the skirt of the hub was actuated.

3.6.3.3 Hub Tilt Indicator

The motion of the hub was measured by using the 285-0956 hub tilt pickup. The pickup consisted of a strain gaged cantilever beam with a ball on one end and a teflon covered fitting attached to the hub structure. The surface upon which the beam rubbed was cylindrical about the feathering axis of the yellow blade so that the pickup registered hub tilt about one axis only. This installation can be seen in Figure 3.6-5.

3.6.3.4 Blade Coning Indicator

Blade coning and flapping was measured using the 285-0947 flap angle pickup. The pickup consisted of a strain gaged beam connected to a spring loaded beam whose outboard end rested on a teflon pad mounted on the blade. This installation can be seen on 285-0947. It was necessary to use the spring loaded beam to cut down the deflection of the strain gaged member. The teflon pad was a cylindrical surface whose center was the feathering axis of the blade. Thus the pickup was uneffected by a change in pitch of the blade. This installation is shown in Figure 3.6-6.

3.6.3.5 Strap Windup Indicator

The amount of strap windup is directly related to the movement of the 285-0303 torque tube assembly with respect to the hub. The pickup was a strain gaged member attached to the hub at one end with the other end connected to the torque tube assembly by a link, as shown on 285-0947. The installation is shown in Figure 3.6-6.

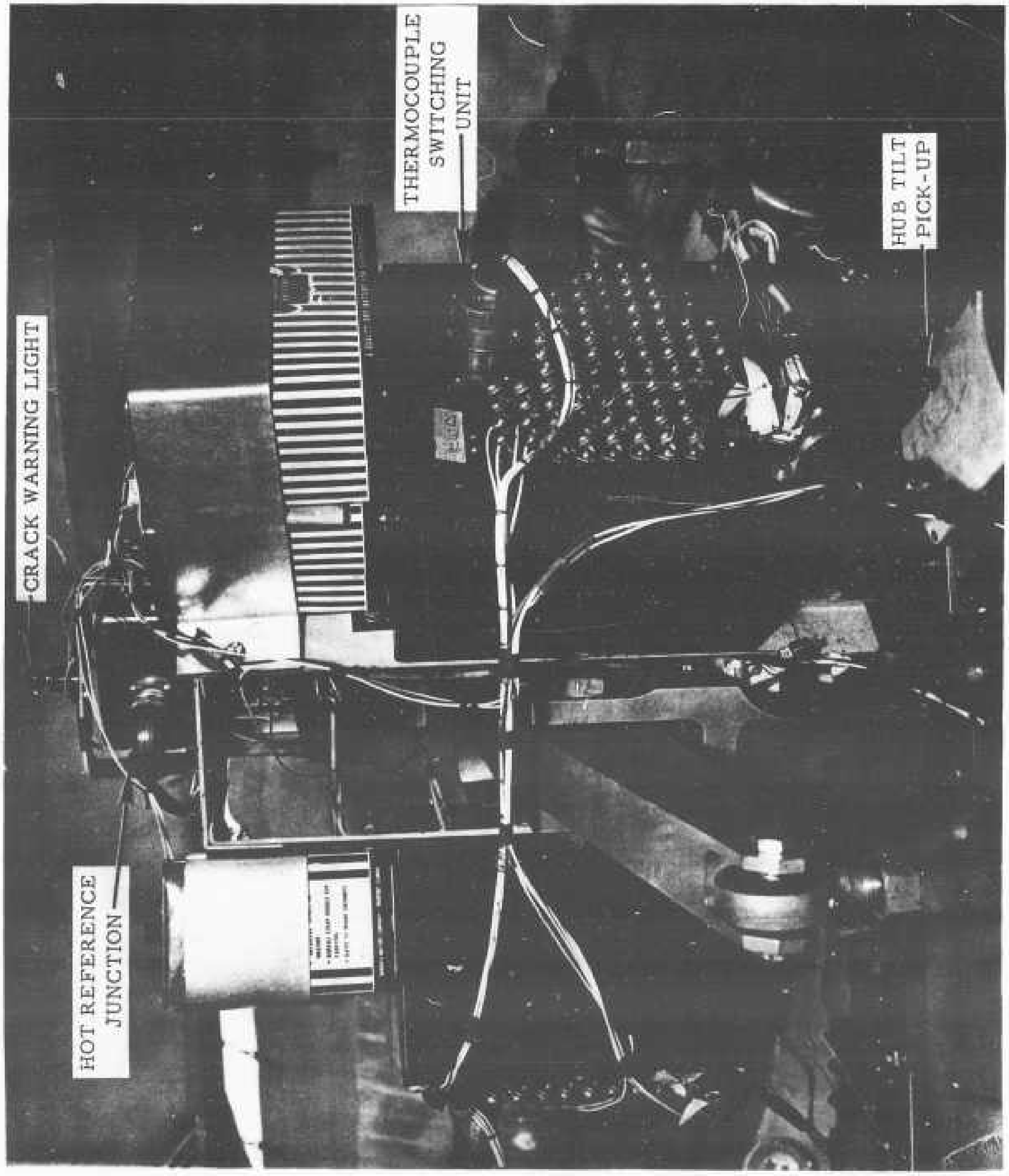


Figure 3.6-5 Instrumentation Installation on Top of Rotor

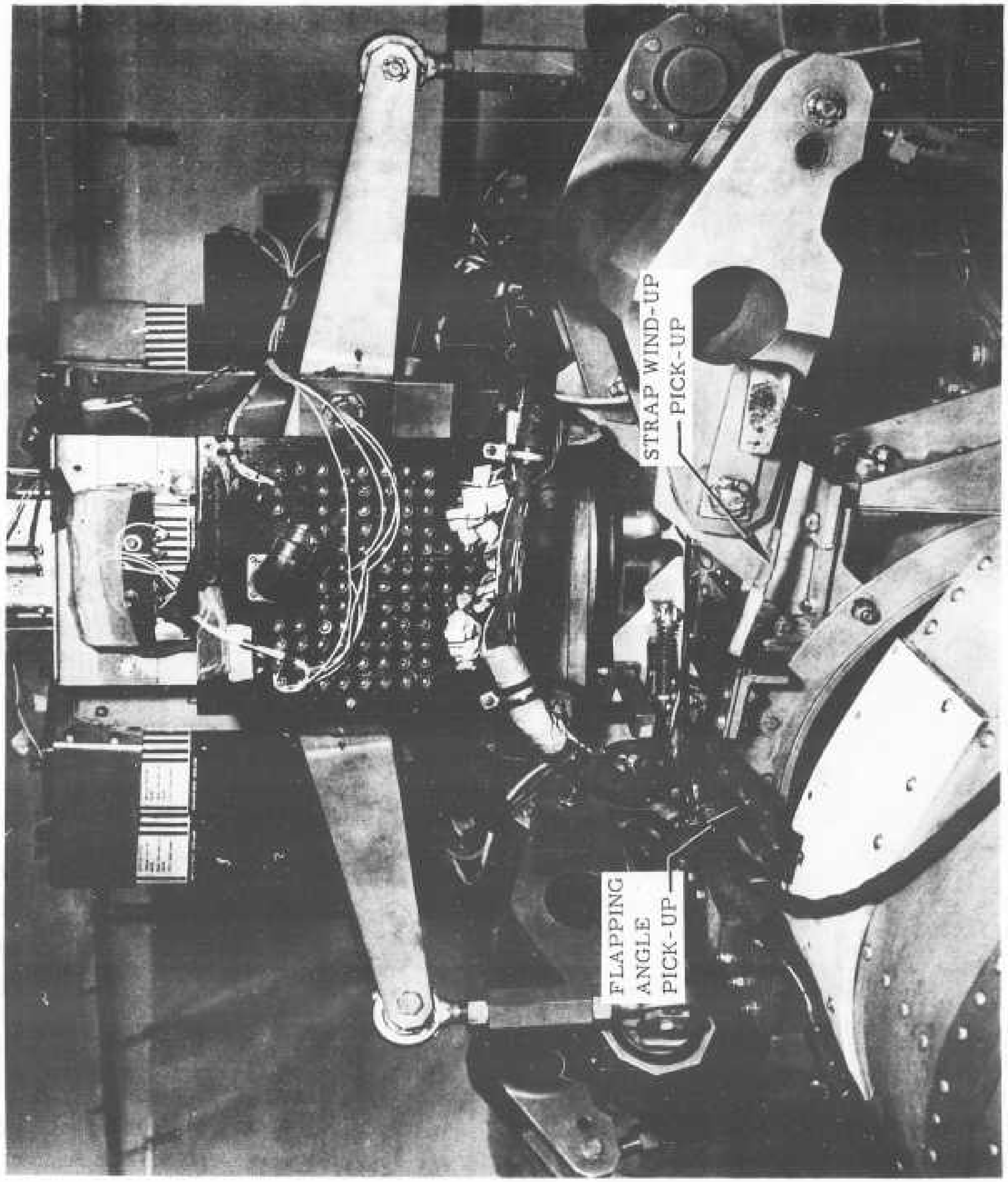


Figure 3.6-6 Instrumentation Installation on Top of Rotor

3.6.3.6 Azimuth and RPM Indicator

An azimuth indicator and rpm indicator were installed for recording this information on the oscillograph records. A magnet was attached to the shaft directly underneath the blue blade. A coil was placed on the stationary structure in such a fashion that when the blue blade was pointing forward it caused a blip on the oscillograph record. In addition, a tachometer generator was attached to the rotor shaft and connected to a tachometer indicator mounted on the instrument panel in front of the pilot.

3.6.3.7 Vibration Pickup

Two accelerometers were placed on the rotor to measure the vibration and check for resonant frequencies. One accelerometer sensitive to horizontal accelerations was mounted on the upper truss 285-0523-1 directly beneath the upper bearing at W.L. -19.0. The other accelerometer, oriented so as to be sensitive to vertical accelerations, was attached to the stationary swashplate 285-0313 at W.L. -57.0.

3.6.3.8 Control Movement Sensors

The movements of the control sticks and the hydraulic control cylinders were monitored by using 3 turn variable potentiometers. The potentiometers were equipped with spring loaded sheaves around which was wrapped the braided wire cable attached to the particular item. One potentiometer was attached to each one of the control hydraulic cylinders. The cyclic pitch control had two potentiometers attached to it. One responded to fore and aft movement of the stick, the other to lateral movements. One potentimeter was also attached to the collective pitch control stick.

3.6.3.9 Oil Temperature Sensors

A thermocouple was installed in the oil return line from the thrust bearing to detect any significant temperature increase. The output of this thermocouple was monitored by a Brown Strip Chart recorder placed in front of the pilot. In addition a thermoswitch set at 225°F was placed in the oil return line from the upper bearing. When this switch closed it flashed a warning light on the panel in front of the pilot.

3.6.4 Pressure Instrumentation

For whirl tests, primary stream pressure instrumentation was provided at three stations; two stations each being parallel branch pairs. These locations are referred to as turbine discharge, flow measuring, and hub stations. The former two stations also include total temperature thermocouples for engine monitoring and flow determination.

The turbine discharge averaging total pressure rake is engine supplied while the flow measuring and hub station rakes are HTC-AD designed and fabricated. Details of these latter two rakes are provided by HTC-AD Drawing 285-1015.

3.6.5 Calibration Procedure

3.6.5.1 Strain Gage Installations

a. Rotor Shaft Axial Bridges

The rotor shaft axial load and lower pylon bridges were calibrated at the same time on the whirl test stand. This was accomplished by hooking a crane to the 285-0765 hoist fitting which was attached to the 285-0306 control support assembly, using a hydraulic cylinder and a 100,000 pound load ring. The load ring was calibrated in the lab before being used. The load ring was strain gaged and the output read on a Baldwin Lima-Hamilton Type 20 strain indicator. The load was applied as follows; 0, 4000, 8000, 12000, 16000, 18000 and 24000 pounds. The output of the pylon strain gage bridge and shaft strain gage bridges were recorded by an oscillograph. The calibration hook up is shown in Figure 3.6-7. The calibration procedures demonstrated that the rotor shaft bending bridges were not sensitive to axial loads. The pylon gages were monitored during the pressure testing so that a correction could be applied to values obtained during the runs.

b. Rotor Shaft Bending Bridges

The rotor shaft bending bridges were calibrated by two methods. During the assembly of the rotor the rotor shaft bending bridges

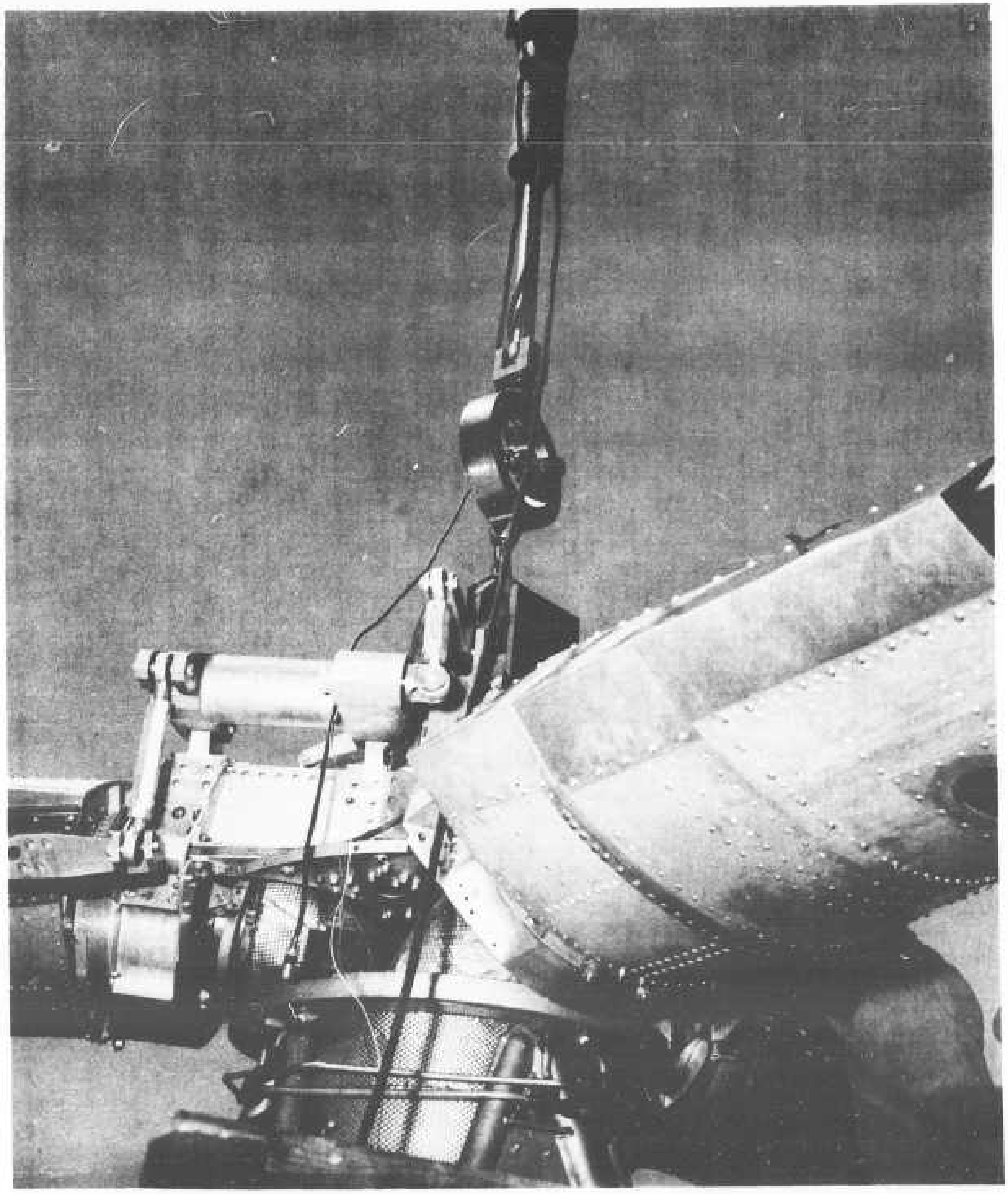


Figure 3. 6-7 Calibration of Lift Measuring Strain Gages (Note load ring and hydraulic cylinder attached between hub shaft and crane.)

were calibrated by attaching a cable to the top of the rotor shaft and applying a load through a hydraulic cylinder and load ring. The load was applied in 200 pound increments up to 1000 pounds and the output recorded using a Type "L" Baldwin strain indicator.

The hub gimbal lugs bridges were also calibrated during assembly in the shop by pulling on the hub with a cable and hydraulic cylinder connected to a load ring. The load was applied in 200 pound increments up to a maximum of 1000 pounds. A cable was also attached to the hub and to the pylon base to prevent rotation of the hub due to eccentric loading. The output of the gages was recorded on a Baldwin Type "L" strain indicator.

After the rotor was installed on the whirl tower following the 35 hour inspection the rotor shaft bending gages in line with the blue blade and the hub gimbal lug gages were calibrated by attaching the 285-0923-3 tip loading fixture to the blue blade and pulling on it with a hydraulic cylinder and load ring attached to a crane. The load was applied in increments of 500 pounds up to a maximum load of 2000 pounds. The blade was supported at the tip by the crane so that it was level and props were placed beneath the hub on the side opposite the blue blade to prevent rotation due to the eccentricity of the blade retention straps and hub trunnion. The calibration of the bending bridge oriented at 90° to the blue blade was accomplished by pulling on the tip of the yellow blade in a similar manner.

c. Flapwise Bending Bridge Calibration

The flapwise bending bridges were calibrated in the shop during the assembly of the rotor with the blade hanging in the 285-0921 blade support fixture which was attached to a gantry crane as shown in 285-0925. The installation is shown in Figure 3.6-8. Shims were inserted between the droop stop rollers and the support fixture so that the blade was prevented from swinging. A flapwise load was then applied at the tip through a load ring and load cell. The 285-0944 loading fixture was attached to the blade at Station 312.6. The load was applied in 20 pound increments up to a maximum of 100 pounds. The output of the strain gages were recorded by an oscillograph.

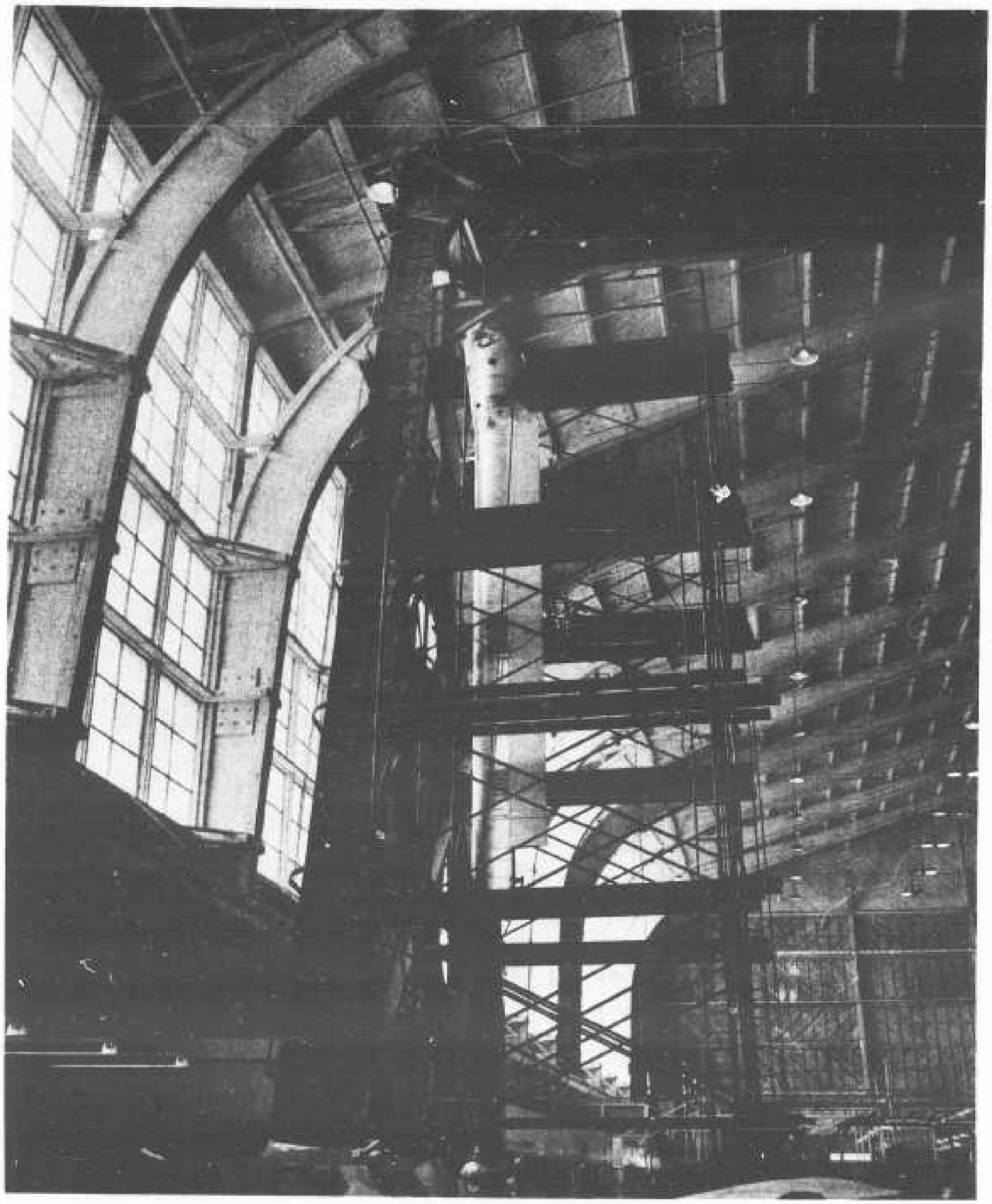


Figure 3. 6-8 Blade Hung Vertically for Bending Calibration and Frequency Measurements

After the inspection which followed 35 hours of whirl testing, the flapwise bending gages were calibrated with the rotor installed on the whirl tower. For this calibration the blade was raised so that it was clear of the droop stop and supported on the 285-0939 blade support between Stations 63 and 73. Dead weight was added in 20 pound increments up to a maximum of 100 pounds at Sation 314.4. The outputs of the strain gages were recorded by an oscillograph.

d. Chordwise Bending Bridges

The chordwise bending gages were calibrated with the blade supported as shown in Figure 3.6-8 and described in 3.6.5.1, above. The 285-0923-3 tip loading fixture was attached to the blade, and to this fixture a cable carried the load of a hydraulic cylinder. This cylinder was placed in series with a 10,000 pound load ring and a 10,000 pound load cell which were attached to an I-beam achored to the floor by lead weights. The 285-0923-7 chordwise load fixture was attached to the blade at Station 320.9. The gages were calibrated by applying an axial load to prevent the blade retention straps from buckling, and then applying chordwise loads in increments. The tip loading fixture was designed so that the axial loads were applied along the feathering axis of the blade. The axial loads with the chordwise load increments were as follows;

7000 pounds; 0, 30, 60, 90, 120, 150 pounds
6000 pounds; 0, 20, 40, 60, 80, 100 pounds
5000 pounds; 0, 20, 40, 60, 80, 100 pounds
4000 pounds; 0, 20, 40, 60, 80, 100 pounds

Dimensional scales were attached to the blade at the tip and near the root, and the deflection of the blade was measured by means of a transit. The output of the strain gages were recorded by using an oscillograph.

e. Blade Torsion and Pitcharm Bridges

The blade torsion and pitch arm strain gage bridges were calibrated with the blade supported as described previously in 3.6.5.1, c. In addition, the 285-0923-5 blade torsion fitting was attached to the end of the blade. The 285-0935 torsion test load jig was hooked to the fitting at the tip of the blade in such a fashion that the torsion was applied without causing translation of the blade tip. A recently calibrated load cell connected the pitch arm assembly to the blade support fixture. The torque applied to the blade by a hydraulic cylinder was measured by both a load ring and a load cell attached in series with a cable which wrapped around the blade torsion fitting. Torque was applied (in both directions) in 1000 inch-pound increments up to a maximum of 10,000 inch-pounds. Blade torsional deflection and the pitch calibration were accomplished at the same time since the load cell attached to the pitch arm assembly measured directly the reaction force at the pitch arm. An oscillograph was used to record the output of the strain gages.

f. Feathering Ball Horizontal Shear Bridge

The strain gage bridge which measures horizontal shear at the feathering ball was calibrated by attaching a cable, load ring, hydraulic cylinder, and load cell in series to the pitch arm and pulling horizontally. The load was applied in 200 pound increments up to a total of 1000 pounds. The output of the load cell as well as that of the horizontal shear bridge was recorded using an oscillograph.

g. Feathering Ball Vertical Shear Bridge

The vertical shear strain gage bridge at the feathering ball was calibrated by applying a load at the attachment for the 285-0133 droop stop installation. The blade was supported at the tip so that the droop stop was clear. The load was applied in 200 pound increments to a maximum of 1000 pounds. The load was applied by using a hydraulic cylinder, load cell, and load ring in series. The output of the load cell and the vertical shear bridges was recorded by an oscillograph.

h. Swashplate Drag Link Bridge

The 285-0332 drag link assembly was reworked to act as a load cell in measuring the stationary swashplate drag loads. The assembly was calibrated in a baldwin static test machine using a Baldwin Type "L" strain indicator. The load was applied in 200 pound increments to a maximum load of 2000 pounds.

i. Control Force Bridges

The 285-0326-3 rod ends were reworked so that they could be used as transducers in measuring the control forces. The rod ends were calibrated in a Baldwin test machine using a Baldwin-Lima-Hamilton Type 20 strain indicator. The load was applied in 500 pound increments to a maximum of 5000 pounds.

j. Horizontal Force Bridges

The hub support upper structural truss stain gage bridges were calibrated in the fore and aft direction at the same time the hub gimbal lugs and rotor shaft in-plane gages were calibrated as described in 3.6.5.1, b. The lateral direction calibration was accomplished by rotating a blade to a position 90° to the fore and aft direction and pulling on the tip with the crane. The blade was held horizontal for this calibration. The load was applied in 500 pound increments to a maximum of 2000 pounds by using a hydraulic cylinder and load ring.

k. Flapping Angle Measuring Bridge

The 285-0948 flapping angle pickup was calibrated by attaching the crane to the tip of the blade and raising it in 2° increments to a maximum of 10° as measured by a precision clinometer on the pitch control arm. Shims were used to hold the hub level and to prevent rotation of the hub about the trunnion. A small outboard load was maintained to prevent damage to the feathering ball during the calibration. The output of the pick-up was recorded by using an oscillograph.

l. Hub Tilt Measuring Bridge

The calibration of the 285-0956 hub tilt pick-up was accomplished by pulling down on the yellow blade with 2° hub tilt stops disengaged. Two climometers were used, one a precision clinometer, to measure the hub tilt, and the other one to make sure that the hub was level in the direction normal to the yellow blade. The hub was tilted in 2° increments until the full travel, 9.6°, was reached. The calibration was performed in both directions, first by pulling down on the yellow blade and then by pulling down on the red blade. An oscillograph was used to record the output of the pick-up.

m. Strap Wind-up Measuring Bridge

The strap wind-up pickup, 285-0948, was calibrated by installing a template at the 3/4 radius point on the blade. The blade was then moved in 2° increments until maximum travel was reached. The angles were measured by using a precision clinometer attached to the template. The output of the strap wind-up pick-up was recorded by an oscillograph.

n. Duct Torsion Bridge

The 285-0178 articulated duct gimbal ring was strain gaged to measure the duct torsion loads. This assembly was supported in the 285-0943 test jig and dead weight loads applied at the end of an arm to give 200 inch pound torque increments up to a maximum of 1000 inch pounds. The output of the gages was monitored by a Baldwin Type "L" strain indicator. The torque was applied in both directions during the calibration.

3.6.5.2 Thermocouple Calibrations

The thermocouple wire used was calibrated by the manufacturer and guaranteed to be within standard tolerances. The various recorders used were calibrated according to the manufacturer's directions several times throughout the whirl test program.

3.6.5.3 Miscellaneous Calibrations

a. Control Cylinder Movement Sensors

The variable potentiometers attached to the hydraulic control cylinders were calibrated by moving the collective control stick the amount which caused the control cylinders to move exactly one inch. Since these potentiometers are linear, it was unnecessary to calibrate to full travel.

b. Control Stick Movement Sensors

The variable potentiometers attached to the collective pitch and cyclic pitch control sticks were calibrated by moving the control sticks through their respective full ranges in 2° increments as measured by a precision clinometer attached to the template at the 3/4 radius point of the blade. The output of the potentiometers was recorded by using an oscillograph.

3.6.6 Recording Instrumentation

3.6.6.1 Strain Gage Instrumentation

a. Strain Gage Wiring

The inboard ends of the strain gage wiring were equipped with a Winchester M4P plug which fitted into a Winchester M4S socket contained on one of three boxes attached to the 285-0306 upper control support assembly. From the three boxes the wires ran to the 285-0310-17 conduit assembly which was supported by spokes in the center of the rotor shaft. The wire ran to a 44 channel slip ring assembly mounted on the lower end of the rotor shaft as shown on 285-0500. The slip ring had coin silver rings and silver graphite brushes. The 44 channel slip ring as installed is shown in Figure 3.6-9. From the slip ring the wires ran to a junction box at the end of the main instrumentation cable. Cannon XL-3 plugs were used in this box. The instrumentation cable ended at the bridge balance boxes in the control van. All strain gage circuits were powered by a parallel power connection at the upper junction box. Thus each bridge required only two wires through the slip ring assembly. This made a total of 21 channels available for strain gage bridges through the slip ring.

b. Strain Gage Bridge Balance Box

Two bridge balance boxes were used to condition the signal for recording by the oscillograph. One, a 20 channel box was built by American Helicopter Corporation while the other, a 15 channel box, was made by HTC-AD. Both bridge balance boxes had individual balance control, and attenuation for each channel. In addition, an internal electrical calibration device was contained in each unit. The balance boxes are shown in Figure 3.6-10.

c. Strain Gage Recording Instrumentation

A CEC[1] 5-119P3-50 model recording oscillograph was used to record the output of the various transducers. The oscillograph, shown in Figure 3.6-10, had provision for 50 channels and a mirror galvanometer compatable with the transducer involved was used in each channel. The magazine was a CEC 5-036C

1 Consolidated Electrodynamics Corporation, Pasadena, California

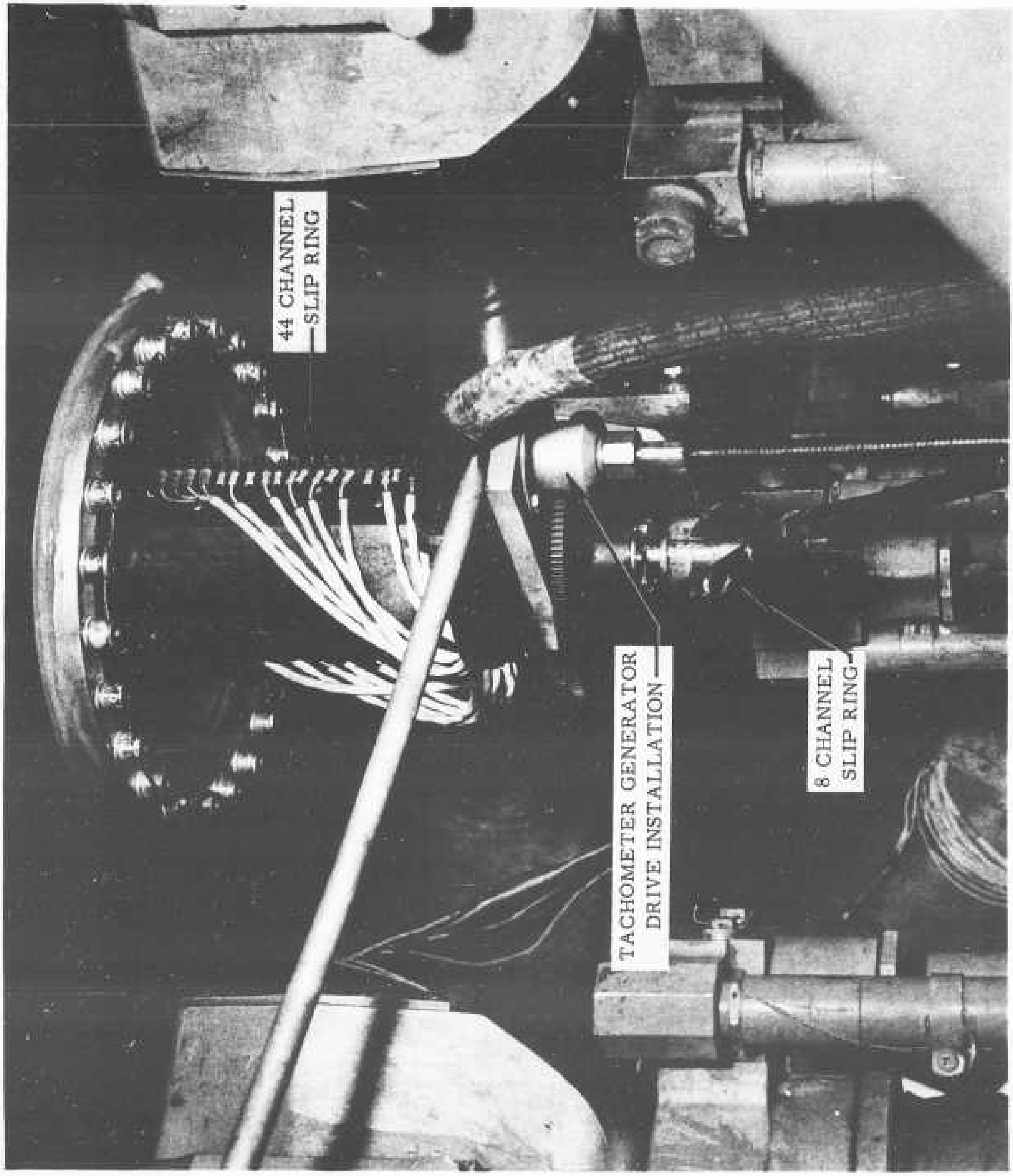


Figure 3.6-9 Slip Ring and Tachometer Drive Installations

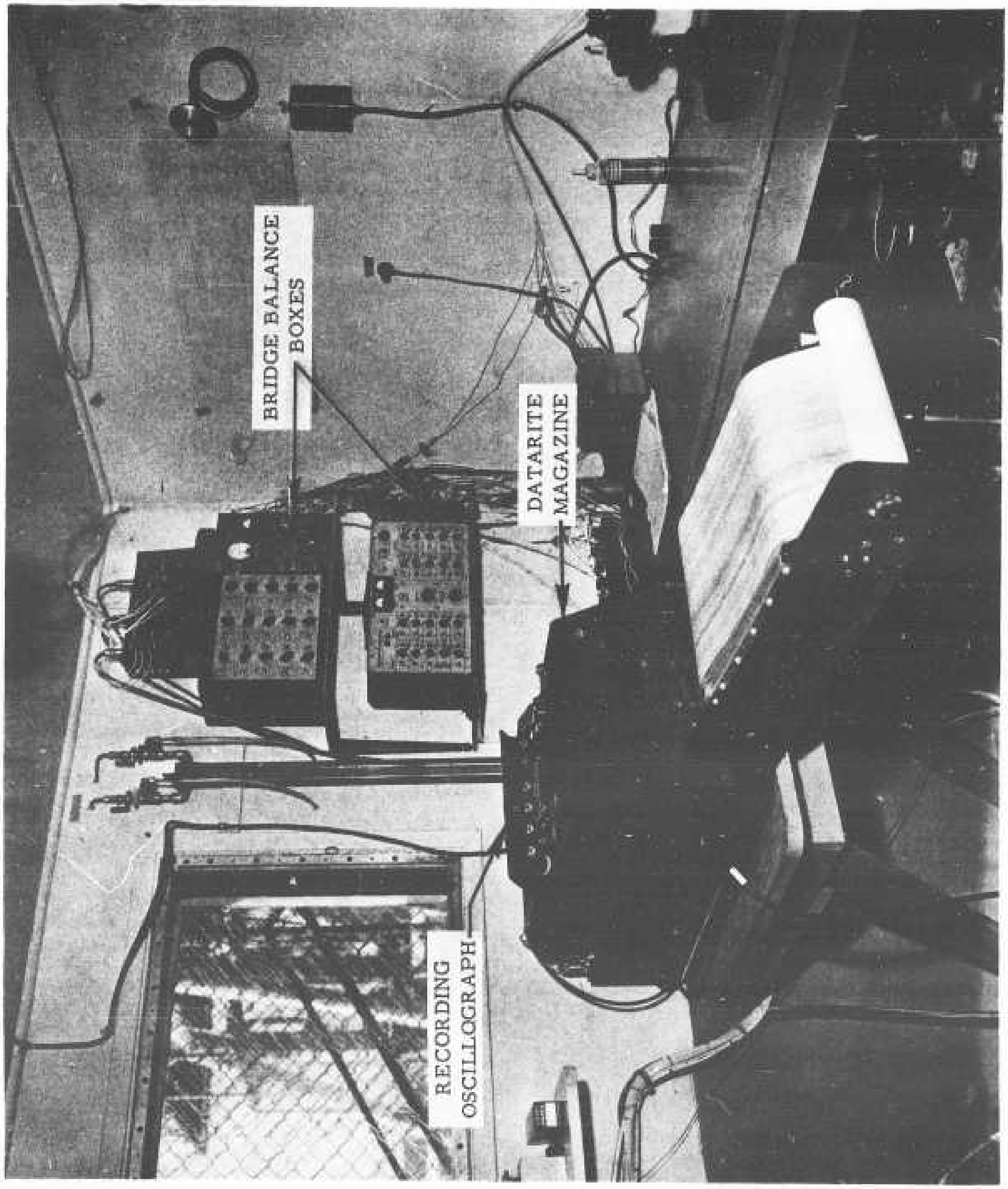


Figure 3.6-10 Oscillograph Installation

Datarite equipped with CEC 5-046 take up reel. The Datarite Magazine processed the record as it was taken, and so provided instant read-out of the test data. Kodak type 33 paper was used throughout the test and proved to be very satisfactory.

3.6.6.2 Thermocouple Instrumentation

a. Thermocouple Switches and Hot Reference Junction

The chromel-alumel thermocouple lead wire was run to the Minneapolis-Honeywell 918W2P aircraft type, 48 point switching unit which had compensated terminals. From the thermocouple switching units the thermocuple lead wires went to a Pace model FRJ-33-3 hot reference junction. The hot reference junction was used so that no error would be introduced by junction of dissimilar metals at the slip ring, plugs, etc.. The 48 point switching unit together with the hot reference junction is shown in Figure 3.6-5.

b. Thermocouple Slip Ring Installation

The thermocouple signal copper leads, together with six other wires necessary for the operation of the hot reference junction and switching units ran through the 285-0310-17 conduit assembly to an eight channel slip ring attached to the bottom of the 44 channel slip ring as shown on 285-0500. The eight channel slip ring can be seen in Figure 3.6-9.

c. Temperature Recorders

Temperatures from the rotor were recorded by a 12 point Brown recorder with a 0 to 1200°F capability. This combination of the 12 point recorder and the three 48 point switching units made it possible to read a total of 144 thermocouples. The Brown recorder and recorder control switches are shown in Figure 3.6-11.

Temperatures at the 285-1015 duct pressure rake installation were recorded on a Leeds and Northrup Speedomax H single point strip chart recorder. The recorder had a range of 0 to 1200°F. A manually operated thermocouple selector switch was provided to monitor the thermocouples. The recorder is shown in Figure 3.6-12.

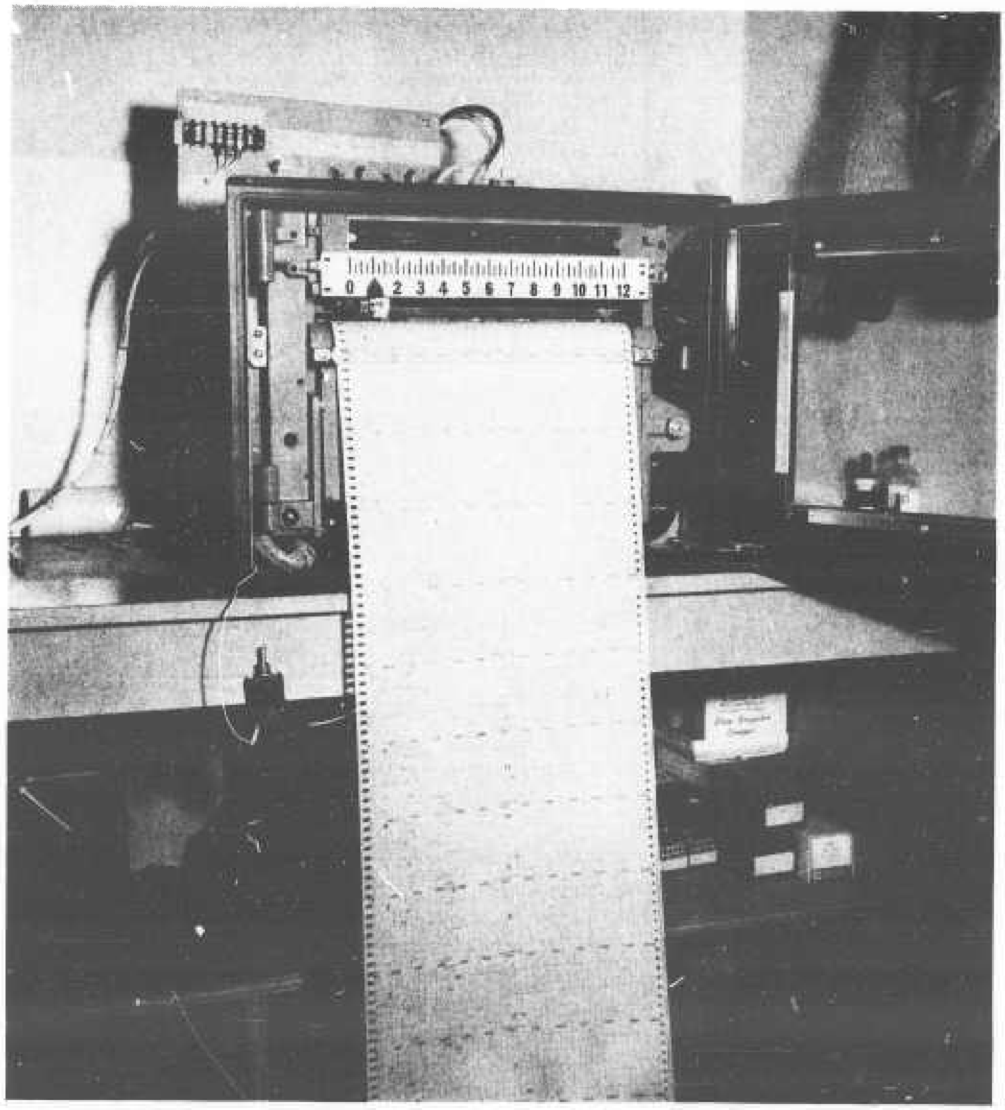


Figure 3.6-11 Brown 48-Point Temperature Recorder

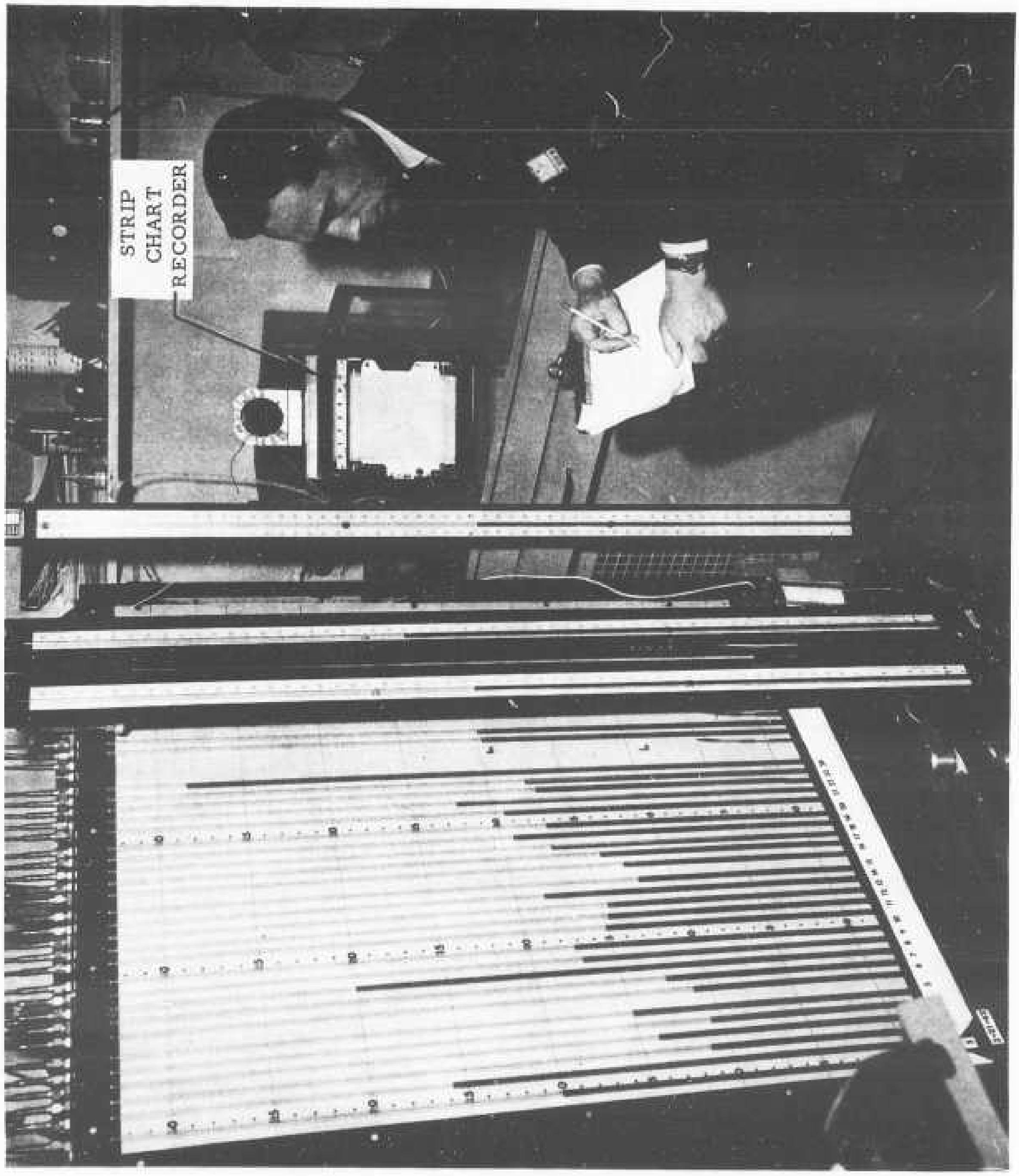


Figure 3.6-12 Multi-tube Manometer Bank and Single-Point Temperature Recorder

Turbine discharge temperature of the J-57 engine was recorded on a Leeds and Northrup Speedomax H single point strip chart recorder with a 0-1000°C temperature range. The recorder is shown in Figure 3.6-13.

Thrust bearing oil return temperature was monitored by a -0.5 to +10.5 millivolt Brown strip chart recorder. The recorder had a scale that was calibrated to read in degrees Fahrenheit. The recorder was connected to a Thermoelectric Company protected type chromel-alumel thermocouple inserted in the oil return line. The recorder is shown in Figure 3.6-13.

3.6.6.3 Manometers

Primary stream pressure distributions were measured with an HTC-AD fabricated 50 tube manometer. The fluid employed therein was TBE manometer fluid with a usable column height of approximately 48 inches. The reservoir pressure was monitored with a single tube, well type mercury manometer (Meriam) and although control of the engine was accomplished by continuous monitoring with a 30 psig maximum Helicoid Pressure Gage, another mercury manometer was used for accurate measurement of the turbine discharge pressure. Figure 3.6-16 is a photograph of these manometer instruments within the control van.

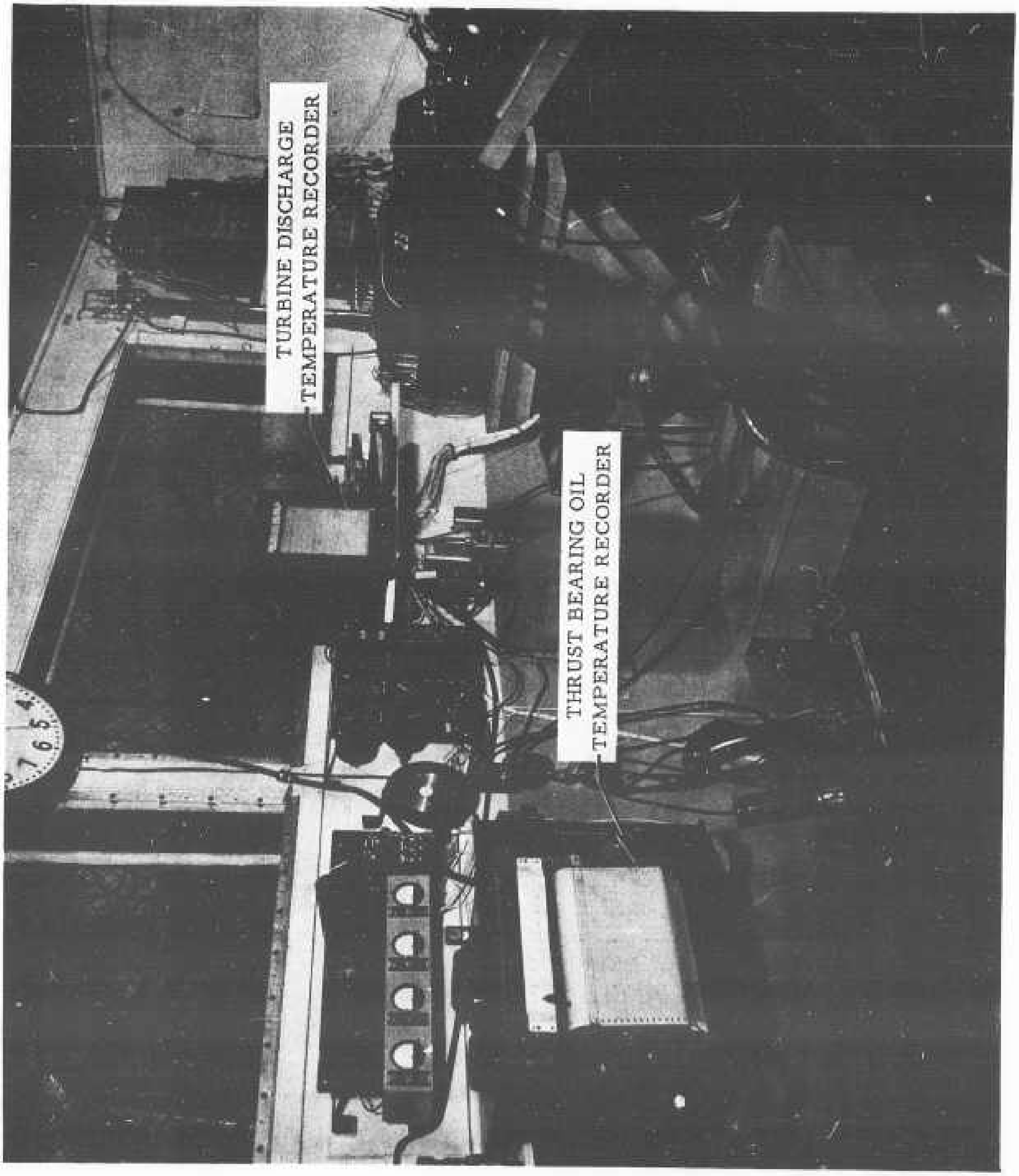


Figure 3.6-13 Engine Turbine Discharge and Rotor Bearing Oil Temperature Recorders

SECTION 4

DESCRIPTION OF TESTS

4.1 GENERAL

This section discusses the procedure used during the whirl test program and summarizes the test conditions. In general, the whirl test program was conducted in accordance with Report No. 285-8-3SR "Proposed Whirl Tower Program," dated November 1961 (Reference 4.1-1).

4.2 PROCEDURES

Following is an outline of the procedures for operation of the equipment described and shown previously in Section 3. The procedures were refined in the early tests and this outline was utilized thereafter in the conduction of the whirl tests.

4.2.1 Ground Equipment

a. Start hydraulic unit for engine oil cooler pumps.
b. Start hydraulic unit for rotor control power units.
c. Start auxiliary starter compressor.

4.2.2 Engine Starting Procedure

Pilot	Power Plant Eng.
	a. 28 V inverter switch to "on".
a. Place Collective Pitch control at 2^o or 4^o as required for particular test.	
b. Place Cyclic Pitch control in neutral.	
c. Start rotor bearing lubricating oil system, vacuum pump first.	
d. Power lever to "fuel cut-off".	
	b. Butterfly valve closed.
	c. Exhaust dump valve full open.
	d. Fuel shutoff valve - open.
	e. Oil cooling hydraulic system - on.
	f. Fuel boost pump - on.
	g. Energize starter (record time)
	h. At 8 to 10% N_2* - energize ignition.
e. At 12 to 15% N_2 move power lever to idle (fuel flow will move to 1000 PPH). Allow engine to accelerate to idle speed (approximately 60 to 70 rotor rpm).	

*N_2 = high pressure compressor rpm

i. Record time to reach idle rpm.
j. De-energize ignition when lite-off is evident.
k. De-energize starter at 25 to 30% N_2 rpm.

4.2.3 Test Procedure

Pilot | **Power Plant Eng.**

Power Plant Eng.:

a. When oscillograph has been calibrated, open butterfly to rotor.
b. Adjust exhaust dump valve to bring engine operation on line.

Pilot:

a. Increase power to produce 170 rpm to disengage centrifugally operated 2° rotor hub tilt stops. (watch for signal light)
b. Adjust cyclic pitch control to level swash plate.
c. Proceed with test maneuvers.

Power Plant Eng.:

c. Adjust exhaust dump valve as necessary to maintain on-line engine operation. For max temp tests adjust dump valve to reduce exhaust area and thus produce temp desired (off-line operation)

Pilot:

d. Following tests, return to 170 rpm.
e. Bring engine to idle.

Power Plant Eng.:

d. Close butterfly to rotor.

4.2.4 Engine Shutdown Procedure

Pilot | **Power Plant Eng.**

Pilot:

a. Power lever to idle for 5 minutes to stabilize engine temperatures.

b. Power lever to 75% N_2 to scavenge oil system for 30 seconds.
c. Power lever - off.

a. Fuel boost pump - off (when engine has stopped.)
b. Fuel shutoff valve - closed.
c. Oil cooling hydraulic system - off.

d. After rotor has coasted to stop, shut off rotor bearing lubricating oil system, pressure pump first.

d. Instrumentation and master electrical switch - off.

4.2.5 Unsatisfactory Engine Start

Note:
a. If fuel flow exceeds 1000 pph - discontinue the start.
b. If exhaust gas temperature exceeds 610°C (1130°F), even momentarily, discontinue start.

Pilot	Power Plant Eng.
a. Power lever - off.	
	a. Ignition switch - off.
	b. Starter switch - off.
	c. Fuel boost pump switch - off (when engine has stopped rotating)

Note: Purge engine exhaust system as follows

Pilot	Power Plant Eng.
b. Power lever - cutoff.	
	d. Ignition switch - off.
	e. Fuel boost pump - on.
	f. Fuel shutoff valve - open.
	g. Engine start switch - on.
	h. Maintain cranking for 10 to 20 seconds.
	i. Engine start switch - off.
	j. Fuel boost pump - off (when engine has stopped)

k. Fuel shutoff valve - closed.

4.2.6 Emergency Shutdown Procedure

4.2.6.1 Controlled Emergency

Pilot	Power Plant Eng.
a. Engine power lever to idle.	
	a. Open exhaust dump valve. b. Close butterfly valve.
b. Collective pitch control to 4-2°. c. Cyclic pitch control to approximately level hub position.	
	c. If possible comply with normal shutdown procedures above.

4.2.6.2 Uncontrolled Emergency

Pilot		Power Plant Eng.
a. Place power lever in cutoff	OR	Use emergency engine shutoff switch.
b. Dump collective pitch.		
c. Cyclic pitch control to approximately level hub position if emergency allows.		

4.3 TEST LOG

A detailed log of the tests is presented in Appendix B. Table 4.3-1 summarizes the hours spent at various temperature levels. The hours at each of the temperatures are further broken down to show the portion of time during the final 25 hours of running during which there were no change of components. Also shown in Table 4.3-1 are the exhaust temperatures of both the standard and an advanced version of the T-64 gas generator (ST129). It can be seen that a total of 5.5 hours were run at temperatures of 1200° to 1275°F which is equivalent to the Take Off rating (five-minute rating) of the T-64 (ST129). A total of 14.8 hours were run at engine discharge temperatures of 1100° to 1200° which is equivalent to the Take Off rating of the standard T-64 and to the Military Power rating of both the standard and ST129 versions of the T-64. Table 4.3-2 compares the hours run at Take Off and Military temperature levels with the hours of running required by Military specifications. Inasmuch as the Hot Cycle rotor is both a rotor and a portion of an engine, both rotor and engine 50 hour specifications are presented. It can be seen that the hours at the Take Off temperature level are approximately twice those called for in the specifications and the hours at the Military temperature level are three to five times the values in the Military specifications. Also shown in Table 4.3-2 is a comparison of the number of power transients performed during the whirl test program with those called for in the Military specifications. It can be seen that the number of transients performed is approximately equal to the average of the two specifications.

Table 4.3-3 lists all components replaced with new parts during the 60 hour whirl test program. The time at which the part was replaced and the total hours in service are tabulated, as well as the reason for the replacement. Note that there were no changes in components whatsoever during the final 25 hours of whirl testing.

TABLE 4.3-1

HOT CYCLE ROTOR WHIRL TEST

TEMPERATURE LOG

T_{T_7} °F Engine Discharge	Equivalent T-64 Engine Rating	Time at Temperature		
		0-35 Hours Whirl Test	35-60 Hours Whirl Test (No Change of Components)	Total
1200-1275	Take-off, ST129: 1225	3.2	2.3	5.5
1100-1200	Military, ST129: 1180 Take-off, Std: 1180 Military, Std: 1150	6.9	7.9	14.8
900-110	NRP, Std. and ST129: 1100 75% NRP, Std. and ST129: 1010	5.8	2.6	8.4
900		19.1	12.2	31.3
TOTALS		35.0	25.0	60.0

TABLE 4.3-2

COMPARISON OF WHIRL TEST WITH

MILITARY SPECIFICATIONS

Power Condition	Hot Cycle Whirl Test	MIL T 8679 50 Hour Rotor Ground Endurance	MIL E 8597 Engine PFRT
Take Off, hours	5.5	2.5	2.7
Military, hours	14.8	2.5	4.0
Number of Transients	37.0	30.0	48.0

TABLE 4.3-3

COMPONENTS REPLACED WITH NEW PARTS DURING WHIRL TEST

HTC-AD Dwg. No. and Description	Time - Rotor Hours			Reason
	Installed	Replaced	In Service	
285-0179-11 Sheet metal cyl. section of inboard artic. duct, 3 blades	0	1	1	Damage resulting from binding of artic. duct outboard seal.
285-0178-5 Flexure assy's of artic. duct inboard gimbal, 3 blades	0	1	1	" " " " " " " " "
	1	35	34	Conservative precaution. No sign of damage.
285-0162 Lip seal, artic. duct outboard, 3 blades	0	7	7	Replaced by 285-0217. Improved design to prevent binding.
285-0217 Lip seal, artic. duct outboard, 3 blades	7	18	11	Conservative precaution. Moderate wear. Small crack in one leaf of one seal.
	18	35	17	Conservative precaution. Moderate wear.
285-0161 Seal cyl., artic. duct outboard, 3 blades	0	35	35	Flame plate spalling due to effect of heat cycles on uneven coating on out-of-round base part.
285-0126 Blade feathering bearing ball, 1 blade	0	35	35	Chrome plate on alum. casting blistered
285-0155 Blade feathering fabric bearing, 2 blades	0	35	35	Teflon fabric scored in handling, 1 blade. Loose bond to metal at corners of fabric segments, 1 blade.

TABLE 4.3-3 (Continued)

COMPONENTS REPLACED WITH NEW PARTS DURING WHIRL TEST

HTC-AD Dwg. No. and Description	Time - Rotor Hours			Reason
	Installed	Replaced	In Service	
285-0121 Armalon anti-fret shims on blade strap, 3 blades	0	35	35	Handling damage.
285-0198 Armalon anti-fret shims on spars, 3 blades	0	35	35	Handling damage.
285-0160 Carbon seal segments, artic. duct inboard, 1 blade	0	35	35	Handling damage.
285-0590 Caron-faced unit, hub inner seal	0	35	35	Carbon softened and eroded.
285-0514 Hub gimbal bearings	0	35	35	Slight fretting.
285-0303 One large Timken bearing, control torque tube	0	35	35	Small amount of rust
285-0307 Rod end bearings, central control rods	0	35	35	To stay within estimated service life. No evidence of damage.
285-0313 Two Fafnir bearing, swashplate	0	35	35	Rust and some roughness.

SECTION 5

TEST RESULTS AND ANALYSIS

This section of the report presents test results and analysis in the areas of performance, dynamics, thermal considerations (temperature and leakage measurements) structure, sound, and post-test inspection.

5.1 PERFORMANCE

5.1.1 Summary

Section 5.1 presents the results of performance measurements made during the 60 hours whirl test program. It is shown that the two key parameters affecting the conversion of engine gas power to rotor power (duct friction coefficient and nozzle velocity coefficient) are both better than originally estimated. It is shown that the duct friction coefficient (and hence the pressure loss) for the test rotor is actually less than the value of .004 used for performance estimates. It is also shown that the nozzle velocity coefficient, which is a measure of efficiency of the tip nozzle in converting pressure energy to jet velocity is about 2-1/2% better than the value of .955 used for performance estimates.

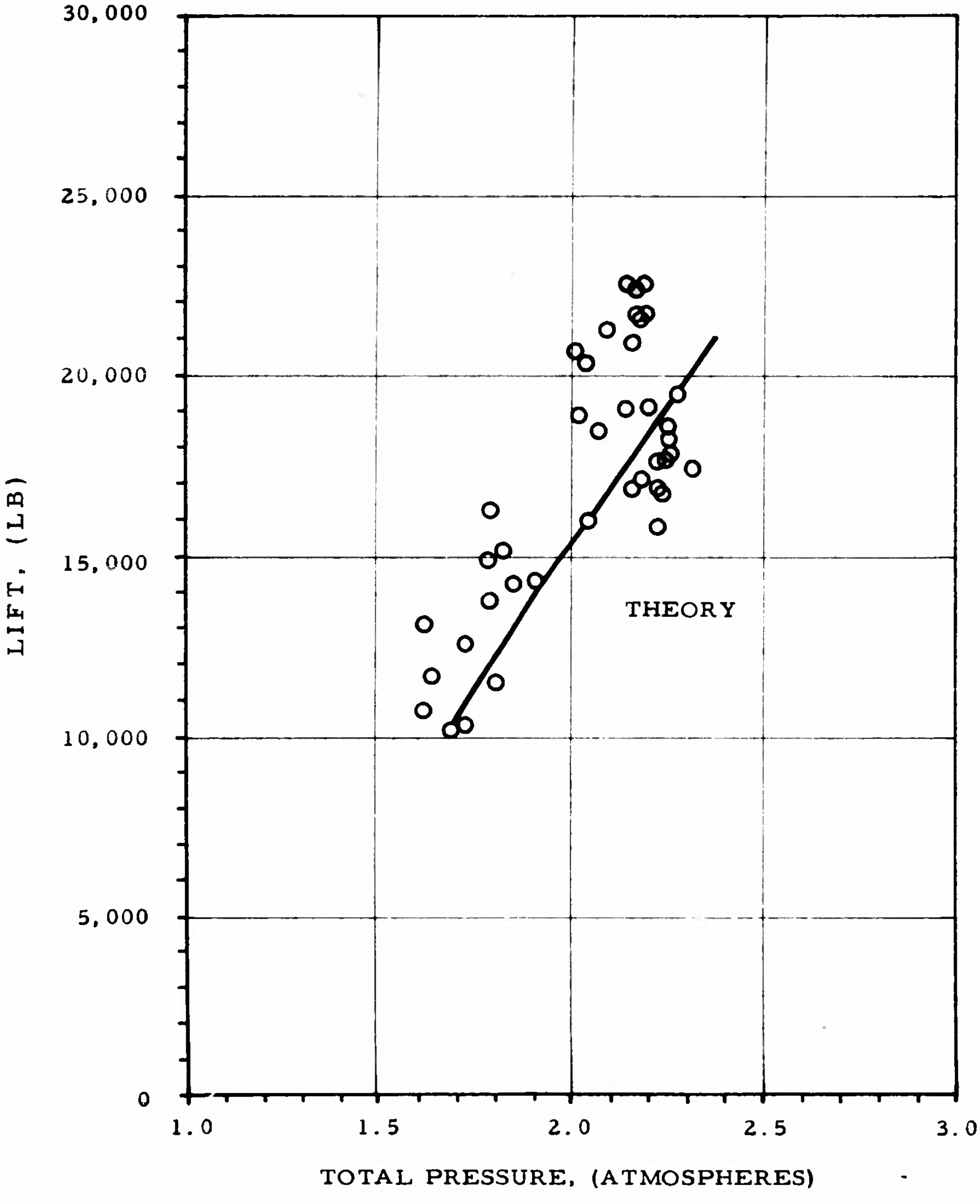
As an over-all check of the performance of the test rotor and propulsion system, Figure 5.1-1 presents a comparison of measured and predicted rotor thrust. It can be seen that the agreement is very good. In this figure, the values of thrust are plotted against total pressure at the rotating seal. In this section, the procedures required to calculate rotor thrust from measurements of total pressure and other data are described. Figure 5.1-1 also shows a maximum value of measured thrust of about 22,000 pounds. For the higher pressure ratio available from the T 64 gas generators ($\approx$2.8 atmospheres) the maximum thrust will be about 28,000 pounds.

5.1.2 Discussion

A performance analysis of the Hot Cycle Whirl Test System requires a study of the internal thermodynamics of the gas generator and ducting coupled with the external aerodynamics of the rotor blades. For simplicity, the performance of the J 57-P-19W gas generator, ducts, and blades are presented separately. Once introduced sequentially, however, the various analyses are assembled into an IBM-7090 computer program to permit a comparison of aerothermal predictions with strain gauge measurements of rotor thrust on the main rotor shaft and support pylons. This comparison, then permits a

FIGURE 5.1-1

HOT CYCLE WHIRL TEST PERFORMANCE



direct check on the over-all efficiency of the system. Also, through pressure and temperature measurements at several stations along the system, the thermodynamic performance can be studied in increments thereby permitting isolation of any possible problem areas.

Nomenclature for this work is given in Appendix F.

5. 1. 3 Internal Thermodynamic Performance

This section presents the pressure and temperature losses from the engine to the rotating seal (hub) station. Duct losses between the rotating seal station and nozzle inlet station are covered in Sections 5. 1. 5. 2 and 5. 1. 7. 1. These sections also present data on the tip nozzle coefficients.

5. 1. 3. 1 Pressure and Temperature Losses

Pressures, temperatures, and flow rates are provided by Table 5. 1-1. The station locations are identified by Figure D-1 in Appendix D. From Table 5. 1-1 column 5, it can be seen that generally, the duct loss in temperature between the engine and the rotating seal station is of the order of 80-100°F for high power runs. These values were fairly constant despite the fact that the blanket of insulation (fiberglass backed with aluminum foil) around the vertical ducts was saturated with rain water on occasion.

The total pressure loss parameter given by column 8 has a range from 0. 071 to 0. 098 showing a total pressure loss between the engine and the rotating seal station from 7. 1 to 9. 8% of engine discharge pressure. The variation of pressure loss is mostly due to changing the position of the exhaust dump valve for off-line operation and these losses agree well with the predicted values for the whirl test installation.

TABLE 5. 1-1

DUCT LOSSES FROM ENGINE TO ROTATING SEAL (HUB) STATION

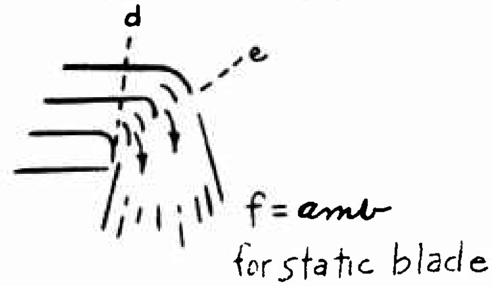
	1	2	3	4	5	6	7	8	9	10
Run	P_{T_7}	T_{T_7}	$P_{T_{Hub}}$	$T_{T_{Hub}}$	$T_{T_7} - T_{T_{Hub}}$	P_{T_7}/P_{amb}	W_{Hub}	$\frac{P_{T_7} - P_{T_{Hub}}}{P_{T_7}}$	T_{amb}	P_{amb}
No.	psia	^oF	psia	^oF	^oF	- -	Lb/Sec		^oF	psia
20	23. 97	707	21. 65	686	21	1. 623	32. 99	0. 097	56	14. 77
21	26. 43	788	23. 92	762	26	1. 790	36. 48	0. 095	56	14. 77
22	29. 58	878	26. 65	831	47	2. 003	40. 85	0. 098	56	14. 77
34	36. 91	1275	34. 08	1186	89	2. 492	46. 10	0. 077	50	14. 81
1	35. 43	1102	32. 56	1006	96	2. 397	47. 41	0. 081	49	14. 78
10*	35. 10	1166	32. 48	1071	95	2. 387	45. 09	0. 075	66	14. 70
11*	35. 30	1239	32. 80	1152	87	2. 401	44. 10	0. 071	66	14. 70
50*	34. 68	1076	31. 73	980	96	2. 362	45. 69	0. 085	62	14. 69
36	36. 37	1275	33. 56	1186	89	2. 455	45. 51	0. 077	55	14. 82
35	35. 05	1230	32. 44	1141	89	2. 366	44. 76	0. 074	54	14. 82
1	36. 33	1115	32. 90	1017	98	2. 452	46. 88	0. 095	49	14. 81

*Test runs of October and November, 1961. All other run numbers correspond to test series of February 27-28, 1962.

5. 1. 3. 2 Nozzle Coefficients

The effective velocity coefficient defined in Reference 5. 1-1 is:

$$C_{vf} = \frac{v_{eff}}{(v_f)_{IS}}$$



where, v_{eff} = jet velocity for full expansion to ambient pressure based on nozzle inlet (Sta. d) conditions = $\frac{F_g}{w/g}$

$(v_f)_{IS}$ = jet velocity for full isentropic expansion to ambient pressure based on nozzle inlet conditions = $\left\{\frac{2g T_{T_d} \gamma R}{\gamma - 1}\left[1 - \left(\frac{P_f}{P_{T_d}}\right)^{\frac{\gamma-1}{\gamma}}\right]\right\}^{1/2}$

A = flow area
p = density
F_g = gross thrust
P = static pressure
w = nozzle flow rate

This coefficient was measured on the tip nozzle as a function of nozzle pressure ratio with the blade non-rotating. From this test, it was seen that the effective velocity coefficient is approximately 0. 98 in the choked region $\left(P_{T_d}/P_f \geq 1.86\right)$ which is 2. 5% better than the 0. 955 value used in earlier performance predictions. Further, due to the discharge of the nozzles into a vortex wake region at the tip of the loaded rotor, the local back pressure on the nozzle is considerably below atmospheric ambient pressure. This causes early choking of the nozzle for engine discharge pressures corresponding to P_{T_d}/P_{amb} considerably below 1. 86. Or, for a loaded rotating blade, $P_{T_d}/P_f > P_{T_d}/P_{amb}$

This is pointed out to show that when considering the operation of the nozzle only, the coefficients may be defined in terms of the local back pressure P_f but for the overall performance of the ship, Pamb is the logical reference since it is the only measurable value.

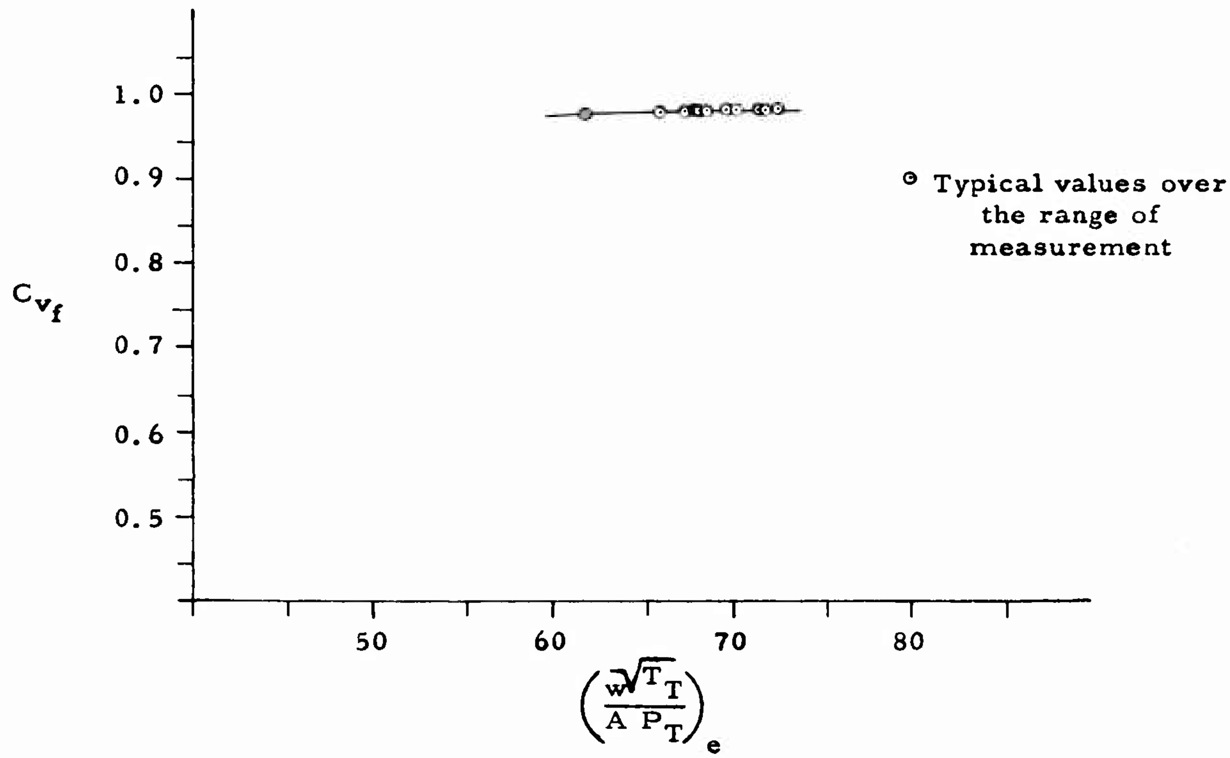
It was found that a rotational speed of 170 rpm (design normal = 240 rpm) at approximately 6° collective pitch was suitable to cause choked flow. For a wide range of engine power, rpm, and collective pitch, Figure 5.1-2 shows the effective velocity coefficient as a function of the nozzle exit flow parameter and shows an almost constant coefficient of approximate 0.98 throughout the performance range of interest. This is substantiated by Figure 5.1-3 which shows the actual and ideal flow vs nozzle pressure ratio (P_{T_d}/p_{amb}) utilizing nozzle coefficients corresponding to choked flow. The lower curve shows the flow function values corresponding to $(P_{T_d}/p_f) = (P_{T_d}/p_{amb})$ which is incorrect when applied to the rotating system as explained above.

5.1.3.3 Refinements of Weight Flow Measurement (See Fig. 5.1-4 for Branch Location)

A correct determination of the mass flow through the rotor is a requisite for accuracy in any subsequent performance calculation. Therefore, when in the early phase of the test program, discrepancies were discovered in the mass flow measurement, an effort was made to determine their origin. As the test data accumulated, it became apparent that in spite of symmetry of the test rig, the flow in the duct system was not symmetrical. In addition, the velocity distribution across the diameter of the duct was distinctly different from the Nikuradse profile used tentatively in previous computations. Eventually, these irregular conditions existing in the system were linked with the rotation of flow generated by the engine since the exhaust gas leaving the turbine disc at an angle contains considerable rotational energy. In a smooth and vaneless duct, the rotation is not immediately converted or dissipated. It moves along with the flow and substantially changes the velocity pattern from a classical distribution. From a large number of test runs taken over the entire range of rotor operation during October 27 through November 1, 1961, this

FIGURE 5.1-2

EFFECTIVE VELOCITY COEFFICIENT VS. FLOW FUNCTION



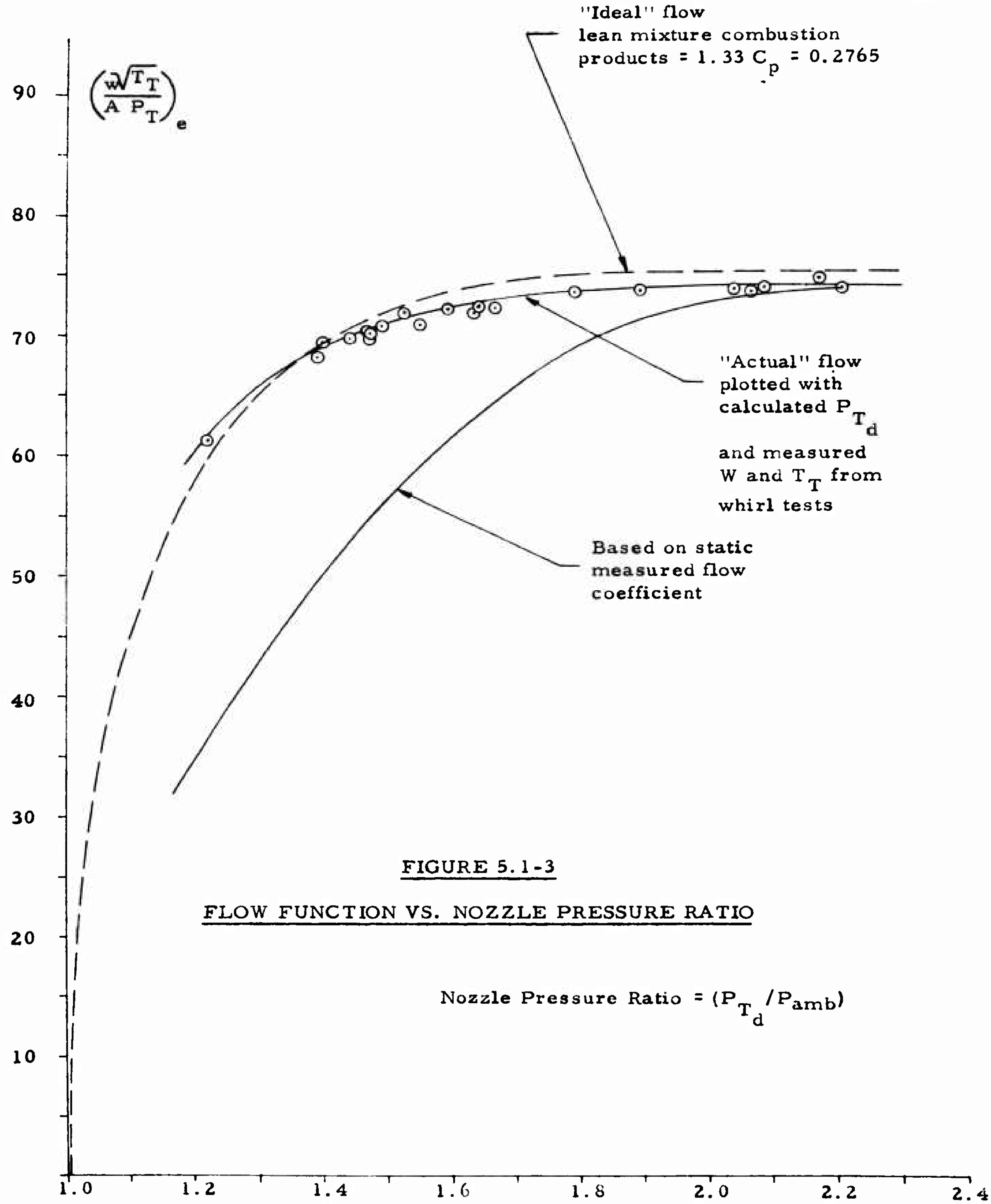


FIGURE 5.1-3

FLOW FUNCTION VS. NOZZLE PRESSURE RATIO

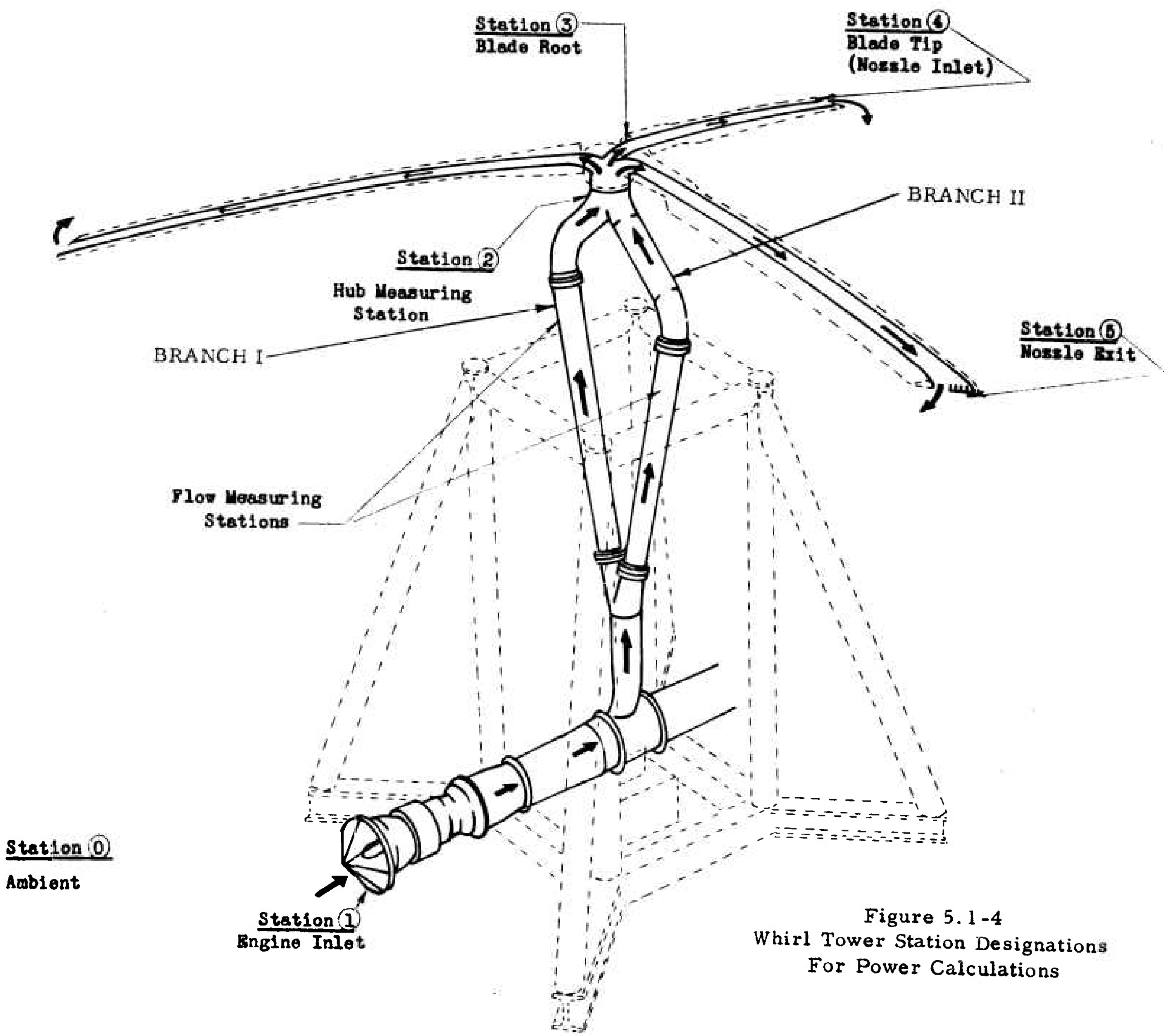


Figure 5.1-4
Whirl Tower Station Designations
For Power Calculations

pattern was found to be fairly stable.

The test data from the flow measuring stations showed that the velocity profiles from the Branch I station plotted as $\frac{v}{v_c}$ vs $\frac{r}{r_p}$ are almost flat in the center over about half of the duct diameter. The curves seem to be pivoted on the center and inclined at various angles from the inboard to the outboard side of the test rig. For the purpose of analysis all curves were transformed into the equivalent symmetrical profiles by plotting their mean ordinates. Or,

$$\frac{v}{v_c}\text{ mean} = 1/2 \left[\frac{v}{v_c}\text{ left} + \frac{v}{v_c}\right]\text{ right} ,$$

where r = radial distance from center line

r_p = pipe radius

v = local velocity

v_c = centerline velocity

left and right = corresponding radial positions either side of center line.

It must be noted that the area weighted velocity computed for the original profile remains unchanged after such a transformation. Applied graphically, this method allows a fast and direct comparison of the large number of test data. It was thus disclosed that when reduced to the symmetrical form, all velocity profiles nearly coincided. Later this significant observation led to a further simplification of the method used in evaluating the weight flow in the system. Additionally, in computing the average velocity, an assumption was made that the transformed profiles also represented the duct sections other than those in the plane of probes. With this assumption, which incidentally is believed to represent the actual flow, a constant could be found showing how the average velocity at the flow measuring station of Branch I is related to the velocity measured in the duct center. Similarly, another constant relationship $\left(\frac{v}{v_c}\right)_{\text{average}}$ was determined for the flow at the Branch II station. Although the velocity distribution in Branch II was markedly different, the same rules as described above were applicable. When the data from 50 test runs were analyzed, over 90% of the transformed profiles were found to be within $\pm$ 1% from their mean value. This narrow spread most likely reflects the error of measurement. Outside of that band, the remaining 10% of the runs did not have a deviation exceeding 3% of the mean value.

In Branch I, low rotation tends to produce the steepest velocity profile.

On the other hand high rotation tends to produce flatter profiles. The range from steep to flat is very small, namely an average velocity equal to .93 v_c to .95 v_c. In Branch II, rotation seems to act in the opposite direction, with effects less visible. The average velocities of the runs analyzed is represented by 935 and 927 as used for the Z_1 and Z_2 values in the computer program (see Appendix D). The interesting fact is that although the average values for Branches I and II may deviate up to .95 v_c and .91 v_c respectively, their mean value remains the same throughout all runs (around .93 v_c). The implication of this relationship is very convenient.

Figures 5.1-5 and 5.1-6 show the typical velocity profiles in Branch I and Branch II respectively. A series of five tests was selected for the purpose of illustrating conditions existing in both ducts. The test runs, taken at a constant pitch of 9^o, cover the range of rpm from 170 to 240. The difference in velocity distribution between Branch I and II is obvious. The spread of the "equivalent" profiles in the two branches is respectively less than $\pm$ .6% and less than $\pm$ .2%. It is seen that the similarity of the "equivalent" profiles persists in spite of the varying power and the apparent scatter of actual velocity profiles.

Figure 5.1-7 shows the accumulated results from the 50 tests with both branches being included. The cross hatched areas around the two "average" profiles include also the most deviated profiles. The heavy line contours represent the majority of 90% of the test runs. Included for comparison are two analytically defined Nikuradse contours. These are drawn for the extreme Reynolds numbers that may occur in the duct. The more pronounced fullness of the actual profiles can be expected as the result of wall cooling of the hot gases which is the present case. The difference between Branch I and Branch II profiles is attributed mainly to rotation.

Figures 5.1-8 and 5.1-9 show a further step in computing the average velocity. The curves on Figure 5.1-8 are directly derived from the Branch I average contour (heavy line) shown in Figure 5.1-7. Figure 5.1-9 similarly corresponds to Branch II of Figure 5.1-7. The area under the upper curves is equal to the result of the integral defining the area weighted total velocity. The area under the lower curve equals the integral used in computing the mass weighted total pressure (see Appendix C).

5.1.4 J 57 Performance

Various aspects of the J 57 engine performance and operational characteristics are presented in Section 3.4 and Reference 3.4-2. To determine the engine air injection rate, an enthalpy balance across the engine is made as follows:

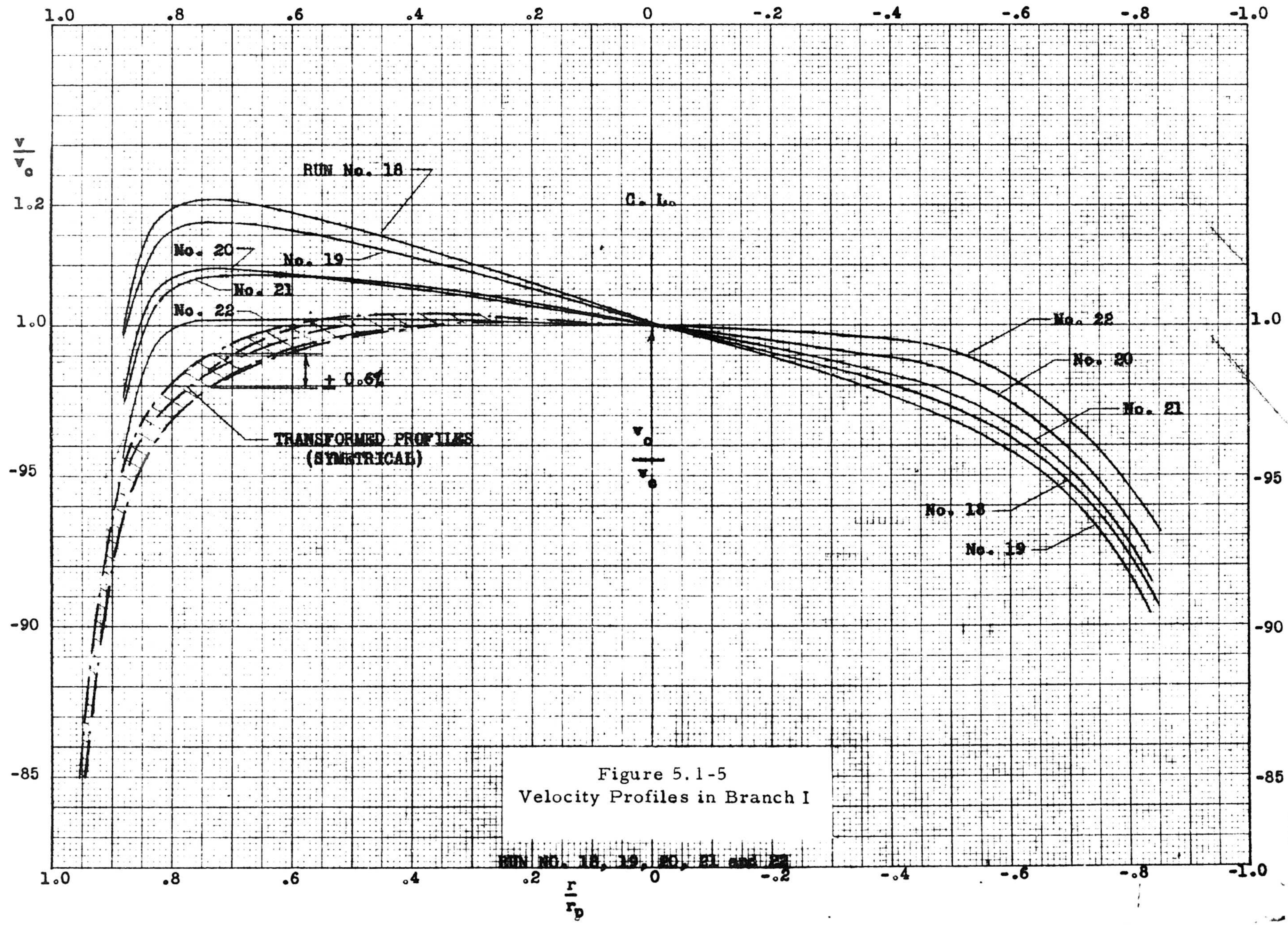


Figure 5.1-5
Velocity Profiles in Branch I

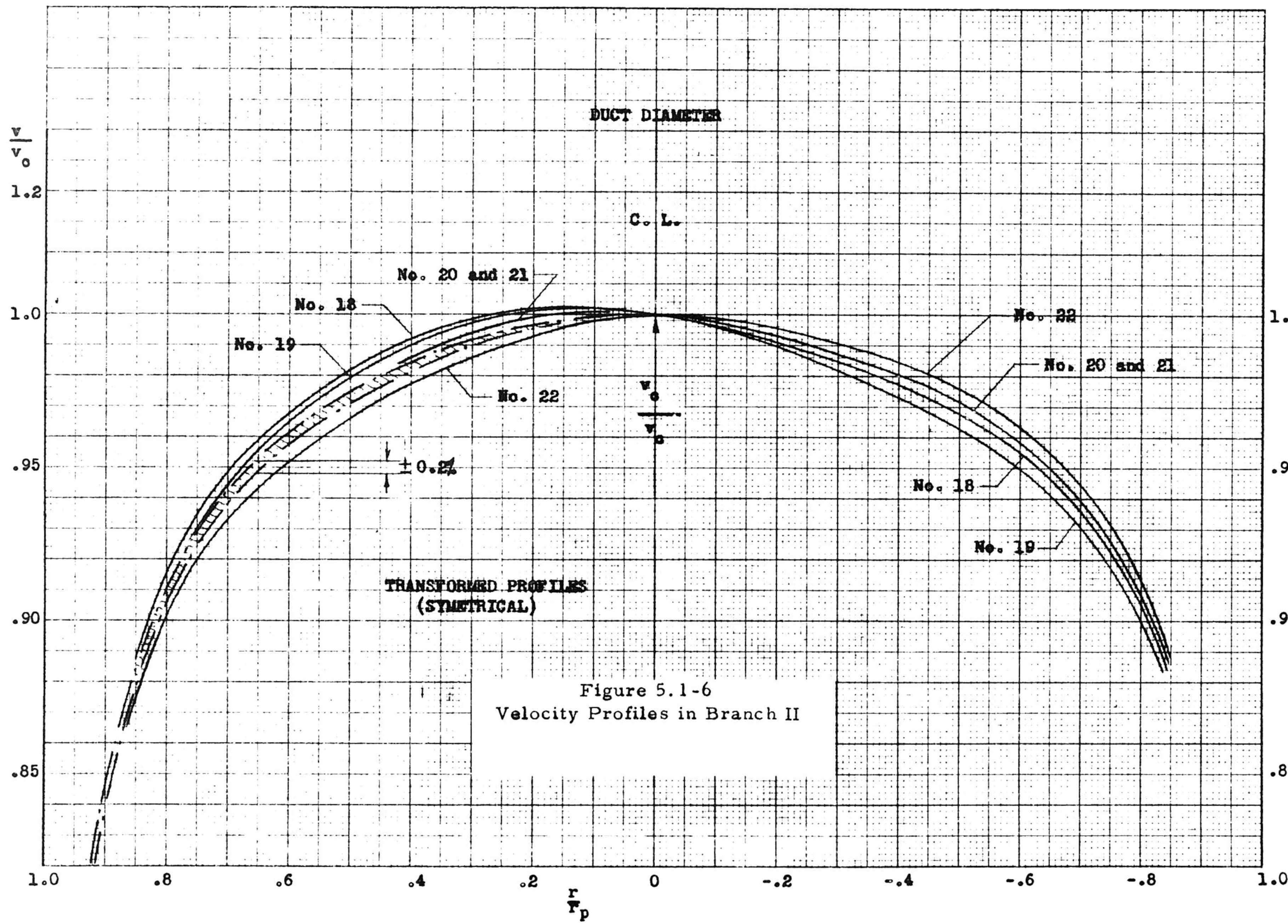


Figure 5.1-6
Velocity Profiles in Branch II

KEUFFEL & ESSER CO. 59-1

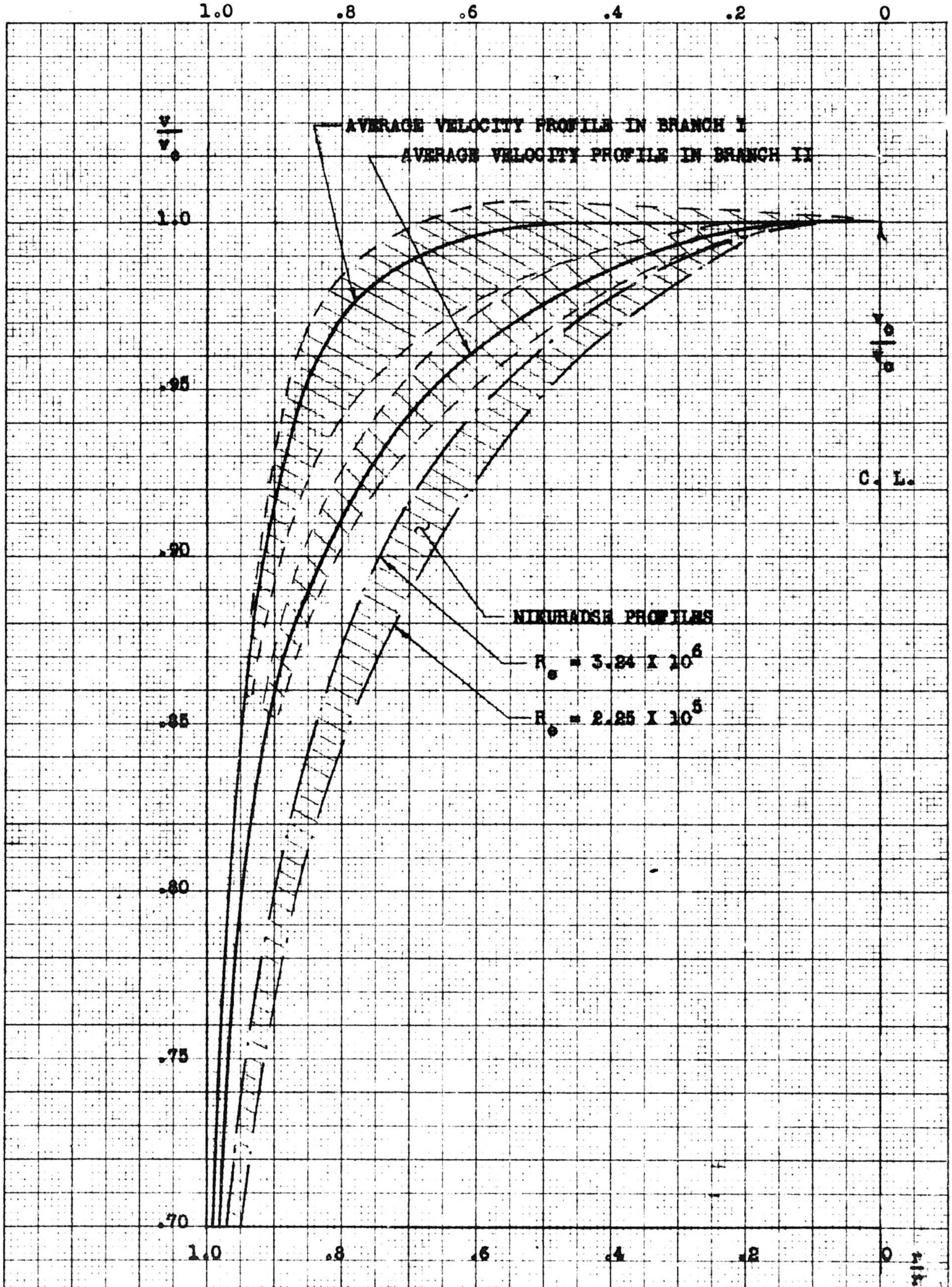


Figure 5.1-7
Average Velocity Profiles

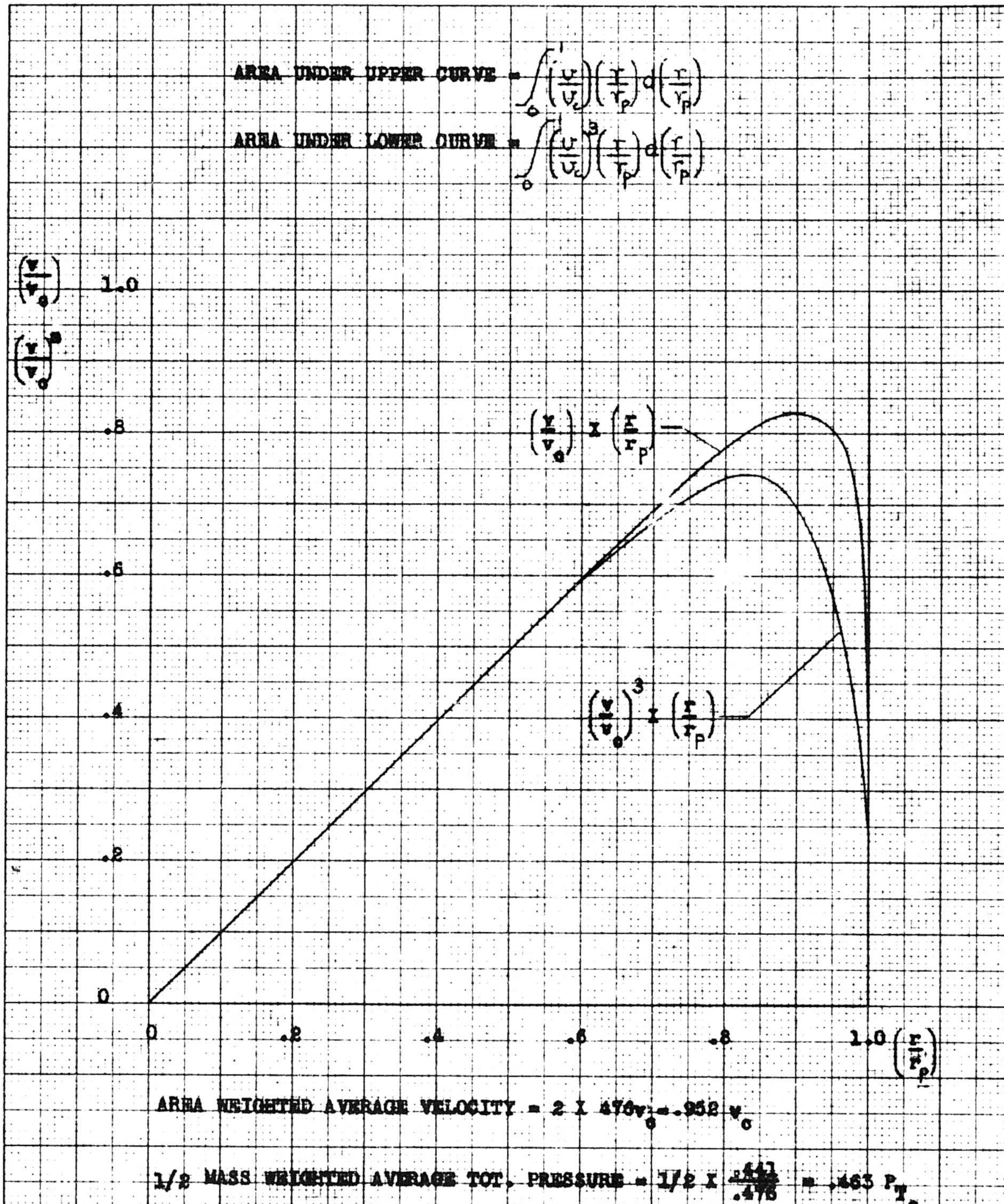


Figure 5.1-8
Graphical Integration of Average Velocity Profile in Branch I from Figure 5.1-7

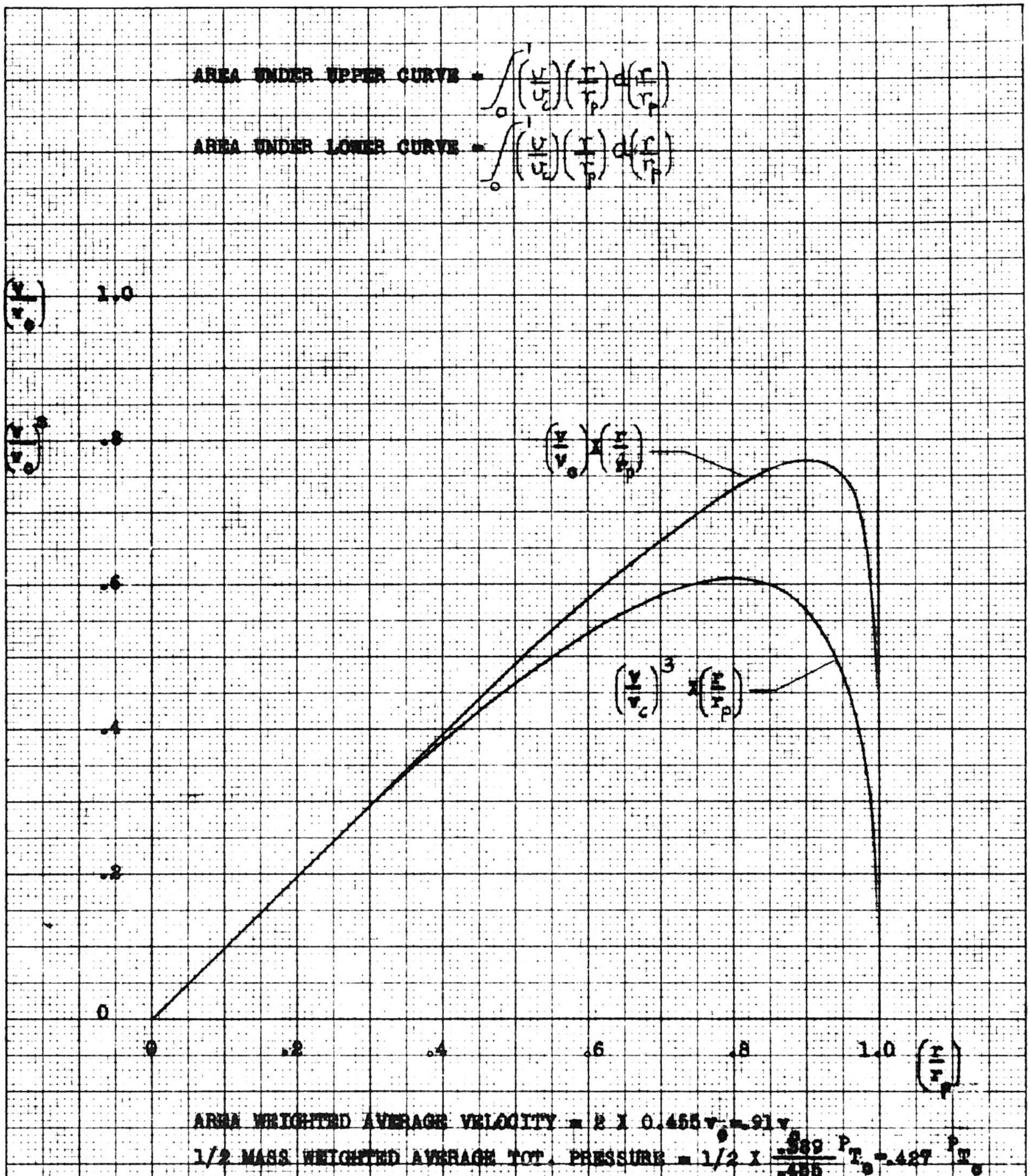


Figure 5.1-9
Graphical Integration of Average Velocity
Profile in Branch II from Figure 5.1-7

$$W_{a_2} h_{T_2} + \eta_B W_f Q_f = h_{T_7} W_7$$

Where	W_{a_2}	compressor inlet air flow rate
	h_{T2}	total enthalpy of incoming air
	η_B	combustion efficiency ($\approx$ 0.96)
	Q_f	lower heating value of JP-4 fuel ($\approx$ 18,400 BTU/LB)
	W_f	fuel flow rate
	h_{T_7}	total enthalpy at turbine exhaust (400% theoretical air)
	W_7	turbine exhaust gas flow rate. $= W_{a_2} + W_f$

Thus, the engine air ingestion rate is

$$W_{a_2} = \frac{(\eta_B Q_f - h_{T_7})}{h_{T_7} - h_{T_2}} W_f.$$

This equation is employed in the Non-Rotating Component equations of Appendix D.

The h_{T_2} values for air are taken from Reference 5.1-4 and are linearized over the ambient temperature range for use in the computer program. Also, the h_{T_7} values are taken from the same reference for 400% theoretical air and is linearized over three temperature ranges for use. The values of specific heat at constant pressure and volume as well as gas constant is computed by the method of Reference 5.1-5.

5.1.5 Rotor Power

To determine the rotor power through aerothermal analysis, the system is separated into two components (rotating and non-rotating) and the corresponding analyses are programmed for the IBM 7090 in subroutine form. For convenience the nomenclature and the input and output formats are given in Appendix F.

5.1.5.1 Non-Rotating Components

The non-rotating components include the J 57 gas generator and ducts required to deliver the hot gas to the rotor hub. Due to the length of the calculation, the details are given in Appendix D.

5.1.5.2 Rotating Components

The rotor power available is computed from the gas conditions of mass flow, temperature, and pressure existing at the tips of the rotating blades. These conditions differ from those at the rotor hub because of friction and centrifugal force acting on the gas. The gas conditions at the rotor hub are assumed equal to those discharging from the non-rotating ducting, described in Section 5.1.5.1. The calculation procedure for computing the changes of gas conditions in going from hub to blade tip is described in Reference 5.1-3. Reference 5.1-3 is based on one dimensional, compressible flow relations developed in Reference 5.1-6 and extended to the rotating helicopter blade case in Reference 5.1-7. Because the treatment of References 5.1-3, -6, and -7 is one dimensional, it was necessary to anticipate a simplification of what is really a complicated three-dimensional flow by computing the output gas conditions on a mass and/or area weighted basis. The gas conditions derived in Appendix D and computed in Steps 38, 100a and 100b are then used directly in this section. The equations that are used to convert gas conditions at the rotor hub to rotor power at the blade tips are as follows:

(1) Blade Root Pressure Ratio

$$P_{T_3} = P_o \times r_2 \times \left(\frac{r_3}{r_2}\right)$$

Where $r_2 = \overline{P}_{T\ Hub}/P_o$

(2) Blade Duct Inlet Number
(Substitute values of W, T_{T_3}, and P_{T_3}, and iterate to 0.1% to find M_3)

$$\left(\frac{W\sqrt{T_T}}{A\ P_T}\right)_3 = \frac{M_3\sqrt{\frac{\gamma g}{R}}}{\left(1+\frac{\gamma-1}{2}M_3^{\,2}\right)^{\frac{\gamma+1}{2(\gamma-1)}}}$$

(3) Change in Mach Number Through Blade Duct

The blade is arbitrarily broken into 100 equal steps for analysis purposes.

$$\therefore \quad \frac{\Delta r}{R} = .01$$

Steps are then numbered n = 0, 1, 2, 3, ...99.

$$M = M_3 \quad (n = 0)$$

$$\Delta M = \frac{2 f \gamma R}{D}\left(\frac{\Delta r}{R}\right)\frac{M^3\left(1 + \frac{\gamma - 1}{2} M^2\right)}{(1 - M^2)}$$

$$- \frac{{V_T}^2 M\left(1 + \frac{\gamma - 1}{2} M^2\right)^2}{g\,(C_p - C_v)\, J\, T_{T_3}\,(1 - M^2)}\left(\frac{2n + 1}{2}\right)\left(\frac{\Delta r}{R}\right)^2$$

$$M_{n=1} = M_3 + \Delta M_{n=0}$$

$$M_{n=2} = M_{n=1} + \Delta M_{n=1}$$

$$M_4 = M_{TIP} = M_{n=99} + \Delta M_{n=99}$$

(4) Pressure Ratio Produced by the Rotation Blade
(Constant duct area, constant total temperature)

$$\frac{\text{Total pressure at tip}}{\text{Total pressure at root}} = \left(\frac{r_4}{r_3}\right)$$

$$= \frac{M_3}{M_4}\left(\frac{1 + \frac{\gamma - 1}{2} {M_4}^2}{1 + \frac{\gamma - 1}{2} {M_3}^2}\right)^{\frac{\gamma + 1}{2(\gamma - 1)}}$$

(5) Gas Conditions at Blade Tip

Mass Flow $W_{g_4} = W_g$

Temperature $T_{T_4} = T_{T_3} = T_{T_2}$

Pressure Ratio $r_4 = r_2 \times \left(\frac{r_3}{r_2}\right) \times \left(\frac{r_4}{r_3}\right)$

(6) Jet Velocity

$$V_j = C_{v_e} \sqrt{2\ g\ J\ C_p\ T_{T_4} \left[1 - \left(\frac{1}{r_4}\right)^{\frac{\gamma-1}{\gamma}}\right]}$$

(7) Rotor Power Available

$$RHP = \frac{W_g\ (V_j - V_T)\ V_T}{g \times 550}$$

It should be noted that computation of rotor power available depends on the value of several coefficients which are functions of the particular Hot Cycle hardware. These coefficients include ζ, the blade duct friction coefficient, C_{V_e}, the nozzle velocity coefficient, and r_3/r_2, the ratio of total pressure at the blade root to that at the rotor hub. These coefficients are established by tests such as References 5.1-1 or 5.1-8, or are given reasonable values based on tests of similar components. Reference 5.1-1 permits determination of C_w, the nozzle flow coefficient, as well as C_{V_e}, the velocity coefficient. However, it was necessary to assume a value for ζ, the duct friction coefficient. By using the flow function, Equation 2, it is possible to make a cross-check on the assumed value of ζ. This is accomplished by recognizing that if there are no leaks, all of the mass flow that leaves the rotor hub must pass through the blade nozzles, which have total area A_N. With the assumption of fixed gas temperature from the hub to the blade tip (which was found to be quite reasonable during whirl tests), the total pressure at the nozzle is therefore fixed. Since the pressure ratio at the hub, $r_2 = P_T \text{ hub}/P_o$ is known, and the pressure ratio from the hub to the blade root, r_3/r_2 is also available, the blade pressure ratio $(r_4/r_3)_N$ that will satisfy the flow function at the nozzle is therefore determined.

Since r_4/r_3 is a function of ζ, in Equations (3) and (4), the accuracy of the assumed value of ζ can be established by comparing the values of r_4/r_3 from Equation (4) with $(r_4/r_3)_N$ from Equation (15). The procedure used to compute $(r_4/r_3)_N$ is as follows; (An iterative procedure is required to establish nozzle pressure ratio.):

(8) Critical Nozzle Pressure Ratio

$$r_{4_{CRIT}} = \left(1 + \frac{\gamma - 1}{2}\right)^{\frac{\gamma}{\gamma - 1}}$$

(9) Initial Assumed Value of Nozzle Pressure Ratio

$$r_{4_a} = (r_4)_{assumed} = 1.15\, r_2$$

(10) Nozzle Mach Number for Assumed Nozzle Pressure Ratio

If $r_{4_a} > r_{4\,crit.}$, $M_5 = 1.000$, otherwise, use following equation:

$$M_5 = \sqrt{\frac{(r_{4_a})^{\frac{\gamma - 1}{\gamma}} - 1}{\frac{\gamma - 1}{2}}}$$

(11) Flow Function at Nozzle Mach Number

$$\left(\frac{W\sqrt{T_T}}{A\;\;P_T}\right)_5 = X = \frac{M_5\sqrt{\frac{\gamma g}{R}}}{\left(1 + \frac{\gamma - 1}{2} M_5{}^2\right)^{\frac{\gamma + 1}{2(\gamma - 1)}}}$$

(12) Nozzle Flow Coefficient C_W

Find C_W for assumed value of r_{4_a}, or assume value $\cong$ .98

(13) Computed Nozzle Pressure Ratio

$$r_{4\,comp.} = \frac{W_g \sqrt{T_T}}{C_w\, A_n\, P_o\, X}$$

(14) Iterated Value of Nozzle Pressure Ratio

If $r_{4comp} < r_{4a}$, reduce r_{4a} by .01 and repeat 10, 11, 12, and 13 until $r_{4comp} \geqslant r_{4a}$. This last value of $r_{4a} = r_{4comp}$.

(15) Blade Pressure Ratio Based on Flow Through Nozzle $(r_4/r_3)_N$

$$(r_4/r_3)_N = \frac{r_{4comp}}{r_2 \times \left(\frac{r_3}{r_4}\right)}$$

The value of $(r_4/r_3)_N$ can be compared to r_4/r_3 of Equation (4) to evaluate the assumed value of duct friction coefficient f.

5. 1. 6 Rotor Thrust Calculation

The computed thrust of the rotor in hovering is determined from the rotor power available and the rotor geometry using standard NACA methods presented in Reference 5. 1-9. The approach is to make the power available equal to the power required; the power required is the sum of the induced power and the profile power. The geometry of the whirl test tower introduces some ground effect; its influence on induced power is determined from the empirical data presented in Figure 5-13 of Reference 5. 1-9. The profile power coefficient presented in Reference 5. 1-9 was obtained for a 12% thick blade. As the Hot Cycle blades are 18% thick, the profile power has been increased by 17% to allow for the increased drag of the thicker section. The blades are twisted -8°; therefore the correction to the over-all power coefficient presented on page 85 of Reference 5. 1-9 is used. Applying the above factors, the equation for power as a function of thrust - Equation 36 of Reference 5. 1-9 becomes:

$$C_P = \sigma_1 \left[\frac{C_T^{\;3/2}}{\sqrt{2}\,B} \left(\frac{T\infty}{T}\right)^{3/2} + 1.17 \left(\frac{\sigma \delta_0}{8} + \frac{2}{3}\,\frac{\delta_1}{a}\,\frac{C_T}{B^2} + \frac{4\delta_2}{\sigma a^2} \left(\frac{C_T}{B^2}\right)^2 \right) \right]$$

This equation is iterated for various values of thrust until the power required is equal to the power available from Section 5. 1. 5.

5.1.7 Rotor Thrust Measurement

The best evidence of the performance of the hot cycle rotor is a direct comparison of measured and computed rotor thrust as a function of engine power. Data were obtained during the 60 hour endurance test and reduced according to the procedures discussed in Section 5.1.5.1 and 5.1.5.2 on Non-Rotating and Rotating Ducting, and Section 5.1.6 on Rotor Thrust. Excellent agreement was obtained for the over-all performance conversion of measured engine output to measured rotor thrust.

5.1.7.1 Rotating Duct Thermodynamics

Computed rotor thrust and measured rotor thrust are both direct functions of rotor power. Rotor power in turn is critically dependent on the actual hardware duct friction coefficient, f, and nozzle velocity coefficient, ${}^{C}V_e$. These two factors are the biggest unknowns in the rotating system. In the initial design stages, assumed values of f = 0.004 and ${}^{C}V_e = 0.955$ were chosen. All performance predicitions in application studies such as Reference 5.1-10 and in the whirl tower performance estimate, Reference 5.1-3 were based on these values of f and ${}^{C}V_e$.

The velocity coefficient ${}^{C}V_e$ was measured during the tether tests discussed in Reference 5.1-1. It is shown in that report that, at maximum nozzle pressure ratios, the measured velocity coefficient of the tip cascade is equal to 0.98 at pressure ratios corresponding to those available from the T-64 gas generator (2.6 - 2.9). This measured value is approximately 2.5% higher than the assumed value of 0.955.

The duct friction coefficient of f = 0.004 was shown to be conservative by comparison of nozzle pressure ratio derived in two different ways. A reference value of r_4 was computed by starting from the hub pressure ratio r_2, multiplying it by the assumed value of

$$\left(\frac{r_3}{r_2}\right)$$

and multiplying again by the blade pressure ratio

$$\left(\frac{r_4}{r_3}\right)$$

which is a function of the assumed duct friction coefficient, f = 0.004 (Equations (1) through (5) of 5.1.5.2). A second value of nozzle pressure ratio, r_{4_N} was computed using the nozzle flow function equation and making the assumption that all of the mass flow that passed through the hub measuring station also passed through the tip nozzle. No evidence whatsoever was found of any appreciable leaks, so it is felt reasonalbe to assume all the gas went out the tip nozzle. When this second value of tip nozzle pressure ration was computed (r_{4_N}, from Equations (8) through (15) of Section 5.1.5.2), it was found that r_{4_N} was 5 to 6% higher than the reference value based on computations using f = 0.004. The tip nozzle pressure ratio computed for the nozzle, r_{4_N}, is the actual pressure ratio required to push the measured mass flow through the nozzle If any lower pressure is available the mass flow will not go through the nozzle. Since it was established that the measured flow did go through the tip nozzles, the reference pressure ratio based on the duct friction coefficient was too low. Since a low computed nozzle pressure is caused by a high duct friction coefficient, a reduction of duct friction coefficient will permit the nozzle pressure based on f to rise to the value permitted by the nozzle equation, r_{4_N}. Therefore, the duct friction must be somewhat lower than the assumed value of 0.004. Consequently, performance computations based on f = 0.004 are conservative, and higher rotor powers will be computed when the lower and more accurate value of f is established.

5.1.7.2 Rotor Aerodynamics

Figure 5.1-1 shows that measured rotor thrust agrees very well with the computer rotor thrust as a function of rotating seal pressure ratio, up to the maximum value available from the J-57 turbojet used during the whirl tests. The calculated curve of Figure 5.1-1 includes an allowance for the power required to centrifically pump the spar cooling air on the test rotor. The mean value of maximum measured lift was approximately 20,000 pounds, at a seal pressure ratio of 2.2 atmosphere. It should be noted that extrapolation of the J-57 data (which agrees very well with theory) indicates that the rotor will produce over 28,000 pounds of lift at a 2.82 pressure ratio which is available from the ST129 model of the T-64 gas generator.

5.2 ROTOR DYNAMICS

A free floating hub configuration was selected for the Hot Cycle Rotor to avoid the need for lead-lag hinges. No dynamic or flutter problems were evidenced during the entire whirl test program. During the early phases of the program, while building up to higher values of rpm and collective pitch, the cyclic and collective controls were pulsed to establish proximity to resonance of flutter conditions. At no time were such conditions in evidence.

Reference 5.2-1 discusses the calculated dynamic characteristics of the Hot Cycle rotor and concludes that there are no resonant conditions in the operating rotor speed range. The absence of any dynamic problems during the whirl test program substantiates the prediction of Reference 5.2-1.

5.3 TEMPERATURE AND LEAKAGE SURVEYS

5.3.1 Comparison of Design With Measured Temperatures

5.3.1.1 Summary

Table 5.3-1 compares measured and estimated component temperatures corresponding to gas temperature as measured at the flow measuring stations. No correction is made to account for the difference in ambient conditions. The analysis of all data leads to the following conclusions:

a. The temperatures of the duct and flexures are as predicted.

b. All remaining components operate at temperatures considerably lower than predicted. Spars, outer skin, and hub temperatures compared with the estimates are more than 40% or 50% cooler. These low thermocouple readings are confirmed by indications of temperature sensitive tape checked at corresponding locations.

5.3.1.2 Discussion

This section contains a brief study of temperature distribution prevailing in the hot cycle rotor under maximum operating conditions. The objective was to provide:

a. A comprehensive presentation of data from the whirl test program.

b. A check of all component temperatures earlier predicted in Reference 5.3-1.

Several figures are prepared to enable a quick review of thermal conditions in the whirling rotor. Where applicable, the "predicted" reference temperature is included for a direct comparison with the measured temperatures. An interpolation equation is given below for reducing estimates to correspond to the actual test component temperatures.

$$T = 100 + \frac{(T_{1200} - 100)(T_{gas} - 100)}{1100}$$

This equation was applied when correcting data tabulated in the summary. It appears that corrections are small and in many cases the basic prediction from Reference 5.3-1 can be used either as a reference or as an indication of the highest possible temperature. The estimates were based on 1200° gas temperature and 100°F day at sea level. One exception was the duct temperature used in the analysis of flexures, which was 1050°F. In this case corrections were used in reverse to predict the average temperature of flexures when the duct temperature increased to 1200°F.

TABLE 5.3-1

COMPONENT TEMPERATURES

COMPONENT	Predicted at 1200°F Gas Temp.	Corrected for 1176°F Gas Temp.	Measured	Estimated Absolute Error*	Actual Error	Component Temp. % of Estimated
Duct 3/8" from chord line BS-1-13	1177	1153	1105	-50, +30	+48	4.2% Cooler
Duct top, BS-18-4 Blade Radial Station	1105	1083	1070	-50, +30	+13	1.2% Cooler
Outer Skin on the Rib, BS-18-7	465	457	272	-60, +100	+185	41% Cooler
Rear Spar BRS-3	430	423	240	-60, +100	+183	42% Cooler
Flexure BC_2 Aver.	645	633	640	- 0, +200	-7	1% Hotter

*ERROR = Measured - Predicted

5.3.1.3 Temperature Survey

Data from the following tests were selected to include two representative maximum temperature steady state runs, a fast acceleration transient, and a high temperature transient.

(1) Test Run No. 66, Dec. 1, 1961, turbine discharge temperature T_{T_7} = 1255°F, turbine discharge pressure P_{T_7} = 21.1 psig, gas temperature at flow measuring stations 1176°F, ambient temperature 64°F, 235 RPM at 8.5° collective pitch.

(2) Test Run No. 11, October 27, 1961, T_{T_7} = 1237°F, P_{T_7} = 20.6 psig, gas temperature at flow measuring stations 1152°F, ambient temperature 65°F, 240 RPM at 9° collective pitch. (Data from Run No. 11 are used only on Figure 5.3-5 for the record of the hub mast temperatures).

(3) Transient test on December 11, 1961, Run No. 19, gas temperature at flow measuring stations 720°F to 1175°F.

(4) Transient test on Dec. 13, 1961, T_{T_7} = 1220°F, P_{T_7} = 21.1 psig, 240 RPM at 8° collective. Gas temperature at flow measuring station not recorded due to thermocouple failure.

Figure 5.3-1 shows duct and outer skin temperatures measured at the inboard segment (No. 1) during Run No. 66.

Figure 5.3-2 shows similar data taken at the outboard Section No. 18 during the same runs. It can be seen that both the duct wall temperature and the temperature of the outer skin are lower than estimated.

Figure 5.3-3 shows the temperature distribution in the flexures, spar and cooling air. This is the most complete set of data that covers any specific area of the rotor. The plot makes a good picture of temperature distribution along the blade.

For the flexure temperature distribution the test results of Figure 5.3-3 positively confirm all predictions. These data are based on 35 active thermocouples. The figure also shows the spread of temperatures that may be expected to exist within any flexure.

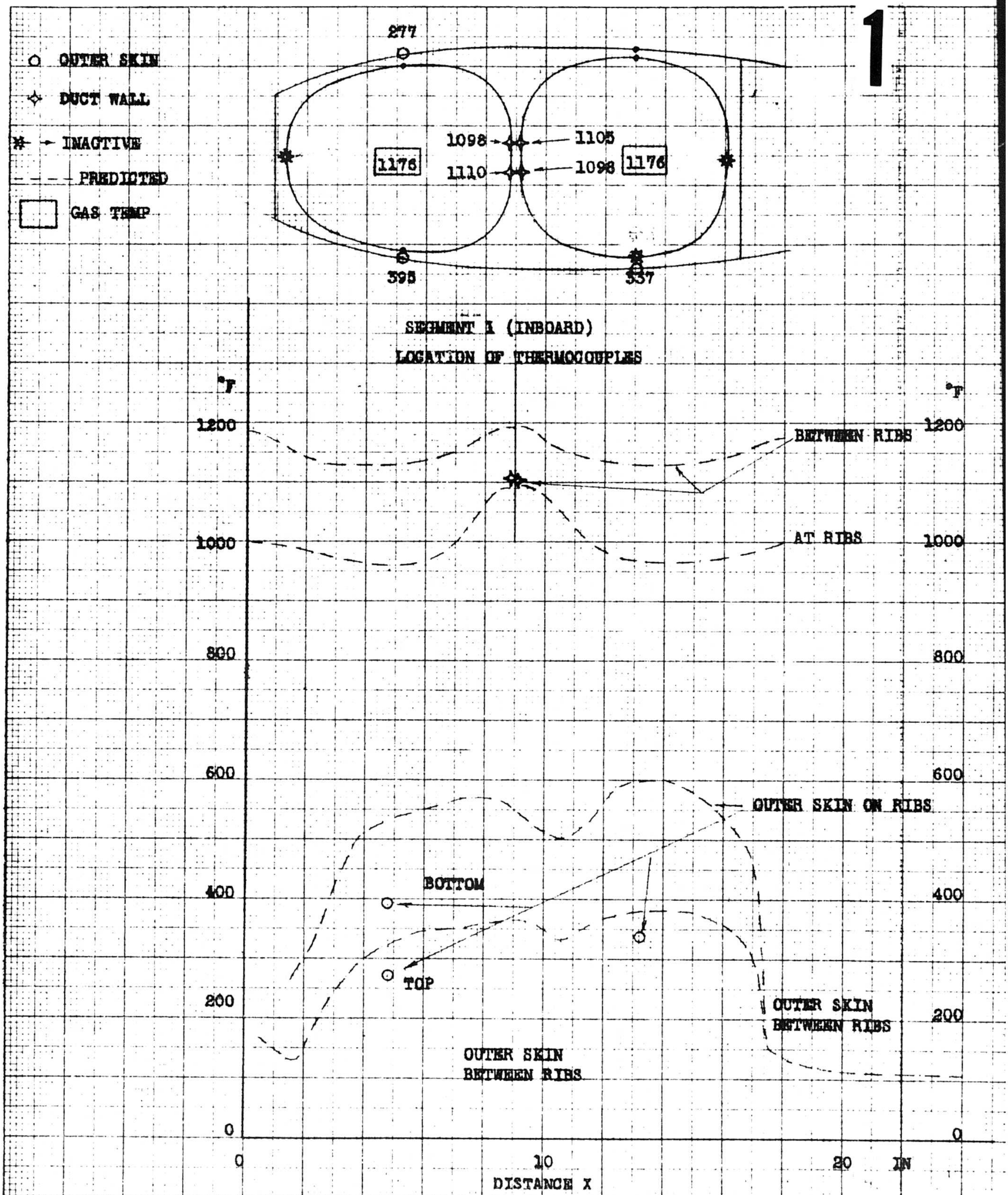
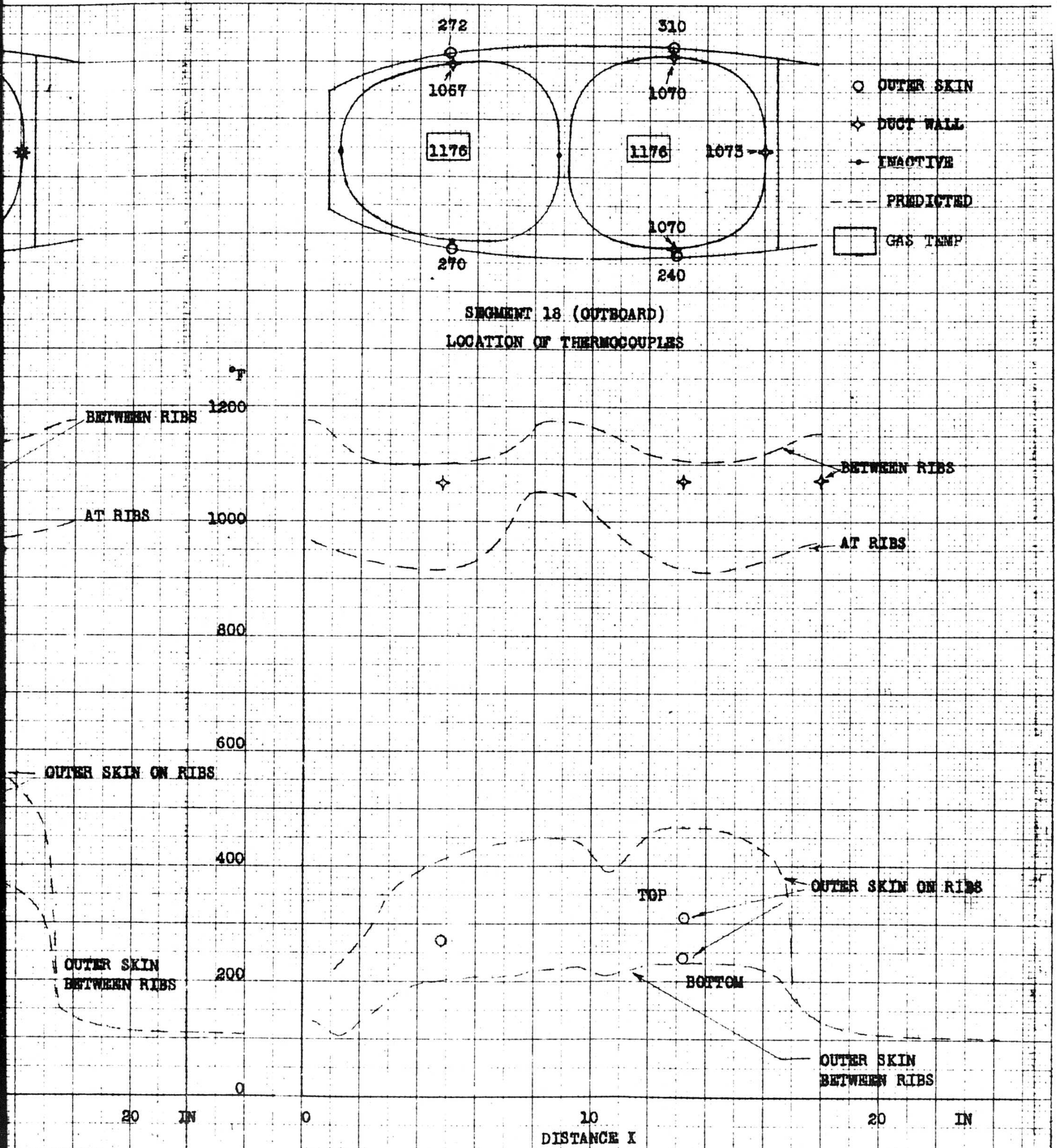


FIGURE 5.3-1
DUCT AND OUTER SKIN TEMPERATURES (INBOARD SEGMENT)
RUN NO. 66



SEGMENT)

FIGURE 5.3-2

DUCT AND OUTER SKIN TEMPERATURES (OUTBOARD SEGMENT)

RUN NO. 66

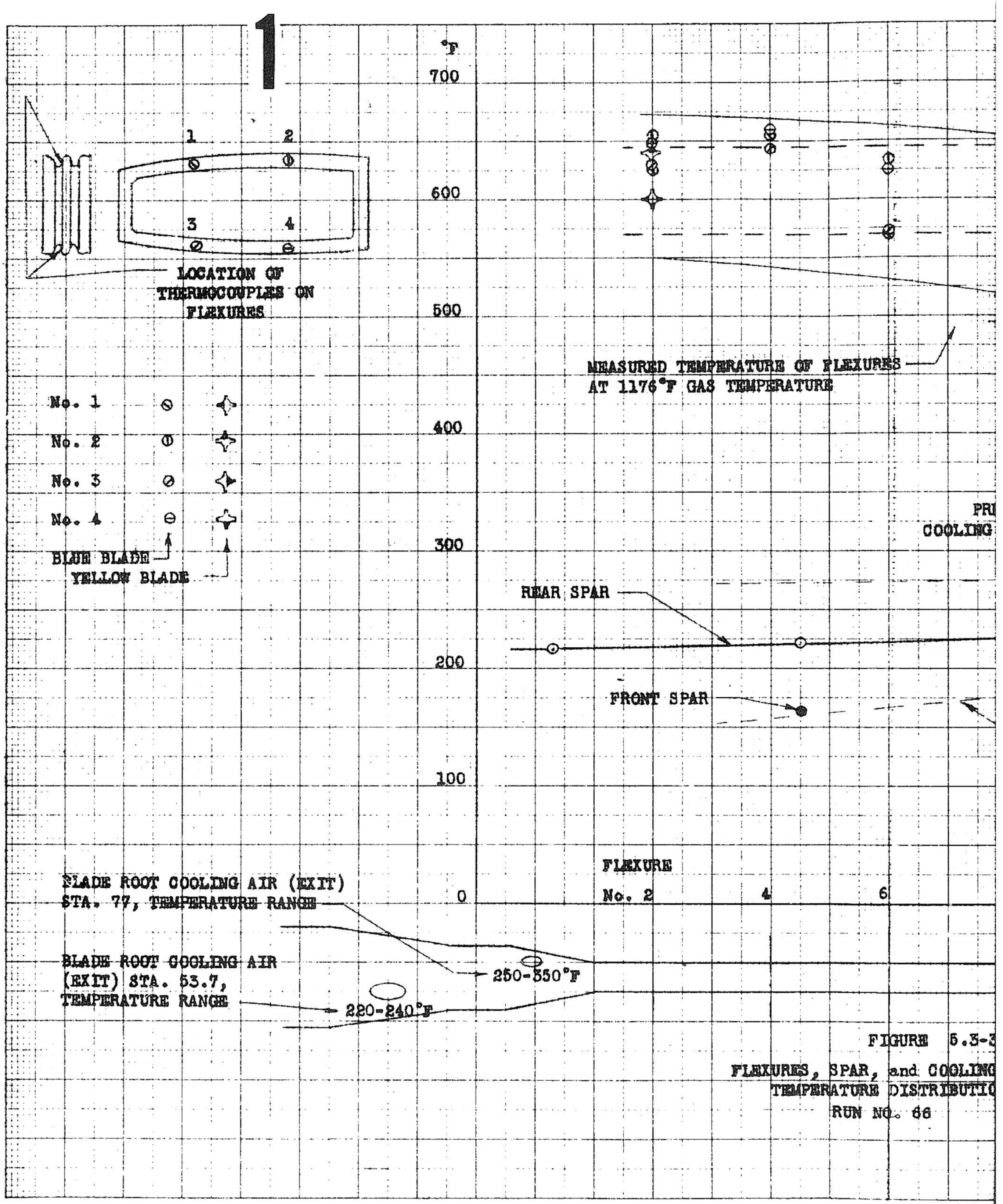


FIGURE 5.3-3

FLEXURES, SPAR, and COOLING
TEMPERATURE DISTRIBUTIO
RUN NO. 66

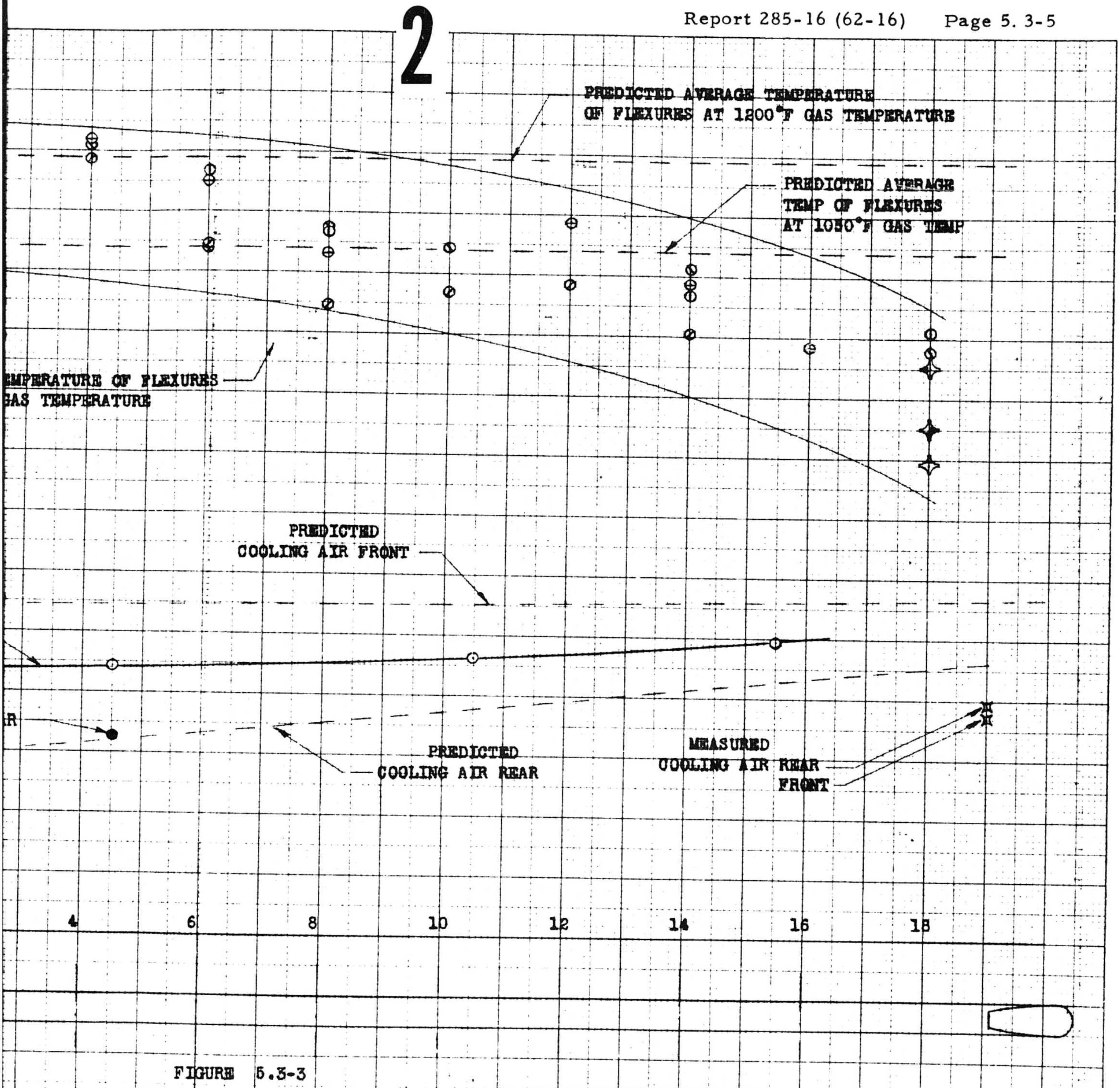


FIGURE 5.3-3

FLEXURES, SPAR, and COOLING AIR TEMPERATURE DISTRIBUTION

RUN NO. 66

The rear spar temperature is included on the same figure. This is also a very well instrumented component covered with 8 active thermocouples. At sections where thermocouples were close together the average values were used in the plot. The front spar is covered only with a single active thermocouple. This thermocouple consistently indicated that the front spar is always cooler than the rear spar. Similarly the front spar cooling air has lower temperature than air in the rear cooling duct. When compared with the estimates, it is evident that both spars actually operate at lower temperatures than predicted.

Figure 5.3-3 also shows the temperatures of the blade root cooling air as measured at Station 53.4 and Station 77 on all three blades.

Figure 5.3-4 shows a plot of transient temperatures during acceleration runs. The curves are directly transcribed from the Leeds Northrup recorder equipped with the selector switch for this purpose. It is interesting to note that the outer skin temperatures change little between idling and the maximum power. The differential temperature between the duct and the skin is largest at steady state. Transient runs did not disclose the existence of any critical thermal conditions in the blade.

Figure 3.3-5 shows temperatures prevailing in the hub of the rotor. Two hot runs are presented. Run No. 66 with gas temperature 1176°F and Run No. 11 with gas temperature 1152°F. It can be seen that the hub assembly temperatures are considerably lower than predicted. Since the hub assembly was not a subject of Reference 5.3-1, the predicted values were taken from Reference 5.3-2. As higher readings from Run No. 66 cannot be explained entirely by the small difference in gas temperature, they evidently indicate some minor leakage in the hub.

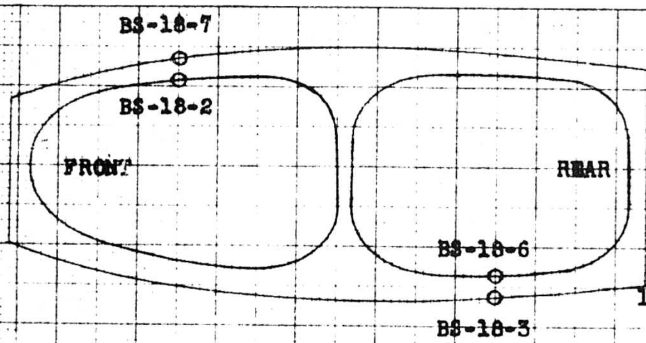
Figure 5.3-6 and 5.3-7 show the relation between the temperature of pertinent rotor components and the turbine discharge temperature T_{T_7}. It is interesting to note that most of the component temperatures are almost directly proportional to T_{T_7}. The data of Figures 5.3-6 and 5.3-7 represent 13 test runs taken at various rotor rpm and engine temperature levels. The hottest run of this series was run No. 11 earlier described in Section 5.3.1.3.

5.3.2 Leakage Results

A typical test setup used for the measurement of gas leakage in the various components of the rotor system is shown on Figure 5.3-8.

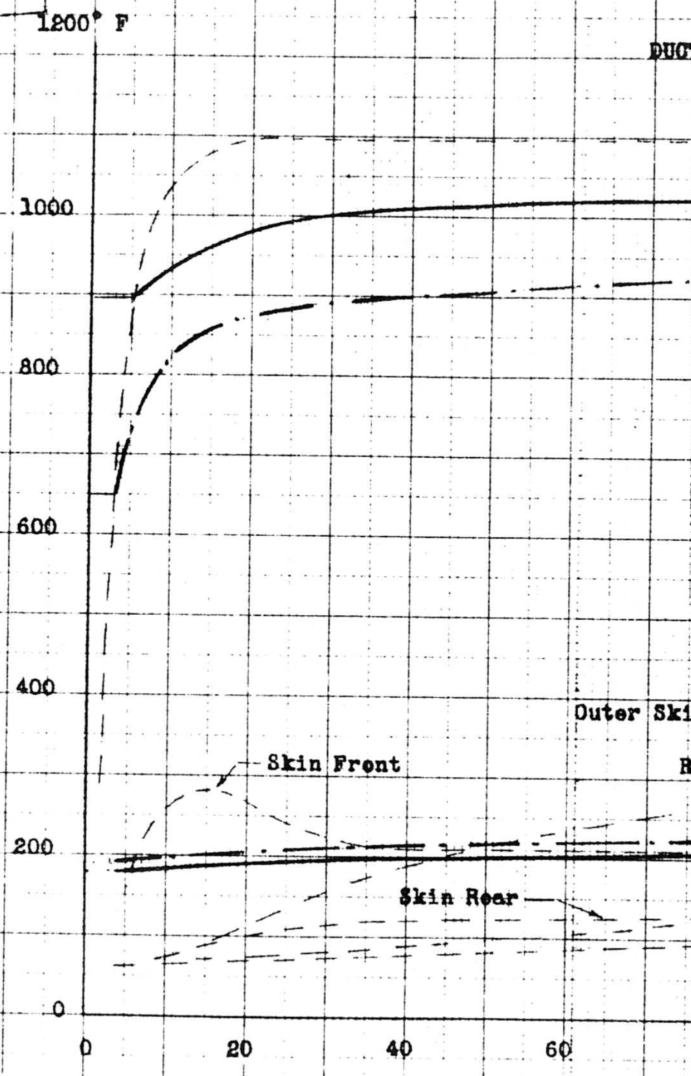
The component under test, having its inlets and outlets sealed, is

1



SEGMENT NO. 18

LOCATION OF THERMOCOUPLES
BETWEEN RIBS



NOTE:

READINGS OF DUCT WALL TEMPERATURE BS-18-2 and BS-18-6 WERE ALMOST IDENTICAL

READINGS OF OUTER SKIN TEMPERATURE BS-18-7 and BS-18-9 WERE WITHIN ± 5% FROM THEIR AVERAGE VALUE.

HEAVY LINES REPRESENT PLOT OF AVERAGE TEMPERATURE OF DUCT WALL OR OUTER SKIN.

TRANSIENT TEMPERATURES:

Test on Dec. 13-1961 at 1230° Eng. Disch. Temp.

Test on Dec. 11-1961 at 1170° Eng. Disch. Temp.

Predicted at 1200° Duct Gas. Temp.

STEADY STATE:

Test Run No. 6 on Dec. 1-1961 at highest recorded gas temp. (1176°F) (spar thermocouples not at No. 18 segment)

FIGURE 5.3-4

TRANSIENT TEMPERATUR
PREDICTED AND MEASURE

2

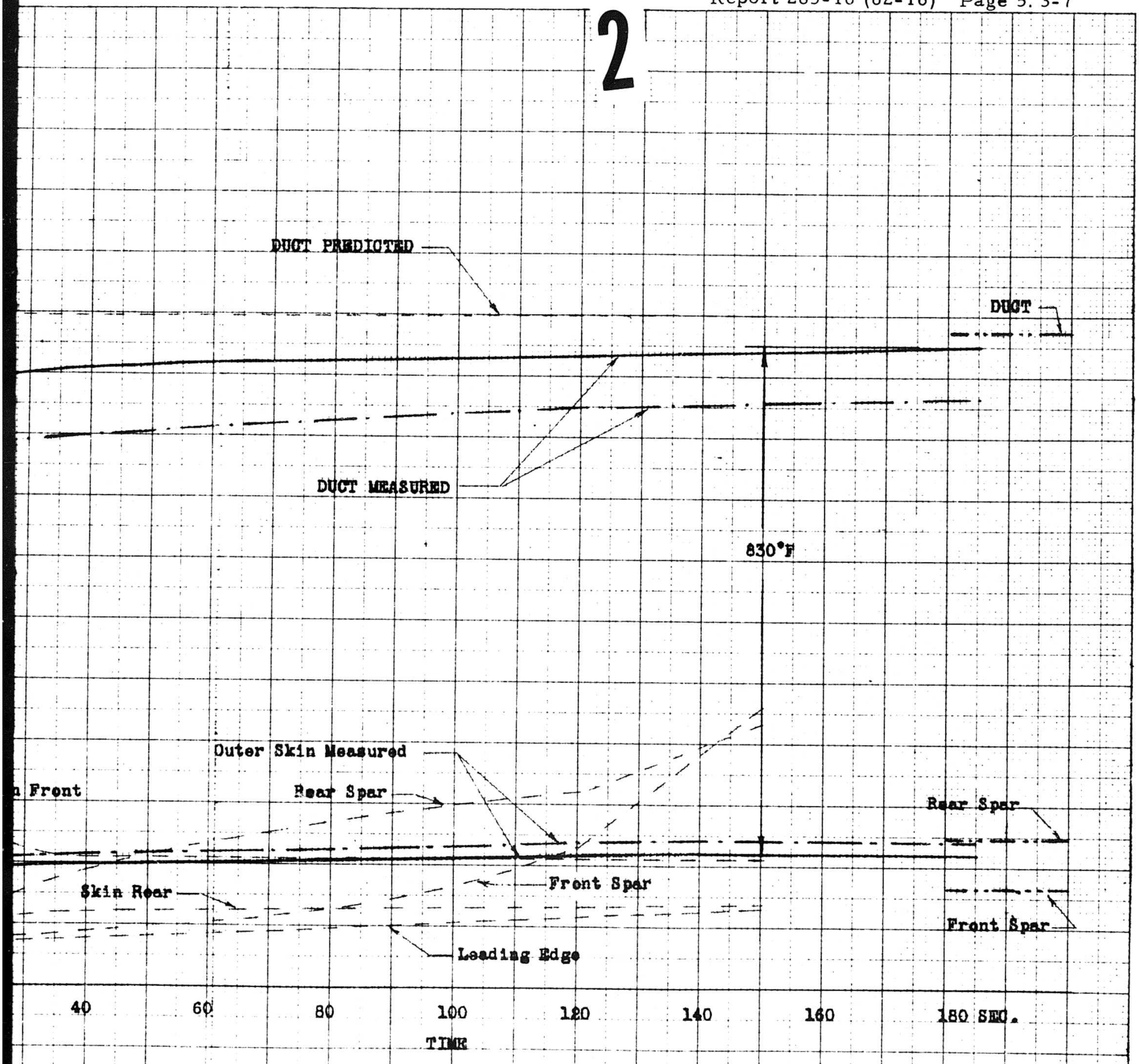


FIGURE 5.3-4

TRANSIENT TEMPERATURE
PREDICTED AND MEASURED

NOTE:

TEMPERATURE INDICATED BY UPPER NUMBER AT EACH THERMOCOUPLE REPRESENTS MEASUREMENTS FROM RUN NO. 11 (Oct. 27-61) AT 1152°F GAS TEMPERATURE THOSE TEMPERATURES ARE CONSIDERED REPRESENTATIVE FOR "HOT" RUNS.

INTERMEDIATE NO. IS RECORDED ON (Dec. 1-61) RUN NO. 6, (66), AT 1176°F GAS TEMPERATURE

HIGH DIFFERENCE BETWEEN TWO READINGS INDICATES LEAKAGE IN THE HUB.

THERMOCOUPLES No. 3, 4 and 8 WERE INACTIVE.

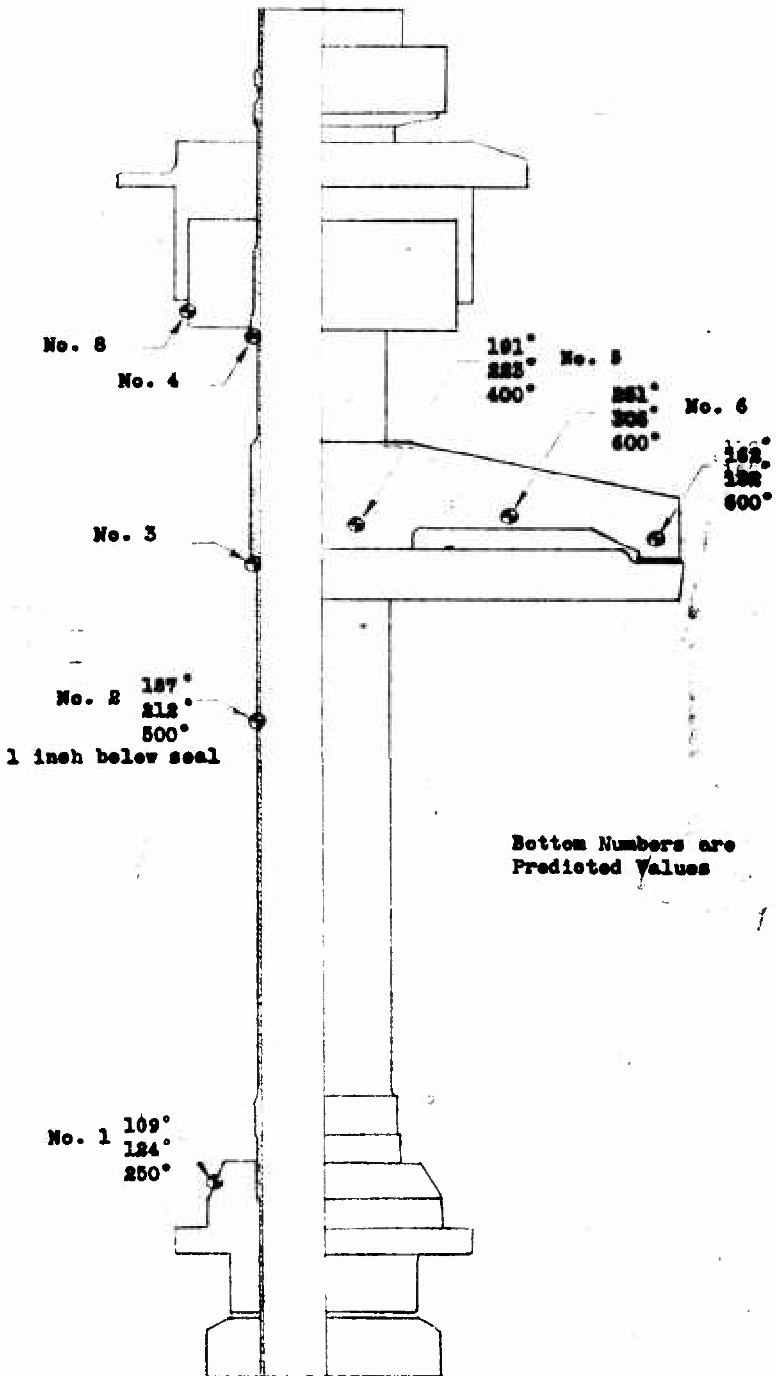
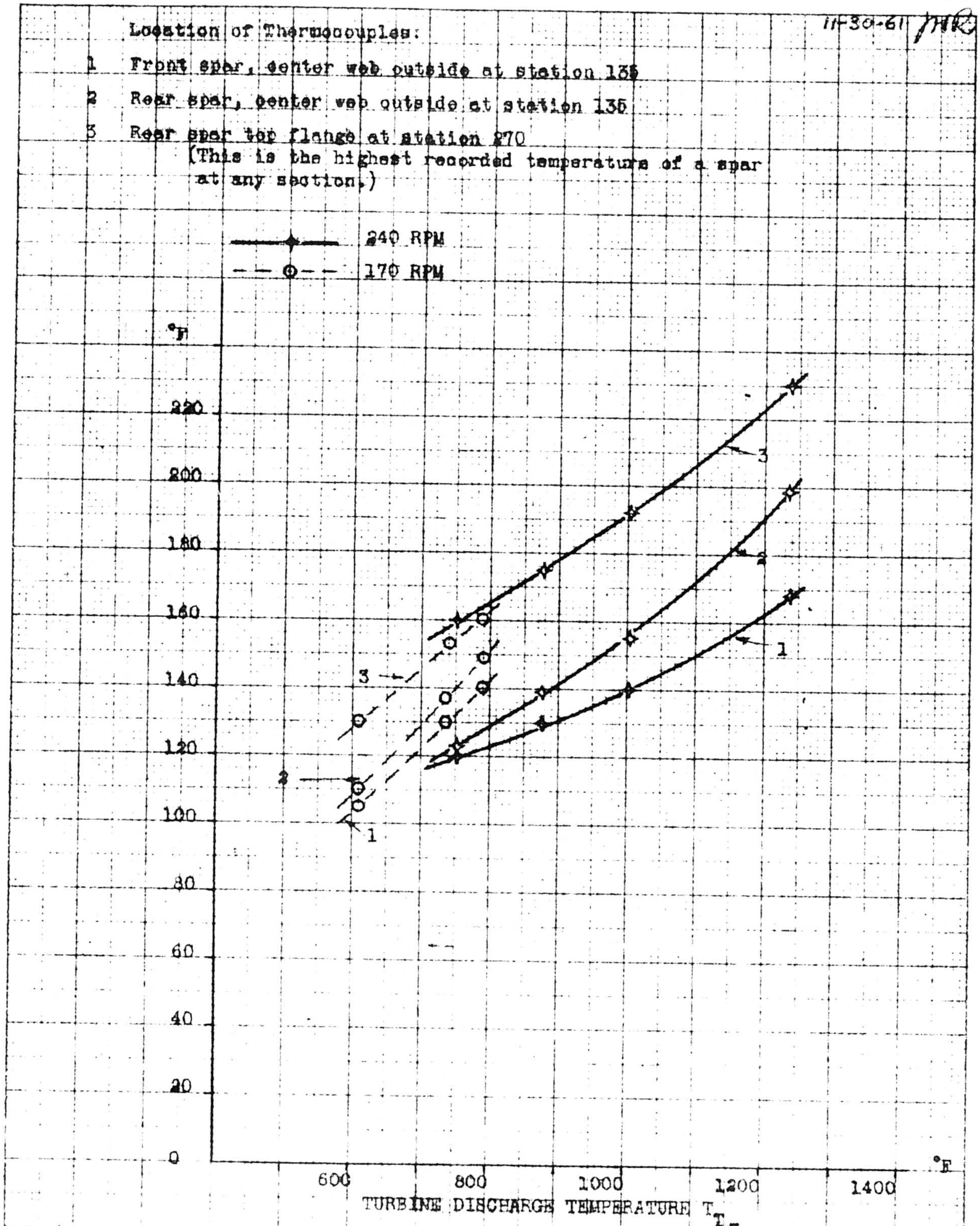


FIGURE 5.3-5

DISTRIBUTION OF TEMPERATURE

IN THE HUB

11-30-61 JHR

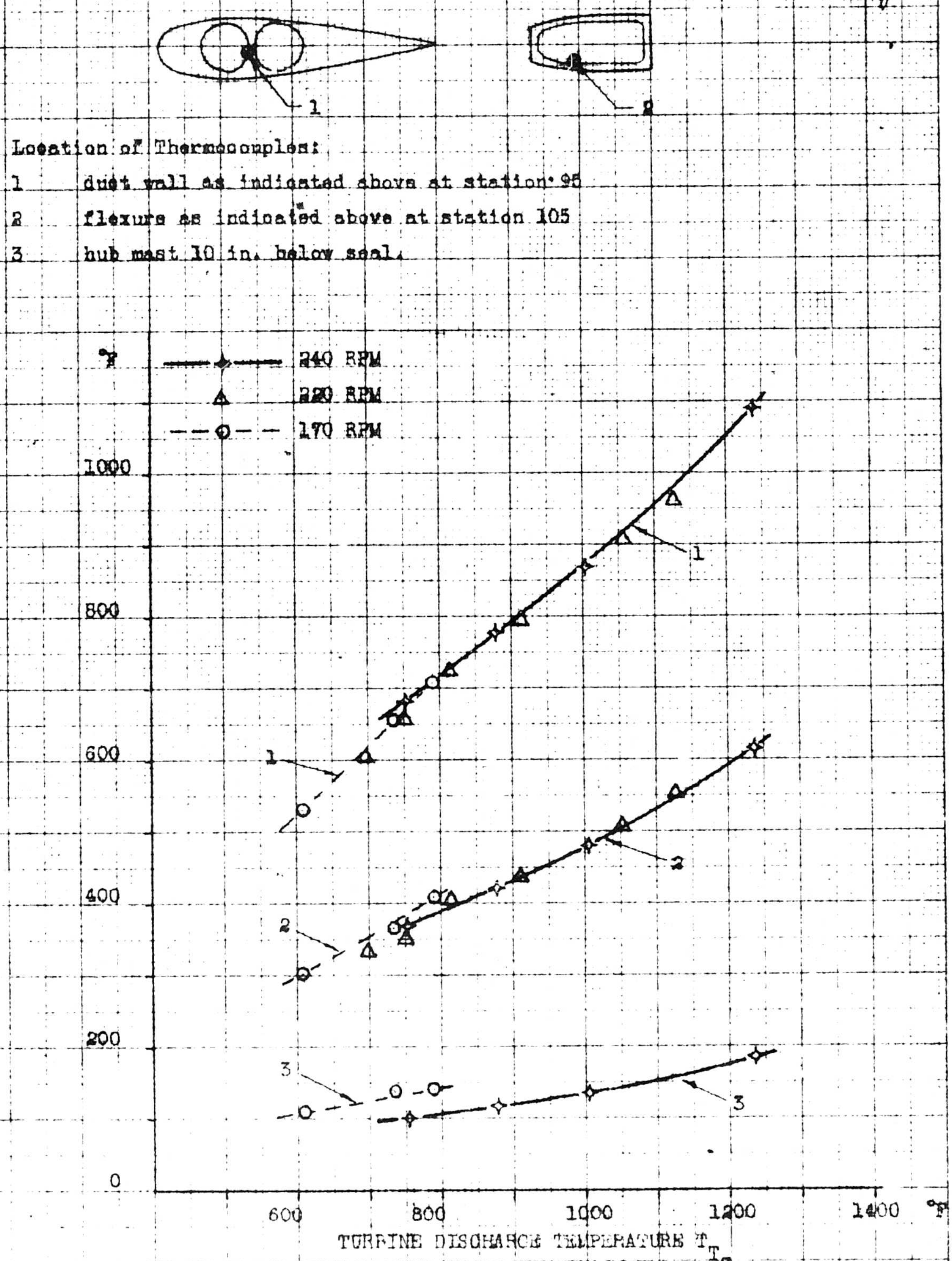


HOT CYCLE HELICOPTER

Fig. 5.3-6

TEMPERATURE OF ROTOR COMPONENTS AT VARIOUS POWER LEVEL

11-30-61



HOT CYCLE HELICOPTER

Fig. 5.3-7

TEMPERATURE OF ROTOR COMPONENTS
AT VARIOUS POWER LEVEL

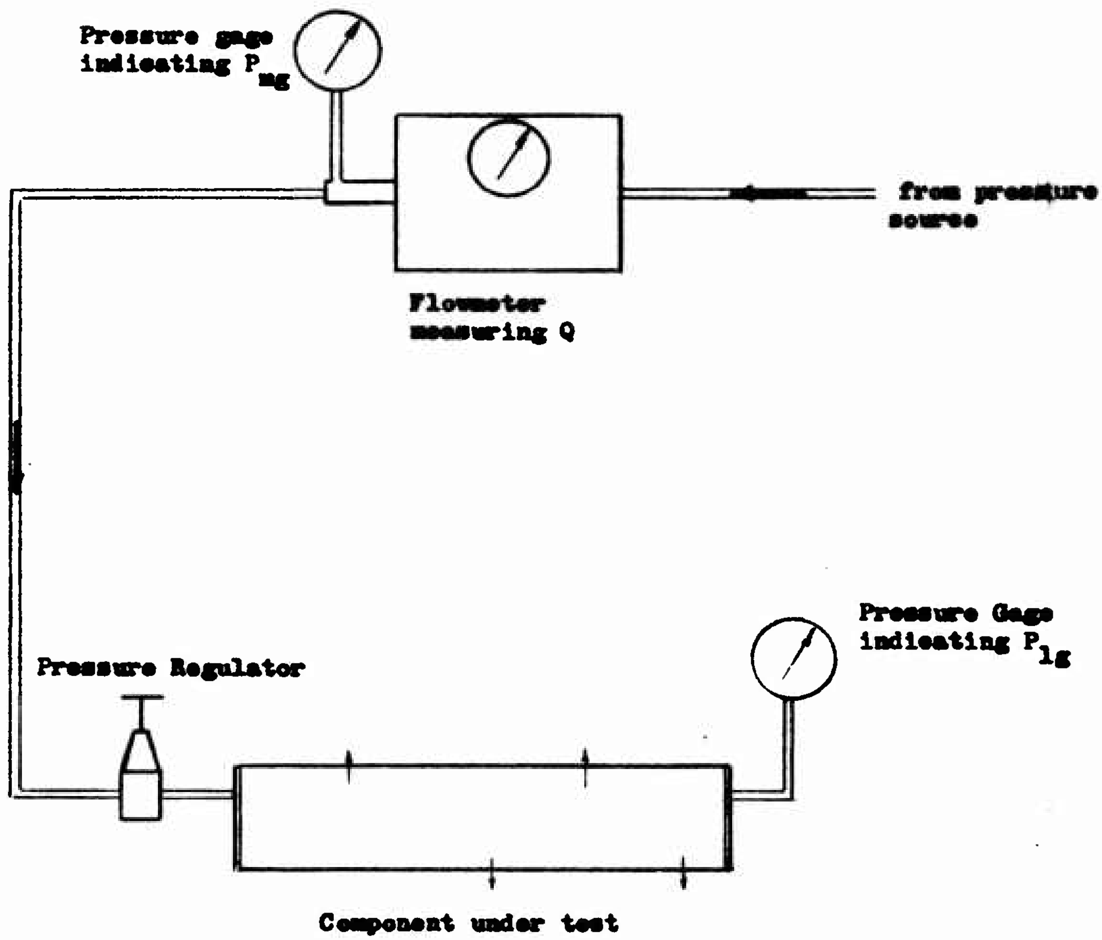


Figure 5.3-8

Leakage Test

Typical Test Setup

connected to the pressure source through a flow meter. One of the two pressure gages required for the test is coupled directly to the meter, while the other measures pressure maintained in the tested duct. The measurement of air flow (cfm) and the indications of the two pressure gages (psig) are used to estimate the rate of leakage under typical high power whirl conditions.

The flow rate through the meter W_m equals the rate of leakage in the component W_1; the ratio of the corrected leakage W_W representing the whirl conditions to the measured leakage can be expressed in terms of a fundamental equation.

$$W_m = W_1 = \frac{Q}{60} \rho_m \quad \text{(lb/sec)}$$

$$\frac{W_w}{W_1} = \frac{K A \rho_w Y \sqrt{2g (P_{wa} - P_{am}) / \rho_w}}{K A \rho_1 Y \sqrt{2g (P_{1a} - P_{am}) / \rho_1}} = \qquad (1)$$

$$= \frac{\rho_w}{\rho_1} \sqrt{\frac{P_{wg} \rho_1}{P_{1g} \rho_w}} = \sqrt{\frac{P_{wg} P_{wa}}{P_{1g} P_{1a}}}$$

Where
Q = flow meter readout (cfm)
ρ = specific weight (lb/ft^3)
W = air flow (leakage) lb/sec
Subscripts single or combined
m flow meter
1 test condition
w whirl condition
g gage pressure
a absolute pressure
am ambient pressure

Equation (1) determines the correction necessary to convert the rate of measured leakage at a duct test pressure P_{1g}, to that which will occur at whirl pressure P_{wg}.

$$W_w = W_1 \sqrt{\frac{P_{wg} P_{wa}}{P_{1_g} P_{1_a}}}$$

In addition, due to the elevated whirl temperature, the density of escaping gas is considerably lower than the density of ambient air used for testing. The ratio of densities at different temperatures (other parameters being constant) is

$$\frac{\rho_w}{\rho_l} = \frac{T_l}{T_w}$$

on the other hand, the effect of temperature on the gas escape velocity acts in the opposite direction. The ratio of the escape velocities is

$$\frac{v_w}{v_l} = \frac{T_w}{T_l} .$$

The combined effect of the above relations results in

$$\frac{W_w}{W_l} = \frac{\sqrt{T_l}}{\sqrt{T_w}} . \qquad (2)$$

The correction factor due to the combined differences of pressure and temperature that exist between the test and the whirl conditions is:

$$\frac{W_w}{W_l} = \frac{\sqrt{P_{wg} \times P_{wa} \times T_l}}{\sqrt{P_{lg} \times P_{la} \times T_w}} . \qquad (3)$$

The rate of leakage measured at the test pressure of 23.6 psig and standard ambient conditions at sea level is converted to the anticipated leakage at the 21 psig blade pressure and 1190°F gas temperature as follows:

$$W_w = \frac{Q}{60} P_m \frac{\sqrt{P_{wg} \times P_{wa} \times T_l}}{\sqrt{P_{lg} \times P_{la} \times T_w}}$$

$$= \frac{Q\, P_{ma}\, 144}{60 \times 53.35 \times 530} \sqrt{\frac{P_{wg} \times P_{wa} \times T_l}{P_{lg} \times P_{la} \times T_w}} \qquad (4)$$

This equation was used to prepare Table 5.3-2.

and for the test pressure $P_1 = 20$ psig,

$$W_w = \frac{5.00}{10^5} Q P_{mg} . \quad (5)$$

Equations (4) and (5) were used to prepare Table 5.3-2.

285-16
(62-16)

TABLE 5. 3-2

LEAKAGE MEASUREMENTS

Assembly Under Test	Hours Whirl Time Before Test	P_1 Psig Duct Test Pressure	Q cfm Meter Flow Rate	W_w #/sec Corrected Leakage	Leakage % of Component Flow	Remarks
Blue Blade	0	23. 6	Less than 1 cfm	0. 00393	0. 027	
Red Blade	0	23. 6	"	0. 00393	0. 027	
Yellow Blade	0	23. 6	"	0. 00393	0. 027	
Hub Ass'y	0	23. 6	"	0. 00393	0. 009	
Blue Blade	18	23. 6	0. 9	0. 00355	0. 024	
Red Blade	18	23. 6	1. 5	0. 00592	0. 038	
Yellow Blade	18	23. 6	2. 8	0. 01105	0. 072	
Total 3 Blades	18	23. 6	5. 2		0. 044	
Rotor System*	18	23. 6	17. 0	0. 0672	0. 146	
Rotor System	18	20	17. 0	0. 0767	0. 168	On the tower
Rotor System	35	Negligible	20. 0	-	High Leak due to defective seal	On the tower
Blue Blade	35	23. 6	1. 5	0. 00593	0. 0388	
Red Blade	35	23. 6	2. 7	0. 0109	0. 0698	
Yellow Blade	35	23. 6	2. 7	0. 0107	0. 0698	
Hub Ass'y	35	23. 6	4. 5	0. 0178	0. 0387	As rec'd from tower
Hub Ass'y	35	23. 6	1. 8	0. 00712	0. 0154	After rapping to seat seals
Hub Ass'y	35	23. 6	0. 6	0. 00237	0. 00515	Reassembled after teardown
Rotor Ass'y	35	20	17	0. 0767	0. 168	Reassembled after teardown
Blue Blade	60	23. 6	2. 0	0. 00792	0. 0517	
Red Blade	60	23. 6	4. 0	0. 0158	0. 103	
Yellow Blade	60	23. 6	3. 2	0. 0131	0. 0855	
Hub Ass'y	60	23. 6	13. 2	0. 0523	0. 114	

* Note: Rotor System includes the hub plus the three blades

5.4 STRUCTURAL EFFECTS

5.4.1 Comparison of Design With Measured Mechanical Strains

Typical Strain Gage data obtained during the whirl test are presented in Figures 5.4-1 through 5.4-4. These are discussed below.

5.4.1.1 Blade Pitch Arm Loads

Pitch Arm cyclic load versus wind speed is presented in Figure 5.4-1. All of the measured cyclic pitch arm loads fall well below the design limit. (Reference 5.4-1)

5.4.1.2 Rear Spar Flapwise Bending Moments at Station 53.5 Inches

Blade cyclic flapwise bending moments versus wind speed are plotted for blade station 53.5 inches in Figure 5.4-2. The moments plotted are the maximum cyclic moments that occurred during typical operating conditions. The measured cyclic bending moments are below the design allowable limit, (Reference 5.4-1) with the exception of one point. A few cycles at this amplitude occurred and probably resulted from wind gusts.

5.4.1.3 Rear Spar Flapwise Bending Moments at Station 73.4 Inches

Blade cyclic flapwise bending moments versus wind speed are plotted for blade station 73.4 inches in Figure 5.4-3. The moments plotted are the maximum cyclic moments that occurred during typical operating conditions. The measured cyclic bending moments are below the design allowable limit, (Reference 5.4-1) with the exception of one point. This point occurred during large wind gusts with the wind varying from 19 to 25 MPH.

5.4.1.4 Front and Rear Spar Cyclic Axial Load (Cyclic Chordwise Bending)

Plotted in Figure 5.4-4 are the measured cyclic axial loads in the rear spar at station 103 inches, and front spar at station 83.3 inches, versus wind speed. The loads plotted are the maximum cyclic loads that occurred during typical operating conditions. Three points for the rear spar and nine points for the front spar fell above the endurance limit, (Reference 5.4-1). It is believed that the spar cyclic axial loads (cyclic chordwise bending) were aggravated by gusty wind conditions. It is estimated that the small number of cycles above the endurance limit, used up a very small percentage of the service life of the blade.

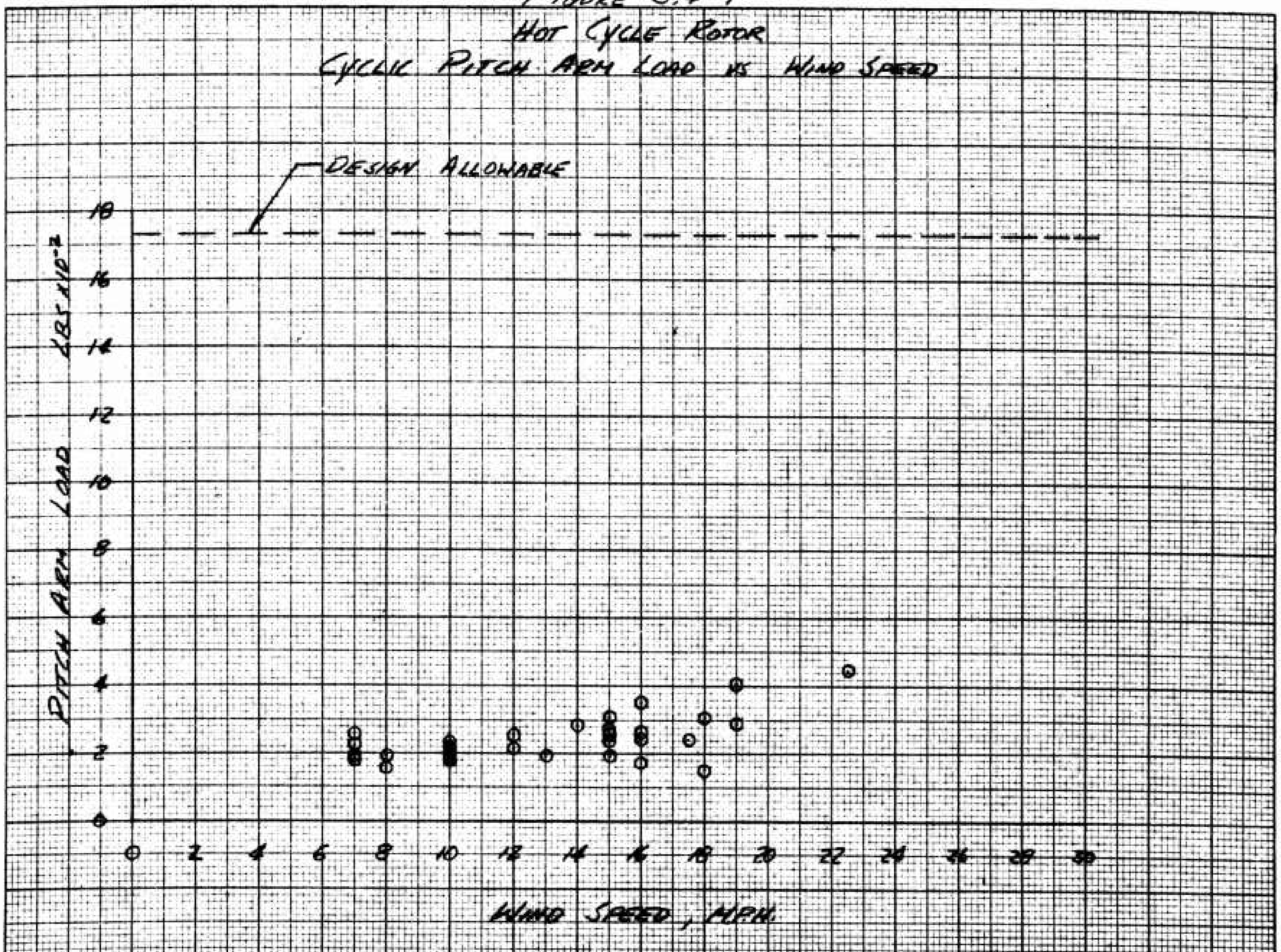


FIGURE 5.4-1
HOT CYCLE ROTOR
CYCLIC PITCH ARM LOAD VS WIND SPEED

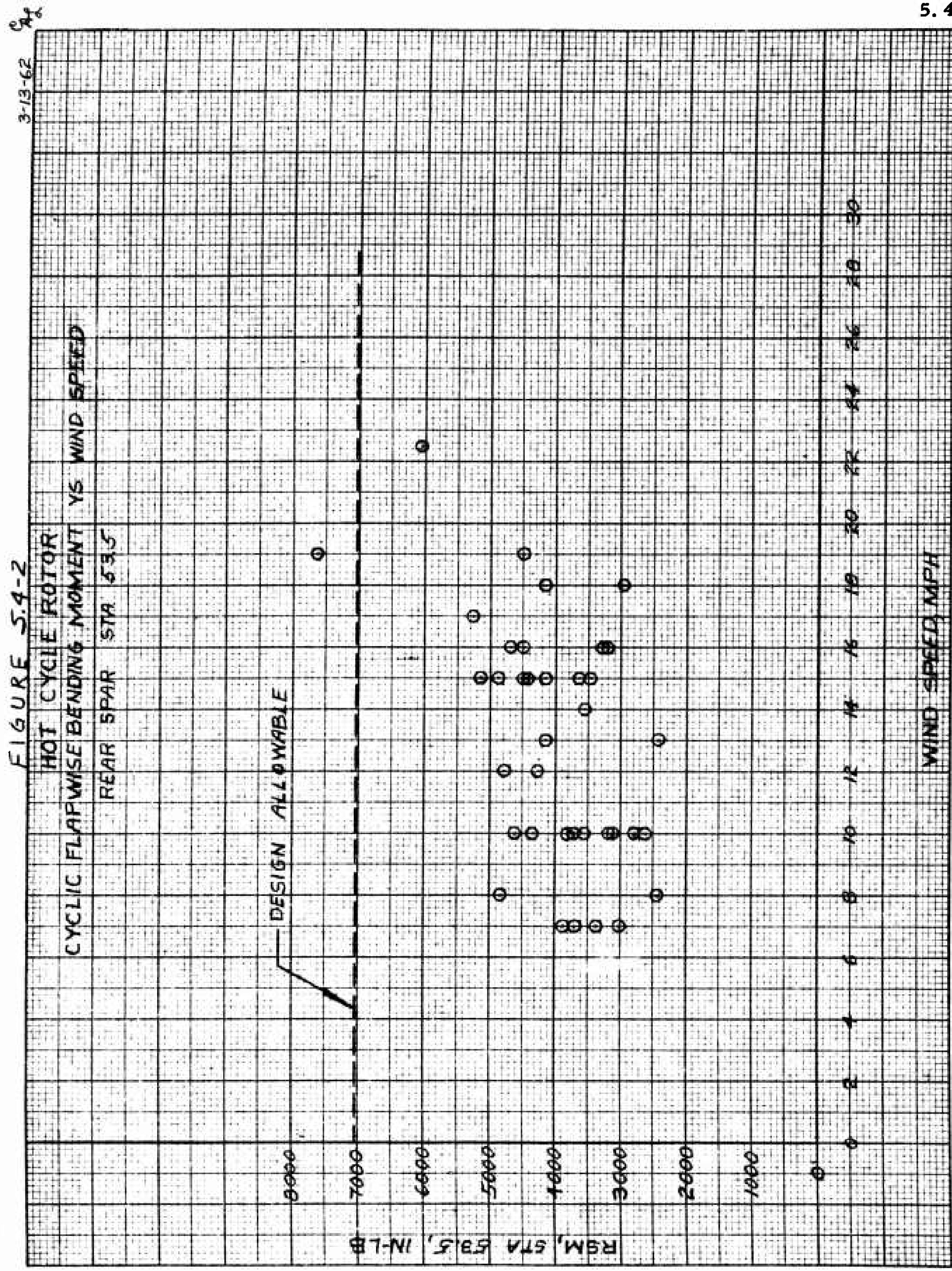


FIGURE 5.4-2
HOT CYCLE ROTOR
CYCLIC FLAPWISE BENDING MOMENT VS WIND SPEED
REAR SPAR STA 53.5
DESIGN ALLOWABLE
RSM, STA 53.5, IN-LB
8000
7000
6000
5000
4000
3000
2000
1000
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
WIND SPEED, MPH
3-13-62

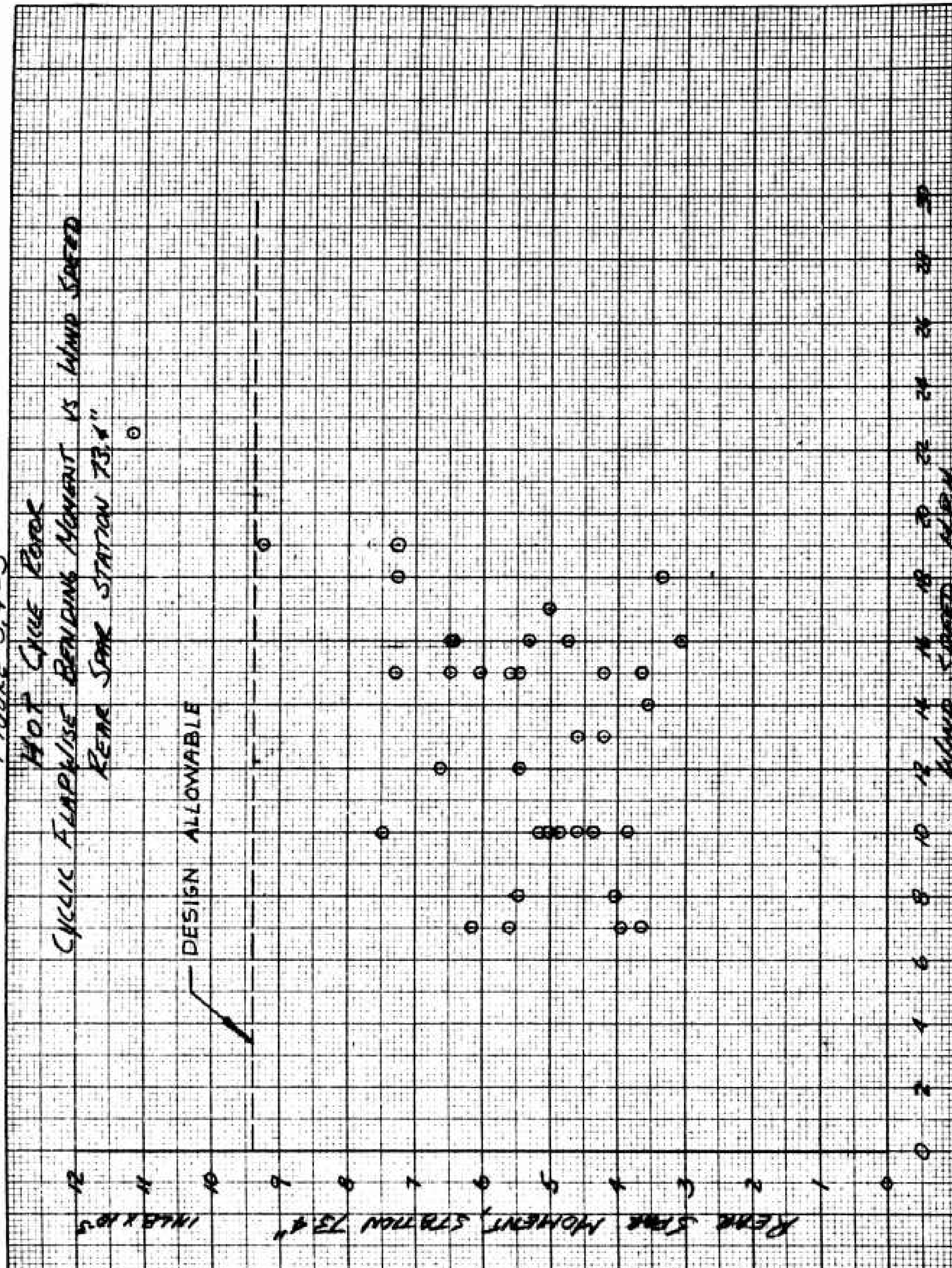


FIGURE 5.4-3
HOT CYCLE ROTOR
CYCLIC FLAPWISE BENDING MOMENT VS WIND SPEED
REAR SPAR STATION 73.4"
DESIGN ALLOWABLE
REAR SPAR MOMENT, STATION 73.4" INLB x 10^5
WIND SPEED, MPH
0
1
2
3
4
5
6
7
8
9
10
11
12
14
16
18
20
22
24
26
28
30

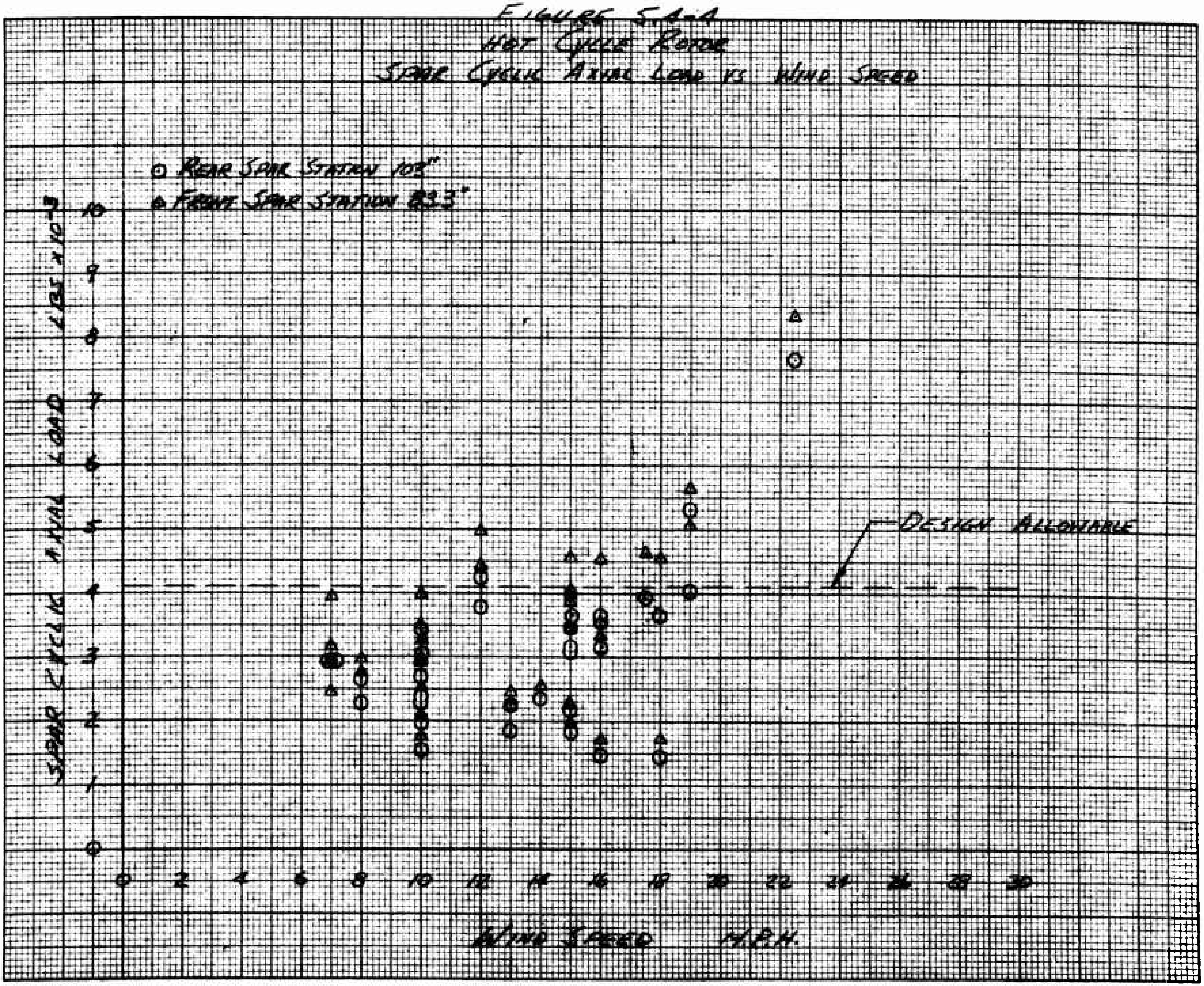


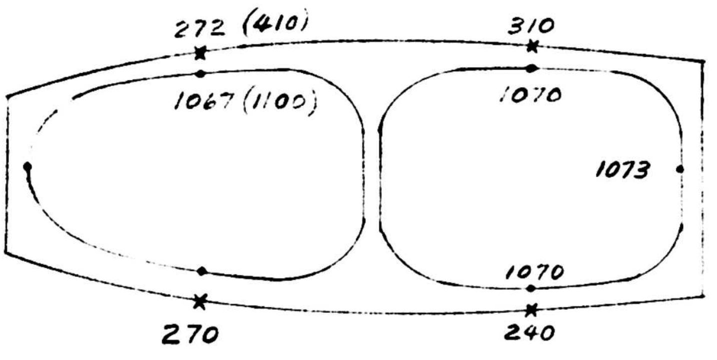
FIGURE 5.4-4
HOT CYCLE ROTOR
SPAR CYCLIC AXIAL LOAD VS WIND SPEED
⊙ REAR SPAR STATION 105"
△ FRONT SPAR STATION 83.3"
DESIGN ALLOWABLE
SPAR CYCLIC AXIAL LOAD LBS x 10^-3
0 1 2 3 4 5 6 7 8 9 10
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
WIND SPEED M.P.H.

5.4.2 THERMAL EFFECTS ON STRUCTURE

A COMPARISON OF DESIGN WITH MEASURED TEMPERATURES FOR THE HOT CYCLE ROTOR IS PRESENTED IN SECTION 5.3.1. THE RESULTS, FOR THE MOST PART, SHOW THAT PREDICTED VALUES USED IN DESIGN WERE REASONABLY ACCURATE FOR CRITICAL COMPONENTS.

THE ANALYSIS WHICH FOLLOWS SINGLES OUT SEVERAL COMPONENTS AND ANALYZES THE THERMAL EFFECTS OF THE MEASURED TEMPERATURES. FROM AN OVER ALL STANDPOINT, INSPECTION OF THE ROTOR SUBSEQUENT TO COMPLETION OF THE WHIRL TESTS SHOWED NO DELETERIOUS EFFECTS OF TEMPERATURE ON THE STRUCTURE.

5.4.2.1 BLADE SEGMENT RIBS



X SKIN TEMP. (°F) AT RIB (MEASURED)

• DUCT WALL TEMP. (°F) BETWEEN RIBS (MEASURED)

( ) VALUES IN PARENTHESES ARE DESIGN VALUES

NOTE: TEMPERATURE COMPARISON SHOWN IS FOR SEGMENT 18. THERMOCOUPLES COULD NOT BE LOCATED ON THE DUCT WALL AT THE RIB BECAUSE OF FABRICATION RESTRICTIONS.

BLADE SEGMENT RIBS (CONT'D)

THERMAL STRESSES AS CALCULATED IN REF. 5.4-1 ARE BASED ON TEMPERATURES AT THE RIB. IF IT IS ASSUMED THAT MEASURED VS. DESIGN TEMPERATURES OF THE DUCT AT THE RIB ARE DIFFERENT BY THE SAME INCREMENT AS THE TEMPERATURES BETWEEN RIBS THE FOLLOWING MAY BE SURMISED:

ΔT (DUCT BETWEEN RIBS) = 1100 - 1067 = 33°F

FROM PREDICTED CURVE T (AT RIB) = 915°F
(REF. SECTION 5.3.1)

$T_{CORRECTED}$ (AT RIB) = 915 - 33 = 882°F

THEN: $\Delta T'$ (DUCT TO SKIN) = 882 - 272 = 610°F

$\Delta T'$ (DESIGN) = 1050 - 500 = 550°F (REF. 5.2-1, PG. 5.2.4.12)

THEREFORE THE THE THERMAL STRESSES BASED ON MEASURED TEMPERATURES ARE HIGHER THAN DESIGN BY THE RATIO:

$R = \frac{610}{550} = 1.11$ OR 11% HIGHER.

ALTHOUGH THE ABOVE ANALYSIS INDICATES THE POSSIBILITY OF HIGHER THERMAL STRESSES POST TEST INSPECTIONS OF THE DUCT WALLS SHOWED NO EVIDENCE OF PERMANENT SET.

5.4.2.2 BLADE SPARS

MEASURED TEMPERATURES OF THE SPARS WERE WELL BELOW PREDICTED TEMPERATURES. AT THESE LOW TEMPERATURES THE EFFECT ON THE MATERIAL PROPERTIES OF TITANIUM IS NEGLIGIBLE.

	DESIGN TEMPERATURE	MAX MEASURED TEMPERATURE
FRONT SPAR	460°F	170°F
REAR SPAR	435°F	230°F

5.4.2.3 BLADE FLEXURES - CONSTANT SECTION

IN THE INITIAL DESIGN, THE FLEXURES JOINING THE BLADE SEGMENTS WERE OF ELECTROFORMED NICKEL. HOWEVER DUE TO A PROCUREMENT PROBLEM WITH THE NICKEL PARTS, THE BASIC FLEXURE WAS CHANGED TO INCONEL "X" WHICH PROVED TO BE SUPERIOR FROM BOTH A FATIGUE AND TEMPERATURE STANDPOINT. THE INCONEL "X" PARTS WERE USED THROUGHOUT WITH THE EXCEPTION OF THE LAST THREE FLEXURES AT THE TIP, WHERE CYCLIC DEFLECTIONS ARE A MINIMUM. A COMPARISON OF PREDICTED AND MEASURED TEMPERATURES IS GIVEN BELOW. POST TEST INSPECTION SHOWED NO DAMAGE TO EITHER TYPE FLEXURE.

FLEXURE	DESIGN TEMP.	MEASURED TEMP.	
ELECTRO-FORM NICKEL	600°F	510°F	(REF SECT. 5.3.1)
INCONEL "X"	600°F *	660°F	

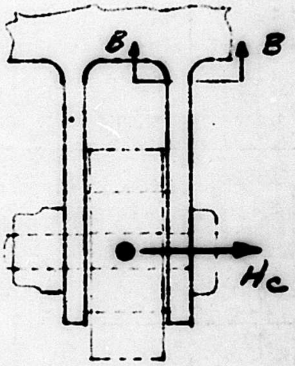
* INCONEL "X" RETAINS ITS STRENGTH TO APPROX. 1000°F

5.4.2.4 ROTOR HUB & SHAFT

MEASURED TEMPERATURES OF SECTION 5.3.1 ARE BELOW PREDICTED TEMPERATURES FOR ALL STRUCTURAL COMPONENTS.

5.4.3 GIMBAL LUG STRESSES

THE HUB IS ATTACHED TO THE GIMBAL RING THRU LUGS THAT EXTEND DOWN FROM THE 285-0529 FITTING AND STRADDLE THE TWO BEARINGS. THE CRITICAL DESIGN LOAD WAS A SIDE LOAD WHICH PRODUCES BENDING IN THE LUGS. A COMPARISON OF DESIGN AND MEASURED LOADS AND STRESSES IS GIVEN BELOW.



LOADS

WEIGHTED FATIGUE (DESIGN):

$H_C = \pm 1050$ LBS.

MEASURED (WHIRL TEST):

$H_{C_{MAX.}} = \pm 3340$ LBS.

$H_{C_{NORMAL}} = \pm 700$ TO ± 1600 LBS.

STRESSES (REF 5.4-1, PG. 5.3.2.12.3)

THE CRITICAL SECTION IN FATIGUE IS SECTION B-B AT THE RADIUS.

$f = 4370 \pm 6580$ PSI (WEIGHTED FATIGUE COND.)

FOR MEASURED WHIRL TEST LOADS:

$$f_{MAX.} = \frac{3340}{1050}(\pm 6580) = \pm 21{,}000 \text{ PSI}$$

$F_a = \pm 26000$ PSI

ALTHOUGH THIS CALCULATED CYCLIC STRESS IS ACCEPTABLE THERE ARE CERTAIN UNKNOWNS INVOLVED SUCH AS THE LOAD DISTRIBUTION BETWEEN LUGS. IN VIEW OF THIS A MODIFICATION WAS MADE AT THE 35 HOUR INSPECTION TO INCREASE THE RIGIDITY AND STRENGTH OF THE LOAD PATH FOR TAKING SIDE LOADS. SET SCREWS WERE ADDED IN THE WALL OF THE HUB SURROUNDING THE GIMBAL TO BEAR DIRECTLY AGAINST THE LUG TO RING ATTACH BOLTS.

GIMBAL LUG STRESSES (CONT'D.)

IN ADDITION FABROID RUB STRIPS WERE INSTALLED BETWEEN THE LUGS AND GIMBAL RING TO LIMIT THE DEFLECTION.

FOR APPLICATION TO A FLIGHT ARTICLE A MINOR DESIGN CHANGE TO STRENGTHEN THE LUGS WOULD BE IN ORDER.

5.5 SOUND LEVEL MEASUREMENT

5.5.1 Test Noise Alleviation

During the early part of the whirl testing sound levels in the vicinity of the test site were relatively high. This was due to the fact that only about one third of the J57 exhaust flow was used to power the rotor, and the surplus flow was exhausted directly to the atmosphere. The noise associated with the surplus exhaust flow of the J57 proved bothersome and inconvenient to test site personnel, some of the neighbors of the test site, and particularly to Loyola University which is located on a hill about 100 feet above the site and 800 feet distant. Because of the orientation of the test installation, the engine inlet was pointed almost directly at the University. The inlet noise is highly directional in nature, and thus in this position both the intake compressor whine and the exhaust roar were a source of irritation to Loyola University personnel.

In an effort to lower the sound levels to an acceptable range, sound suppressors were installed at both intake and exhaust ends of the J57 engine. These suppressors are shown on the frontispiece and on Figures 5.5-1 and 5.5-2. The intake suppressor was designed, built, and installed by General Accoustics Corporation, Los Angeles, California. The exhaust suppressor (Model 1195) was leased from Kittel Lacy, Inc., El Monte, California.

Overall sound level intensity measurements were taken on the crest of a hill above the test site and within 50 feet of the Loyola University cafeteria. These measurements were made with a General Radio 759B Sound Level Meter using the "c" scale only. Refer to Figure 5.5-3. Before installation of sound suppressors the sound intensity was 88 decibels and after suppressors were installed the sound intensity dropped to 76 decibels, considered an acceptable level for this location. This suppressed sound level is one sixteenth of the original unsuppressed sound level.

In addition, octave band sound pressure level measurements were made in St. Roberts Hall, which is the closest building, containing classrooms, to the Hot Cycle Rotor Test Site. These measurements were made with a General Radio type 1550-A Octave-band Sound Analyzer operating from the output of a type 759-B Sound Level Meter. Data obtained and representative curves are shown on Table 5.5-1 and Figure 5.5-4. The curves indicate that noise levels of the Hot Cycle Rotor plus suppressed engine noise fall almost directly on the lower curve of normal ambient classroom noise levels.

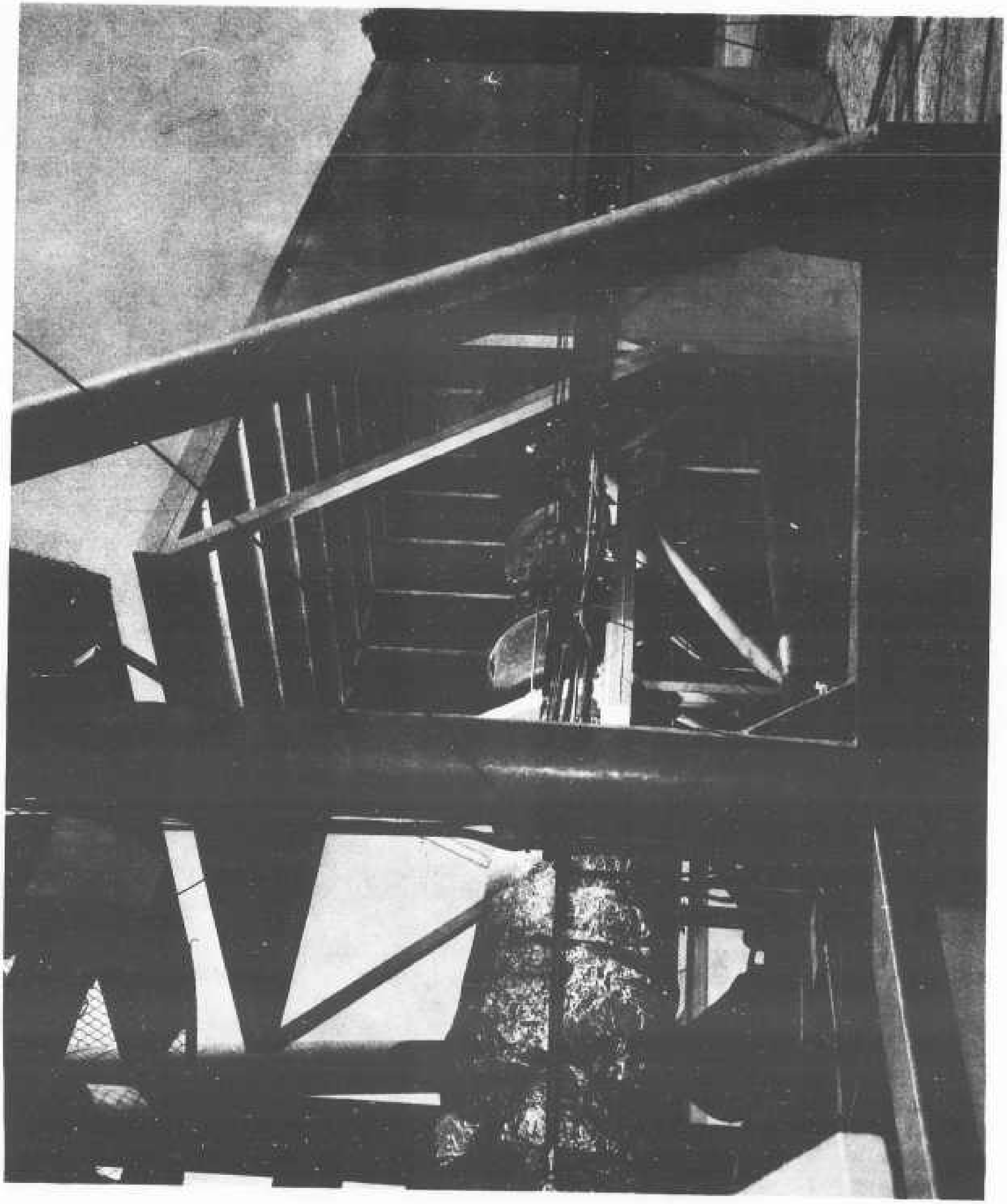


Figure 5.5-1 Engine Inlet Suppressor

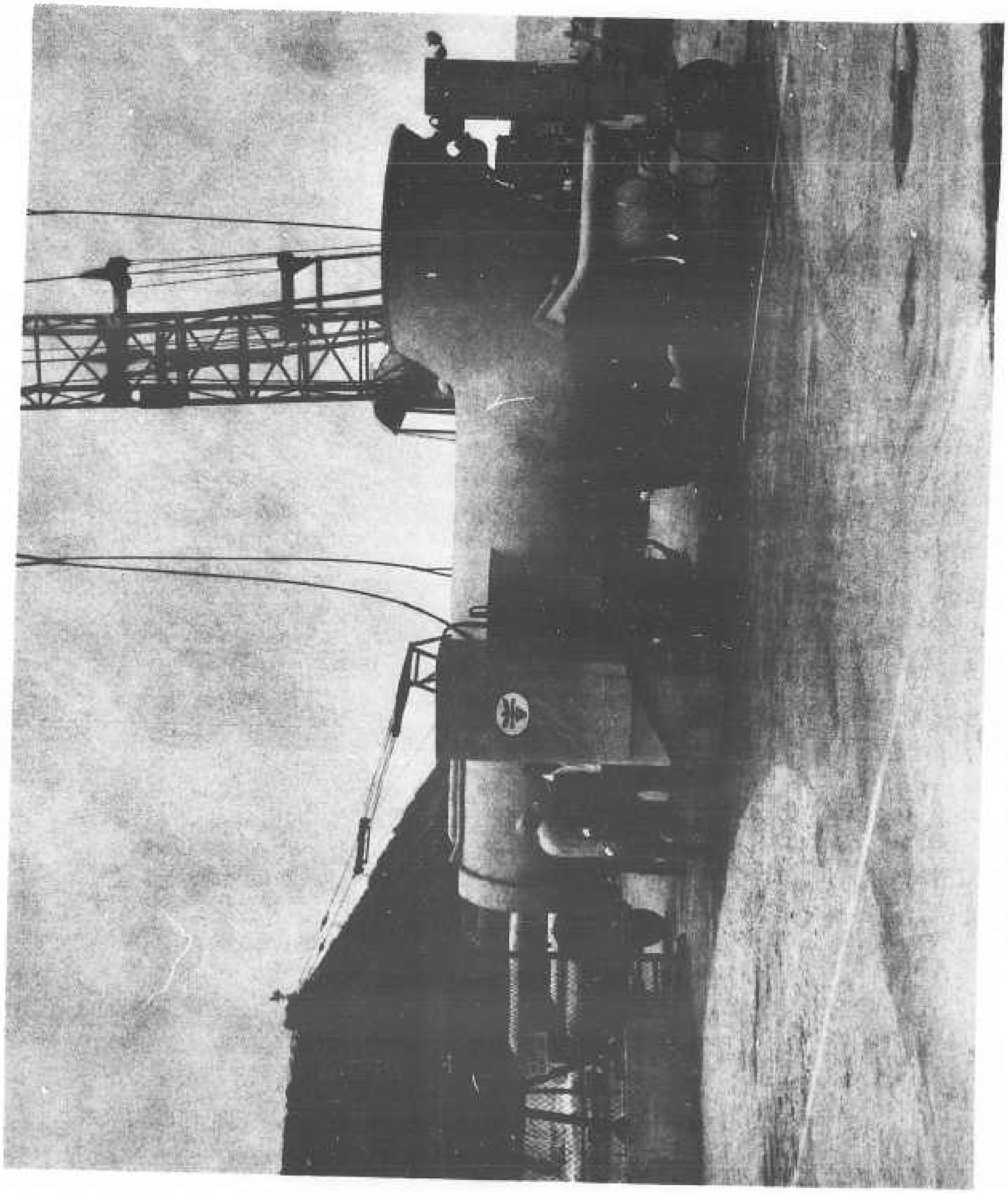


Figure 5.5-2 Engine Surplus Flow Exhaust Suppressor

ANALYSIS
PREPARED BY
CHECKED BY

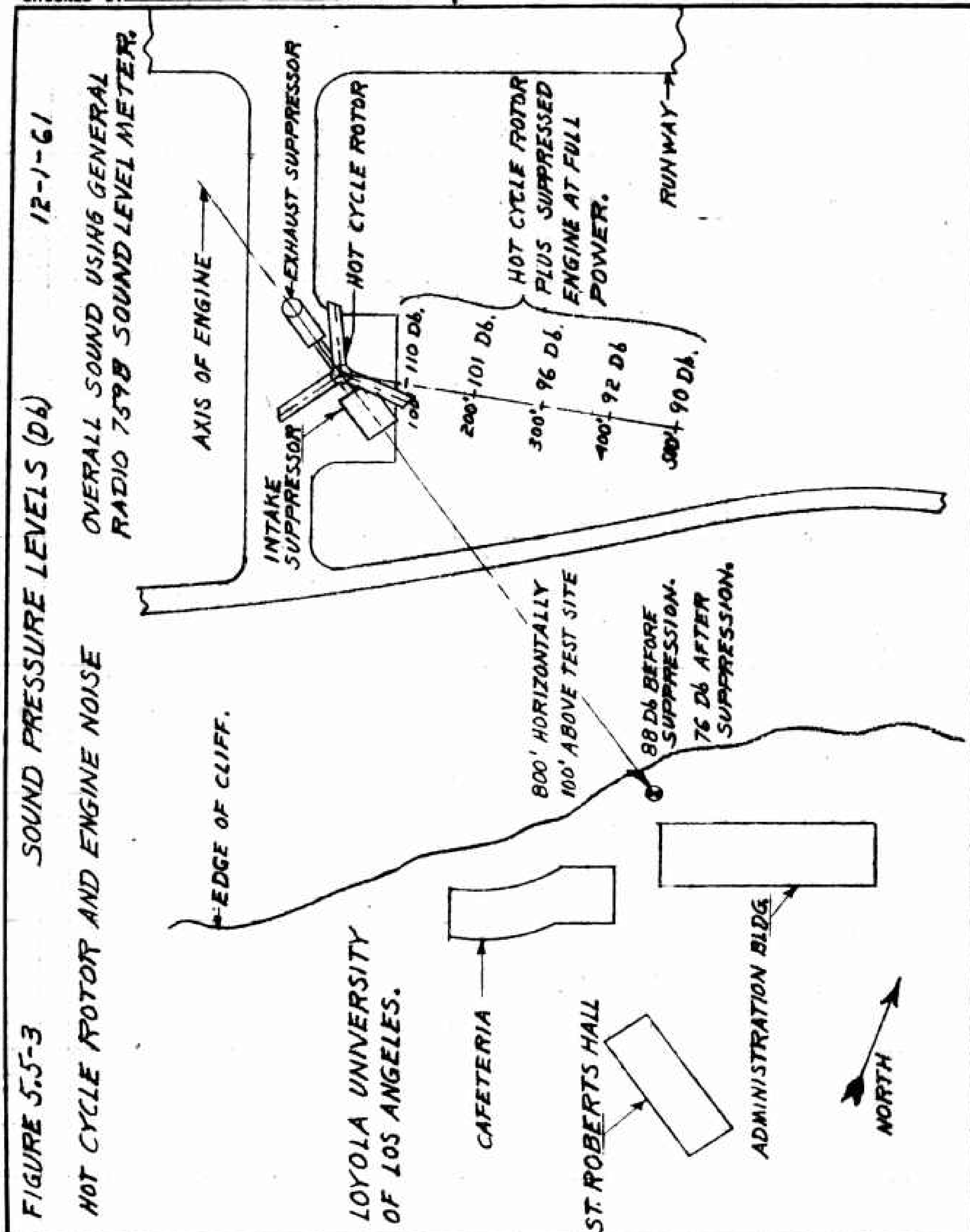


FIGURE 5.5-3
HOT CYCLE ROTOR AND ENGINE NOISE

TABLE 5.5-1 SOUND PRESSURE LEVELS (Db) VS. FREQUENCY (CYCLES/SEC.)
OCTAVE BAND ANALYSIS.

2-27-62

OBSERVERS: R. SAMBRANO
E. SALLOWS

SOUND BAND: RANGE CYCLES/SEC.	SOUND BAND: AVERAGE CYCLES/SEC. (PLOTTED VALUE)	DESIRED VALUE (Db)	LOYOLA UNIV., ST. ROBERTS HALL (Db): NORTH SIDE, FULL CLASS, ENGINE NOT OPERATING.	LOYOLA UNIV., ST. ROBERTS HALL (Db): NORTH SIDE, NO CLASS, ENGINE AT FULL POWER.*	LOYOLA UNIV., ST. ROBERTS HALL (Db): SOUTH SIDE, FULL CLASS, ENGINE NOT OPERATING.
20-75	47	76	66	65	62
75-150	112	64	60-66	64	66
150-300	225	55	58-66	61	66
300-600	450	48	46-62	58	68
600-1200	900	43	46-60	52	60
1200-2400	1800	40	48-52	48	60
2400-4800	3600	38	40-49	44	53
4800-10,000	7400	37	30-36	38	48

TEST EQUIPMENT: GENERAL RADIO TYPE 1550A OCTAVE-BAND NOISE ANALYZER OPERATING FROM THE OUTPUT OF A TYPE 759-B SOUND LEVEL METER.

* HOT CYCLE ROTOR PLUS SUPPRESSED (ENGINE AT FULL POWER) NOISE.

FORM 9707

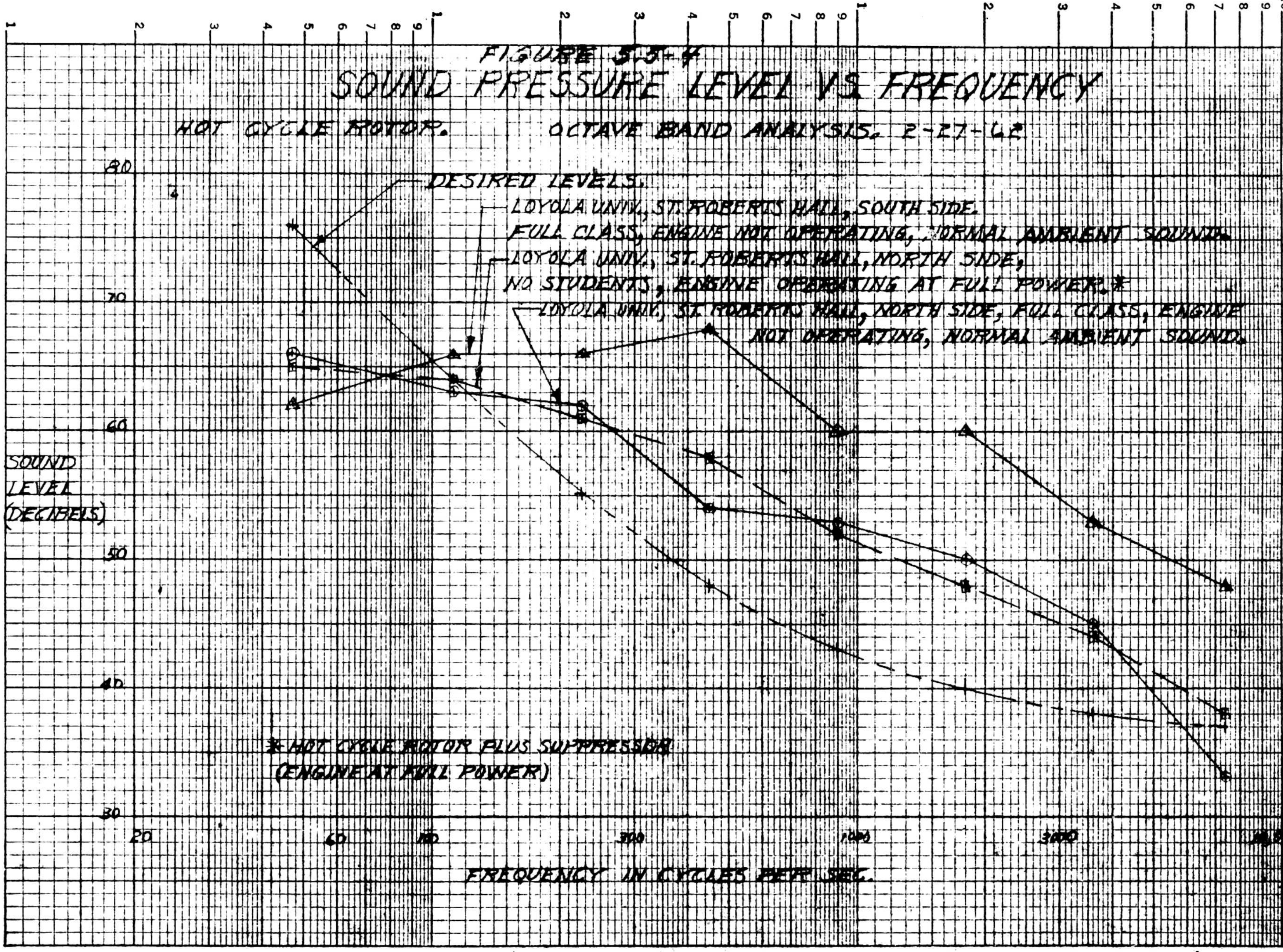


FIGURE 5.5-4
SOUND PRESSURE LEVEL VS FREQUENCY
HOT CYCLE MOTOR.
OCTAVE BAND ANALYSIS. 2-27-62
DESIRED LEVELS.
LOYOLA UNIV., ST. ROBERTS HALL, SOUTH SIDE.
FULL CLASS, ENGINE NOT OPERATING, NORMAL AMBIENT SOUND.
LOYOLA UNIV., ST. ROBERTS HALL, NORTH SIDE,
NO STUDENTS, ENGINE OPERATING AT FULL POWER.*
LOYOLA UNIV., ST. ROBERTS HALL, NORTH SIDE, FULL CLASS, ENGINE NOT OPERATING, NORMAL AMBIENT SOUND.
SOUND LEVEL (DECIBELS)
80
70
60
50
40
30
20
60
100
300
1000
3000
10,000
*HOT CYCLE MOTOR PLUS SUPPRESSOR (ENGINE AT FULL POWER)
FREQUENCY IN CYCLES PER SEC.

5.5.2 Prediction of Rotor Sound Level

After reducing the intake and exhaust noise levels of the J57 engine, overall sound pressure level measurements were made close to the test site so that a preliminary study of rotor blade tip exhaust sound levels could be made. Data obtained and a representative curve are shown on Figures 5.5-3 and 5.5-5.

Operation of the whirl test installation with the suppressor installed on the surplus flow exhaust, provides a good indication of the sound levels to be expected in an actual hot cycle helicopter with the same rotor. However, two differences between the whirl test installation and an actual helicopter should be noted.

1. The engine inlet contribution would be different in the case of an actual helicopter from that of the whirl test installation. Only one-third the air flow would be involved in the helicopter, but the inlet sound suppression would probably not be as effective as that used in the whirl testing. However, an examination of the data of Table III of Mr. Irving's excellent paper on this subject (Reference 5.5-1), indicates a negligible contribution of inlet noise to the over-all sound level of typical turbine-powered helicopters. In each test reported, the lowest sound levels were actually recorded in front of the machines tested. Therefore, it can be concluded that differences in inlet configuration between the whirl test and an actual hot cycle helicopter should not contribute significantly to a difference in sound level between the two cases.

2. In an actual helicopter using the same rotor and two T64 engines, there would be no surplus exhaust flow. Thus, the sound level would be reduced by the amount contributed by the surplus flow of the J57 that is exhausted through the suppressor. Based on the observations of a number of persons with different affiliations and backgrounds, it has been estimated that somewhat more than one-half the sound output of the whirl test installation comes from the surplus exhaust. Accordingly, it has been conservatively estimated that an actual helicopter would have roughly one-half the sound power level, or three db less than measured during the whirl testing.

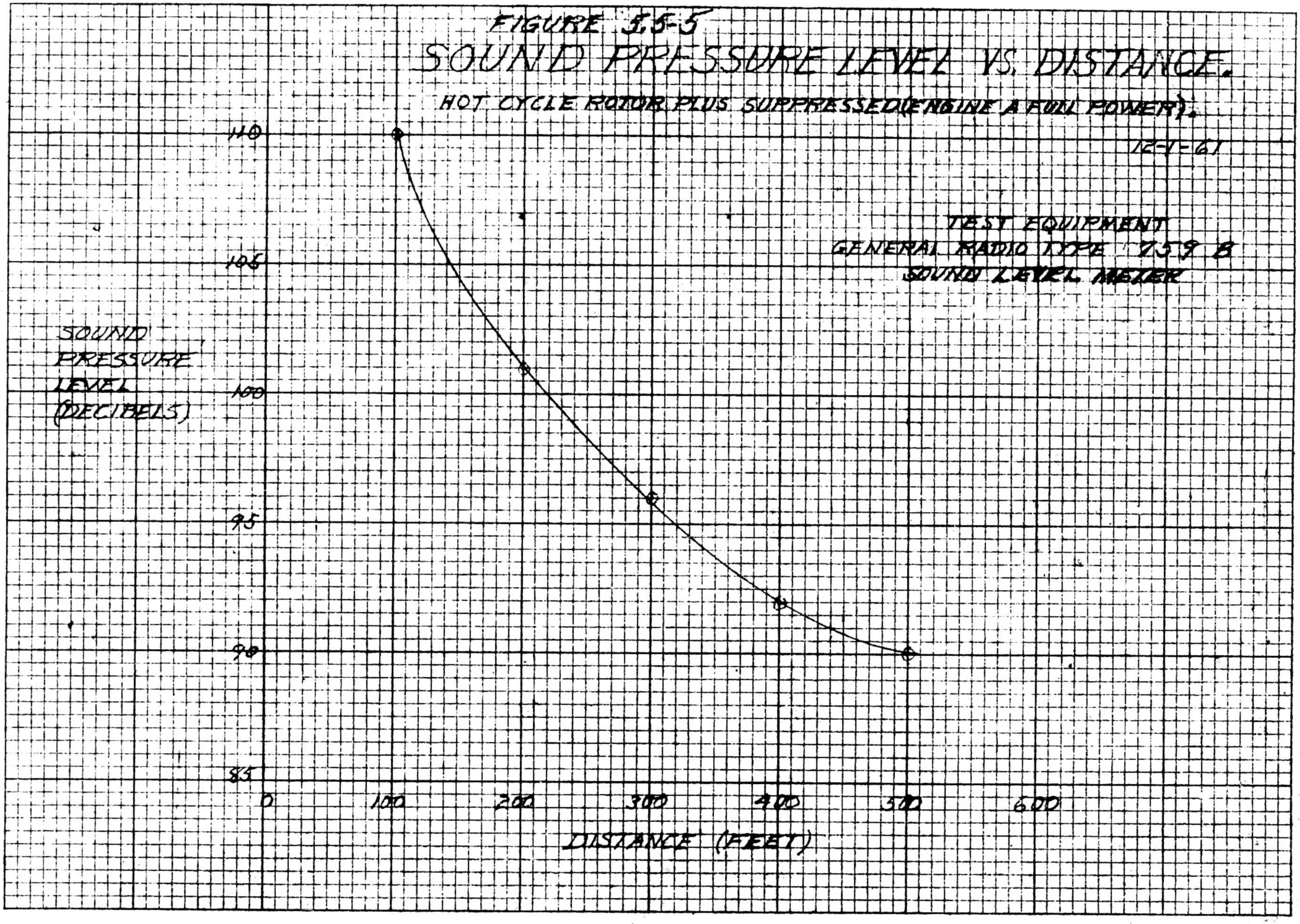
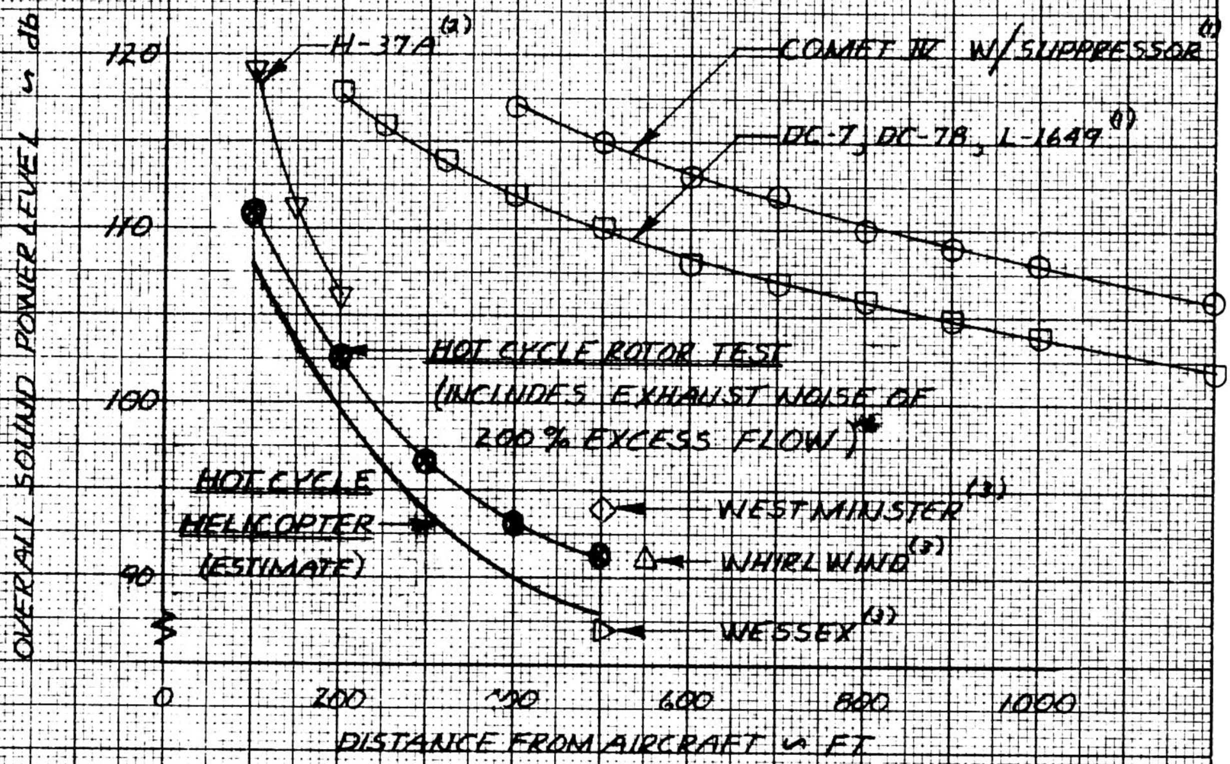


FIGURE 5.5-5
SOUND PRESSURE LEVEL VS. DISTANCE.
HOT CYCLE ROTOR PLUS SUPPRESSED(ENGINE A FULL POWER).
12-1-61
TEST EQUIPMENT
GENERAL RADIO TYPE 759 B
SOUND LEVEL METER
SOUND PRESSURE LEVEL (DECIBELS)
110
105
100
95
90
85
0
100
200
300
400
500
600
DISTANCE (FEET)

Results of the measurements made during the whirl testing are replotted on Figure 5.5-6 in the form of a comparison with other large helicopters and fixed-wing aircraft. The comparison is made for the take-off condition, and presents the over-all sound power level as a function of distance from the observer to the aircraft. It can be seen that the sound level of a hot cycle helicopter is much lower than a typical jet or piston airplane, 22 db lower than (or about 1/2 of 1 percent of) the sound power level of a DC-7. Significantly lower noise than recorded for the H-37A helicopter was also observed during the whirl testing. This measured result was verified by personal observations of individuals who observed the whirl testing and who were also experienced in H-37A operations.

FIGURE 5.5-6
NOISE COMPARISON
FOR
TAKE-OFF CONDITION



REFERENCES:

1. STUDIES OF THE NOISE CHARACTERISTICS OF THE COMET IV JET AIRLINER AND OF LARGE PROPELLER DRIVEN AIRLINERS BY BOLT, BERANEK AND NEWMAN FOR THE PORT OF NEW YORK AUTHORITY, OCTOBER 1958.
2. ARDC H-37A LIMITED STABILITY AND CONTROL EVALUATION, AFFTC-TR-60-15
3. HELICOPTER NOISE SUPPRESSION; H.B. IRVING, JOURNEL OF THE HELICOPTER ASSOCIATION OF GREAT BRITIAN, AUG 1959.

TYPE	ENGINE(S)	HORSEPOWER
WESTMINSTER (S-56)	2 ELANDS	5000
WHIRLWIND (S-55)	GNOME	750
WESSEX (S-58)	GAZELLE	1450

* EXCESS FLOW FROM J-57 EXHAUSTED THRU SUPPRESSOR

HON, 12/18/61; REVISED, RTN, 3/21/62

5.6 POST TEST INSPECTION

5.6.1 General

The hot cycle rotor was given an intensive major inspection three times during the whirl test program. These occurred at the end of eighteen, thirty-five and sixty cumulative hours of whirl testing. (Refer to Figures 5.6-1, 5.6-2, and 5.6-3.) The operating conditions experienced by the rotor system prior to each inspection are discussed in Section 4 of this present report.

For the purposes of the eighteen hour inspection, the rotor hub with blades attached was released from the support pylon and lifted down from the test tower. All fairings, trailing edge segments, tip cascades, cover plates and access panels were taken off. Blade root ducts were removed and the upper rotating duct was lowered out of the hub. All moving seals of the duct system and both bearings of the hub shaft were disassembled.

At the conclusion of the thirty-five hour whirl test period, the entire rotor was removed from the whirl tower to an indoor facility and torn down for inspection. Inasmuch as the inspection was in preparation for 25 hours of life-type testing, a very complete disassembly was undertaken. In addition to the parts taken off for the eighteen hour inspection all other major structural and mechanical components were removed and stripped of fittings, bearings, bushings, etc., and inspected by Magnaflux, Die Penetrant, visual or other methods, whichever was the most suitable in each case. All holes and edges of parts were carefully studied for the existence of such stress raisers as burrs and nicks.

At the conclusion of a total of 60 hours of whirl test, the entire rotor was again removed to an indoor facility. The major components were disassembled and given a thorough visual inspection.

None of the major inspections revealed any basic flaw in the hot cycle system. Of the few components replaced by new parts following inspection, not one was rejected for evidence of imminent structural failure. In general, replacements were made as conservative measures to ensure continued good mechanical performance, taking advantage of the disassembly and reassembly incidental to inspection rather than possibly incurring interruptions and delays of ensuing whirl tests. In a few instances, notably as applies to the hub duct inner seal, components were reinstalled after minor rework to improve their mechanical performance.

The discussions that follow are concerned with inspection findings of special interest. Materials problems are discussed at length in Reference 5.6. Unless stated otherwise, components were found to be in good condition and were kept in service throughout the entire 60 hours of whirl testing.

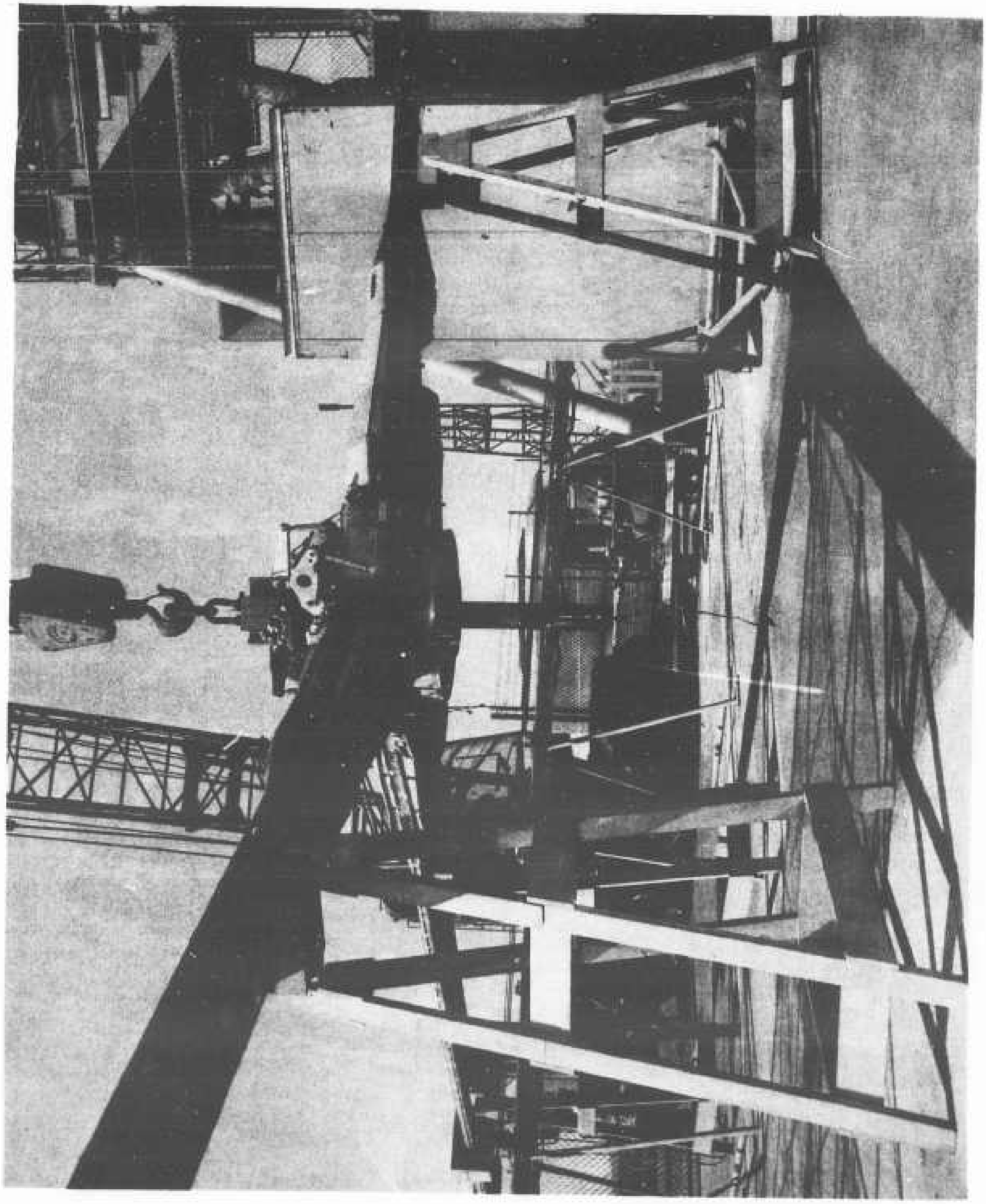


Figure 5.6-1 Rotor Removed from Tower for 18 Hour Inspection

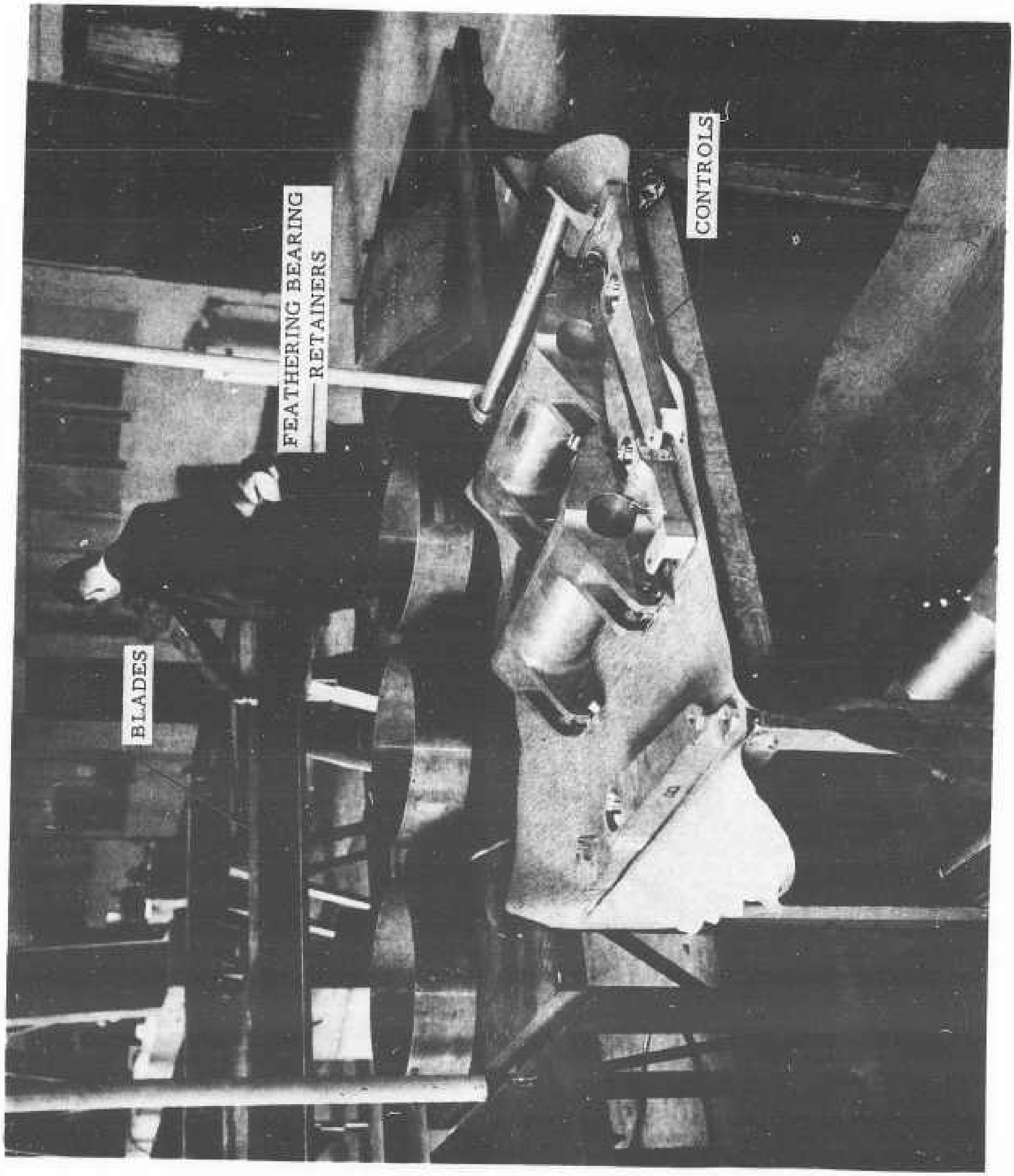


Figure 5.6-2 Rotor Disassembled for 35 Hour Inspection

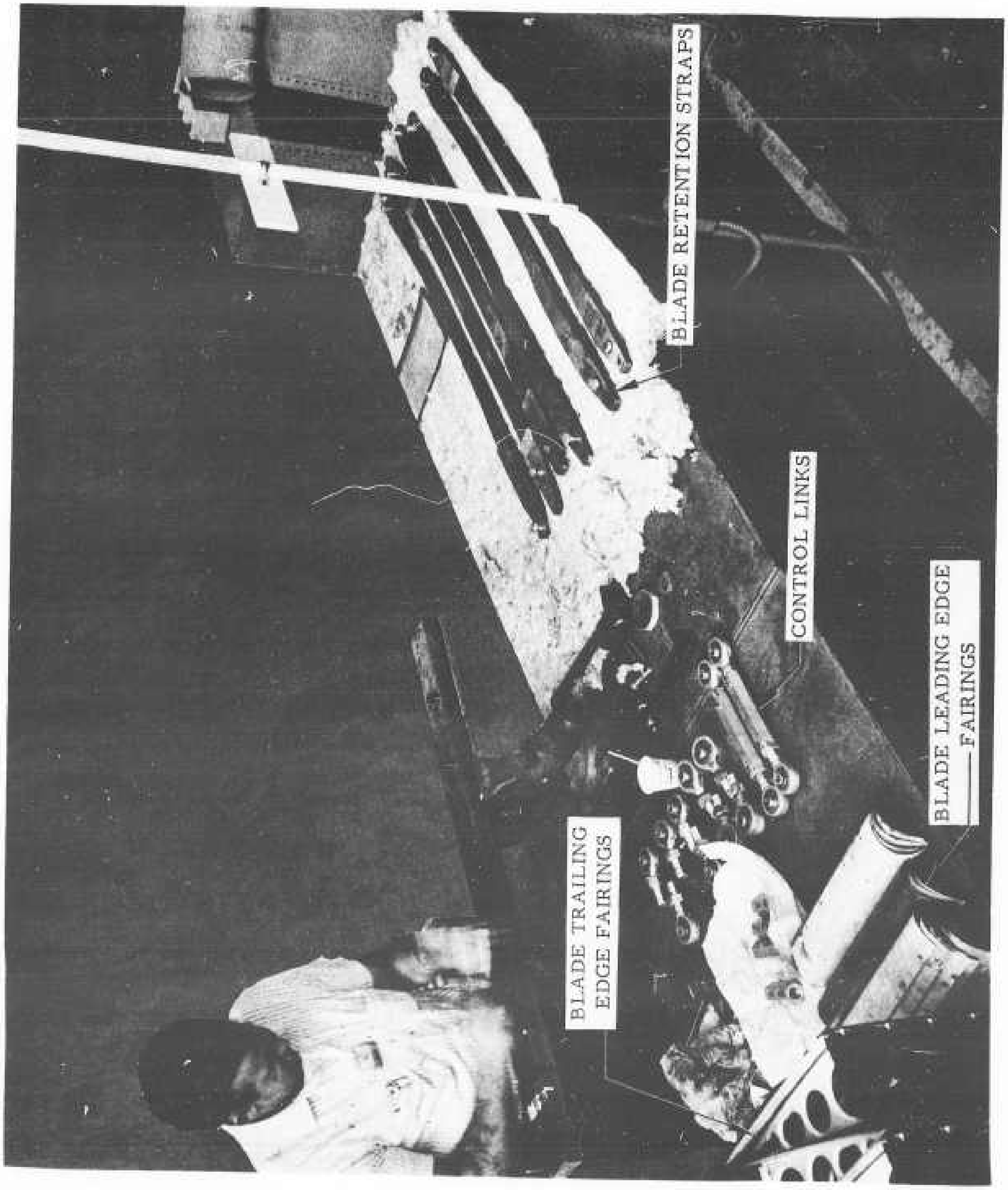


Figure 5.6-3 Rotor Disassembled for 35 Hour Inspection

5.6.2 Mechanical Components

5.6.2.1 Bearings

a. Thrust (Hub lower) Bearing Assembly

At eighteen hours this bearing, which reacts all lift loads, was found to be in good condition. However, circumferential marks (see Figure 5.6-4) on the black oxide surface of the hub shaft indicated the possibility of creep between the inner race and the shaft. Although there was no certainty that creep had occurred either during rotor operation or during assembly, the preload between the two Timken Bearings was reduced upon reassembly and the clamping force across the inner races was considerably increased. In addition, a lubricant was added to the shaft in case there should be a tendency for the race to rotate on the shaft during subsequent testing.

At thirty-five hours, the thrust bearing was again found in good condition. Experience since the eighteen hour inspection had shown the reduction in bearing preload made at that time to be more than adequate. Therefore a housing shim was eliminated to produce an intermediate preload.

b. Hub Upper Bearing

This bearing takes only radial loads. All components of the bearing and oil retaining seals were found to be in excellent condition at all inspections. (Reference Figure 5.6-5)

c. Rotor Gimbal Bearings

These bearings were not accessible for direct inspection at eighteen hours; however, no roughness could be felt when the gimbal was rotated while loaded only by the weight of the shaft. At thirty-five hours, slight fretting was found in two SKF bearings which join the gimbal clevis and ring. All four SKF bearings were replaced. At 60 hours, all bearings revealed slight fretting.

d. Swash Plate Fafnir Bearings

These two ball bearings showed rust and some roughness at thirty-five hours. Although the condition was not serious, they were replaced. At 60 hours, they appeared in good condition.

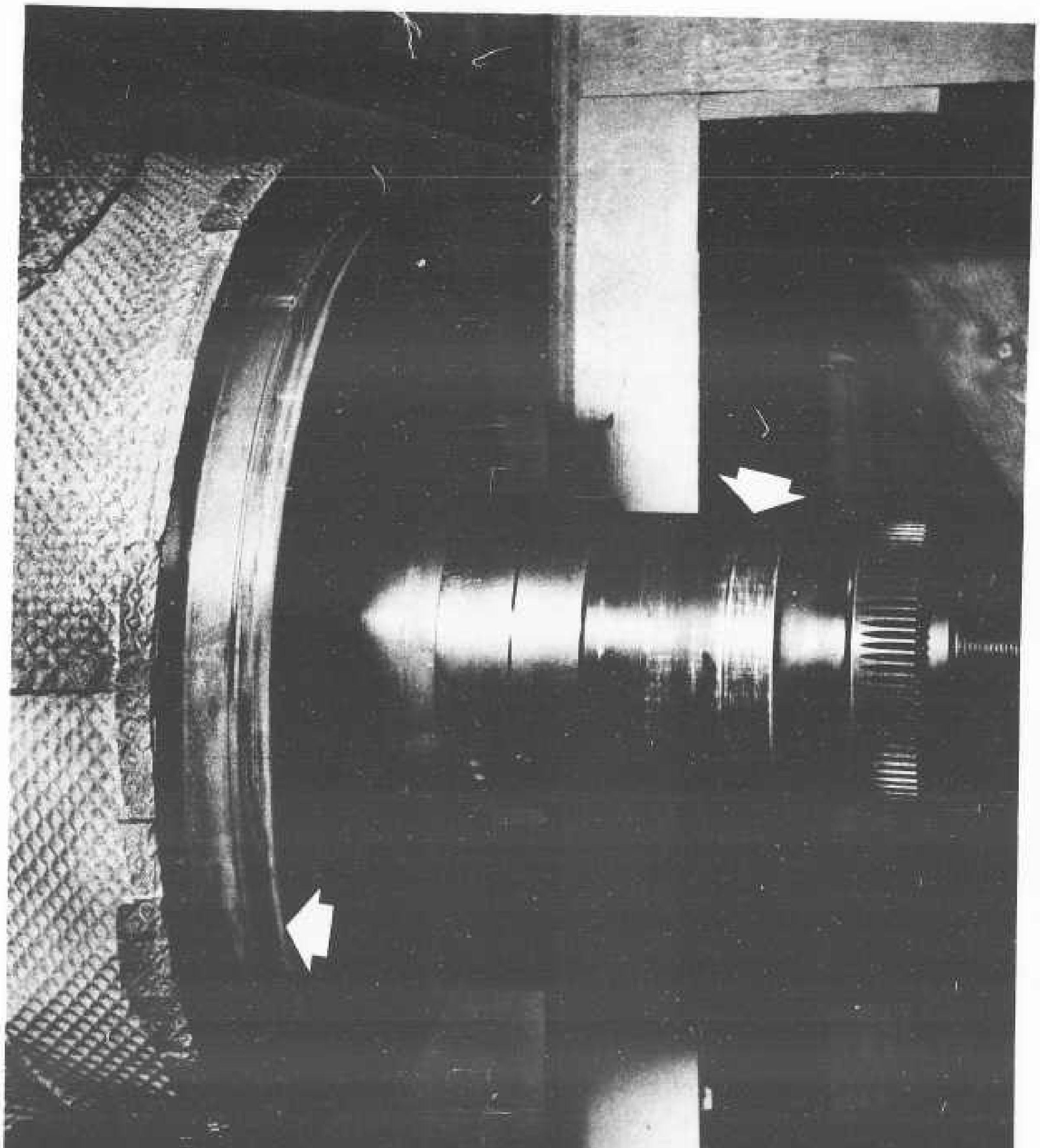


Figure 5.6-4 Hub Lower Shaft and Duct Seal Outer Rotating Surface After 18 Hours. Note lines on shaft at location of thrust bearing and corrosion on lower edge of sealing surface.

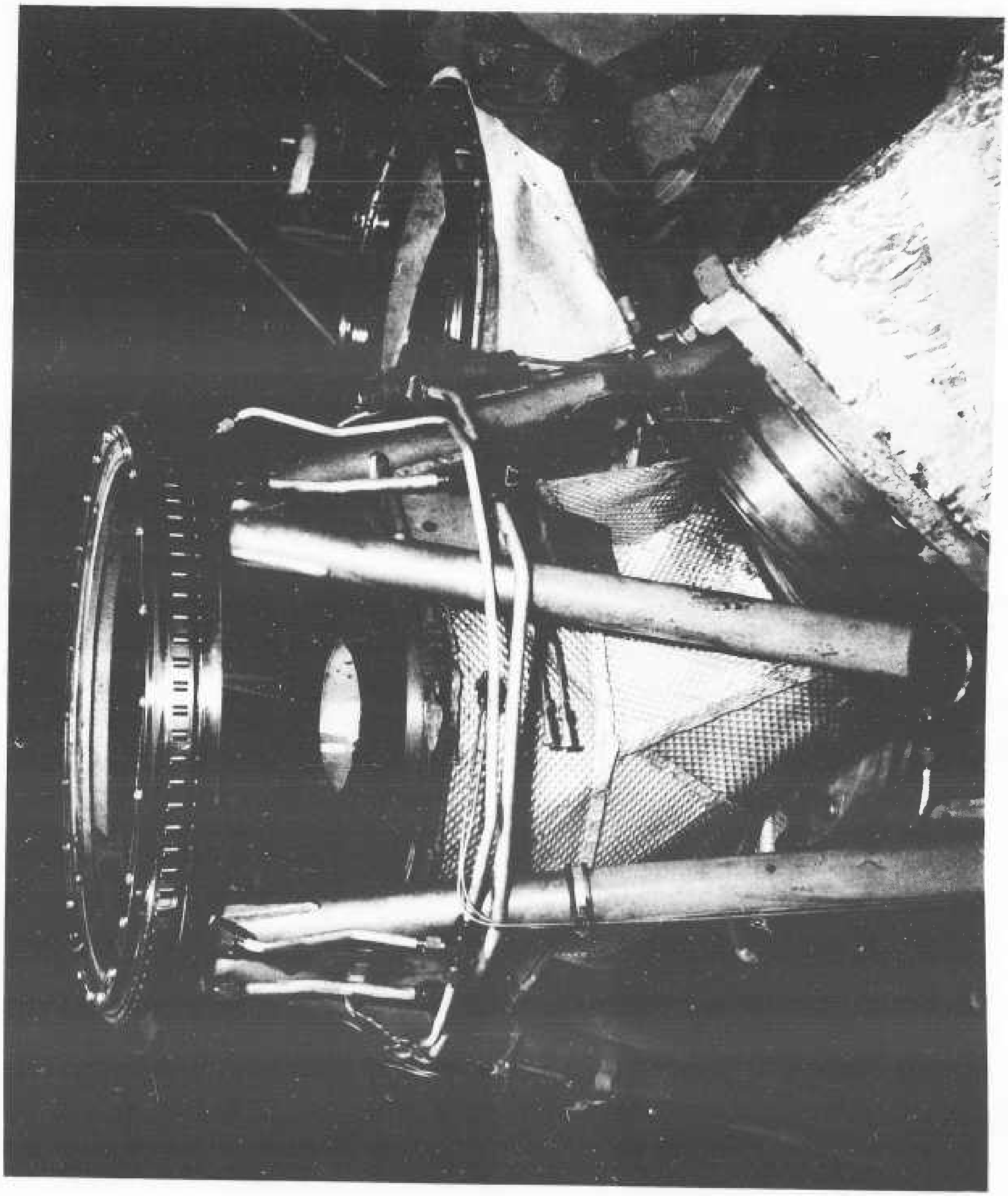


Figure 5.6-5 Hub Upper Radial Bearing and Seals Disassembled After 18 Hours.

e. Torque Tube Timken Bearing

At thirty-five hours a small amount of rust was found on one large Timken bearing in one of the three torque tubes. This particular bearing was replaced.

f. Rod End Bearings, Central Control Rods

At thirty-five hours all six shafer rod end bearings (in the three central control rods only) were replaced. This was done as a conservative measure because calculations indicated a relatively short service life under the design loads for the bearing in this particular location. On the other hand, although a destructive disassembly was not performed, the bearings showed no evidence of damage.

g. Feathering Bearing

This bearing consists of a chromium plated cast aluminum ball rotating within a Fabroid[1] faced ring. At eighteen hours the Fabroid surfaces were inspected by raising and lowering the blades through the maximum available clearance angles to expose the riding surfaces. These appeared to be in excellent condition with no evidence of significant wear.

At thirty-five hours the bearings were disassembled and the Fabroid wear surfaces found to be in generally good condition, as shown in Figure 5.6-6. Local areas of high contact pressure showed a general smearing of the teflon, which appears to have no effect on its load carrying ability or friction coefficient. Because two segments of one bearing had been scored in handling and two segments of another were locally unbonded, all segments of both these bearings were relined.

At eighteen hours the cast aluminum balls showed blisters of the chromium plate, apparently resulting from sub-surface corrosion. This phenomenon is discussed in detail in Reference 5.6-1. No action was taken at that time since the blisters were located outside of critical wear areas. At thirty-five hours one ball showed no blistering, one showed only a very small amount in a non-critical region, while the third had a considerable amount of blistering which approached a critical wear area. This third ball was replaced.

[1] Fabroid is a teflon filament and fiberglass thread woven cloth manufactured by Microprecision Division of Micromatic Hone Company, Los Angeles 32, California

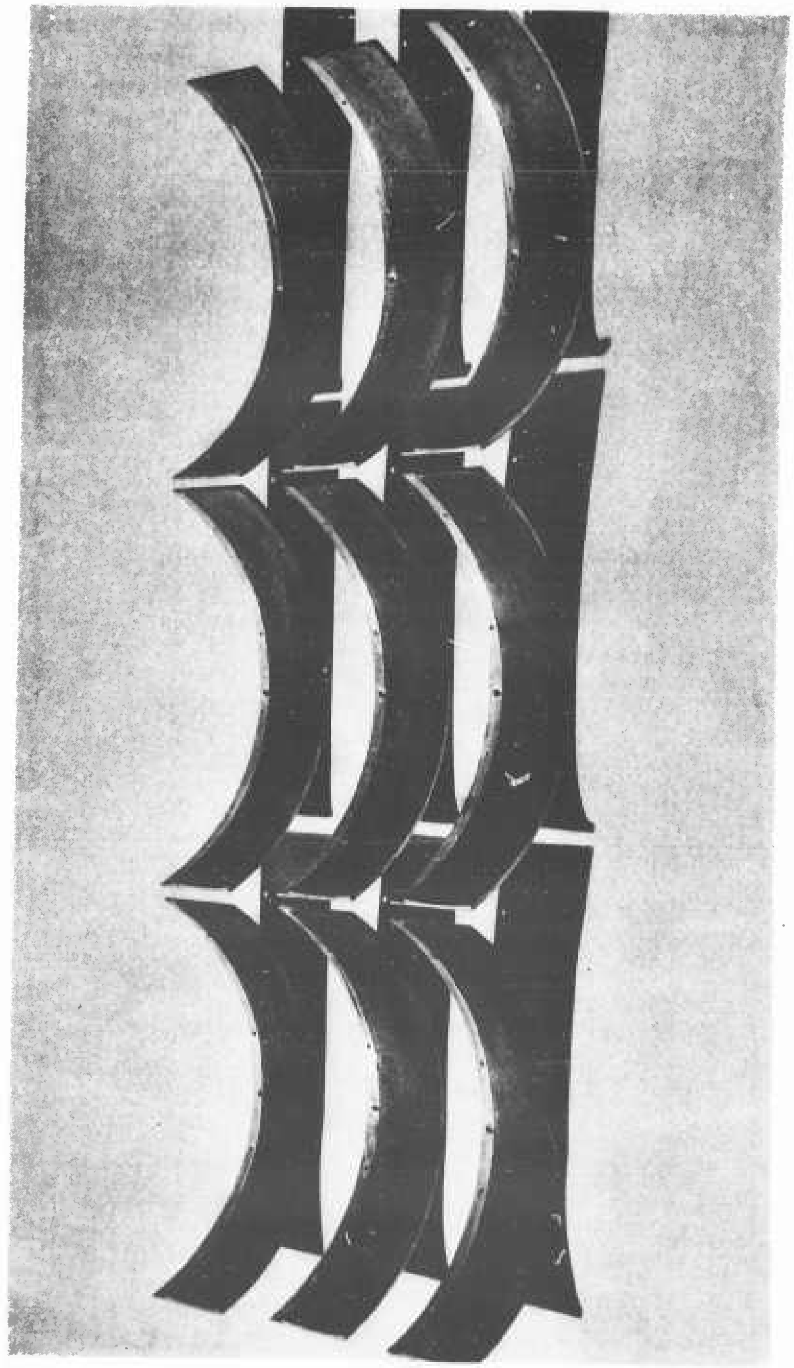


Figure 5.6-6 Fabroid Flapping-Feathering Bearing, Showing Good Condition After 35 Hours

5.6.2.2 Duct Seals

a. Hub Inner Seal (Figure 5.6-7)

This face-type seal prevents escape of gases at the inner surface of the hub stationary-to-rotating duct joint. Contact of the sealing faces is maintained by axial movement of a cylinder at the inner periphery of the stationary duct. At operating temperatures, differential expansion of this cylinder and the duct resulted in increased clearance between the two, and therefore the cylindrical portion of the seal could move freely. However, continued heating and cooling of the units produced slight warpage of the components which eliminated the small clearance originally incorporated into the parts. This interference in turn prevented axial movement and contact of the sealing faces at ambient temperatures, and thus the duct system could not be pressurized during the eighteen hour inspection. Action taken was to machine the surfaces to increase clearance.

Figure 5.6-8 shows what appears to be a slight subsurface corrosion beneath the aluminum oxide flame plate on the type 347 corrosion resistant steel base of the seal mating ring, first noted during the eighteen hour inspection. This corrosion did not become more extensive, and therefore no action was necessary.

The carbon portion of the Hub Inner Seal, after eighteen hours of test, appeared to have some local spots which were softer than the remaining material. This could be an indication of inconsistencies in the raw stock or in the impregnation, with a resultant deterioration of some of the material at the high temperatures encountered. The face of the carbon ring was surface ground to remove the soft spots.

At thirty-five hours, the inner seal showed essentially the same type of softening as had appeared at the 18 hour inspection period. Since it was believed that additional grinding would reduce the thickness of the riding element to an unacceptable dimension, a new part was installed. After 60 hours, this part was in excellent condition.

b. Hub Outer Seal (Figure 5.6-7)

This seal, which consists of two layers of carbon segments riding on a steel ring, apparently functioned with little leakage during

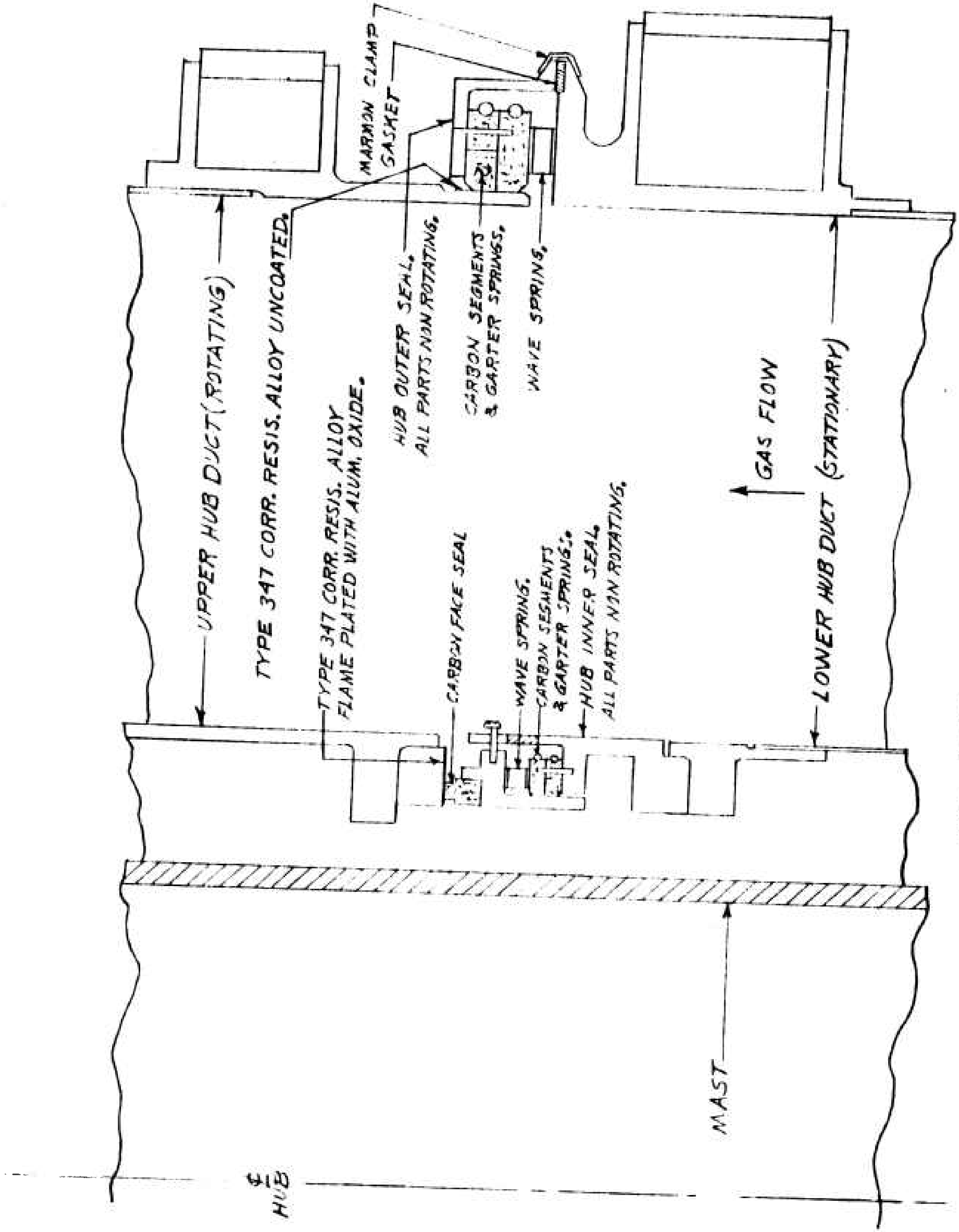


Figure 5.6-7 Hub Inner and Outer Seals

Figure 5. 6-8 Hub Upper Duct and Seal Faces After 18 Hours.
Note apparent sub-surface corrosion
under aluminum oxide plating.

the whirl test. However, at eighteen hours the upper edge of the lower ring of carbon segments was found to be chipped evenly around the periphery (Shown in Figure 5.6-9) and both rings were replaced. Rather exhaustive investigation indicated the damage was probably done during preliminary calibration or trial assembly prior to any testing. Satisfactory performance under these conditions is evidence of the durability and practicality of the design.

At thirty-five (35) hours the seal carbon segments were in excellent condition and were retained. After sixty (60) hours, the upper ring of segments had an etched appearance, the cause of which has not yet been determined.

For ease of handling, the 24 small seal-seating coil springs were replaced by a single wave spring at the 35 hour inspection period.

The mating ring of this seal is fabricated of type 347 corrosion resistant steel. The surface actually in contact with the carbon segments was clean and smooth. However, the edge which was exposed to the hot gases and not wiped by continuous motion of the carbon had corroded severely, as shown in Figure 5.6-4. This corrosion was removed, but it is essential that on service craft more resistant materials or plating be used to prevent such corrosion.

c. Articulate Duct Inboard Seal

These seals, of carbon segments riding on type 347 corrosion resistant steel balls, were generally in good condition at all inspections. As noted above regarding the Hub Outer Seal Mating Ring, the metal balls showed definite corrosion in the area not generally wiped by the carbon. Material or a plating more resistant to corrosion will be required for longer seal life.

As noted for the hub inner seal, the carbon material used here indicated at the 18 hour period a very definite softening of some protions of the carbon segments with a resulting tendency for the edges to errode, as shown in Figure 5.6-10. Nevertheless, since these seals did not show signs of appreciable leakage, the whirl test was continued with these particular carbon segments.

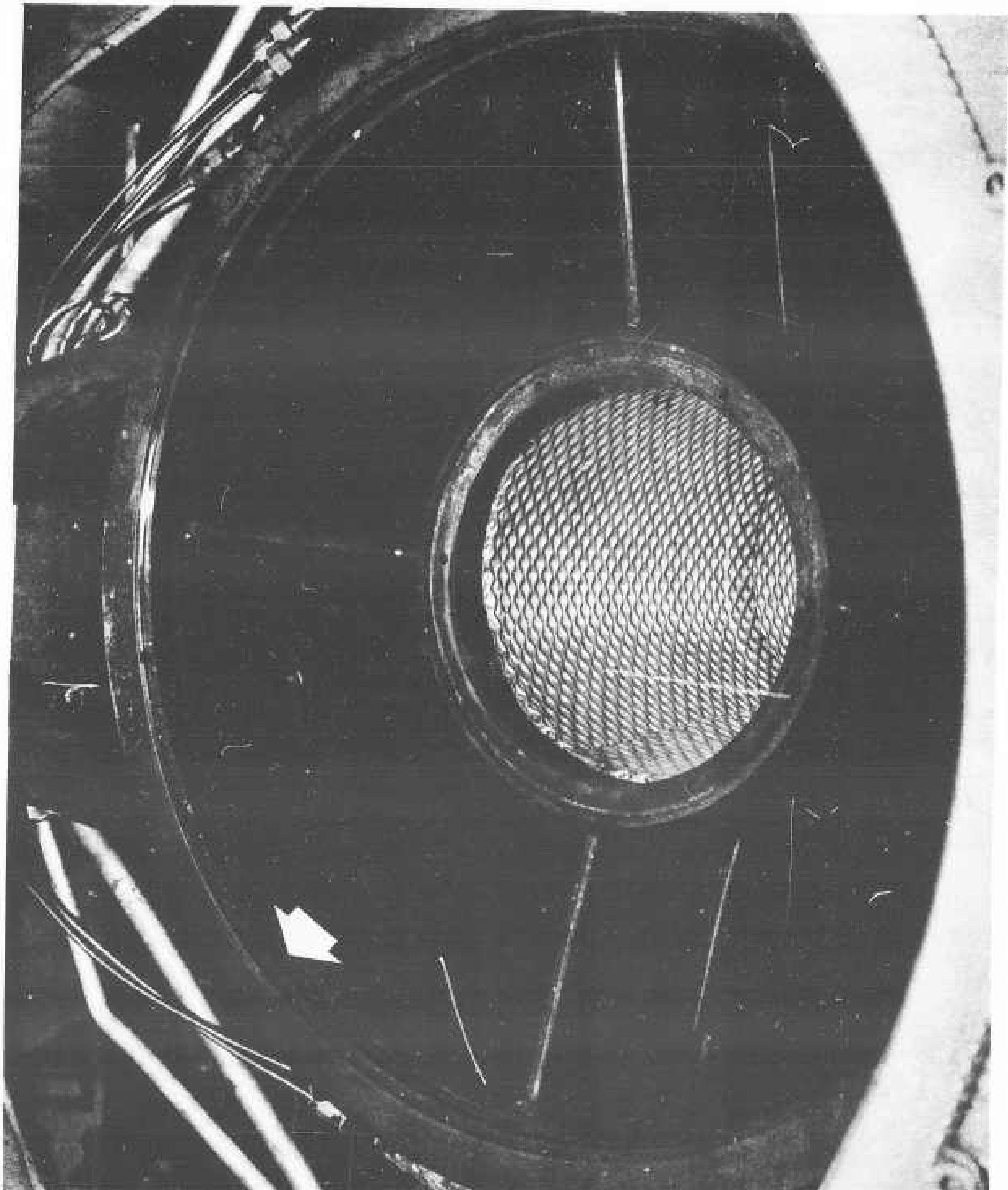


Figure 5.6-9 Hub Lower Duct with Outer Seal Segmented Rings in Position, After 18 Hours. Note uniform chipping (apparently from assembly and checkout operations) on upper edge of lower of two carbon rings.

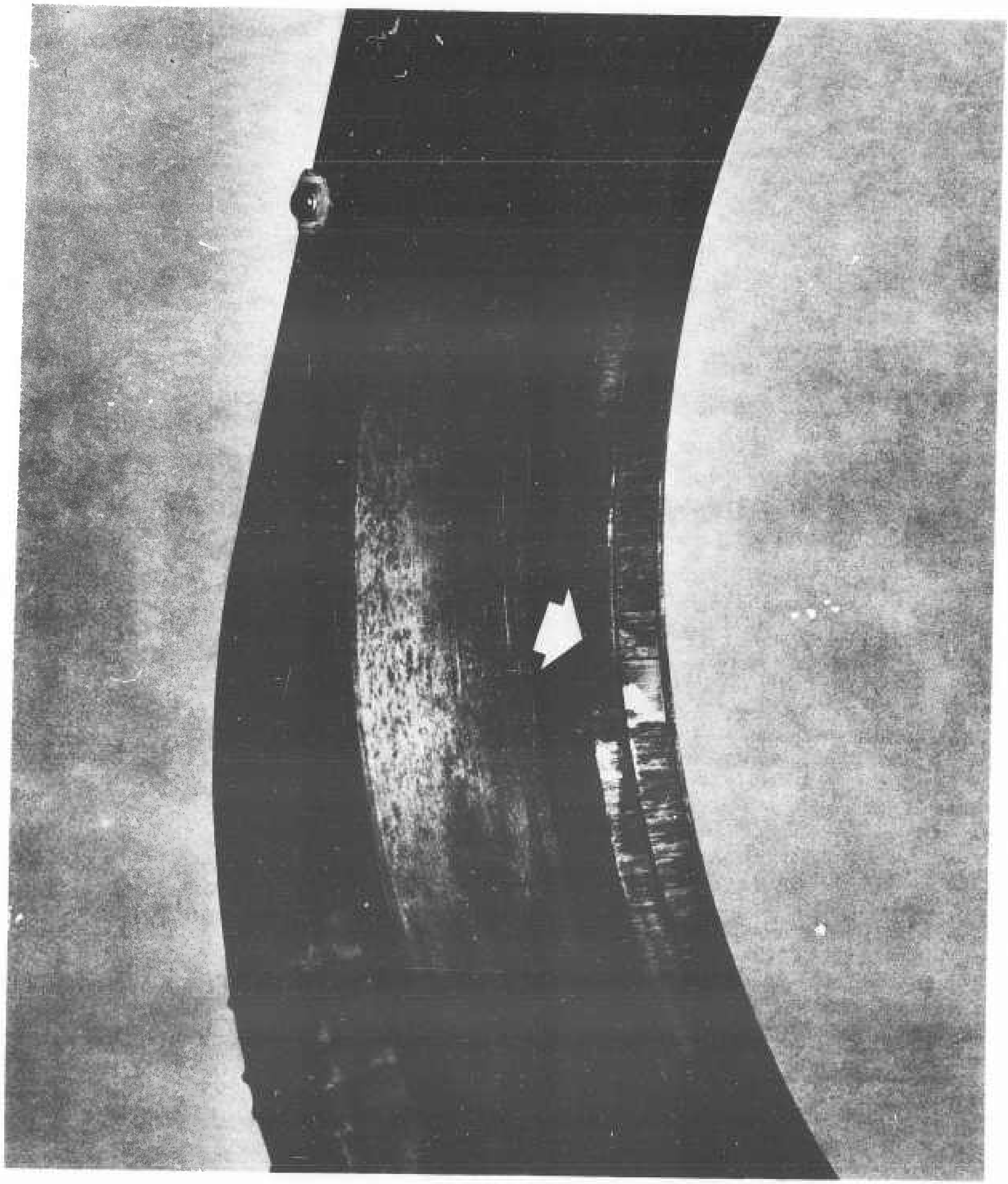


Figure 5.6-10 Close-Up of Articulate Duct Inboard Seal Segmented Carbon Rings. Note local softening of carbon and resulting erosion of edge.

At thirty-five hours their condition did not appear to have changed. Sealing performance had not deteriorated. It was decided, therfore, to continue the whirl tests with these same carbon segments. One set of carbon elements however, was inadvertantly shattered in handling and was replaced by a new one. There was no significant change in any carbons at the end of sixty hours of test.

d. Articulate Duct Outboard Seal

This seal, discussed at length in Reference 5.6-2, consists of metal lips riding on a metal cylinder. The lips are fabricated of Rene' 41, while the cylinder is of type 347 corrosion resistant steel with tungsten carbide flame plate on the rubbing surface. Both surfaces were electrofilmed for lubrication.

At eighteen hours, wear on the lips of the three seals was moderate, but one of the lobes on one lip of one seal had a crack extending circumferentially 1/4 inch. As a conservative measure, a new set of lip rings was installed in all blades. At 35 hours, the metal lips of this seal again showed moderate wear, but there was no evidence of cracking. The lips were once more replaced by a new set.

The cylinders on which the lips rode were flame plated with tungsten carbide. Difficulty in maintaining roundness of the original cylinders during the fabrication process resulted in an uneven thickness of the tungsten carbide. As a result, it was believed the internal stresses due to differential thermal expansion were high. At thirty-five hours the tungsten carbide showed signs of spalling, possibly initiated by attachment of thermocouples or by other handling during the long check out periods on this particular seal, and aggravated by the thermal stresses. There was, therefore, a real possibility of extension of this spalling. In order to avoid an otherwise long delay of the whirl testing, all of the cylinders were replaced at thirty-five hours.

5.6.3 Structural Components

5.6.3.1 Hub Shaft-Spoke Assembly

Gold paint, because of its high heat reflectivity at temperatures in the 100 to 1000°F range, had been applied to the mast and upper hub support spoke piece external surfaces over electroless nickel plate (See Reference 5.6-3 for a more extensive presentation.). At the eighteen hour inspection, the shaft exhibited a tendency to corrode severly, even though the spoke piece did not. Measured temperatures of the shaft and upper support, on the other hand, were well below critical values, and therefore it was decided a coating of less reflectivity could be used. For these reasons, the gold paint was removed and the surfaces coated with a high temperature aluminum paint having a substantially improved corrosion resistance.

At thirty-five hours the shaft-spoke assembly was separated for inspection, particularly in reference to the possibility of fretting and corrosion at the mating surfaces. A ring of corrosion pits was found at the outermost edges of the mating surfaces, in addition to sharp edges around the holes drilled and reamed on assembly for the retaining bolts. Both conditions were corrected, one by polishing off the corrosion area and the other by rounding off and polishing the edges of the holes. In order to facilitate separation at future inspection periods, interference fit between these two parts was reduced to zero. In addition, pitting of the lower part of the shaft due to presence of gold paint as described above, and all tool marks on the shaft were carefully polished away.

5.6.3.2 Hub Gimbal

Rotor horizontal forces, as measured in the gimbal clevises, were higher than originally estimated. Therefore, a reinforcement to the gimbal was installed at the eighteen hour inspection period to reduce the stresses resulting from these loads.

At thirty-five hours the trunnion shaft was found to have a flaw in the original hand forging from which the part was made. Although the original ultrasonic inspection and a final X-ray inspection failed to reveal this defect, it was found to penetrate from outer to inner wall. Fortunately this flaw was located in an area of reasonably low stress and therefore rework could be tolerated. In order to completely remove the flaw, a hole of approximately 1/4 inch diameter was drilled through, rounded at the edges and polished.

5.6.3.3 Swash Plate

It was noted at thirty-five hours that the stationary swash plate, which is aluminum alloy, had been brinnelled around the edges of some bolt holes. Bushings inserted in the holes left insufficient surface under the bolt head for bearing on the surface of the swash plate. The brinnelled areas were spot faced, and large diameter washers were added to increase bearing area.

5.6.3.4 Blade Spars

The spars were removed from the whirl test blades and given close scrutiny during the thirty-five hour inspection. Special attention was directed towards such potential stress raisers as burrs, sharp corners, scratches, nicks and tool marks. Upon reassembly, reinforcement plates, corresponding to that utilized on the Full Scale Fatigue Test specimen (Reference 5.6-4), were added to the rear spars at the bend point. At the end of 60 hours, careful inspection of the spar disclosed no evidence of damage.

SECTION 6

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APPENDICES

A. Whirl Tower Structural Analysis

B. Test Log Sheets

C. Method of Calculation; Area and Mass Weighted Parameters

D. Thermodynamic Calculation Procedure; Non-Rotating Components

E. Summary of Strain Gage and Thermocouple Locations

F. Nomenclature & Computer Program Formats

APPENDIX A

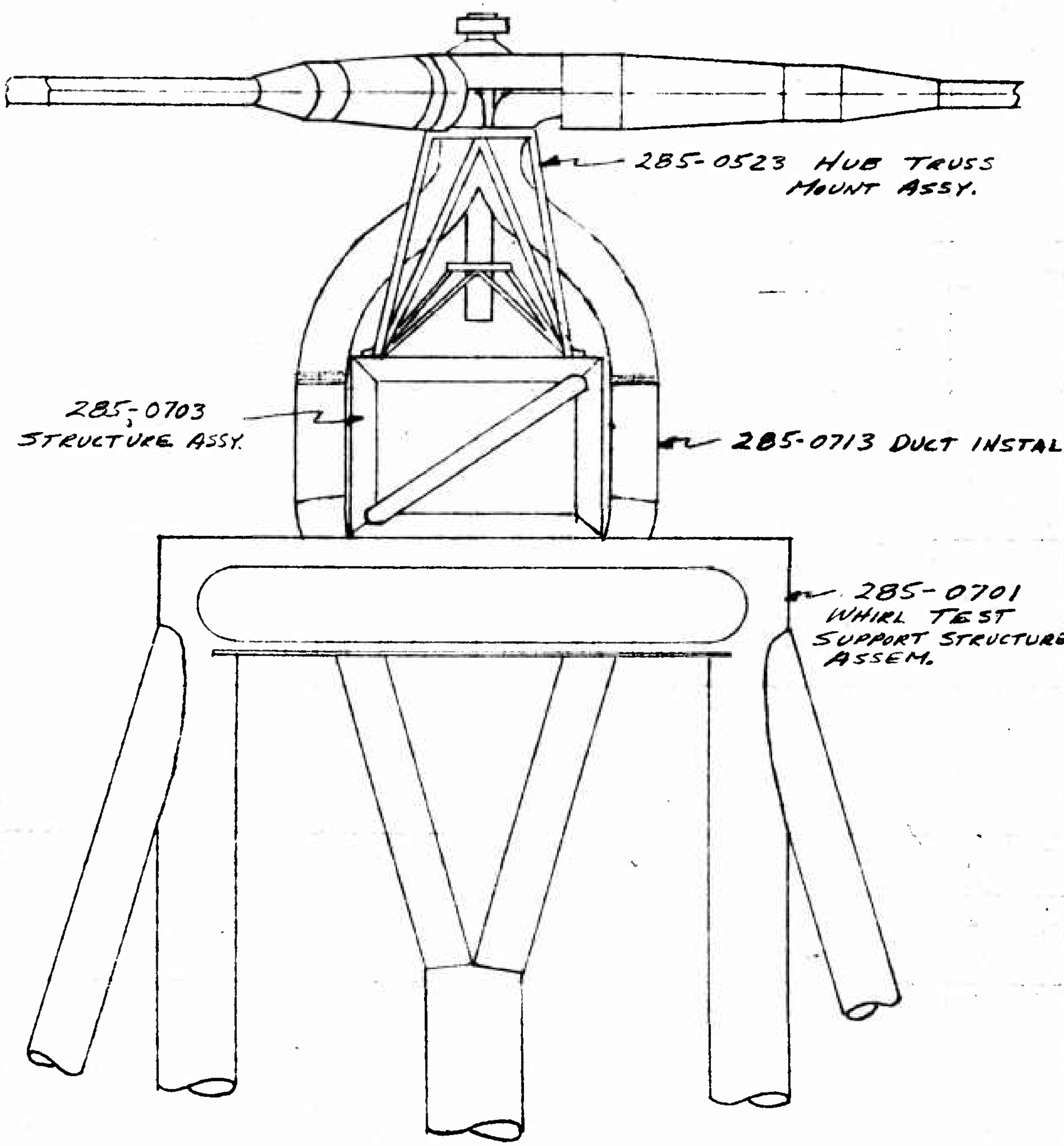
WHIRL TOWER STRUCTURAL ANALYSIS

A.1 INTRODUCTION

This section contains the structural analysis of the whirl tower used for testing the Hot Cycle Rotor System. The analysis includes both the tower structure and the duct system. Loads and pressures used are based on the design criteria given in HTC-AD Report 285-13 (Reference A.1-1), Section 1. A sketch of the whirl tower installation is given in the figure on page 2 of this appendix.

WHIRL TOWER INSTALLATION REF. DWGS. 285-0700, 285-0720, 285-0713

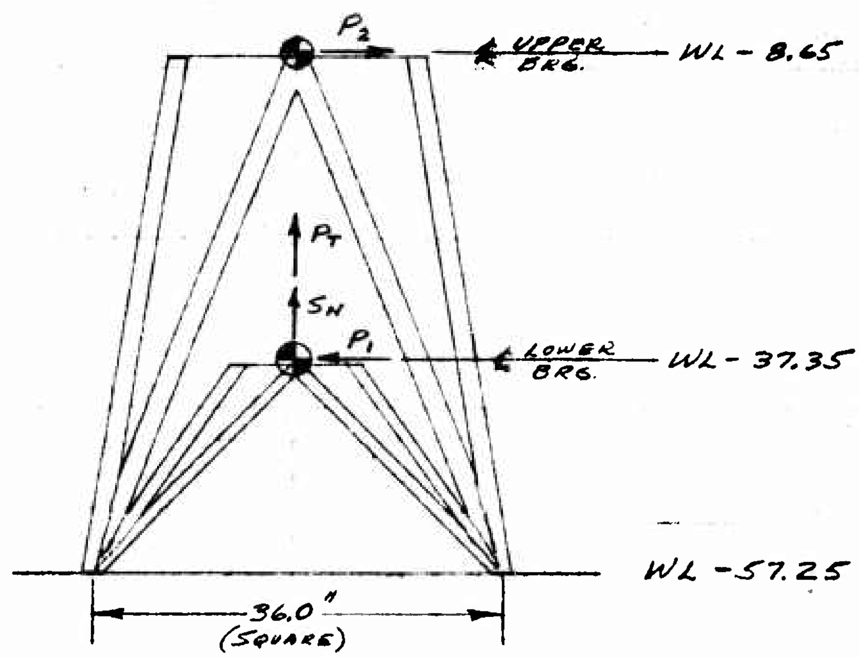
FIGURE A-1



A.2 WHIRL TOWER STRUCTURE

DESIGN LOADS

WHIRL TOWER DESIGN LOADS ARE TAKEN FROM ROTOR SYSTEM LOADS GIVEN IN SECTON 4, REF A.1-1. LOADS USED ARE BASED ON THE MAX. FLIGHT MANEUVER CONDITION AND INCLUDE A LIMIT FACTOR OF 2½. LOADS TRANSFERRED TO THE TOWER ARE FROM THE MAIN ROTOR SHAFT AT THE UPPER AND LOWER BEARING SUPPORTS.



LIMIT LOADS (REF. A.1-1, SECTION 4)

S_N = 38,250 LBS. = ROTOR LIFT VERTICAL COMPONENT

P_T = 8,660 LBS. = DUCT PRESSURE LOAD AT ROTATING SEAL

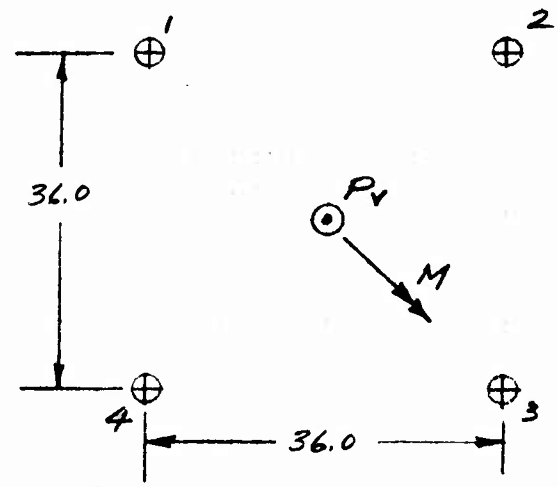
P_2 = 9,770 LBS. = SIDE LOAD FROM UPPER BRG. ($-R_2$)

P_1 = *8,880 LBS. = SIDE LOAD FROM LOWER BRG. ($-R_1$)

* INCLUDES ARBITRARY POWER TAKE-OFF LOAD. WITHOUT POWER TAKE-OFF REQUIREMENT P_1 = 3,030 LBS.

DESIGN LOADS (CONT'D.)

REACTIONS AT BASE OF MOUNTING TRUSS



$P_V = 1.5(38{,}250 + 8{,}660) = 1.5(46{,}910) = 70{,}000$ LBS. ULT.

$P_2 = 1.5(9770) = 14{,}700$ LBS. ULT.

$P_1 = 1.5(3030) = 4545$ LBS. ULT.

$M = 14{,}700(57.25 - 8.65) - 4545(57.25 - 37.35)$

$= 14{,}700(48.6) - 4545(19.9) = 624{,}000$ IN. LBS.

DIAGONAL LENGTH $= \sqrt{2(36.0)^2} = 51.0$ IN.

LOAD AT BOLT # 4 IS:

$P_T = \dfrac{70{,}000}{4} + \dfrac{624{,}000}{51} = 17{,}500 + 12{,}200 = \underline{\underline{29{,}700 \text{ LBS.}}}$

WHIRL TOWER STRUCTURE

MOUNTING TRUSS STRUCTURE

DWG. 285-0523

UPPER BRNG SUPPORT SIDE LOAD:

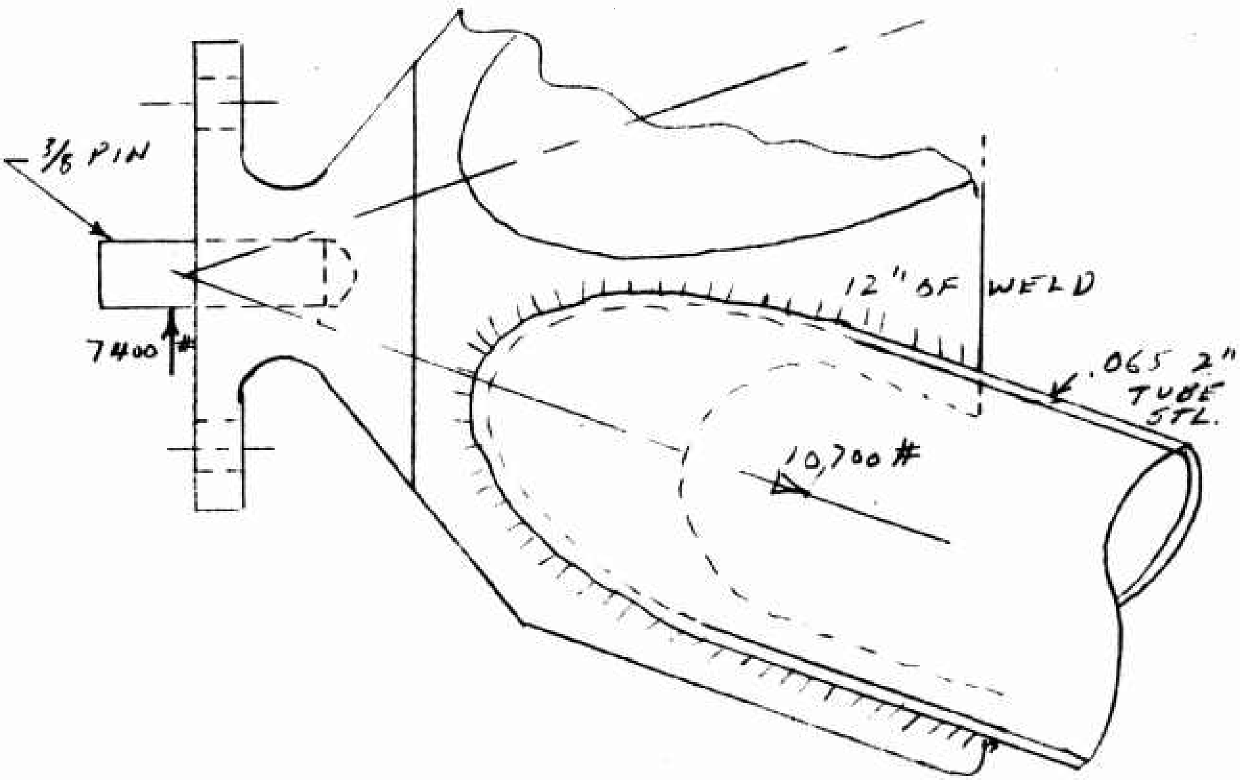
P = 1.5 x 9770 = 14700# ULT.

LOWER SUPPORT:

P_V = 1.5(38250 + 8660) = 70,000# ULT

P_{SIDE} = 1.5 x 8880 = 13,300# ULT
= 1.5 x 3030 = 4,545# ULT (NEGLECTING P.T.O. NOT USED ON WHIRL TOWER)

UPPER SUPPORT STRUCTURE



285-0544-11 PIN

M.S. = $\frac{10500}{7400}$ - 1 = .42

MOUNTING TRUSS STRUCTURE (CONT)
#285-0523

UPPER SUPPORT STRUCTURE (CONT.)

ALLOWABLE WELD LOAD:

$P_{ALLOW} = 12 \times .065 \times 45000 = 35000$#

$P = 10700$#

$M.S. = \frac{35000}{10700} - 1 = \underline{2.28}$

-11 TUBE AS COLUMN

$D/t = 2/.065 = 31$

$l'/\rho = \frac{51.8}{.685} = 75.5$

$A = .395 \square''$

$F_{co} = 42000$ PSI

$P = 10700$#

$M.S. = \frac{42000 \times .395}{10700} - 1 = \underline{.55}$

MOUNTING TRUSS STRUCTURE (CONT)
DWG 285-05-23

LOWER SUPPORT STRUCTURE

LOAD IN -9 TUBE DUE TO $P_V = 70000\#$

$$P_1 = \frac{70000}{8} \times \frac{28.4}{19.5} = \underline{12800\#}$$

LOAD IN -9 TUBE DUE TO $P_{SIDE} = 13300\#$

$$P_2 = \frac{13300}{4} \times \frac{28.4}{17.9} = \underline{5300\#}$$

$P_{MAX} = P_1 + P_2 = \underline{18100\#}$ ULT.

P_{ALLOW} (-9 TUBE) = .32 x 85000 = 27,200#

$$M.S. = \frac{27200}{18100} - 1 = \underline{.50}$$

WELD ATTACHMENT TO 0544-5

$P_{ALLOW} \geq$ 6 x .09[illegible] x 45000

= 23600#

$$M.S. = \frac{23600}{18100} - 1 = \underline{.41}$$

WELD ATTACHMENT TO 0544-3

10" OF WELD; OK BY COMPARISON

BOLT ATTACHMENT TO HOUSING 0524

BOLT IS 9/16 HT 180000 PSI

$$M.S. = \frac{31000}{17500} - 1 = \underline{.77}$$

BOLT ATTACHMENT TO BASE

BOLT IS 5/8 HT 180000

P_T = 29,700 LBS. ULT.

$$M.S. = \frac{39000}{29700} - 1 = \underline{.31}$$

WHIRL TOWER STRUCTURE

STRUCTURE ASSEMBLY 285-0703

THIS ASSEMBLY ACTS AS A SPACER AND SERVES TO TRANSFER LOADS FROM THE ROTOR MOUNTING TRUSS STRUCTURE (285-0523) AND THE MAIN TOWER STRUCTURE (285-0701). IN ADDITION IT PROVIDES THE SUPPORT FOR THE CONTROL SYSTEM ACTUATING CYLINDERS. THE ASSEMBLY IS A WELDED TRUSS STRUCTURE COMPOSED OF 5.0 INCH EXTRA STRONG STEEL PIPE AND IS SATISFACTORY BY COMPARISON TO THE 285-0523 MOUNTING TRUSS.

WHIRL TEST SUPPORT STRUCTURE 285-0701

THIS ASSEMBLY FORMS THE MAIN TOWER STRUCTURE FOR THE ROTOR SYSTEM. IT IS A WELDED ASSEMBLY COMPOSED OF LARGE STEEL TUBES, I-BEAMS AND GUSSET PLATES. THE BASE OF THE TOWER IS ATTACHED TO A 2 FOOT THICK REINFORCED CONCRETE PAD BY 68 1.0 IN. BOLTS. TOWER AND PAD ARE DESIGNED FOR RIGIDITY AND ARE NOT CRITICAL FOR ROTOR SYSTEM LOADS.

NATURAL FREQUENCY OF CONTROL TOWER

DWGS. 285-0701
285-0700

$$\delta = \frac{\partial(\text{Strain Energy})}{\partial P} \quad \text{(Castigliano's 1st Theorem)}$$

$l_1 = 259''$
$l_2 = 280''$
$l_3 = 107''$
$A_1 = A_2 = 19\ \square''$
$E = 29 \times 10^6$

$$\text{Str. Energy} = \sum_i \int_0^{l_i} \frac{1}{2}\frac{P^2}{A_i E}\,dl$$

$$= \int_0^{259} \frac{1}{2}\frac{(l/l_3\, P)^2}{A_1 E}\,dl + \int_0^{280} \frac{1}{2}\frac{(l/l_3\, P)^2}{A_2 E}\,dl$$

$$= \left(\frac{259^3}{2\times 107^2} + \frac{280^3}{2\times 107^2}\right)\frac{P^2}{AE}$$

$$= \frac{1720}{AE}P^2 = 3.12\times 10^{-6}P^2 \quad (\text{IN } 285\text{-}0701)$$

$$\delta = \frac{\partial(3.12\times 10^{-6}P^2)}{\partial P} = 6.24\times 10^{-6}P$$

$P = 2000$ LBS

$\delta = .0125''$ (285-0701)

DEFLECTION OF MOUNT ASSY. 285-0523

$A = .4\ \square''$
$P = 900\#$

$$\text{Str. Energy} = 2\int_0^{52} \frac{1}{2}\frac{(\frac{52}{35.5}P)^2}{AE}\,dl$$

$$= \frac{52^3 \times P^2}{35.5^2 \times .4 \times 3\times 10^7}$$

$$= 9.3\times 10^{-6}P^2$$

$$\delta = \frac{\partial(9.3\times 10^{-6}P^2)}{\partial P} = 18.6\times 10^{-6}P$$

$$\delta = 18.6\times 10^{-6}\times 900 = .0167''$$

HUGHES TOOL COMPANY-AIRCRAFT DIVISION

ANALYSIS Hot Cycle Rotor MODEL 285 REPORT NO. PAGE A.2-8

PREPARED BY C. KAYSING 5/19/60

CHECKED BY

WHIRL TOWER STRUCTURE

NATURAL FREQUENCY OF TOWER (CONT'D)

$\Sigma \delta = .0125 + .0167 = \underline{.0292''}$

$f = 188\,\delta^{-1/2}$ CPM

$= 188 \times .0292^{-1/2}$

$= \underline{\underline{1100 \text{ CPM}}}$

9704

A.3 WHIRL TEST DUCT INSTALLATION

THE DUCT SYSTEM SERVES TO TRANSFER THE HOT EXHAUST GASES FROM THE TURBO JET POWERPLANT TO THE ROTOR SYSTEM. THE SYSTEM IS COMPOSED OF VERTICAL DUCTING TO THE ROTOR AND HORIZONTAL DUCTING FOR OVERFLOW OF EXCESS GASES. BUTTERFLY VALVES ARE LOCATED IN BOTH THE VERTICAL AND HORIZONTAL PATHS TO ADJUST FOR OPERATING REQUIREMENTS. THE DUCT SYSTEM IS SUPPORTED FROM THE TOWER AND BELLOWS ARE PROVIDED TO ALLOW FOR DIFFERENTIAL EXPANSION.

DESIGN LOADS (REF. A.1-1, SECTION 4)

MAX. TEMPERATURES AND PRESSURES ARE:

$t = 1184°F$ $\quad p = 29.0$ psig (LIMIT)

FOLLOWING USED FOR DESIGN:

$t = 1200°F$ $\quad p = 30$ psig (LIMIT)

$= 60$ psig (ULT.)

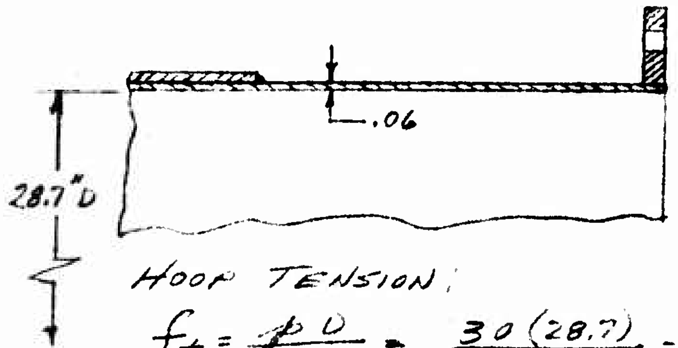
MATERIAL PROPERTIES:

321 STAINLESS STEEL TEMP. = 1200°F

$F_{ty} = 18{,}000$ PSI — YIELD IS CRITICAL

$F_{tu} = 43{,}000$ PSI

ENGINE ADAPTER ASSEM. DWG. 285-0726



MAT'L: 347 OR 321 STAINLESS STEEL

$p = 30$ PSIG LIMIT

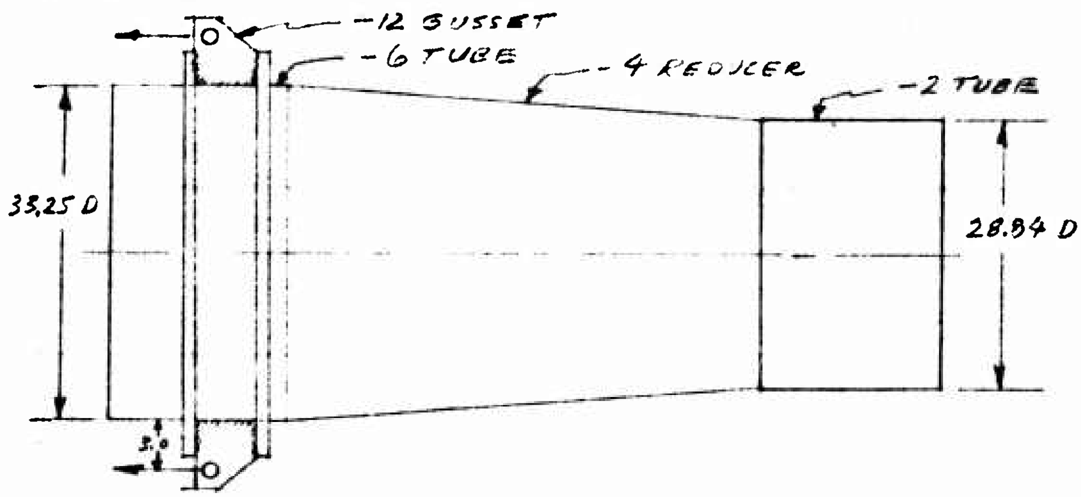
HOOP TENSION:

$$f_t = \frac{pD}{2t} = \frac{30(28.7)}{2(.06)} = 7{,}180 \text{ PSI}$$

$F_{ty} = 18{,}000$ PSI

$$M.S. = \frac{18{,}000}{7180} - 1.0 = \underline{1.50}$$

ENGINE EXHAUST DUCT ASSEM. DWG. 285-0727



MAT'L ALL PARTS 321 STAINLESS STEEL

LOADS: $p = 30$ PSIG LIMIT = 60 PSIG ULT.

-6 TUBE

HOOP TENSION $$f_t = \frac{pD}{2t} = \frac{30(33.25)}{2(.06)} = 8{,}300 \text{ PSI}$$

$F_{ty} = 18{,}000$ PSI

$$M.S. = \frac{18{,}000}{8300} - 1.0 = \underline{1.17}$$

ENGINE ADAPTER ASSEM. (CONT'D.)

END LOAD ON ASSEMBLY IS:

$$P = \frac{\pi}{4}\left(\overline{33.25}^2 - \overline{28.84}^2\right)60 = 12{,}700 \text{ LBS. ULT.}$$

-12 GUSSET

BOLT ATTACH: 2 3/4 IN. AN BOLTS

$$\text{LOAD/BOLT} = \frac{12{,}700}{2} = 6{,}350 \text{ LBS.}$$

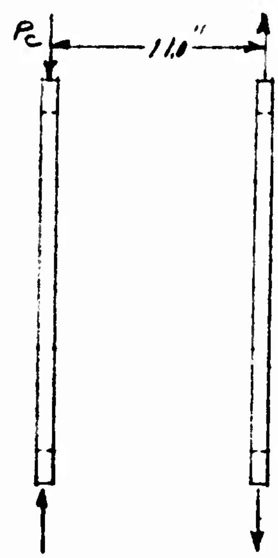
BOLTS OK BY INSPECTON

ATTACH -12 GUSSET TO TUBE:

WELD LENGTH = 10.5 IN. PER SIDE

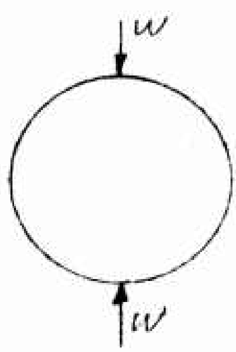
$$q_s = \frac{6350}{2(10.5)} = 302 \text{ LBS./IN.}$$ NOT CRITICAL

-10 RINGS 4130 STEEL PLATE - NORMALIZED



$$P_c = \frac{3.0(6350)}{11.0} = 1730 \text{ LBS. ULT.}$$
$$= 865 \text{ LBS. LIMIT}$$

RING MEDIAN DIA. = 36.0 IN.



$M_{MAX.} = .3183\,WR$

(REF. A.3-1, TABLE VIII, CASE 1)

$M = .3183(1730)18 = 9900$ IN.LBS. (LIMIT)

RING SECTION IS .50 × 2.00

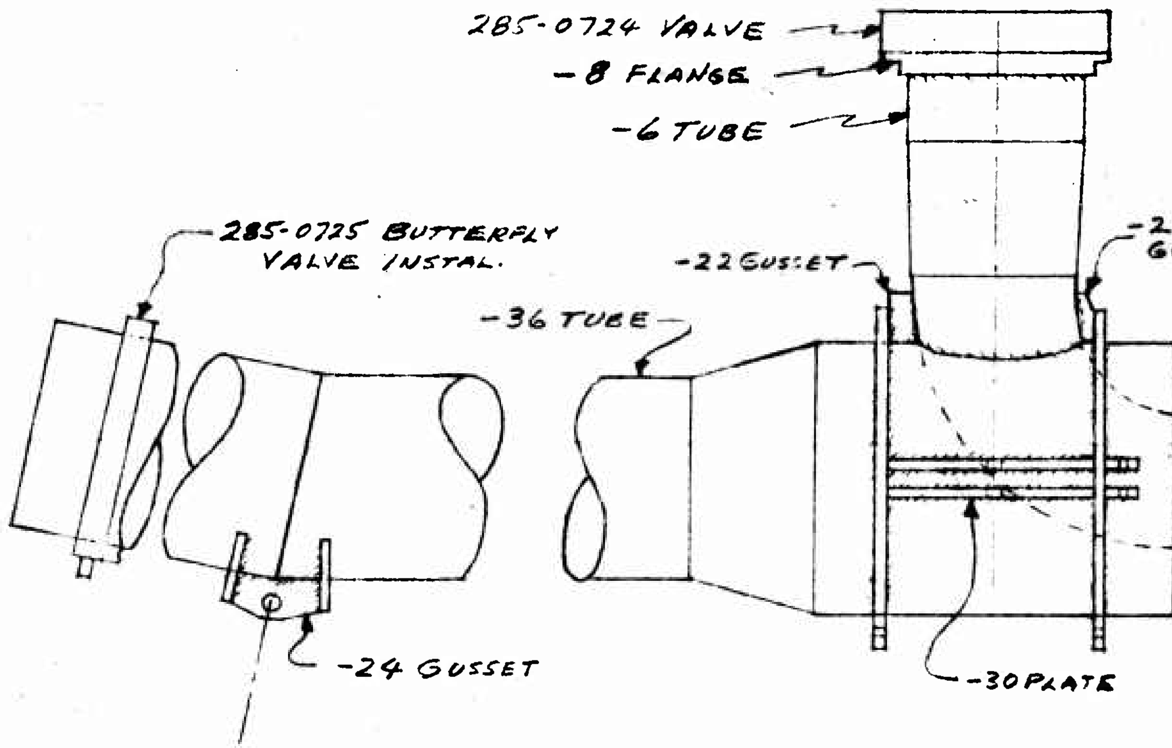
$$f_b = \frac{9900(6)}{.5(2.0)^2} = 29{,}700 \text{ PSI LIMIT}$$

EST. TEMP. = 800 °F

$F_{TU} = .75(95{,}000) = 71{,}000$ PSI (REF. 3.2-3) $M.S. = \frac{71{,}000}{29{,}700} - 1.0 = \underline{1.40}$

9704

EXHAUST DIVERTER ASSEM. DWG. 285-0728



DISCUSSION

ADJUSTMENT OF THE 285-0725 VALVE IN THE OVERFLOW DUCT AND THE 285-0724 VALVE IN THE VERTICAL DUCT DETERMINES THE GAS FLOW. FOR DESIGN THE FOLLOWING LOAD CONDITIONS ARE CONSIDERED:

1. VALVE IN VERTICAL DUCT CLOSED

$p = 30$ psig LIMIT $= 60$ psig ULT.

$t = 1200°F$

2. VALVE IN EXHAUST (HORIZONTAL) DUCT CLOSED

$p = 30$ psig LIMIT $= 60$ psig ULT.

$t = 1200°F$

HUGHES TOOL COMPANY-AIRCRAFT DIVISION

ANALYSIS HOT CYCLE | MODEL 285 | REPORT NO. | PAGE A.3-5
PREPARED BY C.R. SMITH
CHECKED BY

WHIRL TEST
DUCT INSTALLATION

EXHAUST DIVERTER ASSEM (CONT'D.)

ALL DUCTING IS LESS CRITICAL THAN THE 285-0727 DUCT ASSEMBLY BECAUSE OF MUCH GREATER WALL THICKNESS.

-20 & -22 GUSSETS

GUSSETS ARE ASSUMED TO TRANSFER THE TOTAL VERTICAL LOAD WHEN THE 285-0724 BUTTERFLY VALVE IS CLOSED.

$A = \frac{\pi (18.0)^2}{4} = 255 \text{ IN.}^2$ (-2 ELBOW)

END LOAD = 255 (30) = 7650 LBS. LIMIT

WELD OF GUSSETS TO -12 RINGS:

WELD $A = 7.0 (1.0) = 7.0 \text{ IN.}^2$

NOT CRITICAL

-30 PLATES

THESE PLATES, TWO PER SIDE, ATTACH TO THE MAIN TOWER STRUCTURE THRU TUBE TRUSSES AND SERVE TO TRANSFER END LOADS BUILT UP WHEN THE 285-0725 VALVE IS CLOSED.

END LOAD CONSERVATIVELY BASED ON 34" DIA. OF -32 TUBE

$A = \frac{\pi}{4} (34)^2 = 910 \text{ IN.}^2$

$P = 910 (60) = 54,500$ LBS. ULT.

WELD OF PLATES TO -32 TUBE NOT CRITICAL

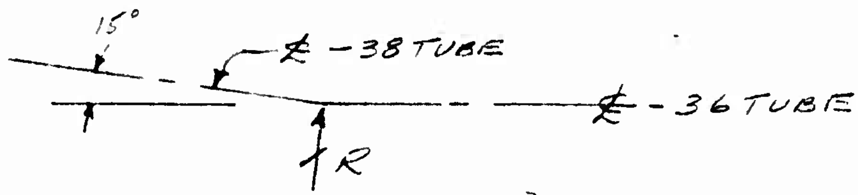
FOR 2 1.0 INCH BOLTS IN DOUBLE SHEAR.

$P_{ALLOW} = 27,489 (4) = 110,000$ LBS.

$M.S. = \frac{110,000}{54,500} - 1.0 = \underline{1.02}$

EXHAUST DIVERTER ASSEM. (CONT'D.)

ATTACH AT -24 GUSSET



DUCT AREA $= \frac{\pi}{4}(26)^2 = 530 \text{ IN.}^2$

$P = 530(60) = 32{,}000$ LBS. ULT

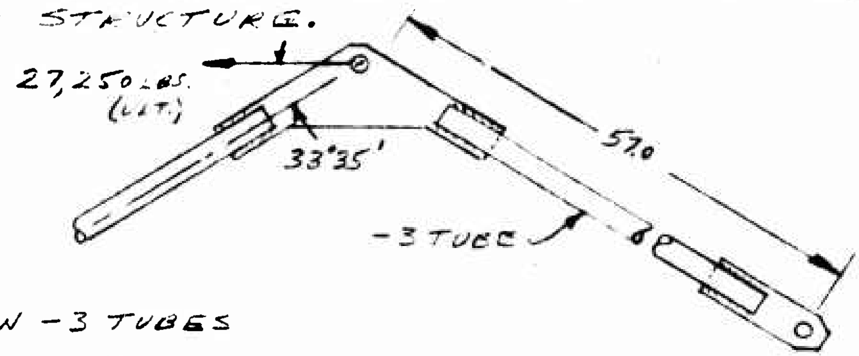
$R = 32{,}000(\sin 7.5°)(2) = 8400$ LBS ULT.

GUSSET IS 1.0 IN. STEEL PLATE AND BOLT IS 1.0 IN. DIA.

OK BY INSPECTION

DIVERTER DUCT BRACE DWG. 285-0744

BRACE ATTACHES TO THE 285-0728-30 PLATES AND TRANSFERS THE END LOAD TO THE TOWER STRUCTURE.



LOAD IN -3 TUBES

$P_C = P_T = \frac{27{,}250}{2(\cos 33°35')} = 16{,}400$ LBS.

$A = .799 \quad \rho = .62 \quad \frac{L}{\rho} = \frac{57.0}{.62} = 92$

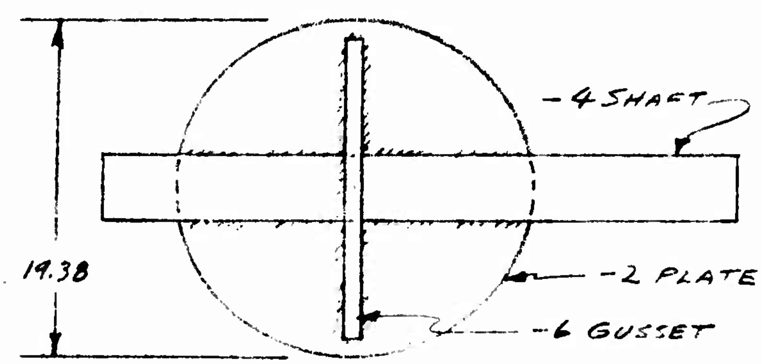
$f = \frac{16{,}400}{.799} = 20{,}500$ PSI

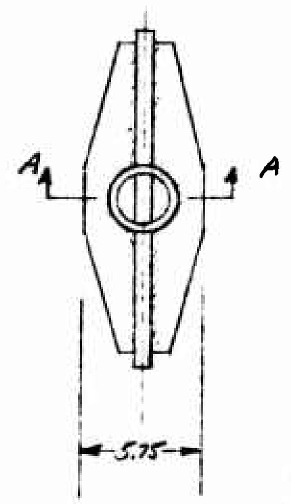
$F_c = 26{,}000$ PSI (REF. 3.2-3)

$M.S. = \frac{26{,}000}{20{,}500} - 1.0 = \underline{.27}$

EXHAUST DIVERTER ASSEM. (CONT'D.)

ROTOR CONTROL BUTTERFLY ASSEM. 285-0724





MAT'L: 321 STAINLESS STEEL

-6 GUSSET $t = .75$ IN.

PRESSURE = 30 psig LIMIT

AREA (SEMI-CIRCLE) $= \frac{\pi (9.7)^2}{2} = 148$ IN.^{2}

LOAD $= 148 (30) = 4450$ LBS.

$M_{A-A} = 4450 (.424)(9.7) = 18,300$ IN. LBS. (LIMIT)

$f \approx \frac{18,300 (6)}{.75 (5.75)^2} = 4420$ PSI

M.S. HIGH

-4 SHAFT 4.0" O.D. × .25 WALL TUBE

$M_{MAX} \approx 4450 (1.00 - .424)\, 10 = 25,600$ IN. LBS. (LIMIT)

$I_{SHAFT} = 5.20$ IN.^{4}

$f_b = \frac{25,600 (2.0)}{5.20} = 9900$ PSI

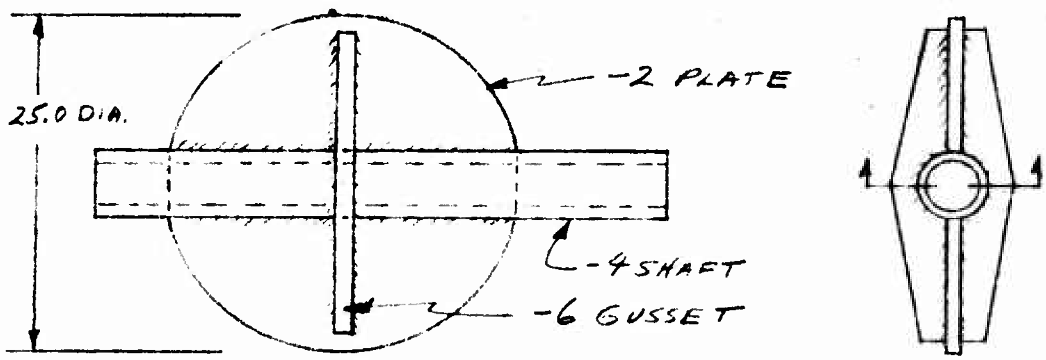
$F_{ty} = 18,000$ PSI

$M.S. = \frac{18,000}{9900} - 1.0 = .82$

-2 PLATE NOT CRITICAL

EXHAUST DIVERTER ASSEM. (CONT'D.)

EXHAUST CONTROL BUTTERFLY ASSEM. 285-0725



MAT'L: 4130 STEEL – NORMALIZED

AT $t = 1000°F$ $F_{tu} = .50(90{,}000) = 45{,}000$ PSI
$F_{ty} = .35(70{,}000) = 24{,}500$ PSI } REF —

-6 GUSSET $t = 1.00$ IN. $p = 60$ PSIG ULT.

$$\text{AREA (SEMI-CIRCLE)} = \frac{\pi}{2}(12.5)^2 = 245 \text{ IN.}^2$$

LOAD = 60 (245) = 14,700 LBS. ULT.

$$M_{A\text{-}A} = 14{,}700(.424)(12.5) = 78{,}000 \text{ IN. LBS.}$$

$$f_b = \frac{78\,000\,(6)}{1.0\,(7.0)^2} = 9550 \text{ PSI}$$

M.S. = **HIGH**

-4 SHAFT 4.0 × .625 WALL

$$M_{MAX.} = 14{,}700(1.0 - .424)(12.5) = 106{,}000 \text{ IN. LBS.}$$

$$I = 9.8 \text{ IN.}^4$$

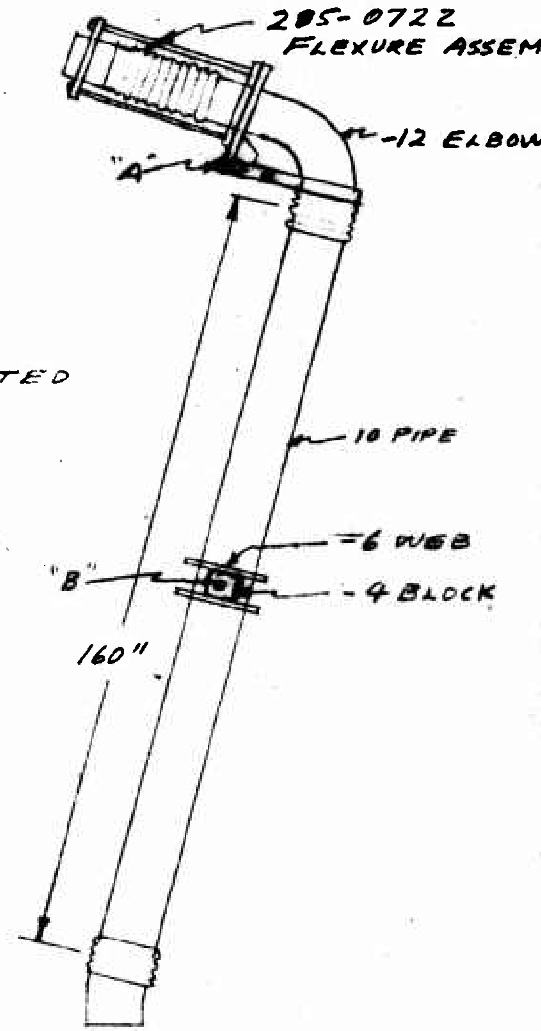
$$f_b = \frac{106{,}000\,(2.0)}{9.8} = 21{,}600 \text{ PSI}$$

$F_{tu} = 45{,}000$ PSI

$$M.S. = \frac{45000}{21600} - 1.0 = 1.08$$

VERTICAL DUCT ASSEM. 285-0723

THE VERTICAL DUCT ASSEMBLY IS ATTACHED TO THE TOWER STRUCTURE AT POINTS "A" AND "B". BELLOWS AT THE ENDS OF THE -10 PIPE ALLOW FOR EXPANSION.



-10 PIPE

THIS CENTER DUCT IS SUPPORTED AT POINT "B" AND IS LOADED BY PRESSURE AND ITS OWN WEIGHT.

PIPE IS 12.5 × 3/8 WALL APPROX. AND IS NOT CRITICAL FOR PRESSURE LOADS

$AREA = \pi(12.5)(.375) = 14.7\ IN.^2/IN.$

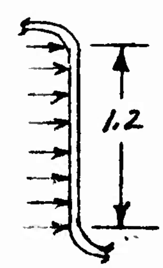
$W = 14.7(.29)(160) = 680\ LBS.$

ATTACH AT "B" - 2 1.0 INCH BOLTS - NOT CRITICAL

BELLOWS (STAINLESS STEEL)

BELLOWS MAX. DIA. = 15.8 IN.
THICKNESS = .062

HOOP TENSION:



$p = 30$ PSIG. LIMIT

$$f_t = \frac{30\,(15.8)}{2\,(.062)} = 3820\ PSI$$

BENDING OF FLATS:

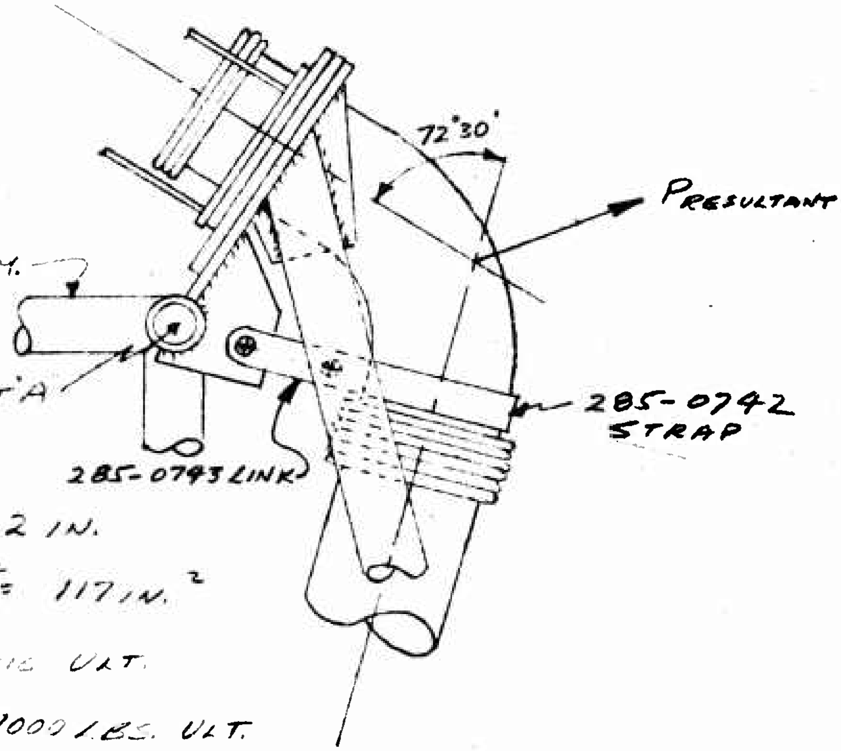
$$M_{MAX} = \frac{wl^2}{12} = \frac{30\,(1.2)^2}{12} = 3.6\ IN.LB.\ LIMIT$$

$$f_b = \frac{3.6\,(6)}{(.062)^2} = 5600\ PSI$$

M.S. HIGH

VERTICAL DUCT ASSEM.

ATTACH AT POINT "A"



DUCT I.D. = 12.2 IN.

AREA = $\frac{\pi}{4}(12.2)^2 = 117\ IN.^2$

FOR p = 60 PSIG ULT.

$P = 117(60) = 7000$ LBS. ULT.

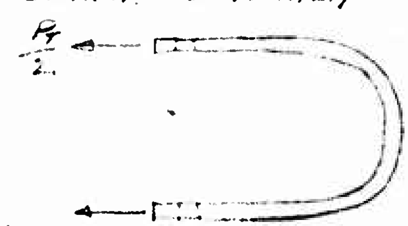
$P_{RES.} = 7000(2)(\cos 53.75°) = 10{,}100$ LBS.

285-0742 STRAP (COMM. STEEL)

P_T = 11,500 LBS. ULT. (BY GRAPHICAL ANAL.)

$A_{/SIDE} = .50(1.50) = .75\ IN.^2$

$f_t = \frac{11{,}500}{.75} = 15{,}400$ PSI



ATTACH BOLTS ARE 1.0 DIA. AND NOT CRITICAL

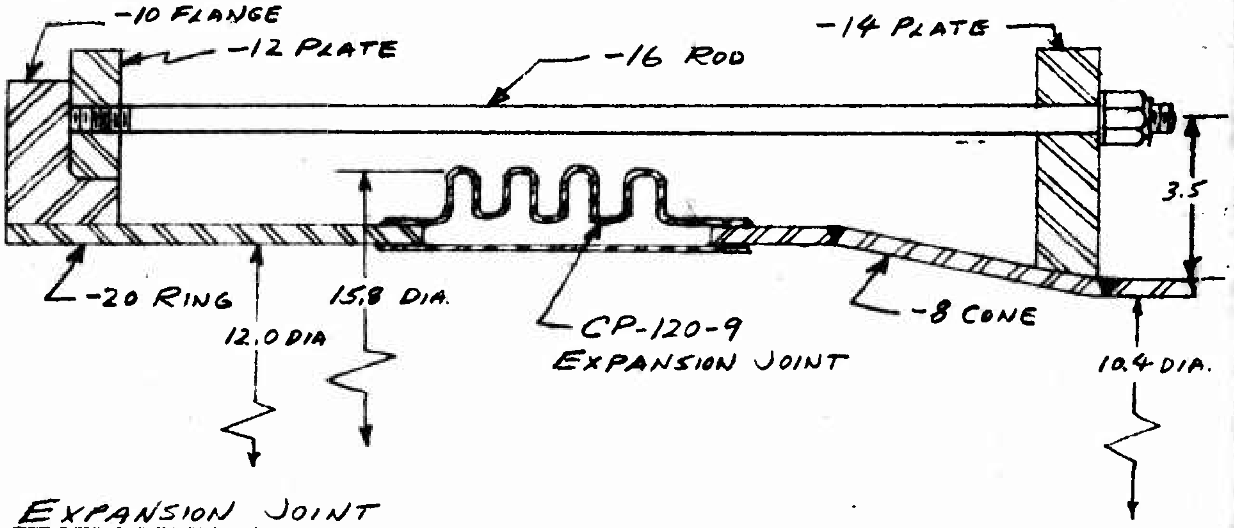
ASSUME F_{tu} (STRAP) = 50% F_{tu} (ROOM t) = 27,500 PSI

$M.S. = \frac{27{,}500}{15{,}400} - 1.0 = \underline{.78}$

285-0743 LINK – LESS CRITICAL THAN STRAP.

VERTICAL DUCT ASSEM. (CONT'D.)

285-0722 FLEXURE ASSEM.



EXPANSION JOINT

SATISFACTORY BY COMPARISON TO 285-0723 BELLOWS CHECKED ON PREVIOUS PAGE.

-16 RODS

$A = \frac{\pi}{4}(\overline{15.8}^2 - \overline{10.4}^2) = 142 \text{ IN.}^2$, $p = 60$ PSI ULT.

$P = 142(60) = 8500$ LBS ULT.

LOAD IS TAKEN BY 3 -16 RODS (½" DIA.)

- OK BY INSPECTION

ATTACH -12 PLATE TO -10 FLANGE

WELD SHEAR AREA $\approx 3.0(.25) = .75 \text{ IN.}^2$

LOAD/PLATE $= \frac{8500}{3.0} = 2830$ LBS. ULT.

$f = \frac{2830}{.75} = 3800$ PSI

M.S. = HIGH

APPENDIX B

TEST LOG SHEETS

B. 1 INTRODUCTION

Included herein are the 44 engine log sheets bearing the signatures of USAF witnesses; a summary of the whirl operation following the 35 hour tear-down inspection; and turbine discharge temperature as a function of time as plotted by a continuous recorder for the most severe transient runs. The latter plots are read with time beginning at the bottom of the page. The space between each horizontal line corresponds to 15 seconds. Each transient is identified by number and date so that corresponding engine data can be read from the engine log sheets.

B.2

WHIRL TEST ~ J57-PW-19W
ENGINE DATA SHEET.

CHECK OUT (runs 1–7, 5-17-61) — CALIBRATION (runs 1–10, 5-18-61)

DATE	RUN NO.	T_0 °F	P_0 In.Hg.	N_1 %	N_2 %	P_{T7} PSIG	T_{T7} °C	W_f LB/HR	P_{OIL} PSIG	T_{OIL} °C	TIME	TOTAL TIME	REMARKS
5-17-61	1	—	—	≈10	≈25	—	—	—	—	—	11:00		MOTORED 4 TIMES FOR 20, 10, 10, 30 SEC. TO DEPICKLE
	2	—	—	35	61	1.0	260	960	46	30	2404 / 2407		INITIAL START TO FAMILIRIZE STARTER RUN 60@30 UNDERLOAD
	3			56	75	2.5	260	1500	48	38	2407 / 2412		RETURN TO IDLE
	4			79	85.8	8.0	355	3050	48	44	2412 / 2415		
	5			89	90.2	12.7	423	4900	50	44	2415 / 2419		
	6				96						2419 / 2421		NO DATA TAKEN
	7				IDLE						2421 / 2426	21	SHUT DOWN NORMAL
5-18-61	1	64	29.97	34.2	60	1.0	255	940	45	36	952 / 1002		30 SEC ON STARTER NORMAL START
	2	63	"	46	70.5	1.8	240	1190	45.5	42	1002 / 1007		
	3	63	"	53.4	75.5	2.7	262	1450	45.8	43	1007 / 1012		
	4	63	29.98	65.4	80.9	4.5	302	2080	46	45	1012 / 1017		
	5				IDLE						1017 / 1023		ELECTRICAL FIRE ON VALVE MOTOR ~ RETURN TO IDLE
	6	63	"	77.2	85.2	7.7	345	2990	47	44	1023 / 1028		
	7				IDLE						1028 / 1031		CHECKED FOR ENGINE FIRE— WAS ONLY OIL BREATHER
	8	62	"	88.2	90	12.5	411	4800	47.5	43	1031 / 1037		
	9	62	"	92	92	14.8	450	5400	47.5	42	1037 / 1043		
	10				IDLE						1043 / 1048	54	RAN OUT OF THROTTLE @ 92% N_2 ~ WILL ADJUST LINKAGE
											1048		NORMAL SHUT DOWN

CUM. TOTAL TIME 1:15 7 STARTS

WITNESSED [illegible signature] USAF

WHIRL TEST – J57-PW-19W
ENGINE DATA SHEET

CALIBRATION (Runs 11–26)

DATE	RUN NO.	T_o °F	P_o IN. HG	N_1 %	N_2 %	P_{T7} PSIG	T_{T7} °C	W_f LB/HR	P_{OIL} PSIG	T_{OIL} °C	TIME	TOTAL TIME	REMARKS
5-18-61	11	66	29.98	34.5	60.2	1.1	260	925	45	36	1311/1316		NORMAL START
	12	64	"	91.9	92	14.5	452	5500	47.5	41	1316/1322		
	13	64	"	95.5	94.1	17.6	492	6300	47.9	41	1322/1326		
	14	64	"	98.2	95.7	19.8	525	7000	48	41	1326/1330		MAX. THROTTLE – WILL CONTINUE AT LOWER POWER
	15	64	"	95.2	93.9	17.2	485	6250	48	41	1330/1334		
	16	64	"	88.8	90	12.2	408	4650	47	43	1334/1337		NOTICED N_1 FLUCTUATION OF ± 0.3%
	17	64	"	76.5	85.1	7.4	342	2930	46.5	46	1337/1342		
	18	64	"	63.4	80.1	4.2	295	1920	46	46	1342/1346		
	19	63	"	52.7	75.3	2.7	248	1420	46	46	1346/1350		
	20				IDLE						1350/1410	59	ATTEMPT TO FIX THROTTLE – NORMAL SHUTDOWN
	21				IDLE						1605/1610		NORMAL START
	22	62	29.95	88.3	90.1	12.5	419	4850	47.5	42	1610/1615		
	23	62	"	99	96.2	20	540	7250	48	40	1615/1618		
	24	62	"	100.3	97	21.2	558	7800	48	41	1618/1621		≈MIL POWER
	25	62	"	98.5	96	19.5	531	7000	48	42	1621/1624		
	26			IDLE							1624/1630	25	NORMAL SHUT DOWN
													WITNESSED

CUM. TOTAL TIME 2:49   9 STARTS

WHIRL TEST ~ J57-PW-19W
ENGINE DATA SHEET

CHECK OUT WITH DUCT AND B.P. VALVE

DATE	RUN NO.	T_o °F	P_o IN.HG.	N_1 %	N_2 %	P_{T7} PSIG	T_{T7} °C	W_f LB/HR	P_{OIL} PSIG	T_{OIL} °C	TIME	TOTAL TIME	REMARKS
5-23-61	1	66	29.96								1337/		ABORTED STARTS (2) NO TACH.
	2	65	29.95		80% IDLE		NOT	REACHED			1344/1436		ABNORMAL START WITH 80% N_2 ~ THROTTLE MUST BE ADJUSTED
	3	65	29.95	64	80.4	4.1	302	1990	46	43	1436/1444		
	4	65	"	83.8	90.2	12.4	448	4700	47.5	46	1444/1449		
	5	66	"	96.2	97	21.2	587	7350	48	44	1449/1452		
	6	66	"	82.8	90	12	440	4450	47.5	48	1452/1455		ADJUSTED B.P. VALVE
	7	66	"	80.8	90	12.85	461	4480	47	46	1455/1500		" " " "
	8	66	"	78.2	90	13.7	489	4450	47.5	48	1500/1503		" " " "
	9	66	"	83.8	90	12.1	440	4500	47	46	1503/1505		" " " "
	10			IDLE							1505/1514	38	RELEASED DETENT & ATTAINED STD. IDLE
											/		NORMAL SHUTDOWN USING EMERGENCY THROTTLE
											/		CUT OFF.
5-24-61	1	66	29.95		IDLE		NORMAL				1000/1004		NORMAL START
	2	66	"	52.2	75	2.2	261	1400	46	44	1004/1016		
	3	67	"	64.5	80.4	4.0	296	1960	46.2	45.5	1016/1020		
	4	~~88.7~~ 67	"	88.7	90	12	410	4700	47.5	45	1020/1026		
	5	67	"	95.6	94.1	17	490	6250	48	45	1026/1032		
	6	66	"	100.4	97.1	20.75	558	7600	48.3	44	1032/1036	36	

CUM. TOTAL TIME 4:05   12 STARTS

Witnessed [signature]

WHIRL TEST ~ J57-PW-19W
ENGINE DATA SHEET

BLADE ROTATION @ IDLE — CHECK OUT WITH DUCT & B.P. VALVE

DATE	RUN NO.	T_o °F	P_o IN.Hg	N_1 %	N_2 %	P_{T7} PSIG	T_{T7} °C	W_f LB/HR	P_{OIL} PSIG	T_{OIL} °C	TIME	TOTAL TIME	REMARKS
5-24-61	7	67	29.95	94.7	93.8	16.6	480	6000	48	45	1036/1045		
	8	67	29.96	96.1	94.7	17.5	500	6400	48	45	1045/1050		NORMAL CONT. ~ WILL CLOSE B.P. VALVE TO
	9	67	"	91.3	94.8	18.2	539	6300	48	45	1050/1053		DETERMINE EFFECT @ THIS THROTTLE SETTING,
	10	67	"	89	94.9	19	563	6300	48	45	1053/1055		HOLDING N_2 CONSTANT
	11	67	"	84.5	94.9	18.9	590	6150	48	45	1055/1058		
	12	67	"	87.1	96.4	21.7	626	7000	48	45	1058/1102		OPENED THROTTLE TO GET MIL. P_{T7} AND MAX. T_{T7}
	13	71	"	95	94.2	17.1	494	6200	48	45	1102/1105		NRP - ON LINE
	14	71	"		IDLE						1105/1109		WILL SIMULATE VALUE FAILURE BY OPENING
	15	71	"		90.1						1109/1113		VALE QUICKLY @ 90% N_2 SLOW ENGINE REACTION,
	16	71	"		IDLE						1113/1118	42	EASILY CONTROLLED — NORMAL SHUTDOWN
6-5-61	1			35.8	60.7	1.0	221	890	45.5	30	1415/1423		NORMAL START - PILOT @ CONTROLS
	2			VARIOUS	POWER SETTINGS						1423/1436		PILOT FAMILURAZATION
	3			36	61	.95	210	870	46	44	1436/1442		OPENED B.F. VALVE ≠ 30 RPM ROTOR CLOSED B.F. VALVE
	4			IDLE							1442/1447	32	NORMAL SHUTDOWN
6-7-61	1	66	29.94	35.5	60.6	1.0	228	890	45.5	32	1033/1042		NORMAL START WIND ESE 6MPH
	2	66	"	35.1	60.3	0.9	212	840	46	43	1042/1101		OPENED VALVE (B.F.) OPER. OF ROTOR CONTROLS CLOSED VALVE (B.F.)
	3				IDLE						1101/1105	33	NORMAL SHUTDOWN
													Witnessed [illegible]

CUM. TOTAL TIME 5:52 . 15 STARTS

WHIRL TEST – J57-PW-19W
ENGINE DATA SHEET

DATE	RUN NO.	T_0 °F	P_0 IN.HG	N_1 %	N_2 %	P_{Tn} PSIG	T_{Tn} °C	W_f LB/HR	P_{OIL} PSIG	T_{OIL} °C	TIME		REMARKS
6-9-61		64	29.89								0943	ABORT	START – MISINTERP. OF START-[illegible] ORDER
	1	"	"	35.4	60.6	1.0	240	890	455	33	0947 / 953		THROTTLE CHOPPED NORMAL START
				ROTOR	2°P		37.5 RPM				953 / 957		OPENED 3.F. WIND S[illegible] 10MPH
				"		FLAT P	38 RPM				957 / 958		
					FULL P		27 RPM				958 / 1000		
					20 P						1000 / 1001		
				2°P	CYC. FULL L.						1001 / 1002		
				"	"	"	" 29 RPM	FULL F.			1002 /		
				"	"	"	R. 29	"	"	"			
				"	"	"	" 28	F. REAR RPM					
				"	"	"	L.	F. REAR			/ 1004		
				NEUTRAL							1004 / 1005		
				COLL. FULL DOWN				CYC. FULL L.					
								F.L. – F.F. F.R. – F.F.					
					33 RPM			FR – FA					
								FL – FA F.L					
			2°	COLL		NEUTRAL					1005 / 1008		
	2	64	29.89	43.2	65.2	1.2	240	940	455	45	1013 / 1016	22	AT 60RPM ROTOR

Witnessed J. Byron USAF

COM. TOTAL TIME 6:14 17 STARTS

WHIRL TEST ~ J57-PW-19W
ENGINE DATA SHEET

DATE	RUN NO.	T_0 °F	P_0 IN.HG.	N_1 %	N_2 %	P_{T7} PSIG	T_{T7} °C	W_f LB/HR	P_{OIL} PSIG	T_{OIL} °F	TIME		REMARKS
6-	3	64	29.89	45	70	1.5	250	1070	46	46	1020 / 1023		76 RPM
	4	64	"	57	77.5	2.3	273	1340	46	48	1029 / 1032		78 RPM
				IDLE							1032 / 1037	14	VALVE SHUT NORMAL SHUT DOWN
													Witnessed [illegible signature]

CUM. TOTAL TIME 6:28   17 STARTS

WHIRL TEST ~ J57-PW-19W
ENGINE DATA SHEET

W3

64

TETHER TEST

DATE	RUN NO.	T_0	P_0	N_1	N_2	P_{T7}	T_{T7}	W_f	P_{OIL}	T_{OIL}	TIME		REMARKS
7-5-61	1	72		34	60	.95	208	900	45.5	39	1243/[illegible]		NORMAL START OPENED VALVE
	1	ATTEMPTED TO GET 630°F									1227/1230		VALVE OPEN
		MANOMETER BLEW DURING TRANSIENT									1230/1236	23	NORMAL SHUT-DOWN
7-6-61					IDLE						944/957		NORMAL START
					IDLE						959/1006		OPENED VALVE
7-6-61	1			66.3	83.1	6.8	295	2500	46.5	48	[illegible]/1013		NO WATER INJECTION
	2			70.1	86	9.4	340	3000	45	50	1016/1021		" " "
	3			73.5	88	11.0	368	3800	47	50	1023/1028		
	4			75	88.8	11.9	382	4100	47	51	1034/1045	ΔP_W	DUCT T/C ARE LOW
	4'			"	"	11.6	378	"	"	"	1043/1050	0.5	WATER INJECTION
	4"										1052/[illegible]	0.25	" "
					IDLE						[illegible]/1057	1:05	NCD - SMOKE OUT OF COMP. T_{T7} TO 220°C ~ MOTORED TO CLEAR
					IDLE						[illegible]/1432		NORMAL START
					IDLE						1433/1435		OPENED VALVE
											1436/1442		ACCEL TO 7E-4 MANU. BLEED
	4			71	86	8.8 / 9.0	336	2980	47	50	[illegible]/1457		
	7			78	91.6	14.7	440	4490	47	50	1504/1528		
					IDLE						1570/1573	-45	NCD

CUM. TOTAL TIME 8:41 20 STARTS

[illegible signatures]

WHIRL TEST ~ J57-PW-19W
ENGINE DATA SHEET

DATE	RUN NO.	T_0	P_0	N_1 %	N_2 %	P_{T_2} PSIG	T_{T_7} °C	W_f LB/HR	P_{OIL} PSIG	T_{OIL} °C	TIME		REMARKS
7-7-61				IDLE							9:30 / 9:35		NORMAL START 0-2 MPH WIND VALVE OPEN
	1			70	84.2	7.5	350	2700	47	49.	9:37 / 9:45		
	2			71	86	9.3	390	3000	47	50	9:47 / 9:53		
	3			75	88.5	11.5	4[illegible]0	4[illegible]	47	[illegible]	9:57 / 10:02		
	4			76	89	12	450	4080	47	50	10:0[illegible] / [illegible]		
	5			88	90.2	13	470	4600	47	50	10:11 / [illegible]		
	6	75		80	91.5	14.5	490	4800	47	50	10:18 / 10:24		
	7			81.2	93.5	16.4	540	5500	48	50	10:28 / 10:32		
	8			100	96.9	19	578	7000	48	50	10:35 / 10:40		
	9			84	96	19.7	573	6300	48	53	10:4[illegible] / 10:4[illegible]		
	10			[illegible]	95.8	19.9	593	6200	48	54	10:49 / 10:5[illegible]		
					IDLE						10:5[illegible] / 11:03	1:33	NCD
7-10-61		76	29.85	IDLE							3:10 / 3:20		NORMAL START
	15			94.2	96	18.2	433	6800	48	49	3:28 / 3:34		
	16			95.5	94.5	16	400	6000	48	50	3:35 / 3:44		
					IDLE						3:44 / 3:48	38	NCD
				IDLE							4:35 / 4:37		NORMAL START
	15			92.5	96.5	20.2	490	7000	48.4	47	4:40 / 4:49	14	

COM. TOTAL TIME 11:06   23 STARTS

Witnessed [illegible]

WHIRL TEST - J57-PW-19W
ENGINE DATA SHEET

DATE	RUN NO.	T_o	P_o	N_1	N_2	P_{T_7}	T_{T_7}	W_f	P_{OIL}	T_{OIL}	TIME		REMARKS
7-10-61	16			72	96.8	20.3	580	6950	48	49	4:49 / 4:52		
	17			92	96.8	20.4	525	6950	"	"	4:52 / 4:55		
	18			88.4	94.8	17.9	440	6000	48	50	4:59 / 5:04		
	19			87.8	94.3	17.6	440	6000	48	50	5:04 / 5:06		
	20			"	"	17.5	440	5950	48	50	5:06 / 5:10		
	21			90.8	93.8	16.2	410	5800	48	50	5:12 / 5:15		
	22			91	94	16.2	410	5800	48	50	5:15 / 5:17		
	23			91	94	16.5	410	5800	48	50	5:17 / 5:20		
	24			87	91.8	14.0	370	5000	47	50	5:22 / 5:2[illegible]		
	25			87.2	91.8	14.1	375	5000	47	50	5:2[illegible] / 5:29		
					IDLE						5:29 / 5:34	45	NCD
7-10-61					IDLE						6:58 / 7:00		NORMAL START
	26			90.2	96.2	41.1 / 20.7	520	6950	48	43	7:03 / 7:07		
	27			89.9	96.3	41.5 / 20.9	495	6950	48	45	7:07 / 7:11		
	28			89.9	96.3	41.3 / 20.6	485	6950	48	45	7:11 / 7:13		Witnessed J. J. Byron USAF QC
	29			90	96.3	41.4 / 20.8	485	6900	48	45	7:13 / 7:16		
	30			77.5	89.2	24.6 / 12.5	400	4300	47	50	7:16 / 7:23		
					IDLE						7:23 / 7:27	29	NCD

309.5 CUM. TOTAL TIME 12:20 24 STARTS

WHIRL TEST ~ J57-PW-19W
ENGINE DATA SHEET

DATE	RUN No.	T_0	P_0	N_1	N_2	P_{T7}	T_{T7}	W_f	P_{OIL}	T_{OIL}	TIME		REMARKS
8-1-61	10:				IDLE						10:5[illegible]		NORMAL START ALL READINGS IN ORDER
											11:0[illegible]		
	1		29.92	100.6	97	19.2	1030 460	7300	48	50	11:10 / 11:20		MIL POWER ~ AT 11:12 SUDDEN INC. IN
		TAKING SOUND LEVEL READINGS ON											N_1 & N_2 WITH DROP IN P_{T7} ~ EXHAUST SUPPRESSOR WAS
					HILL.								LATER FOUND TO HAVE FAILED @ 11:20
					IDLE						11:20 / 11:21	26	NORMAL SHUTDOWN
8-28-61	1				IDLE						1:24 / 1:28		NORMAL START
	2				MIL POWER						1:30 / 1:33		ROTOR BEARING TEMP. TO HIGH. DUCT TEMP. @ 620°F
	3					IDLE					1:33 / 1:37		
	4				MIL POWER						1:37 / 1:38		BEARING TEMP. TO HIGH
	5				IDLE						1:39 / 1:43		
	6				MIL POWER						1:44 / 1:45		BEARING TOO HOT
	7				IDLE						1:48 / 1:50		NORMAL COAST DOWN
	8				IDLE						2:20 / 2:22		NORMAL START
	9				MIL						2:23 / 2:24		BEARING TO HOT
	10				IDLE						2:24 / 2:29	1:05	NCD
													Witnessed [signature]

TOTAL TIME 13:51 27 STARTS

WHIRL TEST - J57-PW-19W ENGINE DATA SHEET

	DATE	RUN NO.	T_0	P_0	N_1	N_2	P_{T_7}	T_{T_7}	W_f	P_{OIL}	T_{OIL}	TIME		REMARKS
	8-25-61					IDLE						9:17 / 9:20		NORMAL START
		1			97.1	97	20.4	1040 571	7300	48	43	9:21		MIL POWER FOR SOUND TEST
		2			96.8	97.1	20.5	1080 575	7100	48	44	9:37 / 9:45		
						IDLE						9:45 / 9:50	33	NCD
	8-28-61					IDLE						13:00 / 13:05		NORMAL START SOUND RUN
		1			97	97	20	1040 571	7000	48	46	13:09 / 13:15		WIND 10 MPH SW
							IDLE					13:15 / 13:20	20	REMOVE EX SUPRESSOR NCD
						IDLE						13:51 / 13:55		NORMAL START NOZ. REMOVED
		2			99.9	96.6	18.8	525	7000	48	48	13:57 / 14:02		
		3			94.8	96.7	20	568	6800	48	50	14:02 / 14:04		
						IDLE						14:05 / 14:10	19	NCD
	8-29-61					IDLE		VARIOUS PS UP TO RUN #1				11:23		NORMAL START VALVE OPENED @ 11:14
1		1	68 62	29.98	57.3	77.7	3.3	264	46	49		11:42 / 12:44		118 ROTOR RPM
						IDLE						12:45 / 12:48	35	NCD
	8-30-61		66 61	29.97		IDLE						9:32 / 9:36		NORMAL START
2		1	69 62		57.4	77.9	5.94 3.4	268	1560	46	45	9:48 / 10:10		12? RPM ROTOR NO WIND
3		2	72 64	29.98	63.7	80.3	7.54 4.1	303	1870	46	46	10:12 / 10:20		140 RPM
4		3			64	82.7	9.4 4.9	308	2160	46	47	10:22 / 10:32	1:00	158 RPM

1:34

16:36

32 STARTS

B.2-12

WHIRL TEST ~ J57-PW-19W
ENGINE DATA SHEET

	DATE	RUN NO.	T_0	P_0	N_1	N_2	P_{T_7}	T_{T_7}	W_f	P_{OIL}	T_{OIL}	TIME		REMARKS	
5		4			72.5	83.9	10.41 5.9	316	2420	47	47	10:39 / 10:44		170 RPM	
6		5			74.3	84.5	11.61 6.3	322	2580	47	47	10:55 / 10:5[illegible]		179 RPM	
7		6			78	85.5	12.35 7.0	325	2440	47	47	10:5[illegible] / 11:06		193 RPM	
8		7			79	86.3	7.5	332	2770	47	47	11:0[illegible] / 11:11		197	
							IDLE					11:11 / 11:[illegible]	39	NCD	1:25
	9-1-61					IDLE						9:49 / 10:03		NORMAL START V.O. 9:57	
					VARIOUS	PS	TO 200 RPM					10:03 / 10:16		10:17 VALVE SHUT	20
						IDLE						10:17 / 9:40		10:38 V.O. 7MPH WIND STOPS OUT @ 150 RPM	
1		1			79.7	86.2	7.4	330	2920	47	46	10:59 / 11:00		200 RPM ROTOR	
2		2			83.2	87.9	8.2	340	3100	47	46	11:03 / 11:25		210 RPM "	
3		3			80.1	88	8.5	350	3600	47	46	11:25 / 11:30		218 RPM "	
4		4			85.2	88.3	9.6	354	3400	47	47	11:31 / 11:35		230 RPM "	
5		5			87	89.2	10.5	370	4100	47	45	11:3[illegible] / 11:40		240 RPM "	
							IDLE					11:4[illegible] / 11:5[illegible]	2:02	NCD	1:01
	9-6-61					IDLE						9:35 / 9:47		NORMAL START 9:37 VALVE OPEN	
+												[illegible] / 10:05		170 RPM	
1		1			80.5	87.4	7.6	350	298	47	55	12:0[illegible] / 11:21		168 ROTOR RPM 6° COLL.	
2		2			83.5	88.5	8.5	358	3400	47	52	[illegible] / [illegible]	52	179 RPM	52

19:59

34 STARTS

Witnessed
J. Byrne

B2-13

WHIRL TEST ~ J57-PW-19W
ENGINE DATA SHEET

	DATE	RUN No.	T_0	P_0	N_1	N_2	P_{T7}	T_{T7}	W_f	P_{OIL}	T_{OIL}	TIME		REMARKS 6° COLL
3	9-6-61	3			86.0	89.1	9.5	365	3800	47	50	10:29 / 10:33		190 RPM 2 MPH SW
4		4			87.5	84.9	10.0	380	4080	47	50	10:35 / [illegible]		200 RPM
5		5			90.1	91.2	11.1	403	4650	47	50	10:4[illegible] / 10:44		210 RPM
6		6			91.8	92	11.9	420	4850	47	50	[illegible] / 10:52		220 RPM
7		7			94.5	93.2	13.8	444	5300	48	50	10:5[illegible] / 10:58		230 RPM
8		8			95.5	94	15.0	465	5700	48	44	10:5[illegible] / 11:0[illegible]		240 RPM 6° COLL
							IDLE					11:0[illegible] / 11:2[illegible]		V.C.
					MIL POWER SOUND RUN							11:25 / 11:46		
						IDLE						11:4[illegible] / 11:57	1:22	NCD
			TOTAL TIME ROTATING TO 9-6-61											15 7HRS 1MIN
	9-25-61					IDLE						10:05 / 10:13		NORMAL START ~~10:08 VALVE OPEN~~
														7° COLL
						IDLE						10:2[illegible] / 10:28		LOST 24 VOLT POWER WIND 7.5 MPH SW
		1			80.2	86.8	8.0	348	3200	47	44	10:3[illegible] / 10:35		170 RPM
		2			98.6	95.8	19.0	518	6900	48	43	10:[illegible] / 10:53		170 RPM
		3			98.5	95.9	18.9	518	6900	48	43	10:5[illegible] / 11:0[illegible]		180 RPM
		4			98.7	95.8	18.5	518	6900	48	43	11:0[illegible] / 11:07		190 RPM
		5			98.5	95.9	19.0	521	6900	48	43	11:0[illegible] / 11:12	1:07	200 RPM

39

23:28 35

WITNESSED [signature]

WHIRL TEST - J57-PW-19W
ENGINE DATA SHEET

DATE	RUN NO.	T_o	P_o	N_1	N_2	P_{T7}	T_{T7}	W_f	P_{OIL}	T_{OIL}	TIME		REMARKS
9-25-61	6			98.6	95.6	18.2	515	6800	48	43	11:1[illegible] / 11:16		210 RPM
	7			98.8	95.7	18.2	516	6850	48	43	11:1[illegible] / 11:25		218 RPM
					IDLE						11:3[illegible] / 11:37	23	NCD
9-26-61					IDLE						8:4[illegible] / 8:48		NORMAL START 8:43 V.O.
	1			95.3	95.4	18.5	528	6600	48	43	9:0[illegible] / 9:08		TRAILING 2.5" NRP - 172.5 RPM
	2			93.6	95.7	18.5	545	6400	48	43	9:09 / 9:14		7° COLL 171 RPM
	3			96.0	95.8	18.6	540	6600	48	44	9:1[illegible] / 9:17		220 RPM
					IDLE						9:1[illegible] / 9:24	41	SUPPRESSOR FAILED NCD
9-26-61					IDLE						10:21 / 10:2[illegible]	-	NORMAL START STARTER RUN 1 MIN. NO LOAD
	4			88.5	94.8	18.1	561	6200	48	43	10:3[illegible] / 10:42		7° COLL 230 RPM
					IDLE						10:43 / 10:49	28	NCD
					IDLE						11:50 / 12:02		NORMAL START 12:00 V.O.
	5			87	94.2	18	554	6000	48	43	12:1[illegible] / 12:1[illegible]		230 RPM
	6			87	94.2	18	552	6050	48	43	12:1[illegible] / 12:20		240 RPM MAX. STRIPE 1/4" HIGH
	7			88.5	94.8	18.1	552	6100	48	43	12:2[illegible] / 12:[illegible]		8° COLL 170 RPM
	8			88.5	94.8	18.3	554	6100	48	43	12:32 / 12:34		WIND STEADY 13 SW 180 RPM
	9			88.4	94.8	18.3	556	6100	48	43	12:3[illegible] / 12:40		190 RPM
	10			88.2	94.8	18.5	562	6200	48	43	12:41 / 12:44	46	200 RPM

25:46 38

119

49

20

WITNESSED
[illegible]
USAF

WHIRL TEST - J57-PW-19W
ENGINE DATA SHEET

DATE	RUN NO.	T_0	P_0	N_1	N_2	P_{T7}	T_{T7}	W_f	P_{OIL}	T_{OIL}	TIME		REMARKS
9-26-61	11			88.8	94.8	18.5	558	6200	48	42	12:[illegible] / 12:4[illegible]		210 RPM 8° COLL.
				IDLE							12:49 / 12:54	9	NCD 10:18 hrs ROTOR
9-27-61											9:13 / 9:18		NORMAL START Vo. 9:15
	1			87.1	94.2	17.9	550	6000	48	42	9:29 / 9:32		210 RPM 8° COLL
	2			86.8	94.2	17.9	550	6000	48	42	9:33 / 9:3[illegible]		220 RPM
	3			86.2	94.2	17.9	550	6000	48	42	9:3[illegible] / 9:42		230 RPM
	4			93.2	95.8	19	555	6600	48	42	9:4[illegible] / 9:54		236 RPM
	5			87.4	94.8	18.0	560	6100	48	42	9:56 / 10:00		9° COLL 170 RPM
	6			87.0	94.8	18.1	566	6000	49	42	10:01 / 10:05		180
	7			88.0	94.8	18.1	566	6000	48	43	10:0[illegible] / 10:16		190
	8			88.7	94.8	18.1	556	6100	48	43	10:19 / 10:23		200
	9			88.5	94.8	18.1	561	6100	48	43	10:2[illegible] / 10:27		210 RPM
	10			88.5	94.8	18.1	585	6100	48	43	10:2[illegible] / 10:32		220
	11			85.6	95.2	19.6	595	6300	48	43	10:3[illegible] / 10:42		230 9° ½" H_2O
	12			84.9	95.2	19.6	600	6300	48	43	10:4[illegible] / 10:51		8° 243 ½" H_2O
	13			88.7	94.9	18.0	555	6000	48	44	10:5[illegible] / 10:58		10° COLL 170 RPM
	14			88.0	94.5	18.0	560	6000	48	44	10:5[illegible] / 11:08		180 RPM
	15			89.0	95.1	18.1	560	6100	48	44	11:05 / 11:13	2:01	140 RPM

49

27:56 39

WITNESSED [illegible]

8-Z-16

WHIRL TEST ~ J57-PW-19W
ENGINE DATA SHEET

DATE	RUN NO.	T_0	P_0	N_1	N_2	P_{t7}	T_{t7}	W_f	P_{OIL}	T_{OIL}	TIME		REMARKS
9-27-61	16			88.5	95	18.0	562	6100	48	44	11:14 / 11:19		10° COLL 200 RPM
	17			90.3	95.1	18.0	554	6100	48	44	11:19 / 11:23	16	210 RPM
					IDLE						11:23 / 11:30		NCD
					IDLE						13:20 / 13:27		NORMAL START V.O. 13:27
	18			86	96.5	21	630	6800	48	44	13:33 / 13:50		235 RPM 9° COLL; LIMIT MIL POWER 239 RPM 9° COLL
	19			88.5	94.7	17.5	550	6000	48	44	1353 / 1357		10° COLL 210 RPM
	20			92.4	96.9	20.5	600	7000	48	44	1358 / 1408	20	10° COLL 220 RPM
	21			96.5	96.2	19.5	555	6800	48	44	1413 / 1426		243 RPM 8° COLL
	22			90	96	19.6	585	6600	48	44	1426 / 1441		243 8°
					IDLE						1441 / 1446		NCD
9-28-61					IDLE						9:00 / 9:07		START T_{t7} INDICATOR RECORDS. V.O. 9:01
		1		86.2	95.8	19.5	610	6400	48	44	9:16 / 9:31		242 8.5° COLL
		2		81.5	95.8	19.9	642	6300	48	44	9:34 / 9:56		242 RPM 8.5° COLL
						IDLE					10:03 / [illegible]	1:08	
9-29-61						IDLE					10:23 / 10:27		V.O. 10:25
		1		82.8	96.2	20.2	645	6400	48	45	10:39 / 11:09	1:29	8.5° COLL 240 RPM
						IDLE					11:19 / 11:24		
		2		82.7	96.2	20.5	655	6600	48	45	11:32 / 12:02		WITNESSED [illegible] USAF 16118

2:10

1.4" H_2O

-40" H_2O

13:09 HRS

13:42

14:49

1.0

2:13

30:09

41

B-2[illegible]

WHIRL TEST - J57-PW-19W ENGINE DATA SHEET

DATE	RUN NO.	T_0	P_0	N_1	N_2	P_{T7}	T_{T7}	W_f	P_{OIL}	T_{OIL}	TIME		REMARKS
9-29-61					IDLE						[illegible] / [illegible]		
	3			81.8	96.1	21.0	658	6600	48	46	12:17 / 12:49		8.5 coll 240 RPM
					IDLE						12:[illegible] / 13:03	1:44	
	4			80.8	96	20.9	660	6600	48	46	13:20 / 13:37		8.5 coll 240
					IDLE						13:40 / [illegible]		NCD TOTAL ROTOR 18:10
10-2-61					IDLE						[illegible] / 1618		NORMAL START V.O. 1617
				DEMONSTRATION AT									
				VARIOUS ROTOR RPM.S								31	
				AND TEMP.									
	1			80	96	21.8	650	6600	48	44	1630 / 1632		8.5° COLL 240 RPM
					DEMO RUNS								
					IDLE						1644 / 1649		NCD V.C 1645 1838
10-20-61				35	60.9	1.2 IDLE	240	940	45.5	28	11:58		START FAMILIARIZATION RUN
				96.4	97.1 MIL	19.75	600	7200	48	45	1203	32	OPERATED DUMP VALVE
					IDLE						1225		
					SHUT DOWN						1239		NORMAL
													WITNESSED J J Byron
													USAF QC

32:56 44 18:38

8-25-1[illegible]

WHIRL TEST ~ J57-PW-19W ENGINE DATA SHEET

DATE	RUN NO.	T_o	P_o	N_1	N_2	P_{T7}	T_{T7}	W_f	P_{OIL}	T_{OIL}	TIME		REMARKS
10/27		65	30.00	37.8	60.5	.6	260	930	45.5	30	1101		START
				IDLE — NORMAL									FAMILIARIZATION RUN WITH BLADES INSTALLED
	1	"	"	65	80	3.0	285	1720	46	50	1107		VALVE OPEN-BUTTERFLY 105 RPM -4° Coll
				IDLE							1121		T_{T7} FLUCTUATED 15°C DURING IDLE
											1134		
	2	"	"	82.5	87	7.0	340	3000	47	48	1149	1:19	B-VALVE OPEN 173 rpm -6° coll
	3	"	"	84.5	87.8	7.7	350	3400	47	48	1153		181 rpm -6° COLL
	4	"	"	88	89	9.1	370	4000	47	46	1156		200 rpm -6° COLL
	5	"	"	88	90	10.7	405	4400	47	46	1201		219 rpm -6° COLL
	6	"	"	92.3	92.5	13.5	455	5200	47	45	1210		243 rpm -6° COLL
						IDLE					1213		
			TO 75% N_2 - 30 SEC -				NORMAL SHUTDOWN				1220		OBSERVED CLATTER FROM STARTER 1:06
10/27		66	29.9[illegible]	34.5	60.2	1.0	260	940	45	34	3:49		START
					IDLE						3:55		
	7			88.5	90	10.4	400	4200	47	46	[illegible]		
	8			94.5	93.2	14.4	470	5500	48	45	412 / 416		240 rpm - 4° COLL
	9			96	95.5	17.0	540	6500	48	45.5	420	57	239 rpm - 6° COLL
	10			87.5	96.5	20.4	630	6700	48	45	430		242 rpm - 9° COLL 36
	11			80.3	96.[illegible]	20.4	670	6400	48	44	434		240 rpm - 9° COLL
	12			95	96.5	20	585	6900	48	45	441		240 rpm - 9° COLL
	13			94.8	94	15.5	490	5700	48	45	446		240 rpm - 8.5° COLL
													220 rpm 8.5 COLL

35.12 46 [illegible] USAF 20:20

B2-13

WHIRL TEST - J57-PW-19W
ENGINE DATA SHEET

DATE	RUN NO.	T_0	P_0	N_1	N_2	P_{T_7}	T_{T_7}	W_f	P_{OIL}	T_{OIL}	TIME		REMARKS
10/29	14			91	92	12.6	445	5000	47	46	851	10	200 rpm, 8.5 COLL
	15			86.5	89.8	10.2	400	4400	47	46	853		180 rpm, 8.5 COLL
					IDLE - SHUTDOWN						856		NORMAL SHUT DOWN
10/30		62	29.89	35.5	61	IDLE 1.2	235	890	44	48	855	START	947 - WIND - 1-2 MPH - NW VALVE OPEN - 856
				74	83.7	5.0	320	2650	46	48	901		170 rpm - 2° COLL
	16	67		86.8	88.8	9.2	380	3800	47	46	919		916 WIND - 1-2 - N & NE 170 rpm - 8.5 COLL
	17			88.5	90.0	10.2	400	4200	47	45	925		181.5 rpm - 8.5° COLL
	18			88.5	90.0	10.2	398	4200	47	45	934	1:30	170 rpm - 9° COLL
	19			90	90.5	10.8	410	4400	47	45	937		180 rpm - 9° COLL
	20			92	92.5	13.5	460	5100	48	45	941		200 rpm - 9° coll
	21			96	94.5	16.5	510	6000	48	44	948		220 rpm - 9° coll
	22			94.2	96.7	20.3	605	6900	48	42	955		240 rpm - 9° coll
	23			90	91	14	420	4500	47	46	1007		1006 WIND - 2 mph - NNE 170 rpm - 10° coll
	24			81	96.2	20.1	670	6300	48	43	1011		231 rpm - 10° coll
				35	61	1.4 IDLE	240	850	45	51	1020		STACK VALVE CLOSED 1:24
					SHUT DOWN						1025		NORMAL

36:52 47 21:49

J. Byron, 2/Lt. U.S.A.F.

WHIRL TEST ~ J57-PW-19W
ENGINE DATA SHEET

DATE	RUN NO.	T_o	P_o	N_1	N_2	P_{T7}	T_{T7}	W_f	P_{OIL}	T_{OIL}	TIME		REMARKS
10/30									START →		1337		
		69	29.83	34	60.2	.9	250	890	45	41	1338 / 1339		1342 - B VALVE OPEN
				START - 1 MIN ON STARTER									
	25			71	83.2	4.9	320	2320	46	47	1344 / 1349		WIND - 14 MPH - NNE 170 rpm, 2° coll
	26			84.9	88.5	8.6	370	3500	47	50	1356 / 1401		Down to 230 at end of data read 241 rpm, 2° coll
	27			97.2	97.1	20.0	590	7000	48	44	1404 / 1409		240 rpm, 9° coll
	28			80	88.4	8.6	395	3200	47	50	1413 / 1416		240 rpm, 2° coll
	29			97.3	97.1	20.4	600	7100	48	45	1419 / 1422		240 rpm, 9° coll
	30			81.2	96.4	20.3	665	6300	48	45	1426 / 1428		231 rpm, 10° coll
	31			97	96.4	18.9	570	6700	48	45	1433 / 1437	2:01	220 rpm, 10° coll
	32			92	93.8	15.0	510	5400	48	45	1441		200 rpm, 10° coll
	33			87	91	12.0	445	4300	48	45	1445 / 1447		WIND - 4 mph - N 180 rpm, 10° coll
	34	69		85.5	90	11.0	425	4200	48	45	1450 / 1452		WIND - 25 mph - NNE 170 rpm, 10° coll
	35			81.4	88.5	8.6	390.	3400	47	49	1506 / 1508		170 rpm, 8° coll
	36			84.1	89.9	9.6	415	3900	47	49	1511 / 1513		180 rpm, 8° coll
	37			88.2	91.1	11.9	445	4600	47	49	1514 / 1518		200 rpm, 8° coll
	38			92.1	93.2	14.4	490	5300	47	45	1520 / 1522		220 rpm, 8° coll
	39			97	96	18.0	545	6500	47	46	1524 / 1527		240 rpm, 8° coll
				34	60.8	1.4	235	850	IDLE → 47	46	1534 / 1539		← NORMAL SHUT DOWN 1:51

38:52 49

2340

B.2-21

WHIRL TEST ~ J57-PW-19W
ENGINE DATA SHEET

DATE	RUN NO.	T_0	P_0	N_1	N_2	P_{T_7}	T_{T_7}	W_f	P_{OIL}	T_{OIL}	TIME		REMARKS
10/30		67	29.82	IDLE 34	60	1.3	250	920	START → 45	44	1607 /		1608 - B VALVE OPEN
	40			79	87	7.5	370	2970	47	49	1613 / 1620		220 rpm - 2° coll
	41			82.5	88.8	8.7	400	3600	47	49	1623 / 1625		WIND - 4 mph - N 220 rpm - 4° coll
	42			87.5	90.9	11.8	435	4500	47	46	1628 / 1629		WIND - 2 mph - N 220 rpm - 6° coll
	43			91.5	93.1	14.3	490	5200	47	45	1633 / 1635		220 rpm - 8° coll
	44			97.7	96.6	19.0	570	6900	48	45	1638 / 1640	1:19	220 rpm - 10° coll
	45			94.8	97.1	20.6	610	7000	48	45	1643 / 1647		WIND - 0 220 rpm - 10.5° coll
	46			92.8	96.0	18.3	580	6300	48	46	1650 / 1652		240 rpm - 8° coll
	47			95	97.2	20.6	610	7000	48	44	1657 / 1659		240 rpm - 9° coll
				67	83	48	340	2010	48	50	1702 / 1708		WIND - 0 170 rpm - 2° coll
											1713 / 1713.35		FORTY SEC 240 rpm - 2° coll
											1715 / 1716.25		1 min - 20 sec 240 rpm - 9° coll 1:06
									IDLE		1719		
											1720 / 1720		NORMAL SHUT DOWN
10/31		58	30.00	36	IDLE 41.2	1.3	230	920	48		8:24 / 8:26.5		WIND E - 4 MPH → START 2.5 MIN
		SHUTDOWN	DUE	TO LOSS	OF LUBE	OT HUB	BEARING				8:31.5 / 8:33.25	1:1.75 min	B VALVE OPEN 8:28 170 rpm, 2° coll
				IDLE							8:34 / 8:41	17	NORMAL SHUT DOWN :08

40:28 51 [signature] 24:54

B.2-22

WHIRL TEST ~ J57-PW-19W
ENGINE DATA SHEET

DATE	RUN NO.	T_o	P_o	N_1	N_2	P_{T_7}	T_{T_7}	W_f	P_{OIL}	T_{OIL}	TIME		REMARKS
10/31		ABORTED START REACHED ONLY N_2 = 20%									955 / 1000	4	ABORT
		63	30.00	IDLE 34.2	60.1	1.5	265	920	START→ 45	39	1008 /		B VALVE OPEN 1009 40 SEC ON STARTER START WAS SLOW
											1013 / 1015		WIND – 0 mph 170 rpm – 2° COLL
	48			98	97	20.5	580	7200	48	44	1017 / 1018		240 rpm – 2° COLL
											1031 /		170 rpm – 2° COLL
											1034 /	1:21	240 rpm – 2° COLL
	49			94.5	97	21	610	7100	48	40	1037 / 1042		WIND – 1 mph – N 240 rpm – 9° COLL
											1045 /		170 rpm – 2° COLL
											1053 / 1108		240 rpm – 2° COLL
											1108.5 / 1111.5		240 rpm – 9° COLL
				97.2	97	21	605	7200	48	45	1122 / 1125		240 rpm – 2° COLL
				35	61	IDLE 1.0	250	780	45	45	1128 /		B VALVE CLOSED 1132

1:23

T. J. Byron
M.A.O.T.

4:53 53

26:17

WHIRL TEST - J57-PW-19W
ENGINE DATA SHEET

DATE	RUN NO.	T_o	P_o	N_1	N_2	P_{T_n}	T_{T_n}	W_f	P_{OIL}	T_{OIL}	TIME		REMARKS
11/1/61		61	29.95	36	61.5	1	230	1000	46	18	1033 / 1039	START	DEMONSTRATION RUN WIND - 5MPH - S
									46	44	1041		170rpm - 2° coll
											1055		HYDRAULIC PUMP MOTOR FAILURE IDLE
											1110	SHUT	NORMAL SHUT DOWN
11/1/61		62	29.90	35.5	IDLE 61	1.1	240	900	45	32	1240	START	WIND - 22MPH - SW
											1245		170rpm - 2° coll
											1250		240rpm - 2° coll
	50			98	97	20	580	7000	48	42	1255		240rpm - 9° coll
											1257		IDLE
											1003	SHUT	NORMAL SHUT DOWN
11/3/61		75	30.0	34.5	IDLE 60.5	1.0	270	900	45	30	929	START	BYVLVE OPEN 9:30 WIND - NNE - 2mph
				75	85.1	5.8	370	2770	47	45	936		170RPM - 4° COLL
				87.2	91	10.5	440	4300	47	50	943		240RPM - 4° COLL
	1	78		95.2	97.3	19.6	602	6900	48	46	958		WIND - 0 240RPM - 7.6° COLL
											1003		170RPM - 4° COLL
		WITNESSED									1008		IDLE
		T J Byron									1010	SHUT	NORMAL SHUT DOWN
		USAF QC											

43-27′ 56 27-41′

B.2-24

WHIRL TEST - J57-PW-19W ENGINE DATA SHEET

DATE	RUN NO.	T_o	P_o	N_1	N_2	P_{T_7}	T_{T_7}	W_f	P_{OIL}	T_{OIL}	TIME		REMARKS
11/8/61		78	29.99	34	IDLE 60	1.5	290	900	45	45	1140	START	WIND SW-2 B VALVE OPEN 1121
											1146		WIND SW-3 170 rpm - 4° COLL
				77.5	88.2	8.2	400	3100	47	52	1153		WIND SW-2 200 rpm - 4° coll
	2			97	97.3	19	590	6900	48	50	1154		240 rpm - 7.6° coll
											1204		IDLE
											1208	STOP	NORMAL SHUT DOWN
11/9/61		75	29.96	34	IDLE 60.4	1.3	280	900	45	44	209	START	WIND SW-4 B VALVE OPEN-210
											215		170 rpm - 4° coll
											218		WIND SW-3 200 rpm - 4° coll
	3			97.5	97.2	19	580	6900	48	50	223		WIND S-2 - FUEL FLOW METER FLUTTER NOTED 240 rpm - 8° coll
						IDLE					228		FUEL FLOW STEADY
											234	STOP	Normal Shut Down
											ENGINE TIME 44-14'		STARTS 58 BLADE Hand Time 28-18'

Witnessed J. J. Byron USAF QC

B.2-25

WHIRL TEST - J57-PW-19W
ENGINE DATA SHEET

DATE	RUN NO.	T_0	P_0	N_1	N_2	P_{T7}	T_{T7}	W_f	P_{OIL}	T_{OIL}	TIME		REMARKS
12/1/61		64	30.01	35	60.5	1.1	245	890	45	32	1:20	START	STARTER SLUGGISH 500°C START - 12 SEC
											1:27		VALVE OPEN 5MPH - NE
				53.5	77	4.6	355	1820	46	45	1:36		170 RPM - 2°C oll
		66	29.97	77.8	89	11.6	470	4100	47	44	1:40		ENE - 7MPH 192 RPM 8°C oll
				87.8	96.5	20.2	630	6600	48	41	1:47		228 rpm 8.7°C oll
	4			96.3	97	20.4	595	7100	48	48	1:49		5MPH - E 230 rpm 8.5°C oll
	5			79.5	96	20.8	670	6300	48	44	1:59		234 rpm - 8.5°C oll
	6			79	96	21.1	682	6400	48	44	2:11		5MPH - E 235 rpm - 8.5°C oll
											2:23		5mph - ESE 170 rpm - 4°C oll (5")
											2:29		4mph - ESE 240 rpm - 4°C oll
											2:31		240 rpm - 8.5°C oll (15")
				35	IDLE 60.6	1.3	230	780	45	52	2:34		2:36 VALVE CLOSED
											2:39	STOP	
12/5/61		61	30.15	36	61.4	IDLE 1.2	240	960	45	17	11:07	START	SLOW START - T_{T7} 490°C 10mph - W
											11:14 11:20		VALVE OPEN 11:10
	7			91.5	96.9	20.4	610	6900	48	40	11:32		12 mph - W 218 rpm - 10°C oll
	8			79.2	96	21.1	670	6500	48	41	11:35		221 rpm - 10°C oll
											11:38		170 rpm - 4°C oll

WITNESSED

WHIRL TEST ~ J57-PW-19W
ENGINE DATA SHEET

DATE	RUN NO.	T_0	P_0	N_1	N_2	P_{T_7}	T_{T_7}	W_f	P_{OIL}	T_{OIL}	TIME		REMARKS
12/5/61	9	64	30.10	79	95.9	21.1	687	6500	48	42	12:05		12 mph - W 240 rpm 8° COLL
				35	60.8	IDLE 1.2	235	800	45	48	12:09		
											12:1[illegible]	STOP	
12/4/61		62	30.00	34.5	60	IDLE 1.5	280	980	45	26	11:32	START	530°C START SOUND MEASUREMENTS
				79.7	96	20.4	675	6350	48	41	11:37		11:43 AT MAX TEMP WSW - 10 mph
				71	88.8	12.5	500	4000	47	49	11:54		
				79.7	90.9	12.5	485	4300	47	46	12:06		
						IDLE					12:14	STOP	

WITNESSED [illegible signature]

B2-27

WHIRL TEST - J57-PW-19W
ENGINE DATA SHEET

DATE	RUN NO.	AMBIENT TEMP. - °F	AMBIENT PRESS. in Hg.	LOW COMPRESSOR % SPEED	HIGH COMPRESSOR % SPEED	TURBINE DISCHARG PRESS. - PSIG	TURBINE DISCHARG TEMP. - °C	FUEL FLOW RATE - Lb/Hr	OIL PRESSURE PSIG	OIL TEMP. °C	WIND VELOCITY MPH	WIND DIRECTION	ROTOR rpm	COLLECTIVE PITCH	TIME	STARTS	REMARKS
—	—	T_0	P_0	N_1	N_2	P_{T7}	T_{T7}	w_f	$P_{o.i}$	$T_{o.i}$	V_{wind}	Dir.	rpm	Pitch			
12/8/61	1	60	29.82	36	61	1.3	240	920	46	18	4	SE	—	—	1:43	START	500°C START IDLE - VALVE OPEN - 1:48
															1:52		170 rpm - 2° coll RED LIGHT OUT - SPARK CHECK
															1:55		IDLE | DETECTOR INDICAT VALVE CLOSED - 1:57
																	WIRE HAD PARTED
																	VALVE OPEN - 2:13
															2:15 2:18		170 rpm - 2° COLL
																	YELLOW LIGHT OUT VALVE CLOSED 2:19
											15	SW			2:31		VALVE OPEN 2:30 170 rpm - 2° coll
				35	60.1	2	240	800	45	45					2:34		VALVE CLOSED - 2:36 IDLE
															2:39	STOP	
12/11/61		56	30.05	35.5	60.8	1.3	240	910	45	28	5	SW			10:45	START	500°C START - VALVE 10:46 IDLE
	12 13			91.5	83.0	5.2	310	2800	46	40	4	W	170 185	2 6	10:51 10:59		
	14 15												202 200	7 9.5	11:03 11:07		
	16 17			78.2	97	21	585	7300	48	40	6	NE	220 221	9 9	11:10 11:12		
	18												220	2	11:16		
	19												220 230	2 9	11:20		TRANSIENT 8 SEC
	20												230 75	9 2	11:23		TO IDLE 10 SEC

WITNESSED [illegible] HQ

B.2-28

WHIRL TEST - J57-PW-19W
ENGINE DATA SHEET

DATE	RUN NO.	AMBIENT TEMP. - °F	AMBIENT PRESS. in Hg.	LOW COMPRESSOR % SPEED	HIGH COMPRESSOR % SPEED	TURBINE DISCHARGE PRESS. - PSIG	TURBINE DISCHARGE TEMP. - °C	FUEL FLOW RATE - Lb/Hr	OIL PRESSURE PSIG	OIL TEMP. °C	WIND VELOCITY MPH	WIND DIRECTION	ROTOR rpm	COLLECTIVE PITCH	TIME	START	REMARKS
12/11/61	21												220	2	11:33		
	22												220 220	2 9	11:34		5SEC TRANSIENT
	23												220	9 2	11:38		TO IDLE 10SEC TRANSIENT
															11:43	STOP	NORMAL S.D.
		58	30.00	35.2	60.8	1.6	245	890	45	48	10	SW			1:46	START	480°C START IDLE - 1:48 V. OPEN
													220 230	2 9	1:51 1:54		1:58 Valve Closed
	24												220 230	2 9	2:11		2:08 Valve Open 5SEC TRANSIENT
	25												240	8	2:16		5SEC TRANSIENT TO IDLE
		0° to 7° LEFT & RIGHT CYCLIC									8	SW	240	4	2:19 2:2[illegible]		
							IDLE								2:43 2:48	STOP	NORMAL S.D.
CUMULATIVE TIME & NUMBER OF STARTS →																	STARTS ~ 62 ENGINE TIME ~ 52 hr. 17 m. BLADE TIME ~ 53 hr. 4 m. E. Fanella
12/12/61		58	30.04	35	60	IDLE 1.4	260	920	45	26	7	N			1:03	START	500°C START 1:04 B VALVE OPEN
											5	N	200	4	1:10		
	26	0° to 8° FWD CYCLIC				440 - 1° RIGHT Cyclic					4	NW	240	4	1:11 1:29		WITNESSED T. J. Bynon U.S.A.F.Q.
	27	0° to 8° AFT CYCLIC - 1° LEFT Cyc									5	NE	240	4	1:30 1:33		
				94	75	18.7	550	6400	48	40	5	NE	240	6	1:41		

B-2-29

WHIRL TEST - J57-PW-19W
ENGINE DATA SHEET

DATE	RUN NO.	AMBIENT TEMP. - °F	AMBIENT PRESS. in Hg.	LOW COMPRESSOR % SPEED	HIGH COMPRESSOR % SPEED	TURBINE DISCHARGE PRESS. - PSIG	TURBINE DISCHARGE TEMP. - °C	FUEL FLOW RATE - Lb/Hr	OIL PRESSURE PSIG	OIL TEMP. °C	WIND VELOCITY MPH	WIND DIRECTION	ROTOR rpm	COLLECTIVE PITCH	TIME	START	REMARKS
12/14/61	28	0° TO 8° FWD CYCLIC					550	1° RIGHT CYCLIC					240	6	1:44 1:48		
	29	0° TO 8° AFT CYCLIC					550	1° RIGHT CYCLIC					240	6	1:49 1:57		
				83	96.2	20.5	642	6400	48	40	3	W	240	7.5	2:05		
	30			83	96.2	20.5	642	6400	48	40	5	N	193	12	2:06		
	31			"	"	"	"	"	"	"	"	"	"	"	2:08		
							IDLE								2:09 2:14	STOP	B VALVE CLOSED 2:10
	ENGINE TIME - 53 hr 28 m - BLADE - 34 hr 10 m														—	63 STARTS	
12/13/61		52	30.00	36.7	61.8	1.4	235	920	46	14	7	NE			9:44	START	500°C START IDLE
													170	2	9:52		B VALVE OPEN 9:46
															9:53		TO IDLE - TILT STOP and CHECK DET. LIGHTS OFF
																	B VALVE CLOSED - 9:55 B VALVE OPEN - 10:04
							1° RIGHT CHECK						170	2	10:16		
				81.4	96	21.1	160	6600	48	35	8	NW	240	8	10:19		0 TO 8 FWD CYCLIC 0 TO 7° LEFT "
																	0 TO 7° RIGHT " 0 TO 8° AFT "
				"	"	"	"	"	"	"	"	"	200	12			
													195	4	10:42		FULL LEFT - FULL FWD " RIGHT - " AFT
															10:45	STOP	IDLE
	ENGINE TIME - 54 hr. 34 m BLADE - 35 hr 5 m															64 STARTS	

WITNESSED [signature]

8-2-30

WHIRL TEST – J57-PW-19W
ENGINE DATA SHEET

DATE	RUN NO.	AMBIENT TEMP. – °F (T_o)	AMBIENT PRESS. in Hg. (P_o)	LOW COMPRESSOR % SPEED (N_1)	HIGH COMPRESSOR % SPEED (N_2)	TURBINE DISCHARGE PRESS. – PSIG (P_{T_7})	TURBINE DISCHARGE TEMP. – °C (T_{T_7})	FUEL FLOW RATE – Lb/Hr (W_f)	OIL PRESSURE PSIG (P_{oil})	OIL TEMP. °C (T_{oil})	WIND VELOCITY MPH (V_{wind})	WIND DIRECTION (Dir.)	ROTOR rpm	COLLECTIVE PITCH	TIME	STARTS	REMARKS
...	...																
1/4/61				34.5	60.1	–	290	1000	47	22					10:43	START	Monthly Run Up of Engine
				77	90.5		550	5300	47	35					10:50		40 sec in Start 500°C light off
				34	60.3		320	790	45	48					10:58		IDLE
															11:05	Stop	Normal Shut Down
8/16/62	FIRST WHIRL RUN AFTER 35 HR INSPECT																
		60	30.01	36	61	1.2	240	1000	46	18	15	SW	40	4	2:40	START	33 sec in Start 500°C Start
				79	86	6.4	320	2250	47	41	15	SW	175	4	2:47		VALVE OPEN – 2:42
				98.5	97.1	21.1	595	7400	48	41	15	SW	240	8	2:52		MIL. PWR
				79.8	96	21.1	670	6500	48	41	15	SW	240	8	2:57		MAX TEMP – T_7 STICK VIBRATIONS IN COLLECTIVE
				36	61.8	1.5	240	800	45	49	15	SW	–	–	3:01		IDLE, VALVE CLOSED – 3:03
															3:06	STOP	NORMAL.
3/4/62		57	30.06	36	61.3	1.3	235	940	45	20	4	SE	–	–	10:31	START	IDLE – 500°C START 40 SEC ON STARTER
													170	4	10:48		VALVE OPEN – 10:45
				97.5	97	21.3	600	7500	48	38	3	E	240 / 240	8 / 4	11:00 / 10:55		MIL PWR
															11:05		IDLE 11:06 VALVE CLOSED
															11:20		BVALVE OPEN

Witnessed J.E. Cox 3/4/62

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WHIRL TEST - J57-PW-19W
ENGINE DATA SHEET

B.2-31

	Symbol	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8					
DATE		2/6/62										ASS'T SEC DEFENSE		
RUN NO.		1	2	3	4	5	6	7	8					
AMBIENT TEMP. - °F	T_o													
AMBIENT PRESS. in Hg.	P_o													
LOW COMPRESSOR % SPEED	N_1	35	"	34.9	34.4	35	"	34.5	34.4	74	99.5	99.5		
HIGH COMPRESSOR % SPEED	N_2	60.5	"	60.3	60	60.5	"	60.3	60	84.8	96.4	95.4		
TURBINE DISCHARGE PRESS. - PSIG	P_{T_7}	1.4	"	"	1.6	1.45	"	"	1.6	6.5	21	24.1		
TURBINE DISCHARGE TEMP. - °C	T_{T_7}	275	"	280	312	270	"	283	305	325	580	670		
FUEL FLOW RATE - Lb/Hr	W_f	910	"	"	"	910	"	"	"	2720	7500	6600		
OIL PRESSURE PSIG	P_{oil}	45	"	"	"	"	"	"	"	46	48	"		
OIL TEMP. °C	T_{oil}	44	"	"	"	"	"	"	"	44	45	40		
WIND VELOCITY MPH	V_{wind}	5	"	"	5	5	"	"	5	5	12	14		
WIND DIRECTION	Dir.	SW	"	"	SSW	S	SW	S	SW	SW	SW	"		
ROTOR rpm	rpm	60	58	43	13	60	58	43	13	170	240	240		
COLLECTIVE PITCH	Pitch	4	"	"	"	"	"	"	"	"	8	8		
TIME		11:25	11:28	11:32	11:34	" 37	11:41	11:45	11:49	11:57	12:27	12:30	12:31	12:36
STARTS														STOP
REMARKS		B VALVE OPEN	" 3/4	" 1/2	" 1/4	B VALVE OPEN	" 3/4	" 1/2	" 1/4	B VALVE OPEN			B VALVE CLOSED 12:33 IDLE	NORMAL SHUT DOWN

Witnessed 2/6/62 [signature]

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B.2- 32

WHIRL TEST - J57-PW-19W
ENGINE DATA SHEET

DATE	RUN NO.	AMBIENT TEMP. - °F (T_o)	AMBIENT PRESS. in Hg. (P_o)	LOW COMPRESSOR % SPEED (N_1)	HIGH COMPRESSOR % SPEED (N_2)	TURBINE DISCHARGE PRESS. - PSIG (P_{T_7})	TURBINE DISCHARGE TEMP. - °C (T_{T_7})	FUEL FLOW RATE - Lb/Hr (W_f)	OIL PRESSURE PSIG (P_{oil})	OIL TEMP. °C (T_{oil})	WIND VELOCITY MPH (V_{wind})	WIND DIRECTION (Dir.)	ROTOR rpm (rpm)	COLLECTIVE PITCH (Pitch)	TIME	STARTS	REMARKS
2/12/62		59	30.06	36	61.5	1.2	225	980	45	20	16	SW	—	—	1:54	START	35 SEC ON STARTER 510°C START
				78	86	6.4	335	2950	48	46	16	SW	170	4	2:05		1:59 - 13 VALVE OPEN
	9			93.2	92.8	13.5	455	4200	48	45	16	SW	240	5	2:25		2:35 - 5° L,R,Fwd, Aft Cyclic
	10			95.2	94	16	490	6000	48	40	22	SW	240	5.75	2:40		5° Left Cyclic 2:48 - 5° L,R Fwd, Aft Cyclic
	11			96.9	95	16.7	510	6250	48	41	16	SW	240	6.5	2:52		5° LEFT CYCLIC 2:56 - 5° L,R,Fwd, Aft Cyclic
	12			98.2	95.7	18	530	6700	49	41	18	SW	240	6.7	3:02		6° LEFT CYCLIC 3:06 - 5° L,R,Fwd, Aft Cyclic
															3:09		IDLE
	13			99	95.7	17.5	525	6800	48	41	16	SW	240	6.5	3:22		5° LEFT CYCLC 3:28 - 5° L,R,Fwd, Aft Cyclic
	14			98	97	19.8	565	7200	49	41	19	SW	240	7.5	3:32		5° LEFT CYCLIC 3:37 - 5° L,R,Fwd, Aft Cyclic
	15			98.2	97.1	20.4	580	7200	49	41	11	SW	240	8.0	3:44		5° CYC - L
	16			99.0	96	21.0	670	6400	48	41	16	SW	240	8.0	3:47		5° CYC - L
3/13/62 [illegible]															3:49		3:56 - 13 VALVE CLOSED Fluid BACKED UP IN MANOMETER
															4:00	STOP	NORMAL SHUT DOWN
3/14/62		58	30.05	36	61	1.5	242	910	45	32	15	SW	IDLE		3:1?	START	35 SEC START 320°C START
																	8 VALVE CLOSED - 3:27
	17			98	97	20.1	585	7200	49	41	18	SW	240	7.5	3:48		8 VALVE OPEN - 3:39 5° LEFT CYCLIC
	18			94	96.9	20.8	600	7100	49	41	16	SW	240	7.5	4:00		

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B.2-33

WHIRL TEST - J57-PW-19W
ENGINE DATA SHEET

Witnessed S.P.B. 2/13/62

DATE	RUN NO.	AMBIENT TEMP. - °F (T_0)	AMBIENT PRESS. in Hg. (P_0)	LOW COMPRESSOR % SPEED (N_1)	HIGH COMPRESSOR % SPEED (N_2)	TURBINE DISCHARG PRESS. - PSIG (P_{T_7})	TURBINE DISCHARG TEMP. - °C (T_{T_7})	FUEL FLOW RATE - Lb/Hr (W_f)	OIL PRESSURE PSIG (P_{oil})	OIL TEMP. °C (T_{oil})	WIND VELOCITY MPH (V_{wind})	WIND DIRECTION (Dir.)	ROTOR rpm (rpm)	COLLECTIVE PITCH (Pitch)	TIME	STARTS	REMARKS
2/13/62	19	59	30.05	94	96.9	20.6	595	7100	48	40	15	SW	240	7.5	4:04		5° L,R, aft, fwd cyclic; 5° LEFT CYCLIC
				94	96.9	20.8	600	7100	48	41	15	WSW	240	8.0	4:13		"
	20			94.1	96.9	20.8	598	7100	48	41	20	WSW	240	8.0	4:16		5° LEFT CYCLIC
	21			82.7	90.8	11.2	440	4200	48	41	14	SW	240	3.5	4:19		4° LEFT CYCLIC
															4:26		IDLE
	22			36	61.2	1.5	240	900	48	41	14	SW	70	4.0	4:32		B VALVE OPEN - 2° LEFT CYC.
	23			36	61.2	1.5	238	900	48	41	18	WSW	66	4.0	4:34		3/4 OPEN
	24			35.9	61	1.6	242	920	47	41	18	SW	51	4.0	4:37		1/2 OPEN
	25			35.5	60.8	2.0	270	1000	47	45	18	SW	20	4.0	4:38		1/4 OPEN
															4:43		B VALVE CLOSED - 4:45
															5:00	STOP	
2/14/62		65	30.03	36	61.5	1.2	235	910	45	18	10	SW	IDLE	IDLE	10:27	START	40 SEC START 500°C
				72	84.6	6.4	380	2630	45	43	10	SW	170	4.0	10:39		B VALVE OPEN 10:31
	26			96	97	20.4	590	7100	48	40	10	WSW	240	7.5	10:48		
	27			89.5	96.8	20	610	6700	48	40	10	SW	231	8.25	11:02		11:07 - 5° L,R, Fwd, Aft Cyclic; 11:14 - Repeat; 11:21 Repeat
													IDLE	IDLE	11:24		B VALVE CLOSED 11:24
															11:29	STOP	NORMAL SHUT DOWN

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B.2-34

WHIRL TEST - J57-PW-19W
ENGINE DATA SHEET

DATE	RUN NO.	AMBIENT TEMP. - °F (T_o)	AMBIENT PRESS. in Hg. (P_o)	LOW COMPRESSOR % SPEED (N_1)	HIGH COMPRESSOR % SPEED (N_2)	TURBINE DISCHARGE PRESS. - PSIG (P_{T7})	TURBINE DISCHARGE TEMP. - °C (T_{T7})	FUEL FLOW RATE - Lb/Hr (W_f)	OIL PRESSURE PSIG (P_{oil})	OIL TEMP. °C (T_{oil})	WIND VELOCITY MPH (V_{wind})	WIND DIRECTION (Dir.)	ROTOR rpm (rpm)	COLLECTIVE PITCH (Pitch)	TIME	STARTS	REMARKS
2/14/62															2:29	START 5	40 SEC ON START ABORTED START
																STOP	NO FUEL FLOW WITH THROTTLE IN DETENT 520°C START
		62	30.02	36	61.5	1.0	250	910	45	28	13	SW	IDLE	IDLE	2:40	START	30 SEC ON STARTER
							340						170	4	2:51		B VALVE OPEN 2:45
				86.8	89.5	10	390	4200	48	45	13	SW	220	4	2:55		
													220	2	2:59		50 LEFT CYCLIC
													IDLE	IDLE	3:02		B VALVE CLOSED 3:02
															3:08	STOP	NORMAL SHUT DOWN

Cumulative Time - Engine - 62 hrs 7 min ; Starts → 72 ; Blade 44 hrs 16 min

[signature] 2/14/62

B.2-35

WHIRL TEST - J57-PW-19W
ENGINE DATA SHEET

Witnessed 2/20/62 [signature]

DATE	RUN NO.	AMBIENT TEMP. - °F	AMBIENT PRESS. in Hg.	LOW COMPRESSOR % SPEED	HIGH COMPRESSOR % SPEED	TURBINE DISCHARGE PRESS. - PSIG	TURBINE DISCHARGE TEMP. - °C	FUEL FLOW RATE - Lb/Hr	OIL PRESSURE PSIG	OIL TEMP. °C	WIND VELOCITY MPH	WIND DIRECTION	ROTOR rpm	COLLECTIVE PITCH	TIME	STARTS	REMARKS
...	...	T_o	P_o	N_1	N_2	P_{T7}	T_{T7}	W_f	P_{oil}	T_{oil}	V_{wind}	Dir.	rpm	Pitch			
2/20/62		58	29.00	36	61	—	—	980	45	22	8	S	IDLE		10:39	START	T_7 not recording
	28	"	"	93.9	93.9	14	900 °F	5800	47	40	5	S	240	6	11:01		R valve open 10:57; T_7 read on adequate T-couple - ITEM 7 - RUN #15
	29	"	"	95	94.8	15.5	940 °F	6200	47	41	10	SW	240	6	11:12		11:17 - 5° LEFT CYCLIC
	30	"	"	96.5	95.5	16.6	540	6600	48	41	13	SW	240	7	11:17		5° LEFT CYCLIC
	31	"	"	97.5	96.4	17.5	555	7000	48	41	10	SW	240	7	11:22		"
	32	"	"	95.2	96.8	19.8	590	7000	48	40	12	SW	240	7.6	11:33		"
	33	"	"	95.2	96.8	19.8	590	7100	48	40	7	SW	240	7.5	11:40		11:36 5° L,R,F,A Cyclic; 0 CYCLIC
	34	"	"	77.8	87.5	7.6	378	3200	47	44	13	SW	222	2	11:44		5° LEFT CYCLIC
	Ⓐ	TRANSIENT RUN FROM RUN #34													11:53		5 SEC ACCEL TO FULL PWR; 5 SEC TO IDLE - 5° L CYCLIC
	35	"	"	77.8	78	7.5	370	3100	46	44	7	SW	220	2	11:50		11:58 - 5° L,R,F,A CYCLIC; 5° L CYCLIC
	Ⓑ	TRANSIENT RUN FROM RUN #35													12:05		SAME AS ABOVE
	Ⓒ														12:10		0.5° L CYCLIC; "
	36	"	"	90.8	96.5	19.8	610	6800	48	41	13	SW	240	7.6	12:14		5° L,R,F,A CYCLIC; 5° L CYCLIC
																	12:22 5° L,R,F,A CYCLIC; 5° L CYCLIC
				45	71	2	250	1100	X5	50	10	W	100	2	12:27		FULLVE CLOSED 12:30; 0° CYCLIC
															12:33	STOP	Normal
Note: 20 min Engine time - Run 30 was added to correct this.																	

64 hr 31 min 73 42 hr 49 min

WHIRL TEST - J57-PW-19W
ENGINE DATA SHEET

8-2-36

Witnessed [illegible] 4/20/62

DATE	RUN NO.	AMBIENT TEMP. - OF (T_o)	AMBIENT PRESS. in Hg. (P_o)	LOW COMPRESSOR % SPEED (N_1)	HIGH COMPRESSOR % SPEED (N_2)	TURBINE DISCHARG. PRESS. - PSIG (P_{T_7})	TURBINE DISCHARG. TEMP. - °C (T_{T_7})	FUEL FLOW RATE - Lb/Hr (W_f)	OIL PRESSURE PSIG (P_{oil})	OIL TEMP. °C (T_{oil})	WIND VELOCITY MPH (V_{wind})	WIND DIRECTION (Dir.)	ROTOR rpm (rpm)	COLLECTIVE PITCH (Pitch)	TIME	STARTS	REMARKS
4/20/62		55	29.88				IDLE								1:25	START	500°C START
				35	60.8	1.2	215	890	45	43	10	W	62	2	1:32		B VALVE OPEN - 1:32
				65	77	6.2	330	2980	48	40	10	SW	170	4	1:38		10° L CYCLIC
	37	"	"	79	96	19.4	670	6500	48	41	8	W	240	7.6	1:40		5° L, R, A, F CYCLIC - 1:55; ~~RET TO [illegible]~~ " - 2:07
* Note - Leak found in P_7 line															2:06		B VALVE CLOSED 2:07
															2:12	STOP	NORMAL SHUT DOWN
		55	29.93	36	61.5	1.5	230	900	45	38	8	NE	—	—	4:11	START	B VALVE OPEN 4:13
	38	"	"	92	96.5	20.7	600	7000	48	38	10	NE	240	7.5	4:22		4:20 - 5° R CYCLIC; 4:32 - 5° R, L, F, A
	39	"	"	96.4	97	21	590	7200	48	40	8	NE	240	7.3	4:35		5° CYCLIC - R; 4:40 - 5° R, L, F, A CYCLIC
	40	"	"	89.5	94.5	20.5	610	6900	49	40	10	NE	230	8	4:45		5° R CYCLIC; 4:50 - 5° R, L, F, A CYCLIC
	41	"	"	87.5	92.6	15.5	500	5340	48	40	13	NE	230	6	4:51		5° R CYCLIC
	42	"	"	90	96.5	20.7	615	6900	48	40	10	NE	230	8	4:59		5° R, L, F, A CYCLIC - 5:03; 5° R CYCLIC - L 5:09
		"	"	43	69	2.2	245	1050	45	45	10	NE	100	2	5:11		B VALVE - CLOSED 5:18
															5:24	STOP	

B2-37

WHIRL TEST - J57-PW-19W
ENGINE DATA SHEET

DATE	RUN NO.	AMBIENT TEMP. - °F (T_o)	AMBIENT PRESS. in Hg. (P_o)	LOW COMPRESSOR % SPEED (N_1)	HIGH COMPRESSOR % SPEED (N_2)	TURBINE DISCHARGE PRESS. - PSIG (P_{T_7})	TURBINE DISCHARGE TEMP. - °C (T_{T_7})	FUEL FLOW RATE - Lb/Hr (W_f)	OIL PRESSURE PSIG (P_{oil})	OIL TEMP. °C (T_{oil})	WIND VELOCITY MPH (V_{wind})	WIND DIRECTION (Dir.)	ROTOR rpm (rpm)	COLLECTIVE PITCH (Pitch)	TIME	STARTS	REMARKS
---	---																
4/21/62		55	29.95	36	61.5	1.2	230	910	46	16	7	NE	IDLE	IDLE	9:47	START	B VALVE – 9:48 – OPEN 500°C START
													170	4	9:53		3° R CYCLIC
													IDLE	IDLE	9:59		B VALVE – 10:02 CLOSED 10:06 OPEN
													170	4	10:07		5° R CYCLIC
		"	"	97.2	96.6	20.4	590	7200	46	38	10	NE	240	7.3	10:11		5° R CYCLIC
	43	"	"	96	96.2	20	570	7000	48	38	5	E	240	7	10:17		" – 10:22; 5° R,L,F,A – 10:32
	44	"	"	99.7	96.5	20.8	610	6900	48	38	5	NE	240	7.5	10:42		5° R CYCLIC 10:41; 5° R L F A – 10:48
				"	"	"	"	"	"	"	"	"	230	8	11:06		5° R CYCLIC 10:53 11:02; 5° R L F A – 11:12
	45	"	"	91	94.2	16.8	525	6000	48	40	4	E	240	6	11:13		
		"	"	90	96.7	20.4	610	6900	48	40	5	E	240	7	11:23		5° R CYCLIC; 5° R,L,F,A – 11:26
	46	"	"	90	96.7	20.1	610	6700	48	40	8	SW	230	8	11:31		5° R CYCLIC; 0° CYCLIC – 11:35
	47	"	"	72	86	8.2	370	2950	48	44	12	SW	220	2	11:36		1° L CYCLIC
	ⓐ		Transient from Run 47 Settings												11:46		5 sec to max Pwr 5 sec to Idle
	ⓑ														11:49		"
	ⓒ														11:52		"
	48	"	"	92	96.5	20.2	610	7000	48	40	13	SW	240	7.5	11:57		5° L CYCLIC; 5° L,R,F,A – 12:00 12:05
													100	2	12:12		B VALVE CLOSED 12:11 12:17
															12:18	STOP	NORMAL

Witnessed [illegible] 4/21/62

Engine 68-58   76 Starts
Blade 46-53

B.2-38

WHIRL TEST - J57-PW-19W
ENGINE DATA SHEET

DATE	RUN NO.	AMBIENT TEMP. - °F (T_0)	AMBIENT PRESS. in Hg. (P_0)	LOW COMPRESSOR % SPEED (N_1)	HIGH COMPRESSOR % SPEED (N_2)	TURBINE DISCHARGE PRESS. - PSIG (P_{T7})	TURBINE DISCHARGE TEMP. - °C (T_{T7})	FUEL FLOW RATE - Lb/Hr (W_f)	OIL PRESSURE PSIG (P_{oil})	OIL TEMP. °C (T_{oil})	WIND VELOCITY MPH (V_{wind})	WIND DIRECTION (Dir.)	ROTOR rpm	COLLECTIVE PITCH	TIME	STARTS	REMARKS
2/21/62		55	29.92	36	61.5	1.3	230	900	45	30	16	SW	IDLE	IDLE	2:00	START	500°C Start B valve open - 2:05
															2:07		
	49	"	"	98.5	97	20	570	7200	48	42	17	SW	240	7.5	2:15		10L CYCLIC
				81	94	16.7	570	5500	48	42	16	SW	240	6	2:28		10L CYCLIC
	50	"	"	90	95.3	18.2	570	6300	48	42	16	SW	240	6.5	2:45		10L CYCLIC
	51	"	"	88	96.5	20	620	6700	48	42	16	SW	240	7.5	3:00		10L CYCLIC
	52	"	"	79.2	96	21	670	6400	48	42	18	SW	240	8	3:10		10L CYCLIC
				91.5	94.4	16.7	520	6000	48	42	18	SW	240	6	3:25		10L CYCLIC 3:30 5°L R/FA CYCLIC
	53	"	"	87.8	96.4	20.5	600	6800	48	42	19	SW	240	7.5	3:32		3:30 5° CYCLIC-L 3:59 2° L CYCLIC
											22	SW	100	2	4:08		
							320	2600	46	42	15	SW	190	3.5	4:15		4:15 2°L CYCLIC
	54			80.5	95	18.8	620	6000	48	42	15	SW	230	8	4:35		5°L CYCLIC 4:30
				89	94	16.6	540	5800	48	42	15	SW	240	6	4:5[illegible]		
	55			77	93.5	18.5	620	5800	48	42	15	SW	230	8	5:02		5°L CYCLIC
2/2[illegible]/62													100	2	5:12		BFLY CLOSED 5:18
															5:18		IDLE
															5:23	STOP	NORMAL SHUTDOWN

Witnessed [illegible] Col

72hrs 4min ENGINE
[illegible]

77 STARTS

ENGINE - 75-10 BLADE 52-45 79 Starts

WHIRL TEST - J57-PW-19W ENGINE DATA SHEET

B-2-39

Parameter																	
DATE			W. ... P.B. ... 4/26/60				4/26/60										4/26/60
RUN NO.				60						59		58		57	56		
T_o AMBIENT TEMP. - °F							59										55
P_o AMBIENT PRESS. in Hg.							29.94	ENGINE - 74-4									29.95
N_1 LOW COMPRESSOR % SPEED		98.5		95						85		85.7		83	83	76	37
N_2 HIGH COMPRESSOR % SPEED		94.5		97						95.5		95.8		95.1	95	85	61.5
P_{T7} TURBINE DISCHARGE PRESS. - PSIG		16.5		20						19.2		19.1		18.6	19.8	6.5	1.2
T_{T7} TURBINE DISCHARGE TEMP. - °C	320	535		590	605					610	540	610		605	605	340	230
W_f FUEL FLOW RATE - Lb/Hr		5800		7000						6200		6200		6100	6100	2840	910
P_{oil} OIL PRESSURE PSIG		48		48				BLADE 51-40		48		48		48	48	46	45
T_{oil} OIL TEMP. °C		47		42						42		42		40	40	40	14
V_{wind} WIND VELOCITY MPH	15	13		16		15				12		10		5	4	4	4
Dir. WIND DIRECTION	SW	SW		SW		SW			IDLE	SW		SW		SW	S	E	NE
rpm ROTOR rpm	170	240		240	240	170		78 STARTS		240	240	240	240	240	230	170	IDLE
Pitch COLLECTIVE PITCH	2.0	6.0		7.0	7	4				7.5	6	7	4.5	6.5	8	4	
TIME	2:36	2:29		2:05	1:57	1:35	1:30	11:45	11:40	11:25	11:20	10:50	10:45	10:30	10:14	10:10	10:02
STARTS							START	STOP									START
REMARKS	1° L CYCLIC	5° L CYCLIC	2:16 - RLFA - 5° CYCLIC	1° L CYCLIC 2:10 5° AFT CYCLIC	1° L CYCLIC	2° L CYCLIC	1:31 BVALVE OPEN	NORMAL	11:40 - CRACK LIGHT OUT BVALVE CLOSED - 11:41	11:31 - R,L,FA - 11:36 - 5° CYCLIC L	11:14 / "	10:52 - RLFA - 5° CYCLIC 10:57 / 5° CYCLIC - R		10:31 > RLFA, 5° CYCLIC 10:36 / 10:41 / CYCLIC - 5° R	10:17 - RLFA 5° CYCLIC 5° R - CYCLIC	10:28	B VALVE OPEN - 10:06 35 Sec START 510°C

B.2-40

WHIRL TEST - J57-PW-19W ENGINE DATA SHEET

ENGINE - BLADE - 92 starts

DATE	RUN NO.	AMBIENT TEMP. - °F (T_0)	AMBIENT PRESS. in Hg. (P_0)	LOW COMPRESSOR % SPEED (N_1)	HIGH COMPRESSOR % SPEED (N_2)	TURBINE DISCHARGE PRESS. - PSIG (P_{T_7})	TURBINE DISCHARGE TEMP. - °C (T_{T_7})	FUEL FLOW RATE - Lb/Hr (W_f)	OIL PRESSURE PSIG (P_{oil})	OIL TEMP. °C (T_{oil})	WIND VELOCITY MPH (V_{wind})	WIND DIRECTION (Dir.)	ROTOR rpm	COLLECTIVE PITCH	TIME	STARTS	REMARKS
7/26/62				36	60	290	290		45	49					3:13		B VALVE CLOSED @ 3:14
															3:20	STOP	NORMAL
				ENGINE 75-54					BLADE 58-23						79	STARTS	
7/27/62		46	30.04	36	61	1.3	225	910	45	22	15	NW	IDLE		9:15	START	500°C START 9:18 B VALVE OPEN
				76	84.9	6.6	325	2850	46	40	15	NW	184	4	9:17		0.5°L CYCLIC
				93	92.2	15	460	4500	47	35	13	NW	240	6	9:30		"
	1			93.9	96.6	21.7	595	7200	48	35	16	NW	240	8.5	9:34		"
													IDLE		9:40		SHORT IN 24 VOLT CIRCUIT
															9:43	STOP	B VALVE - 9:42 EMERGENCY FUEL CUTOFF ACCIDENTALLY ACTUATED
															10:46	START	B VALVE OPEN - 10:47
						10							IDLE		10:49	STOP	LOW ENG. OIL PRESSURE - LINE BROKE
Wednesday 2/28/62		53	30.09	36	61	1.3	240	900	45	32	15	NW	65	2	11:19	START	B VALVE OPEN - 11:20
	2			71.5	83	5.4	303	2380	46	41	4	NE	170	2	11:26		0.5°R CYCLIC
	3			76	85	6.4	335	2850	47	42	5	S	200	2	11:33		"
	4			80.2	87	7.6	355	3100	47	42	5	W	220	2	11:38		"
	5			83.8	88.8	9	380	3800	47	42	5	S	240	2	11:42		"
	6			80	88	8	350	3100	47	41	5	S	220	2	11:47		"

B 2-41

WHIRL TEST - J57-PW-19W
ENGINE DATA SHEET

Witnessed

DATE	RUN NO.	AMBIENT TEMP. - °F (T_o)	AMBIENT PRESS. in Hg. (P_o)	LOW COMPRESSOR % SPEED (N_1)	HIGH COMPRESSOR % SPEED (N_2)	TURBINE DISCHARGE PRESS. - PSIG (P_{T_7})	TURBINE DISCHARGE TEMP. - °C (T_{T_7})	FUEL FLOW RATE - Lb/Hr (W_f)	OIL PRESSURE PSIG (P_{oil})	OIL TEMP. °C (T_{oil})	WIND VELOCITY MPH (V_{wind})	WIND DIRECTION (Dir.)	ROTOR rpm	COLLECTIVE PITCH	TIME	STARTS	REMARKS
2/21/62	7			70	83	5.2	300	2220	46	46	7	SW	170	2	11:54		0° CYCLIC
	8			75	87.8	6.3	330	2660	46	46	7	SW	170	4	11:55		0° CYCLIC
	9			80.5	87	8	350	3100	46	46	7	S	200	4	11:58		"
	10			84	88.5	9.2	375	3900	47	42	5	SW	220	4	12:03		"
	11			86	89.5	10	395	4200	47	42	7	SW	240	4	12:07		"
	12			79	86.8	7.8	350	3000	47	42	5	S	200	4	12:11		"
	13			73	84	6	320	2500	46	44	8	SW	170	4	12:16		"
							610						240	8.5	12:17		
												IDLE			12:18		BVALVE CLOSED 12:21
	14			77	85.3	7	335	2910	46	44	10	SW	170	6	12:28		BVALVE OPEN 12:25 0.5°L CYCLIC
	15			84.6	88.4	9.5	370	3910	47	42	10	SW	200	6	12:31		"
	16			87.8	89.9	11	400	[illegible]	47	42	10	SW	220	6	12:35		"
	17			92	92.1	14	445	5200	47	41	8	WSW	240	6	12:39		"
	18			87.5	90	11	400	4500	47	41	16	SW	220	6	12:43		"
	19			77.5	86	7	340	2920	47	42	15	SW	170	6	12:48		"
	20			87.8	88.4	9.3	375	4000	47	42	18	SW	170	8	12:55		2°L CYCLIC
	21			89.9	91	10	420	4800	47	42	16	SW	200	8	12:57		"

B-2-42

WHIRL TEST - J57-PW-19W
ENGINE DATA SHEET

Witnessed 2/27/62

DATE	RUN NO.	AMBIENT TEMP. - °F (T_0)	AMBIENT PRESS. in Hg. (P_0)	LOW COMPRESSOR % SPEED (N_1)	HIGH COMPRESSOR % SPEED (N_2)	TURBINE DISCHARGE PRESS. - PSIG (P_{T7})	TURBINE DISCHARGE TEMP. - °C (T_{T7})	FUEL FLOW RATE - Lb/Hr (W_f)	OIL PRESSURE PSIG (P_{oil})	OIL TEMP. °C (T_{oil})	WIND VELOCITY MPH (V_{wind})	WIND DIRECTION (Dir.)	ROTOR rpm (rpm)	COLLECTIVE PITCH (Pitch)	TIME	STARTS	REMARKS
2/27/62	22			94	93	15.1	470	5600	47	42	15	SW	220	8	1:04		2°L CYCLIC
	23			93.5	95	18.3	540	6200	47	42	13	SW	240	8	1:10		BLADE TACHOMETER FLUCTUATING
	24			86	91	13.7	450	4800	47	42	15	SW	200	8	1:18		"
													IDLE		1:23		1:24 BVALVE CLOSED
															1:28	STOP	
				ENGINE 78-29						BLADE-55-42						82	STARTS
2/27/62		53	30.10	36	61.5	1.3	230	900	47	42	15	SW	IDLE	IDLE	4:13	START	500°C START
	25			94.8	96.5	20.9	595	7200	48	42	15	SW	240	8.5	4:23		BVALVE OPEN - 4:19 1°L CYCLIC
	26			79.8	95.7	20.9	660	6600	48	40	15	SW	240	8.5	4:29		"
	27			79	95.6	21.4	670	6400	48	40	15	SW	240	8.4	4:40		5°L, R, FA CYCLIC (4:45) 5°L CYCLIC
				91	94	17	522	5900	48	40	15	SW	240	7	4:47		"
	28			79	95.7	21.1	670	6400	48	40	10	SW	240	8.7	4:54		5°L, R, FA CYCLIC (5:00) 5°L
	29			79	95.7	21.6	680	6600	48	40	12	SW	240	8.7	5:12		5°L, R, FA CYCLIC (5:10) 5°L
	30			95.5	96.9	21.5	595	7200	48	40	10	SW	240	8.7	5:25		5°L, R, FA CYCLIC (5:15) 5°L (5:21)
				92.2	94.3	17.5	521	6000	48	40	10	SW	240	7	5:26		5°L 7° COL
							640		48	40	10	SW	240	8.5	5:36		5°L
							215	870	45	45	10	SW	IDLE		5:42	5:48 STOP	BFV CLOSED 5:42

ENGINE - 80-04

BLADE 57-05

NORMAL - 83 STARTS

B.2-43

WHIRL TEST - J57-PW-19W
ENGINE DATA SHEET

DATE	2/28/62																
RUN NO.				31	32	33	34			(a)		(b)	(c)	(d)	(E)	(F)	(G)
T_o AMBIENT TEMP. - °F	47																
P_o AMBIENT PRESS. in Hg.	30.14																
N_1 LOW COMPRESSOR % SPEED	35.5	65	69	93.6	93.4	93.4	78	90.5	77	TRANSIENT FROM ABOVE SETTINGS		TRANSIENT SAME AS (a)					
N_2 HIGH COMPRESSOR % SPEED	61.1	78	85.5	96.5	96.8	96.9	95.8	93.8	86.4								
P_{T7} TURBINE DISCHARGE PRESS. - PSIG	1.2	5.2	10.2	21.3	21.5	21.5	22	16.8	8.3								
T_{T7} TURBINE DISCHARGE TEMP. - °C	220	340	425	602	602	602	690	578	360								
W_f FUEL FLOW RATE - Lb/Hr	910	2050	3400	7200	7200	7200	6700	5800	2970				"	"	"	"	"
P_{oil} OIL PRESSURE PSIG	45	45	46	48	48	48	48	48	48								
T_{oil} OIL TEMP. °C	12	33	41	35	35	36	36	36	42								
V_{wind} WIND VELOCITY MPH	7	10	9	7	7	7	7	7	7		IDLE						
Dir. WIND DIRECTION	NE	NE	NE	NE	NE	NE	NE	NE	NE								
rpm ROTOR rpm	IDLE	170	240	240	230	240	240	240	220								
Pitch COLLECTIVE PITCH	IDLE	4	4	8.5	9.5	8.5	9	6.5	2								
TIME	8:33	8:40	8:44	8:48	9:05	9:11	9:17	9:21	9:29	9:33	9:37	9:46	9:55 10:04	10:06	10:08 10:11	10:15 10:20	10:23 10:26
STARTS	START																
REMARKS		BUDLVR OPEN 8:37 1°R, CYCLIC	"	5°R,L,F,A CYCLIC PITCH (8:55 9:0[illegible]) 5°R CYCLIC "	"	1°R, CYCLIC	1°R CYCLIC	5°L,R,F,A CYCLIC PITCH "	1°R CYCLIC 5°R CYCLIC - 9:33	"		"	" CYCLIC MANVR.	CONTINUOUS DUCT RECORD "	" CYCLIC MANVR.	CONTINUOUS TIP GAS RECORD CYCLIC MANVR.	" CYCLIC MANVR.

Wilmarth[illegible]

ENGINE 81-57

13 LADE-58-54

84 STARTS

B.2 44

WHIRL TEST - J57-PW-19W
ENGINE DATA SHEET

DATE	RUN NO.	AMBIENT TEMP. - °F	AMBIENT PRESS. in Hg.	LOW COMPRESSOR % SPEED	HIGH COMPRESSOR % SPEED	TURBINE DISCHARGE PRESS. - PSIG	TURBINE DISCHARGE TEMP. - °C	FUEL FLOW RATE - Lb/Hr	OIL PRESSURE PSIG	OIL TEMP. °C	WIND VELOCITY MPH	WIND DIRECTION	ROTOR rpm	COLLECTIVE PITCH	TIME	STARTS	REMARKS
--- 2/28/62	---	T_o	P_o	N_1	N_2	P_{T_7}	T_{T_7}	W_f	P_{oil}	T_{oil}	V_{wind}	Dir.	rpm	Pitch			
(H)				73.5	83.5	7.6	355	2900	47.5	43	6	W	200	2°	10:36		CONTINUOUS TIP AFT AIR RECD
				POWER TRANSIENT FROM ABOVE											10:45		5°-0 AFRL MAN'R
(I)								"							10:46		"
(J)								"							10:53		CONTINUOUS SKIN RECORD
(K)								"					'		11:00		5°-0AFRL CYCLIC MAN'VR 5°L CYCLIC SKIN RECORD
	35			80	95.8	20.9	665	6500	48	42	10	SSW	240	9	11:05		5° A,F,R,L MAN'VR (11:0X) (11:11) (11:20) (11:30) (11:35) 5°L CYCLIC
				70.3	85	7.4	365	2800	48	47	10	SW	220	2	11:36		"
(L)				TRANSIENT FROM ABOVE CONDITION											11:43		" CONT- COOLING AIR RECD
	36			78.8	95.5	21.4	690	6500	48	42	12	SW	240	9	11:45		5°L CYCLIC
				LOWERED POWER IN STEPS TO PREVENT SEAL POSSIBLE HANGUP											11:51		LEVEL HUB - 11:52 1.5°L CYCLIC
															12:00	STOP	BVALVE CLOSED - 11:57 NORMAL
				ENGINE - 83-31 BLADE 60-25												84	STARTS

Witnessed 2/28/62

B. 3
OPERATION SUMMARY OF HOT CYCLE AFTER 35 HOUR INSPECTION

DATE	T_{T7} °F	rpm	Coll. Pitch	Cyclic Pitch	Time Min.	Coll. Rotor Time	Coll. Engine Time	Starts	Page
2-5-62					2	—	2	66	30
	464	40	4		5	5	7		
	608	175	4		5	10	12		
	1105	240	8		5	15	17		
	1240	240	8		4	19	21		
					2	21	23		
					3	—	26		
2-6-62	460				14	—	40	67	
		170	4		3	24	43		
		170	4		7	31	50		
		240	4		5	36	55		
	1112	240	8		5	41	60		
					1	42	61		
					14	—	75		
					5	47	80		
	527	60	4		3	50	83		31
	527	58	4		4	54	87		
	536	43	4		2	56	89		
	590	13	4		3	59	92		
	518	60	4		4	63	96		
	518	58	4		4	67	100		
	540	43	4		4	71	104		
	585	13	4		8	79	112		
	615	170	4		30	109	142		
	1076	240	8		3	112	145		
	1240	240	8		1	113	146		
					2	115	148		
					3	—	151		
2-12-62	437				5	—	156	68	32
	437				6	121	162		
	635	170	4		20	141	182		
	850	240	5	5	15	156	197		
	914	240	5.25	5	12	168	209		
	950	240	6.5	5	10	178	219		
	986	240	6.7	5	7	185	226		
					13	198	239		
	975	240	6.5	5	10	208	249		

OPERATION SUMMARY OF HOT CYCLE AFTER 35 HOUR INSPECTION

DATE	T_{T_7} °F	rpm	Coll. Pitch	Cyclic Pitch	Time Min.	Coll. Rotor Time	Coll. Engine Time	Starts	Page
	1050	240	7.5	5	12	220	261	69	32
	1076	240	8	5	3	223	264		
	1240	240	8	5	2	225	266		
					7	232	273		
					4	—	277		
6-13-62	470				13	—	290		
	470				2	234	292		
	470				10	—	302		
	1085	240	7.5	5	9	243	311		
	1112	240	7.5	5	12	255	323		
	1112	240	7.5	5	4	259	327		33
	1104	240	7.5	5	9	268	336		
	1112	240	8	5	3	271	339		
	1110	240	8	5	3	274	342		
	824	240	3.5	4	7	281	349		
					6	287	355		
	464	70	4		2	289	357		
	460	66	4		3	292	360		
	470	51	4		1	293	361		
	518	20	4		5	298	366		
					2	300	368		
					5	—	373		
	455				4	—	377	70	
	455				8	308	385		
	662	170	4		9	317	394		
	1094	240	7.5	5	14	331	408		
	1130	231	8.25	5	22	353	430		
					5	—	435		
	ABORTED START							71	34
	482				5	—	440	72	
	482				6	359	446		
	482	170	4		4	363	450		
	644	220	4		5	368	455		
	734	220	2	5	3	371	458		
					5	—	463		

OPERATION SUMMARY OF HOT CYCLE AFTER 35 HOUR INSPECTION

DATE	T_{T_7} °F	rpm	Coll. Pitch	Cyclic Pitch	Time Min.	Coll. Rotor Time	Coll. Engine Time	Starts	Page
2-20-62					18	371	501	73	35
	900	240	6		4	375	505		
	900	240	6		11	386	516		
	940	240	6	5	5	391	521		
	1004	240	7	5	5	396	526		
	1030	240	7	5	11	407	537		
	1094	240	7.6	5	7	414	544		
	1094	240	7.5	0	4	418	548		
	715	222	2	5	12	430	560		
	698	220	2	0.5	18	448	578		
	1130	240	7.6	5	13	461	591		
					3	464	594		
					3	464	597		
2-20-62					7	—	604	74	36
	419	62	2		6	470	610		
	626	170	4	1	2	472	612		
	1240	240	7.6	5	26	498	638		
					1	499	639		
					5	—	644		
					2	—	646	75	
	446				8	508	655		
	1112	240	7.5	5	13	521	668		
	1094	240	7.3	5	10	531	678		
	1130	230	8	5	6	537	684		
	932	230	6	5	8	545	692		
	1140	230	8	5	12	557	704		
	473	100	2	0	7	564	711		
					2	—	713		
2-21-62	446				1	—	714	76	37
					5	569	719		
		170	4	5	6	575	725		
					3	578	728		
					4	—	732		
					1	579	733		
		170	4	5	4	583	737		
	1094	240	7.3	5	6	589	743		
	1058	240	7	5	25	614	768		
	1130	240	7.5	5	24	638	792		
	1130	230	8	5	7	645	799		
	977	244	6		10	655	809		
	1130	240	7	5	8	663	817		

OPERATION SUMMARY OF HOT CYCLE AFTER 35 HOUR INSPECTION

DATE	T_{T_7} °F	rpm	Coll. Pitch	Cyclic Pitch	Time Min.	Coll. Rotor Time	Coll. Engine Time	Starts	Page
2-21-62	1130	230	8	5	5	668	822		
	698	220	2	1	18	686	840		
	1130	240	7.5	5	18	704	858		
		100	2		5	709	863		
					1	-	864		
	446				5	-	869	77	38
	446				2	711	871		
					8	719	879		
	1058	240	7.5	1	13	732	892		
	1058	240	6	1	17	749	909		
	1058	240	6.5	1	15	764	924		
	1148	240	7.5	1	10	774	934		
	1238	240	8	1	15	789	949		
	968	240	6	1	7	796	956		
	1112	240	7.5	5	28	824	984		
		100	2		15	839	999		
	608	190	3.5	2	13	852	1012		
	1148	230	8	5	26	878	1038		
	1004	240	6		8	886	1046		
	1148	230	8	5	10	896	1056		
		100	2		6	902	1062		
					5	-	1067		
2-22-62					4	-	1071	78	39
	446				4	906	1075		
	644	170	4		4	910	1079		
	1118	230	8	5	16	926	1095		
	1118	240	6.5	5	15	941	1110		
		240	4.5	5	5	946	1115		
	1130	240	7		30	976	1145		
	1004	240	6	5	5	981	1150		
	1130	240	7.5	5	15	996	1165		
					1	997	1166		
					4	-	1170		
					1	-	1171	79	
					4	1001	1175		
		170			22	1023	1197		
	1121	240			8	1031	1205		
	1094	240			24	1055	1229		
	995	240			7	1062	1236		
	608	170			37	1099	1273		40

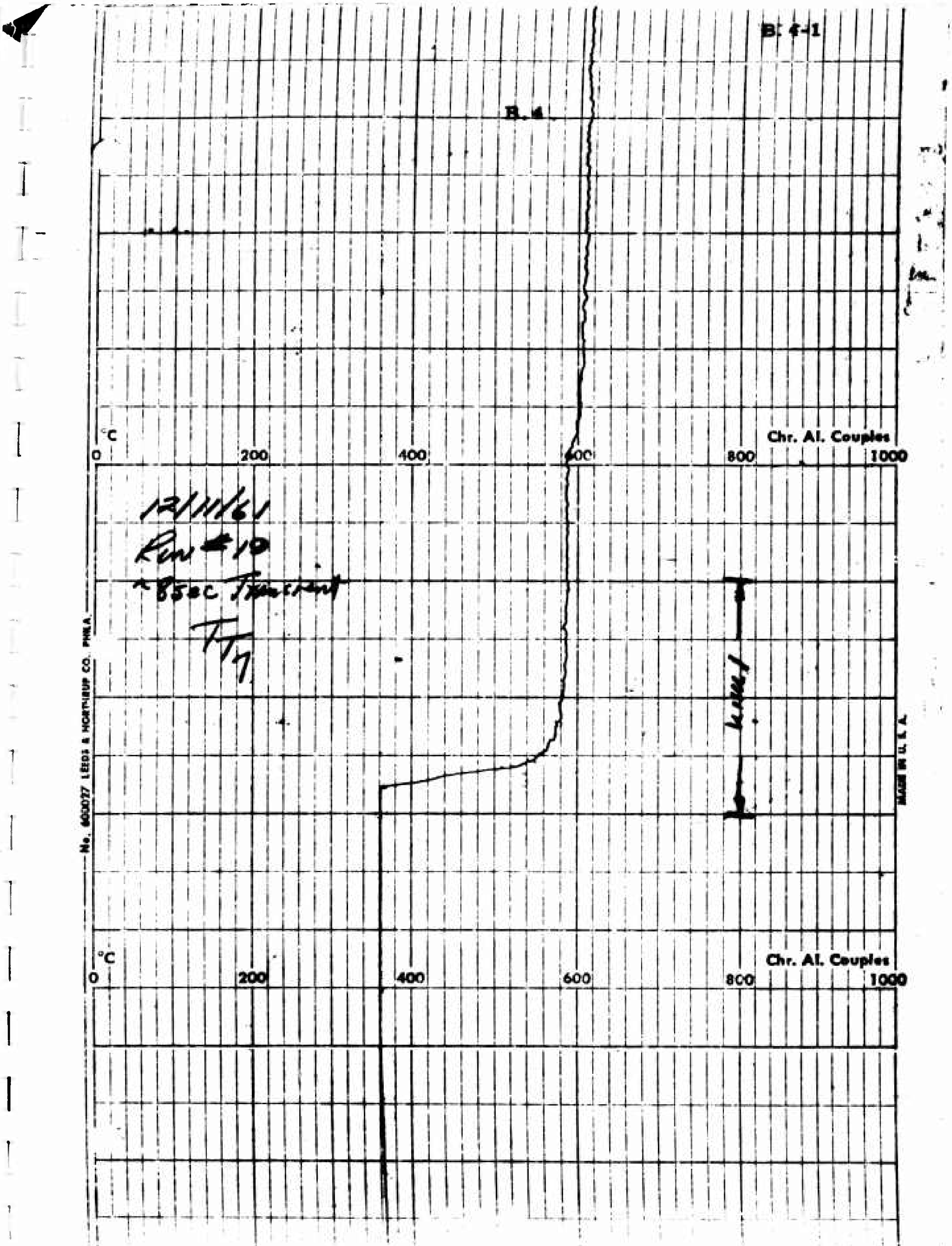
OPERATION SUMMARY OF HOT CYCLE AFTER
35 HOUR INSPECTION

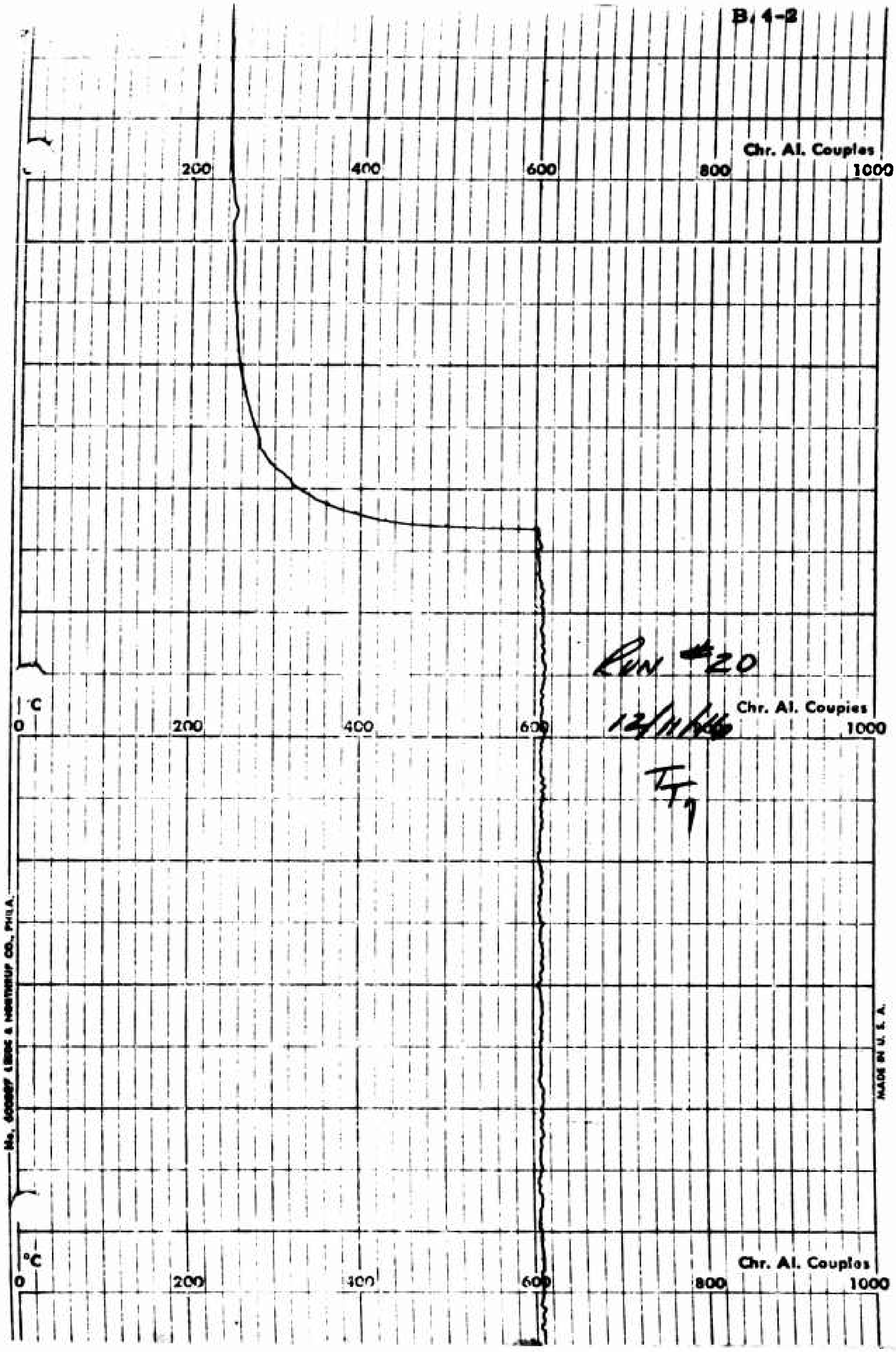
DATE	T_{T_7} °F	rpm	Coll. Pitch	Cyclic Pitch	Time Min.	Coll. Rotor Time	Coll. Engine Time	Starts	Page
					1	1100	1274		
					6	—	1280		
2-27-62	437				1	—	1281	80	
					1	1101	1282		
	617	184	4	.5	13	1114	1295		
	860	240	6	.5	4	1118	1299		
	1103	240	8.5	.5	6	1124	1305		
					2	1126	1307		
					1	—	1308		
					1	—	1309	81	
					2	1128	1311		
					1	—	1312	82	
	464	63	2		6	1134	1318		
	576	170	2		7	1141	1325		
	635	200	2		5	1146	1330		
	671	220	2		2	1148	1332		
	716	240	2		7	1155	1339		
	667	220	2		5	1160	1344		
	572	170	2		3	1163	1347		41
	626	170	4		4	1167	1351		
	662	200	4		4	1171	1355		
	707	220	4		4	1175	1359		
	743	240	4		4	1179	1363		
	662	200	4		5	1184	1368		
	608	170	4		1	1185	1369		
	1130	240	8.5		1	1186	1370		
					3	1189	1373		
					4	—	1377		
					3	1192	1380		
	635	170	6	.5	3	1195	1383		
	698	200	6	.5	4	1199	1387		
	752	220	6	.5	4	1203	1391		
	833	240	6	.5	4	1207	1395		
	752	220	6	.5	5	1212	1400		
	644	170	6	.5	7	1219	1407		
	707	170	8	2	4	1223	1411		
	788	200	8	2	5	1228	1416		42
	878	220	8	2	6	1234	1422		
	1004	240	8		8	1242	1430		
	842	200	8		5	1247	1435		

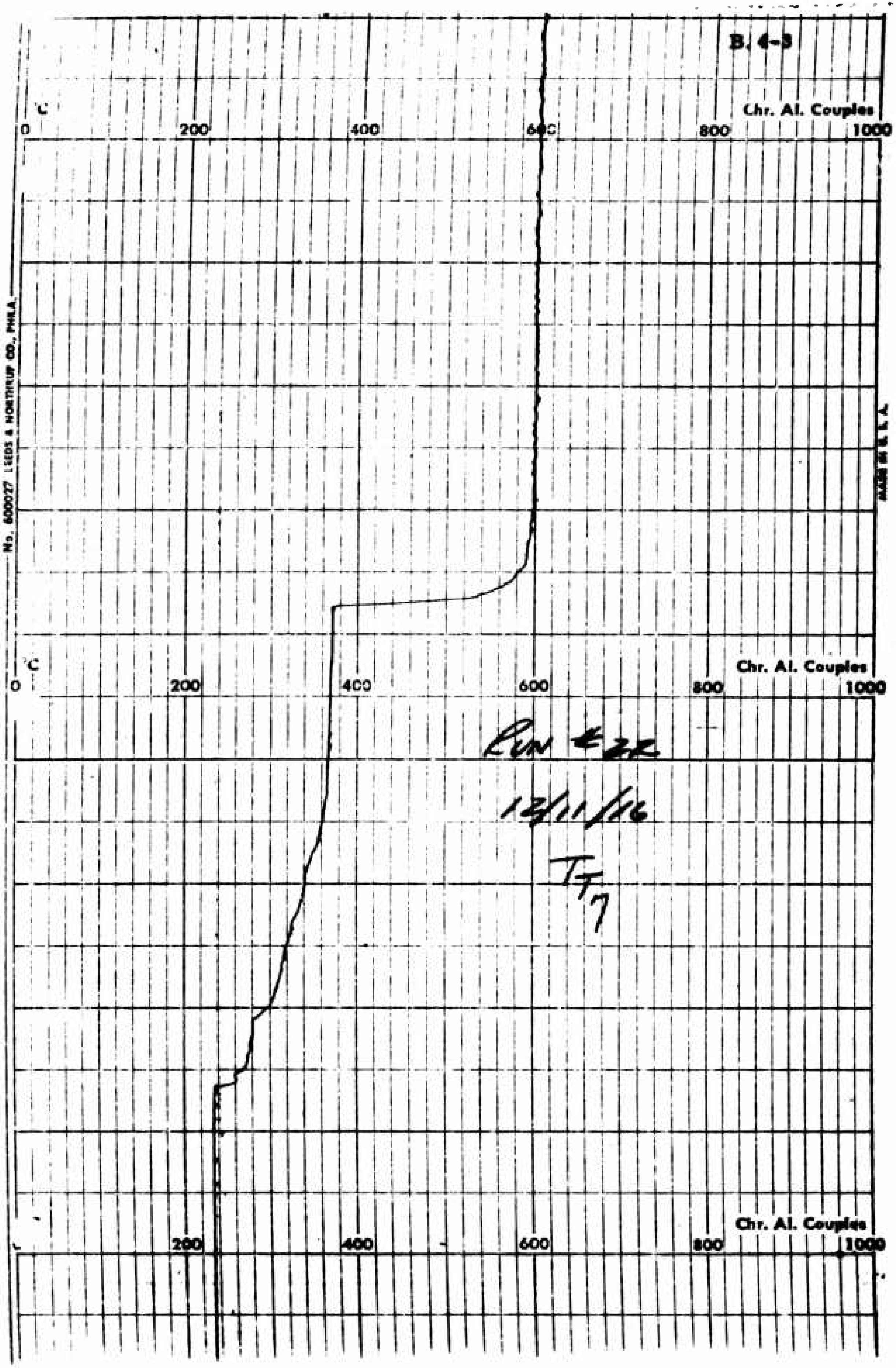
OPERATION SUMMARY OF HOT CYCLE AFTER 55 HOUR INSPECTION

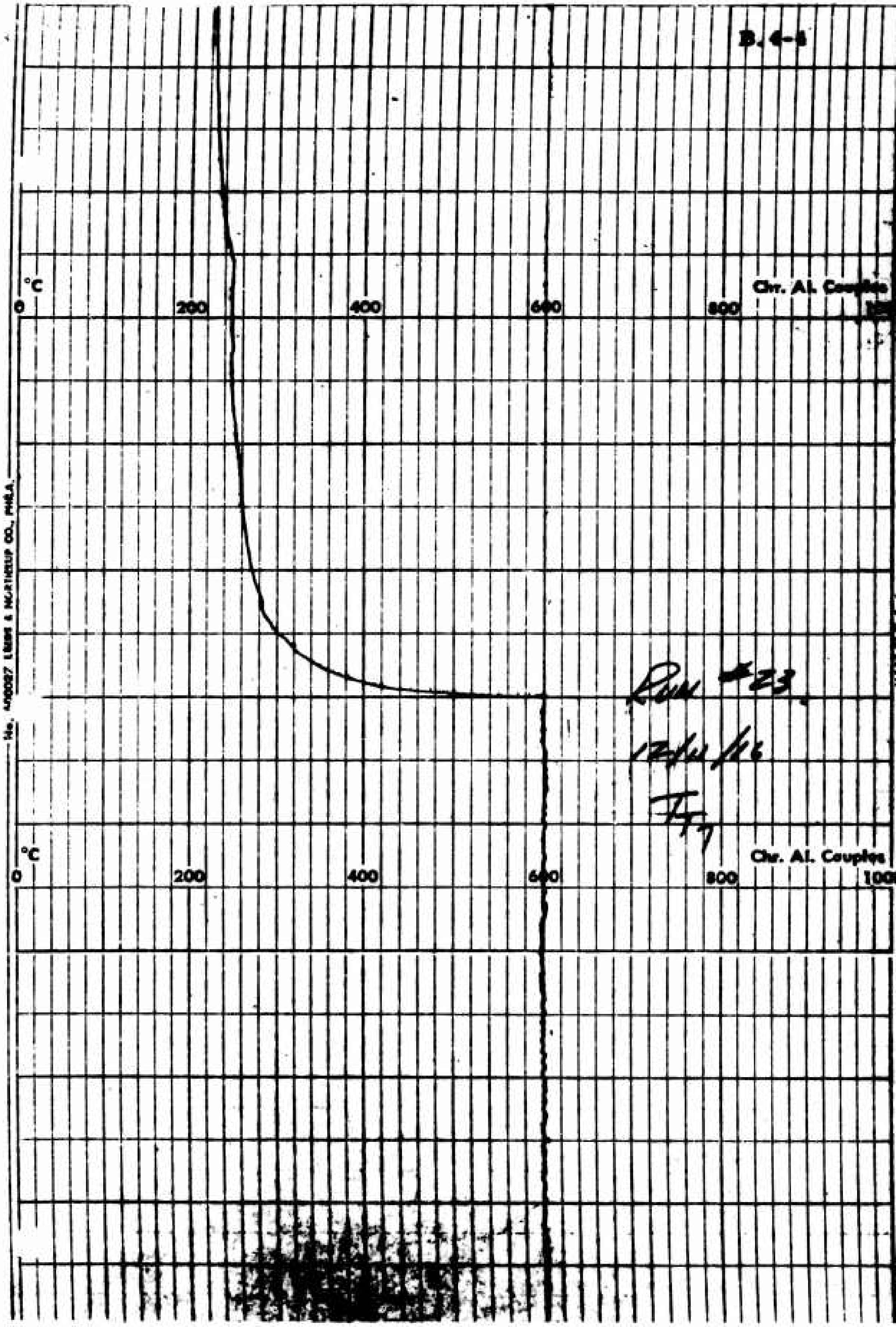
DATE	T_{T_7} °F	rpm	Coll. Pitch	Cyclic Pitch	Time Min.	Coll. Rotor Time	Coll. Engine Time	Starts	Page
2-27-62					1	1248	1436		
					4	-	1440		
					6	-	1446	83	
					4	1252	1450		
	1103	240	8.5	1	6	1258	1456		
	1220	240	8.5	1	11	1269	1467		
	1238	240	8.4	5	7	1276	1474		
	972	240	7	5	7	1283	1481		
	1238	240	8.7	5	18	1301	1499		
	1256	240	8.7	5	13	1314	1512		
	1103	240	8.7	5	1	1315	1513		
	970	240	7	5	10	1325	1523		
	1152	240	8.5	5	6	1331	1529		
					6	-	1535		
					4	-	1539		43
2-28-62	428				3	1334	1542	84	
	644	170	4		4	1338	1546		
	797	240	4		4	1342	1550		
	1116	240	8.5		17	1359	1567		
	1116	230	9.5		6	1365	1573		
	1116	240	8.5		6	1371	1579		
	1274	240	9		4	1375	1583		
	964	240	6.5		8	1383	1591		
	680	220	2		67	1450	1658		
	671	200	2		29	1479	1687		44
	1229	240	9		31	1510	1710		
	689	220	2		9	1519	1727		
	1274	240	9		6	1525	1733		
					6	1531	1739		
					3	-	1742		

B: 4-1

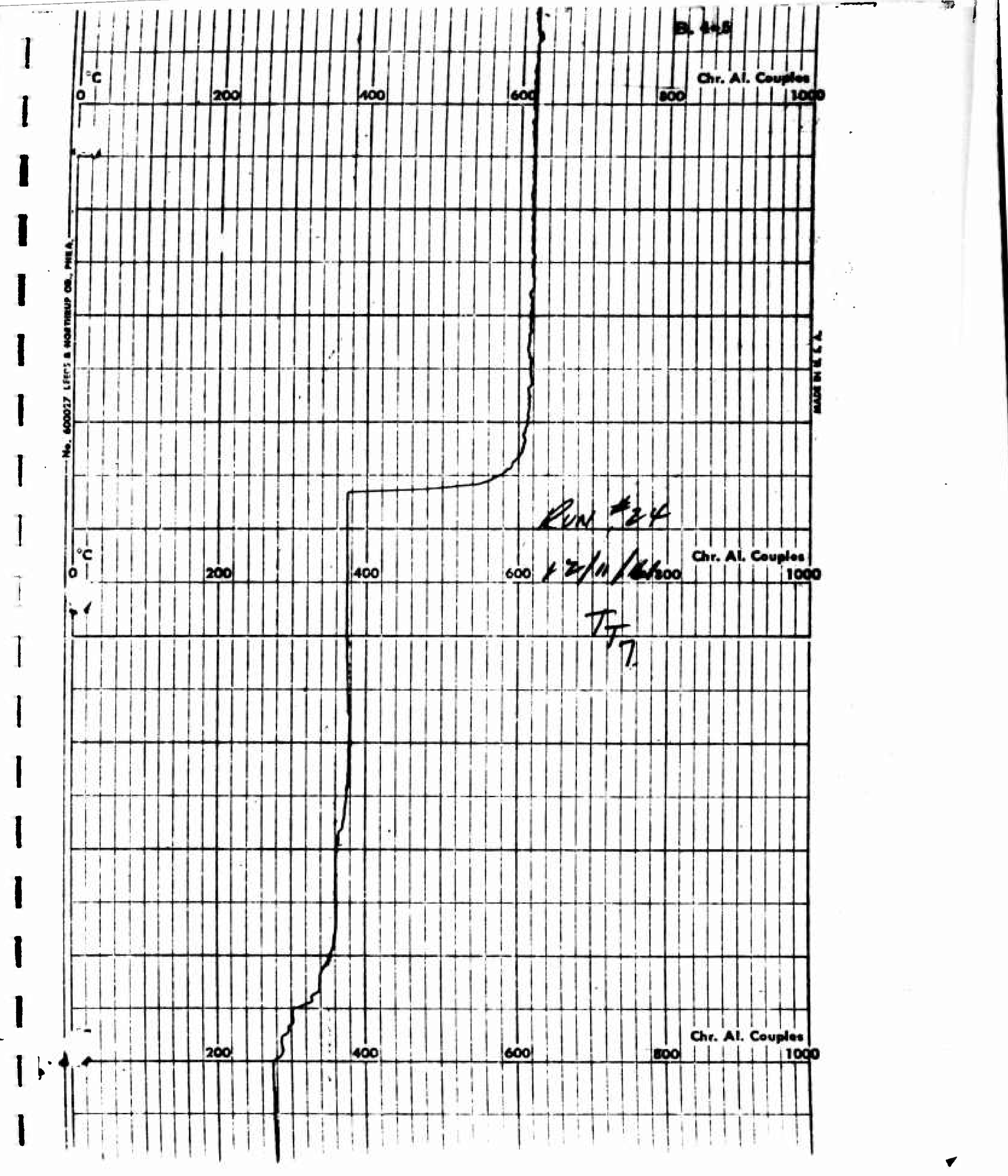

B. 4
°C
0
200
400
600
800
1000
Chr. Al. Couples
12/11/61
Run #10
~8sec Transient
No. 600027 LEEDS & NORTHRUP CO. PHILA.
MADE IN U.S.A.


Chr. Al. Couples
200
400
600
800
1000
°C
0
Chr. Al. Couples
200
400
600
1000
Run #20
°C
0
Chr. Al. Couples
200
400
600
800
1000
MADE IN U. S. A.


B. 4-3
°C
Chr. Al. Couples
0
200
400
600
800
1000
No. 600027 LEEDS & NORTHRUP CO., PHILA.
MADE IN U.S.A.
Run #2
12/11/46
T7

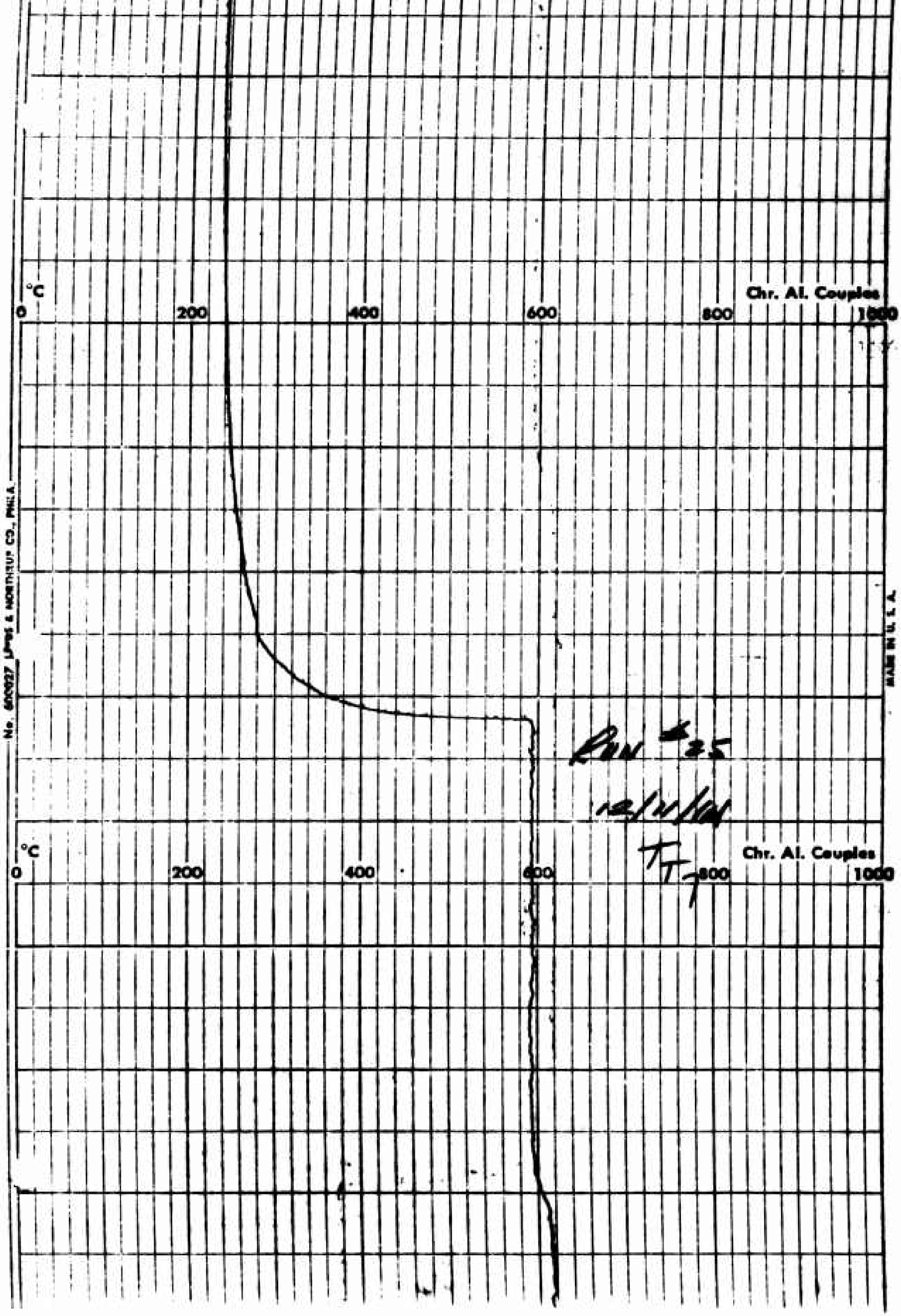


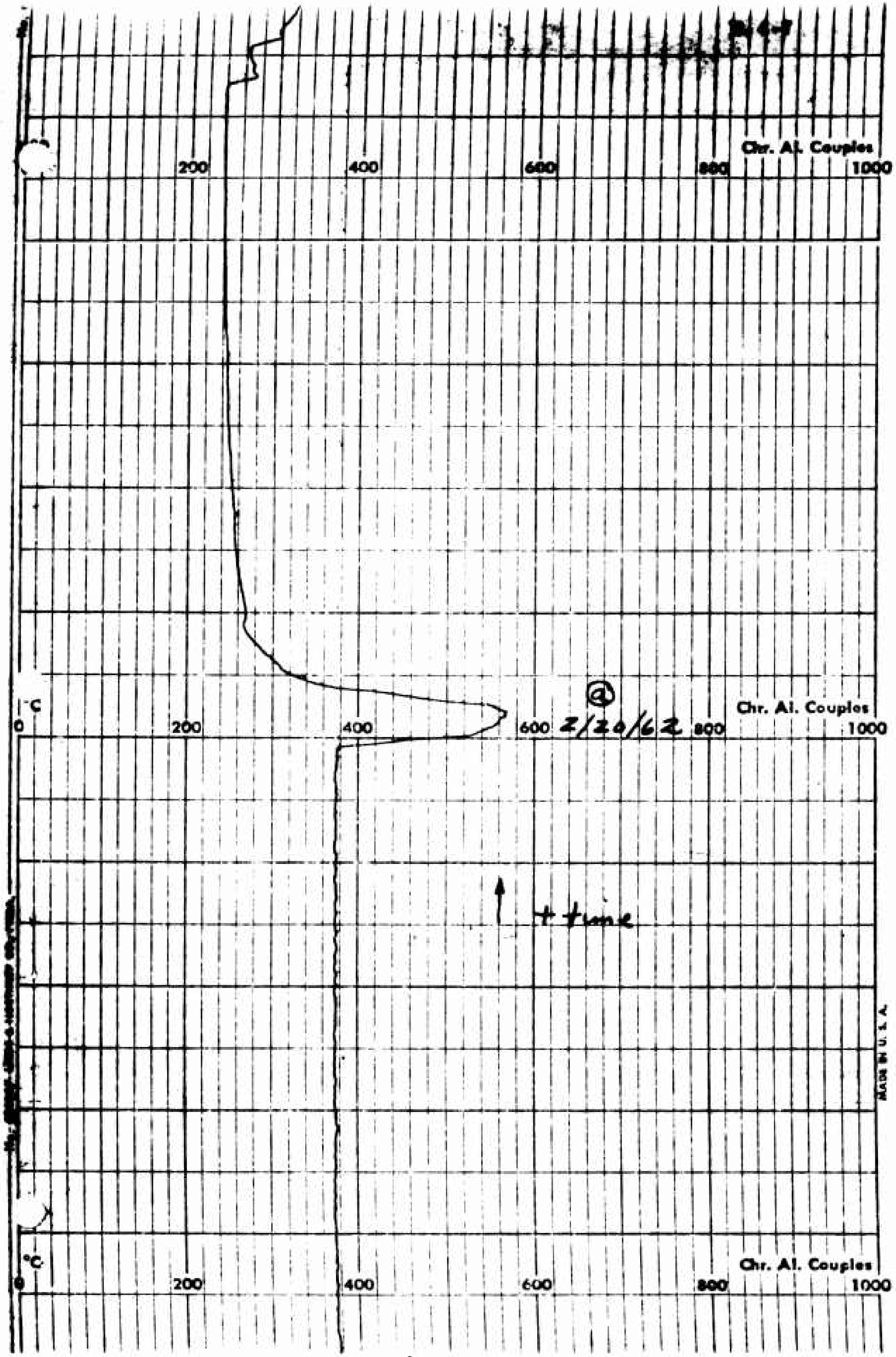
°C
0
200
400
600
800
1000
Chr. Al. Couples
Run #23



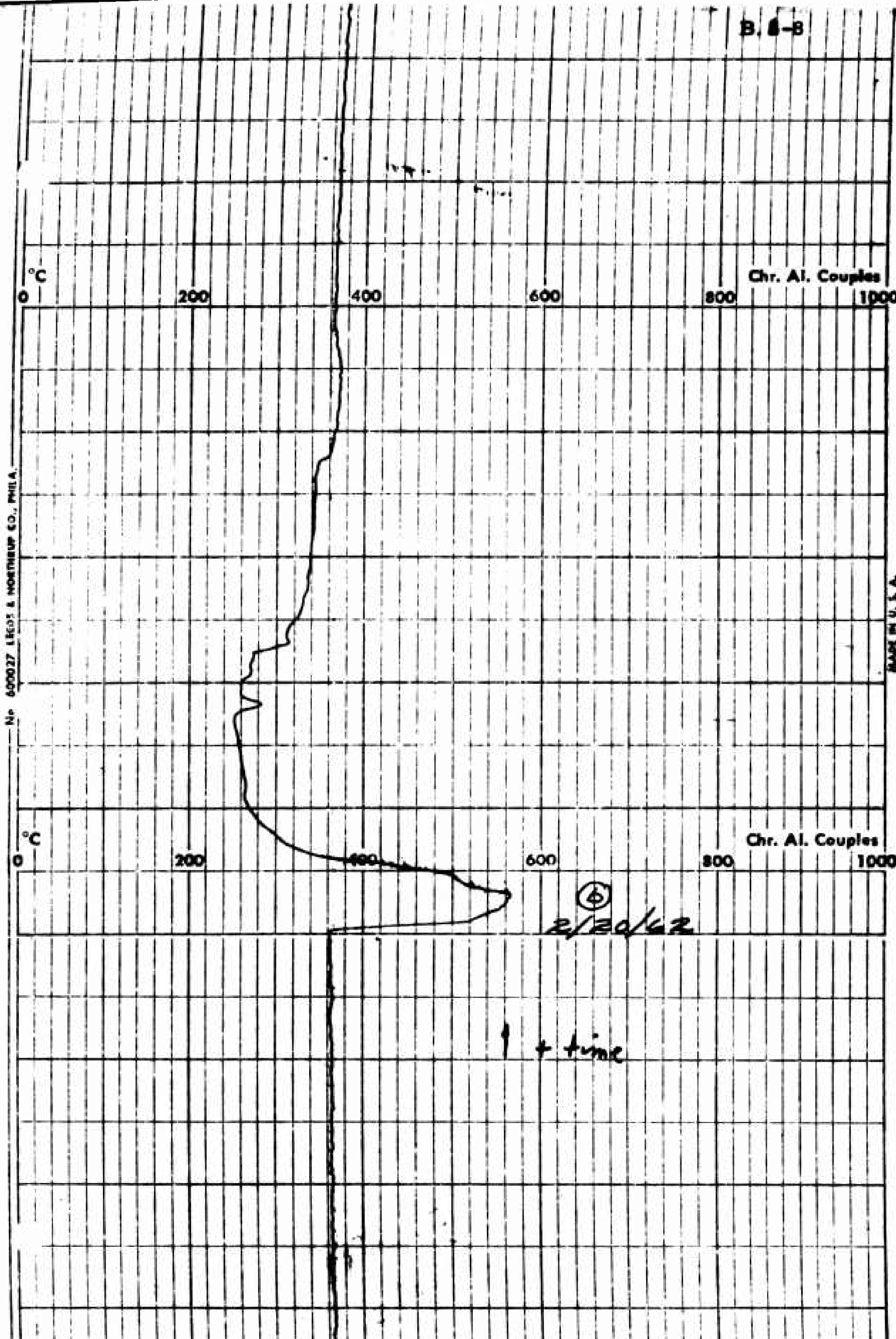
B. 445
°C
Chr. Al. Couples
0
200
400
600
800
1000
No. 600027 LEEDS & NORTHRUP CO., PHILA.
MADE IN U. S. A.
Run #24
12/11/61
TT

B. 4-6

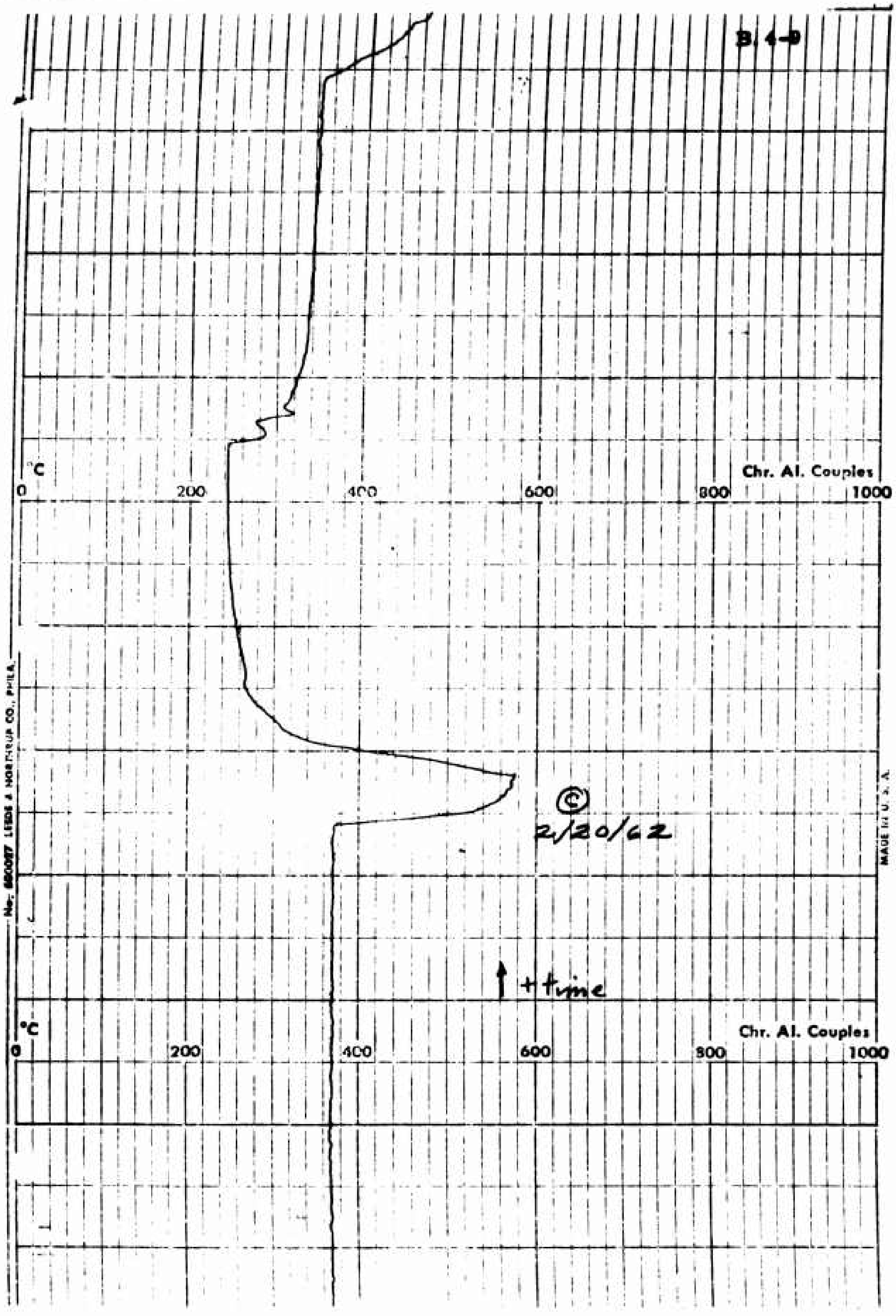

°C
Chr. Al. Couples
0
200
400
600
800
1000
°C
Chr. Al. Couples
0
200
400
600
800
1000
No. 600027 LEEDS & NORTHRUP CO., PHILA.
MADE IN U. S. A.
Run #25


Chr. Al. Couples
200
400
600
800
1000
°C
Chr. Al. Couples
0
200
400
600
2/20/62
800
1000
+ time
MADE IN U. S. A.
°C
Chr. Al. Couples
0
200
400
600
800
1000

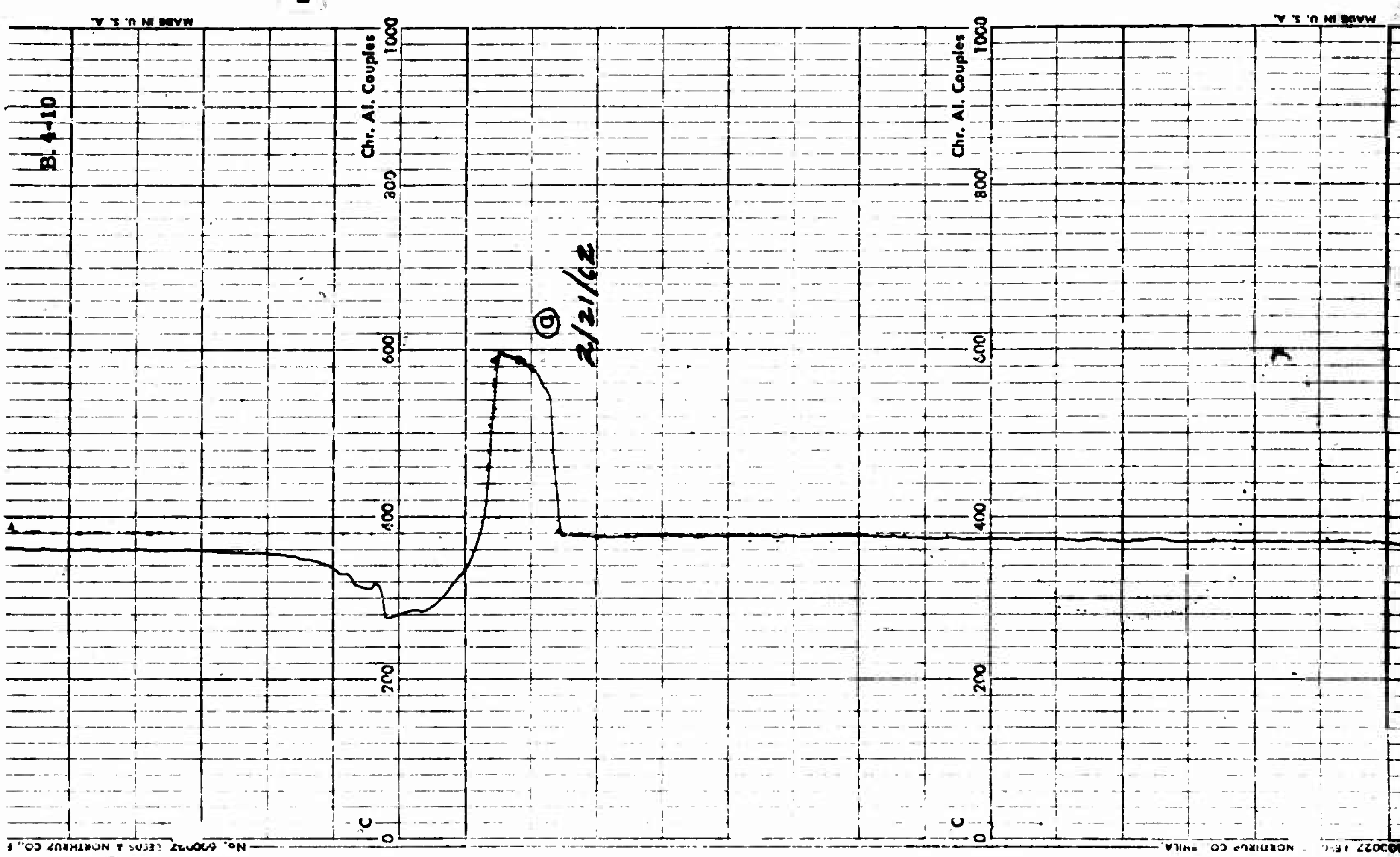
B. 6-8



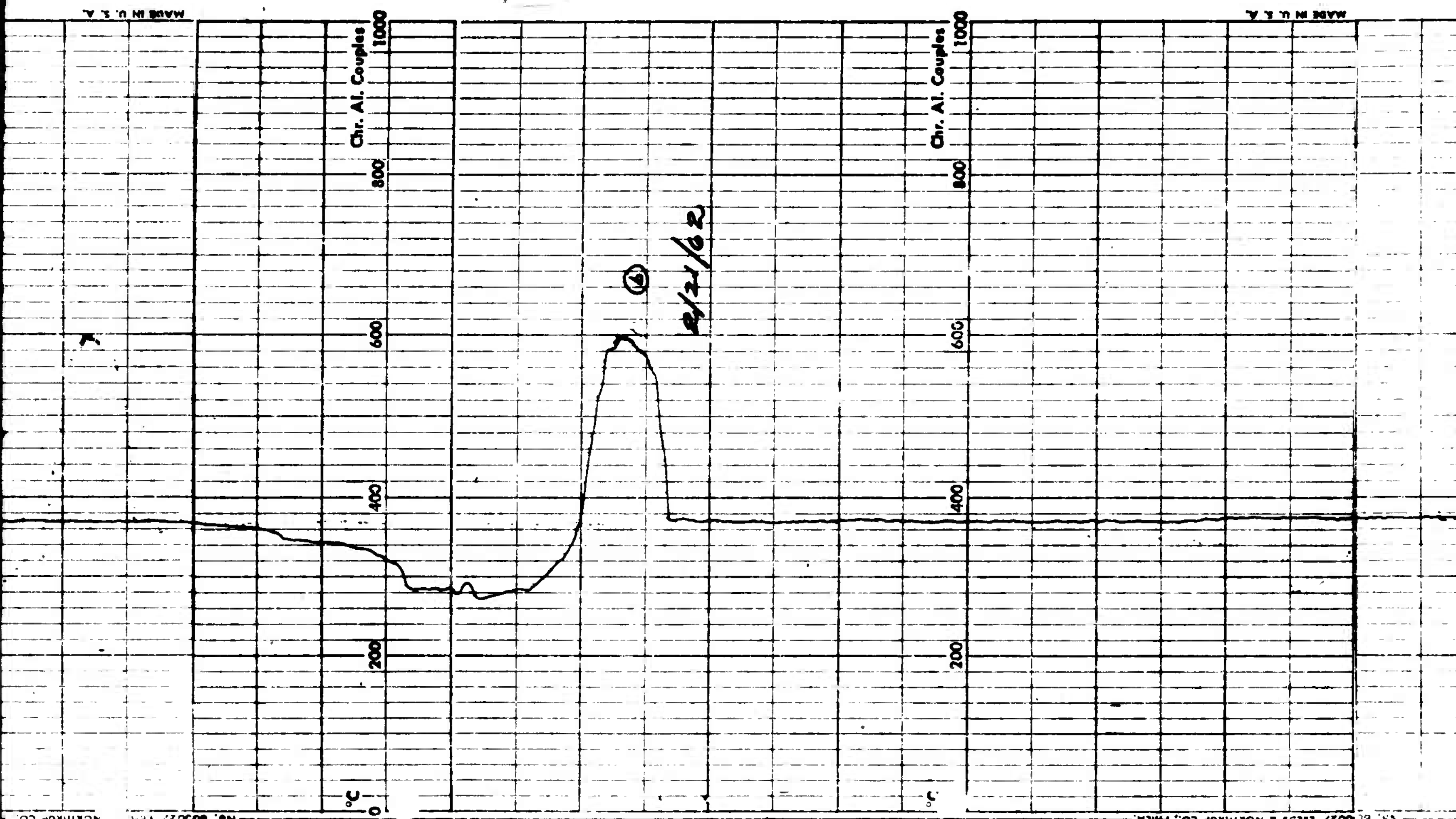
°C
Chr. Al. Couples
0
200
400
600
800
1000
°C
Chr. Al. Couples
0
200
400
600
800
1000
No 600027 LEEDS & NORTHRUP CO., PHILA.
MADE IN U. S. A.
6
2/20/62
↑ time


B. 4-9
°C
Chr. Al. Couples
0
200
400
600
800
1000
© 2/20/62
+ time
No. 600097 LEEDS & NORTHRUP CO., PHILA.
MADE IN U.S.A.

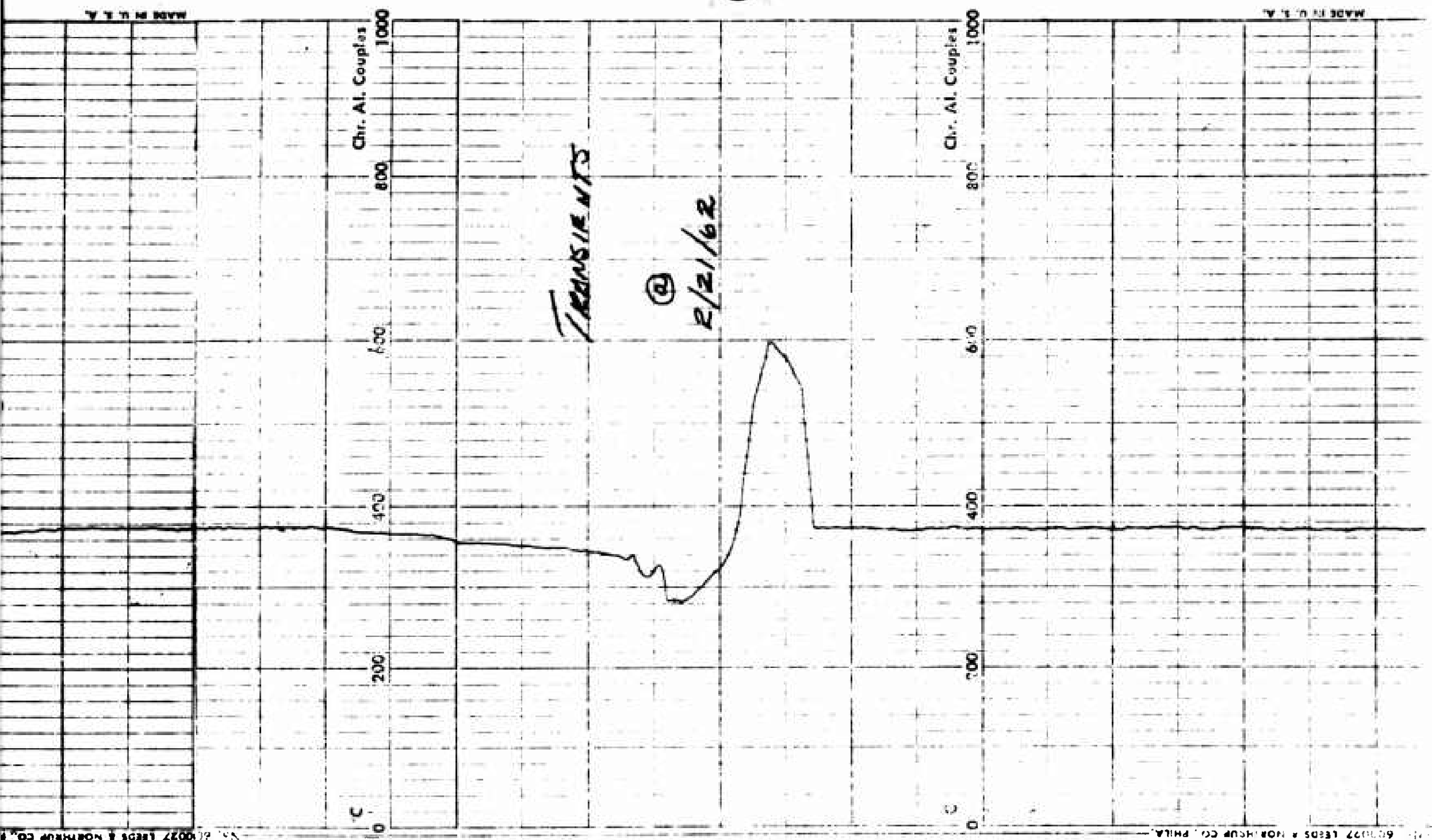
1



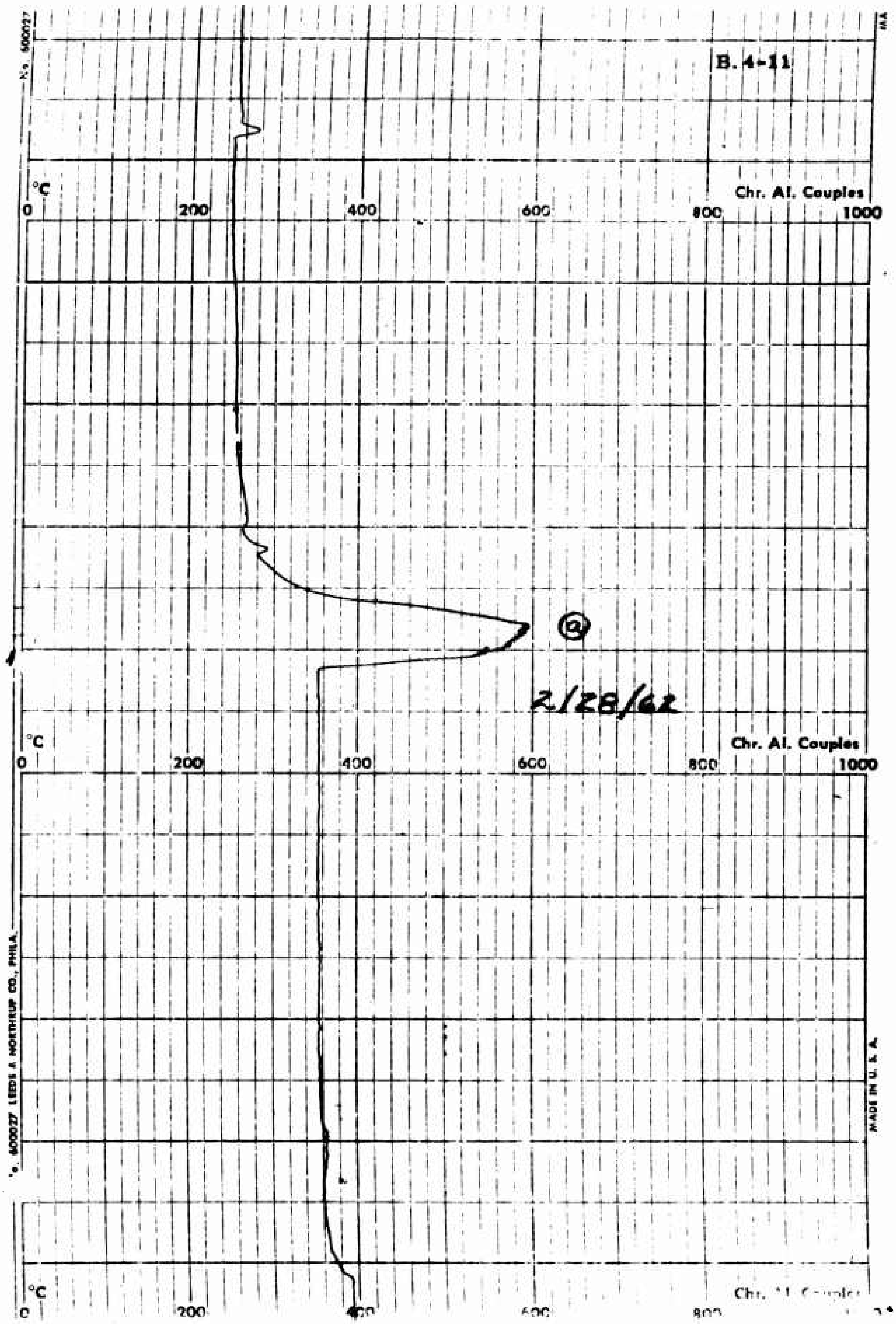
2

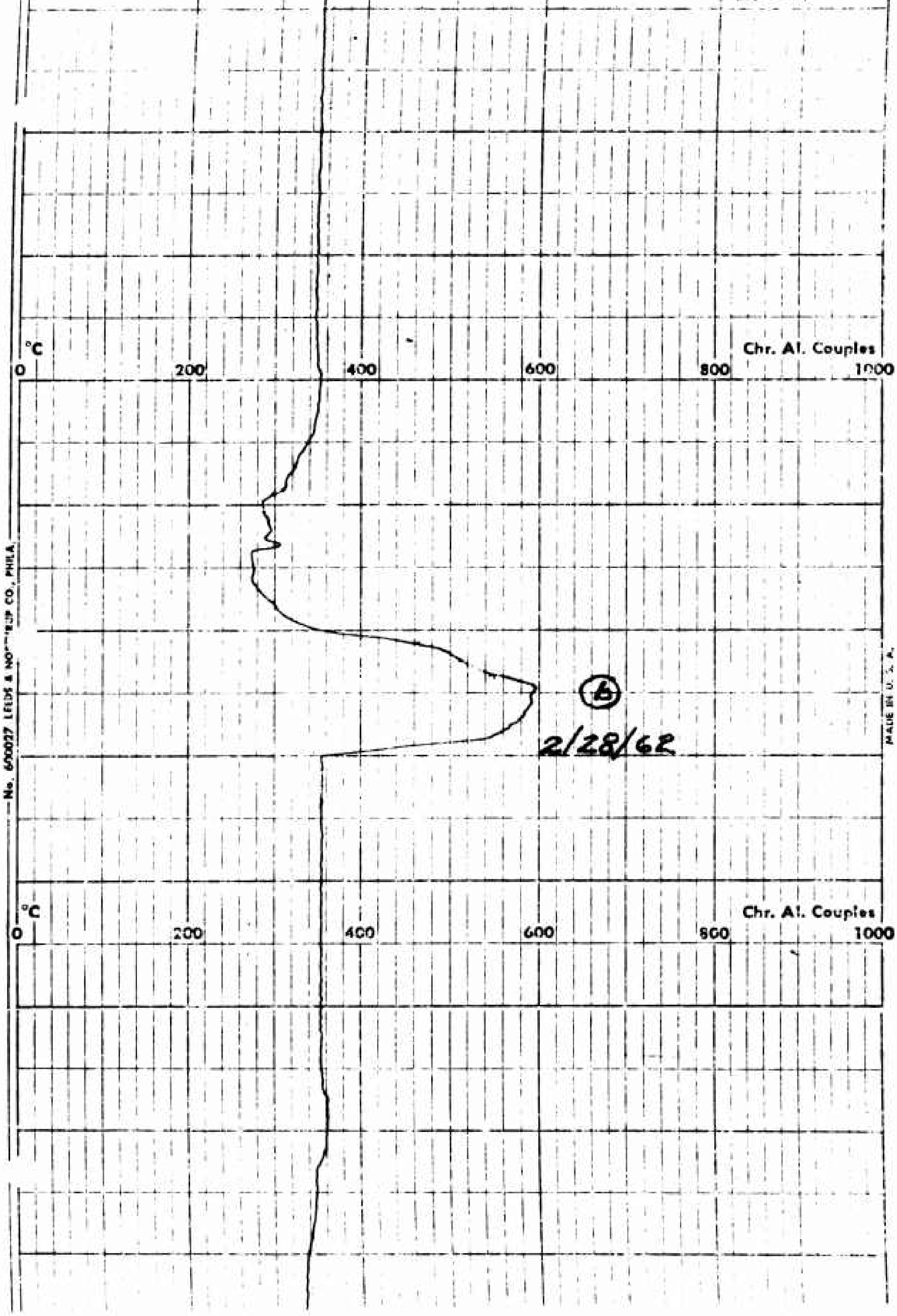


3

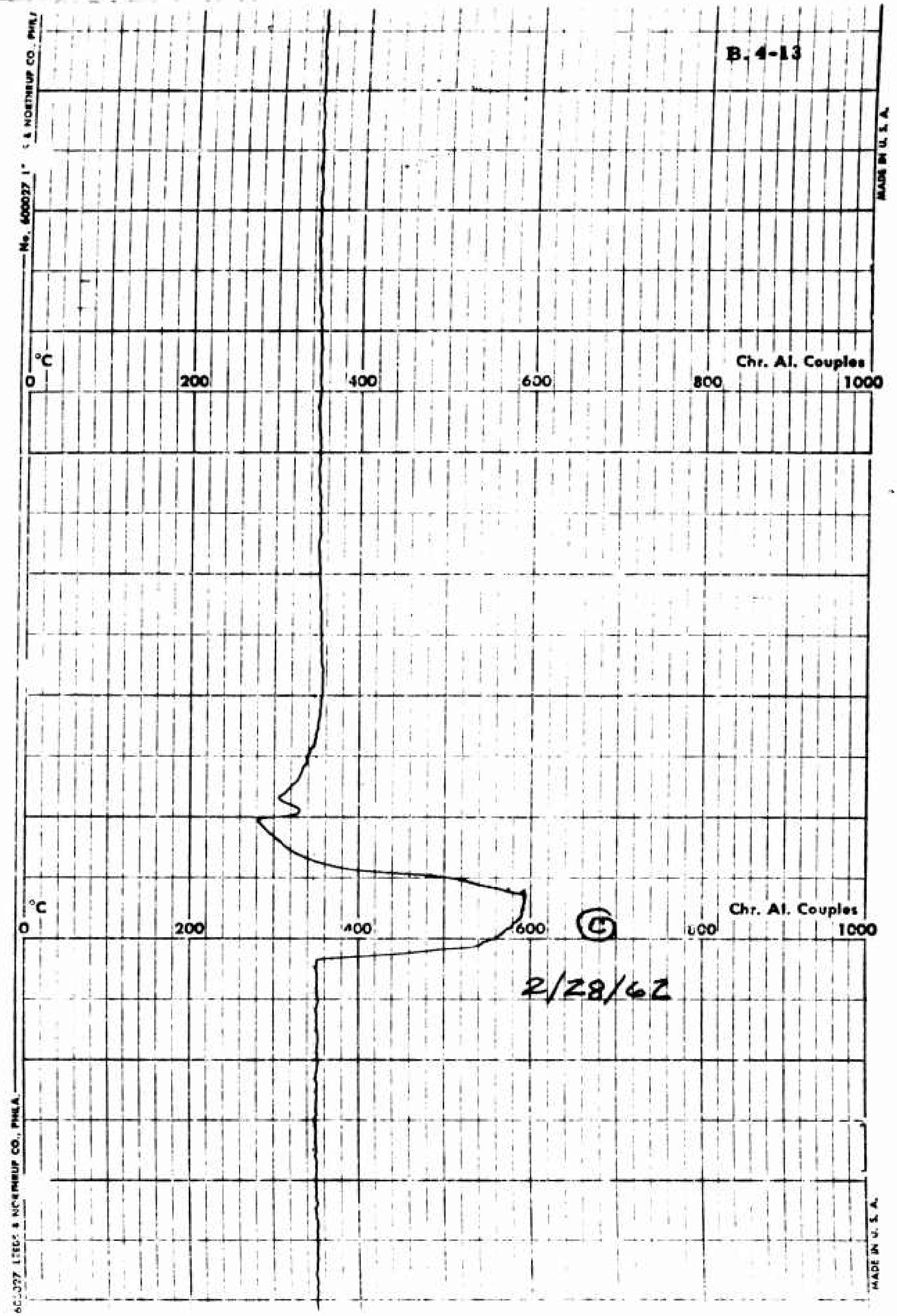


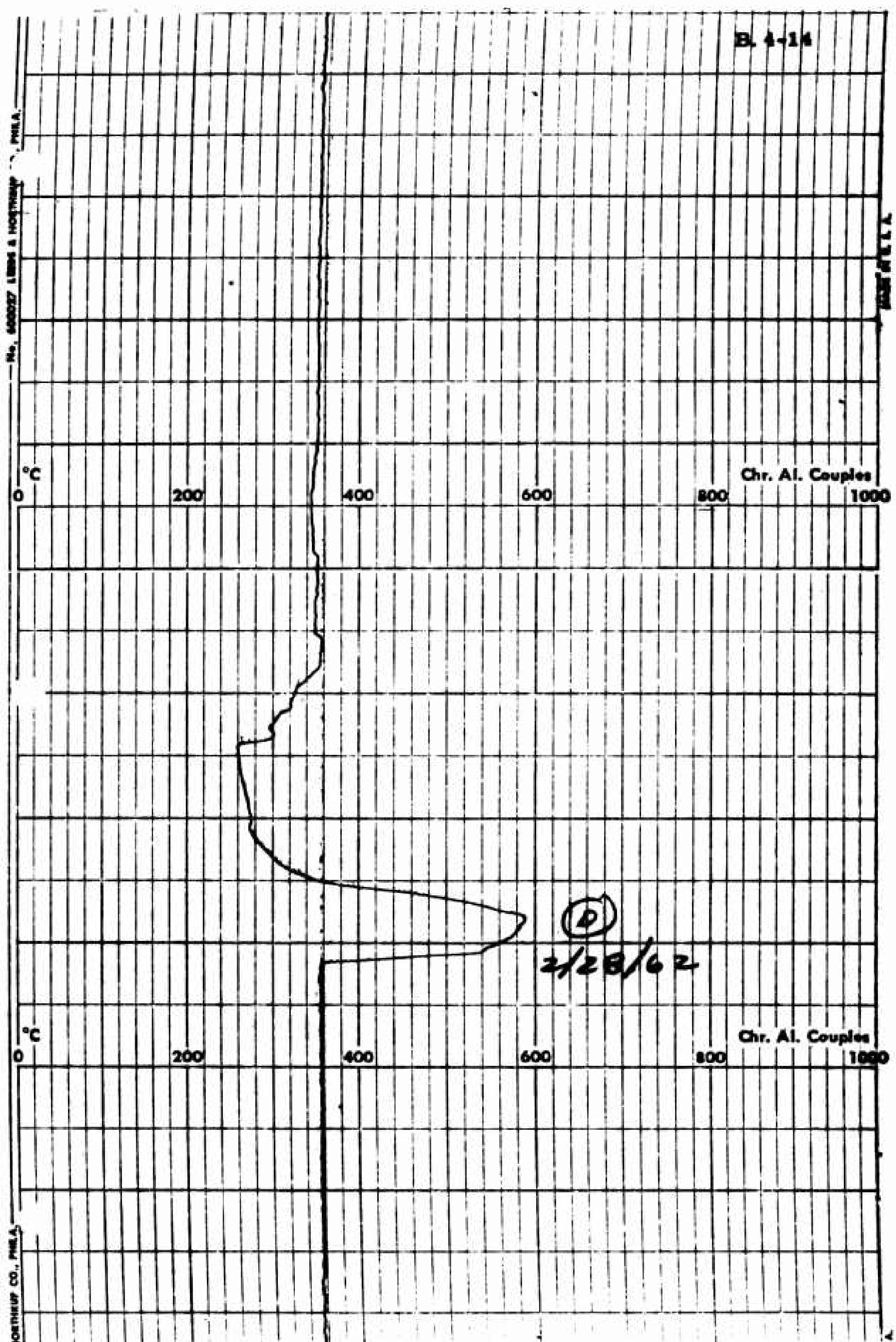
Chr. Al. Couples
1000
800
600
400
200
0
TRANSIENTS
@
2/21/62
MADE IN U. S. A.


B. 4-11
°C
Chr. Al. Couples
0
200
400
600
800
1000
ⓐ
2/28/62
MADE IN U.S.A.
No. 600027 LEEDS & NORTHRUP CO., PHILA.

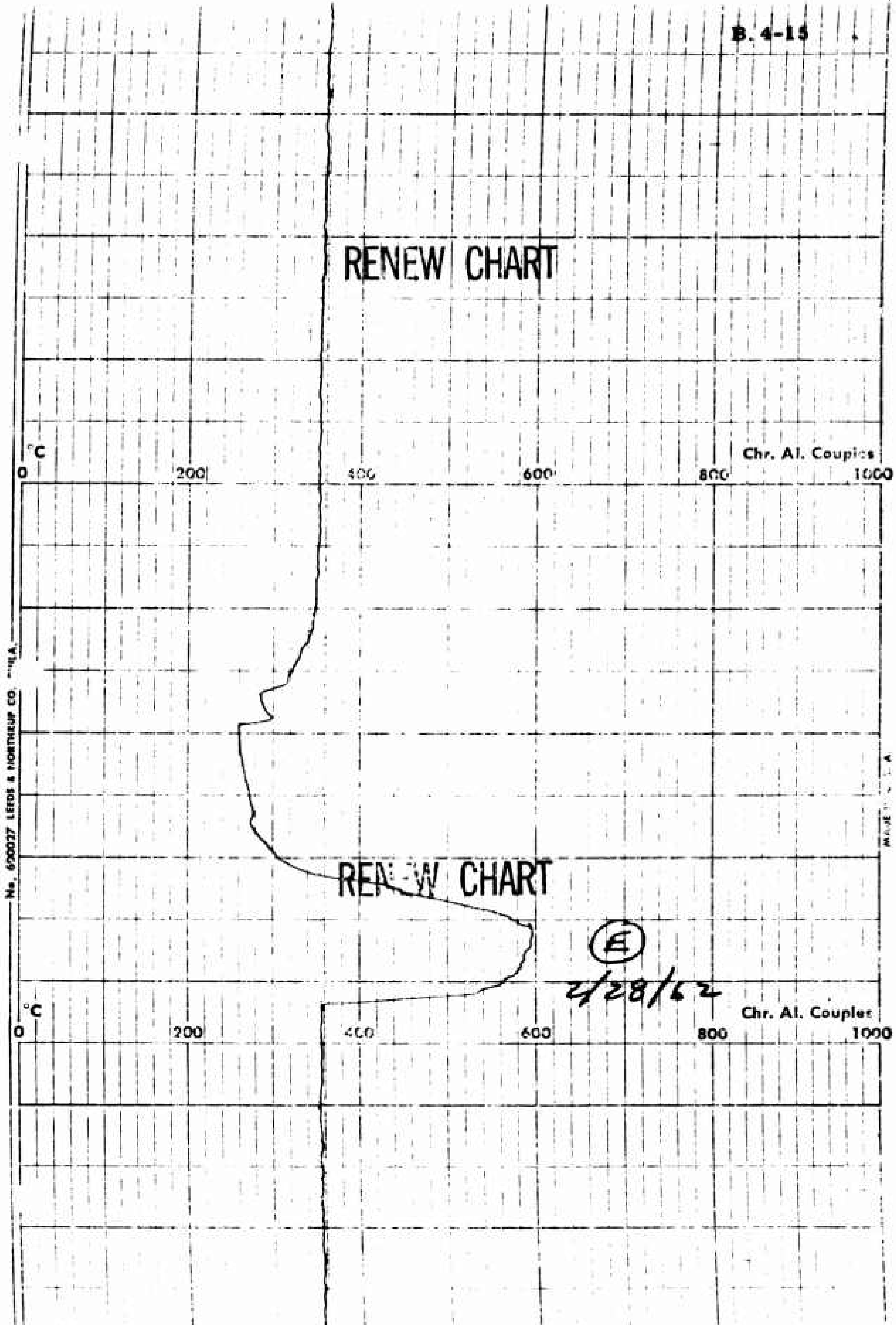


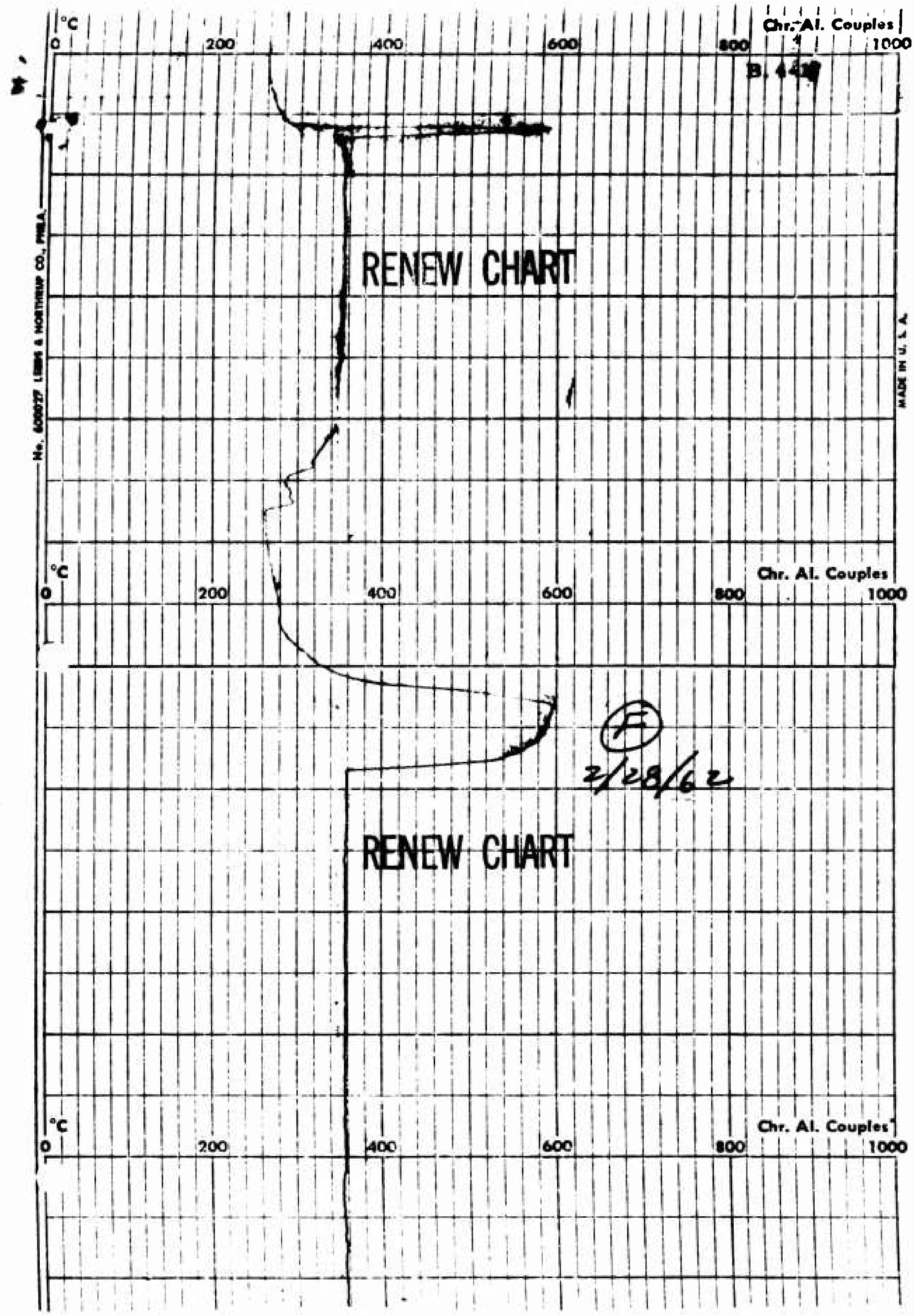
°C
0
200
400
600
800
1000
Chr. Al. Couples
MADE IN U.S.A.
(b)
2/28/62
°C
0
200
400
600
800
1000
Chr. Al. Couples


B. 4-13
°C
0
200
400
600
800
1000
Chr. Al. Couples
°C
0
200
400
600
1000
Chr. Al. Couples
C
2/28/62
No. 600027
LEEDS & NORTHRUP CO., PHILA.
MADE IN U. S. A.



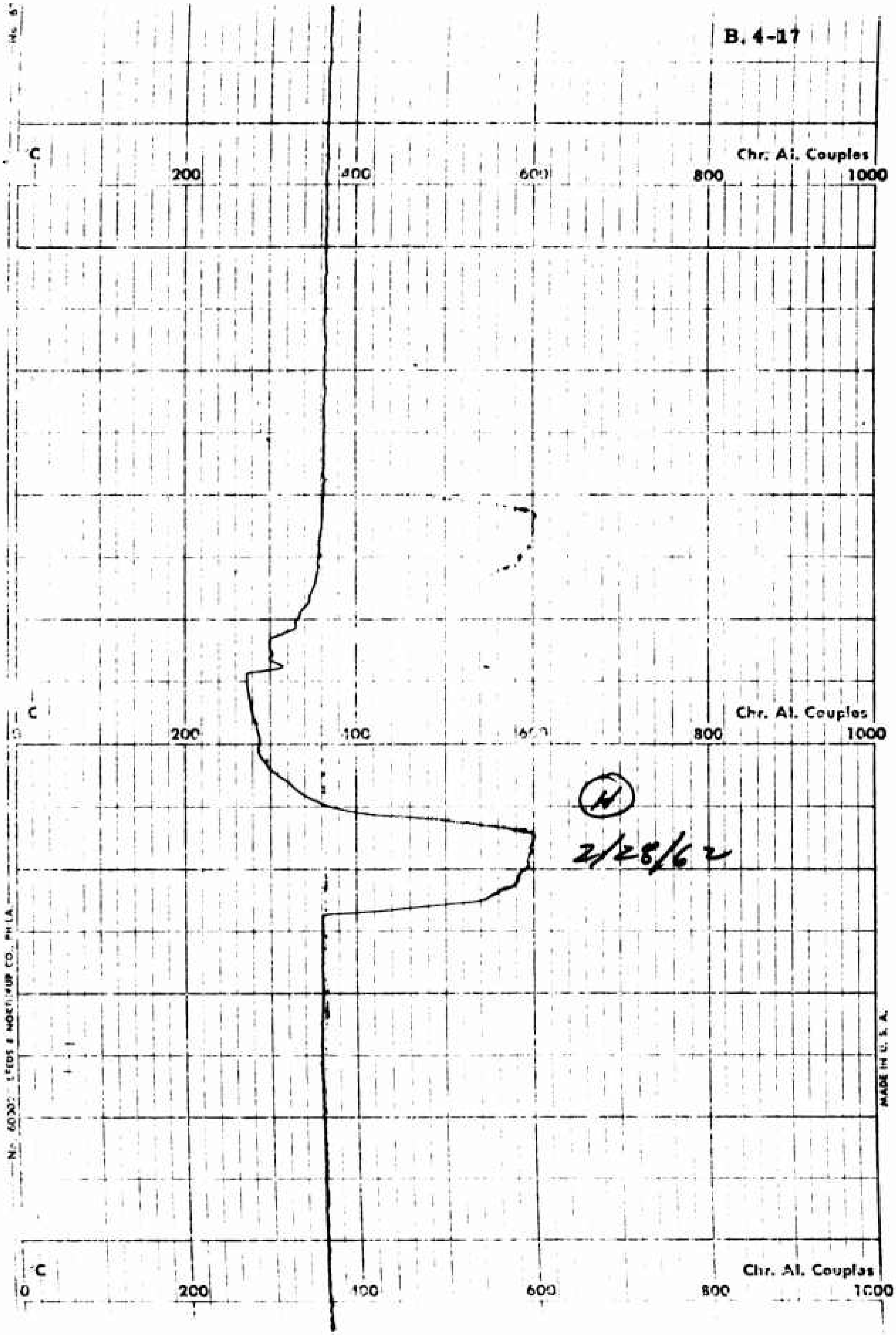
B. 4-14
°C
0
200
400
600
800
1000
Chr. Al. Couples
2/28/62
°C
0
200
400
600
800
1000
Chr. Al. Couples

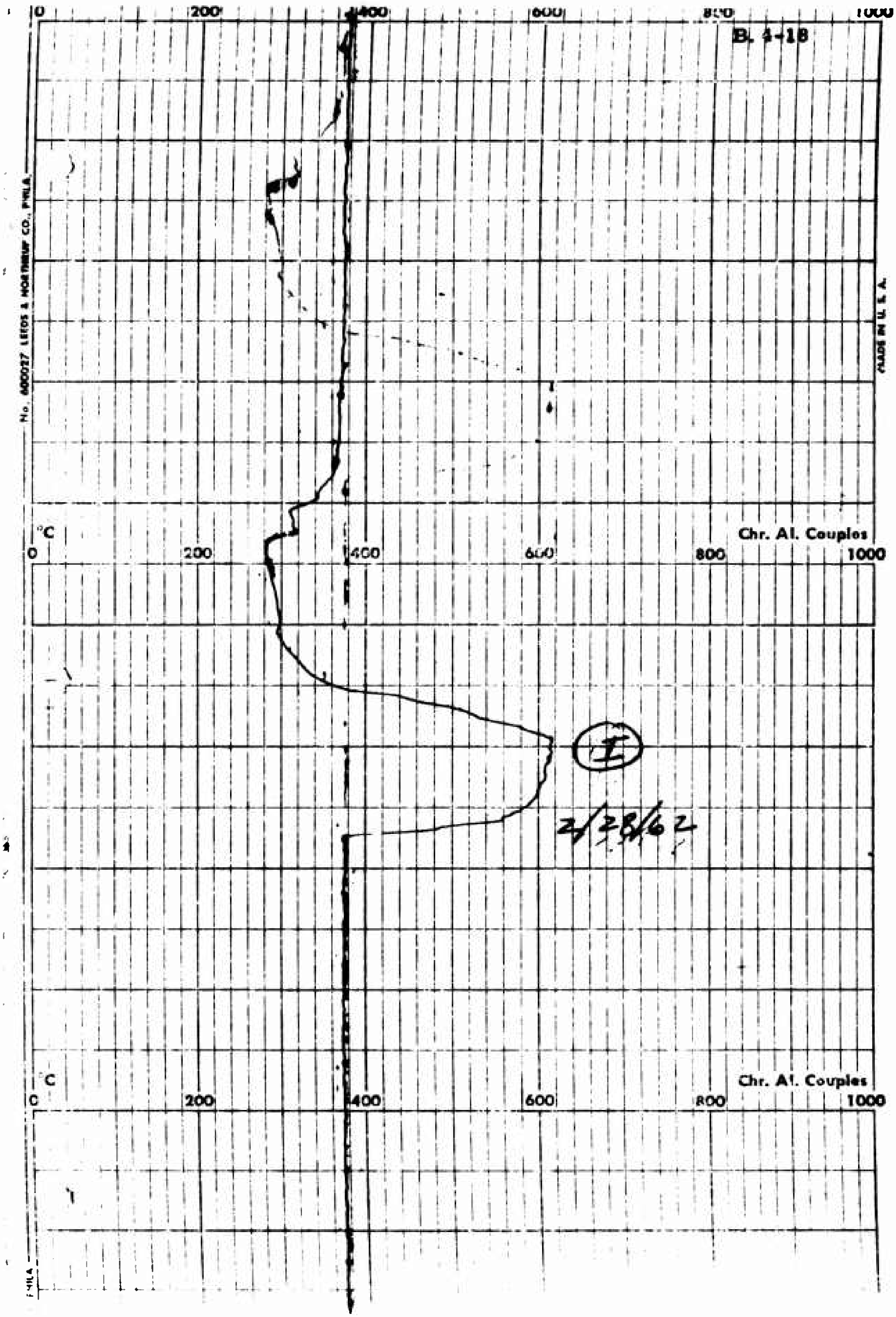

RENEW CHART
°C
Chr. Al. Couples
0
200
400
600
800
1000
No. 600027 LEEDS & NORTHRUP CO.
RENEW CHART
E
2/28/62
°C
Chr. Al. Couples
0
200
400
600
800
1000



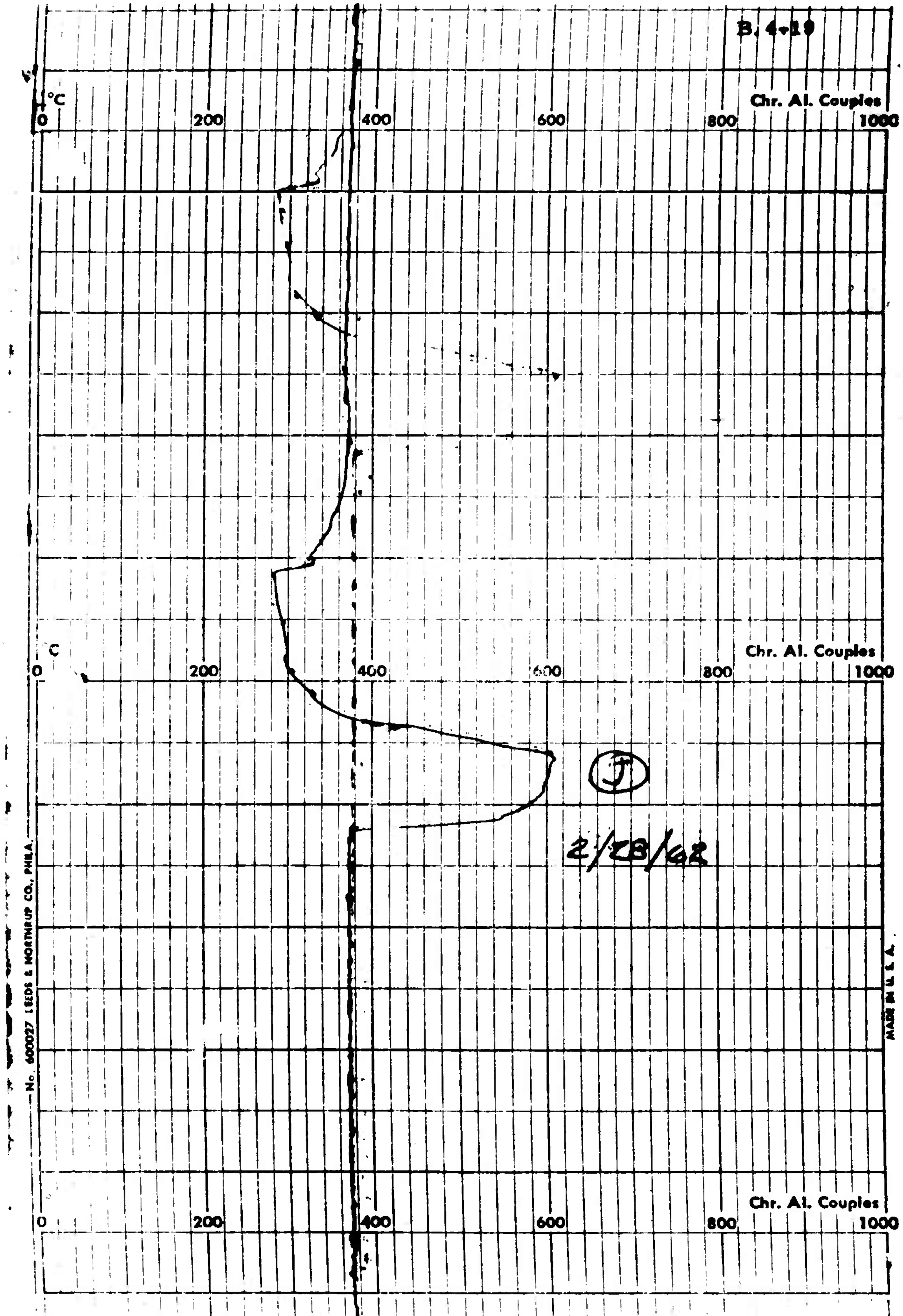
°C
0
200
400
600
800
1000
Chr. Al. Couples
RENEW CHART
No. 600027 LEEDS & NORTHRUP CO., PHILA.
MADE IN U. S. A.
°C
0
200
400
600
800
1000
Chr. Al. Couples
F
2/28/62
RENEW CHART
°C
0
200
400
600
800
1000
Chr. Al. Couples

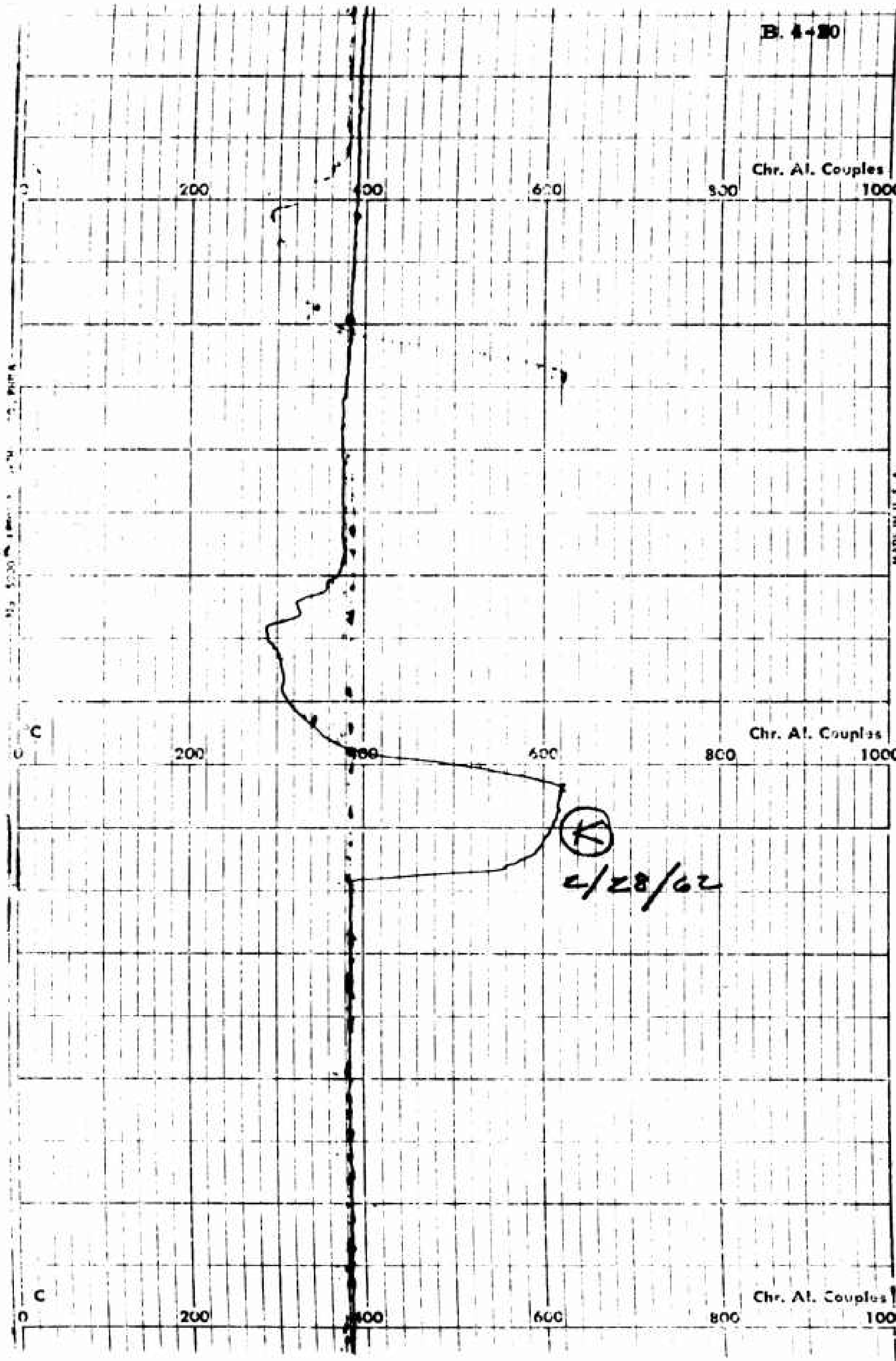
B. 4-17


Chr. Al. Couples
C
200
400
600
800
1000
Chr. Al. Couples
C
200
400
600
800
1000
H
2/28/62
Chr. Al. Couplas
C
0
200
400
600
800
1000
No. 60302 LEEDS & NORTHRUP CO., PHILA.
MADE IN U. S. A.



B. 4-18
No. 600027 LEEDS & NORTHRUP CO., PHILA.
MADE IN U. S. A.
°C
Chr. Al. Couples
0
200
400
600
800
1000
I
2/28/62


B. 4-19
°C
Chr. Al. Couples
0
200
400
600
800
1000
°C
Chr. Al. Couples
0
200
400
600
800
1000
J
2/28/62
Chr. Al. Couples
0
200
400
600
800
1000
No. 600027 LEEDS & NORTHRUP CO., PHILA.
MADE IN U.S.A.



Chr. Al. Couples
0
200
400
600
800
1000
C
Chr. Al. Couples
0
200
400
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K
6/28/62
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0
200
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800
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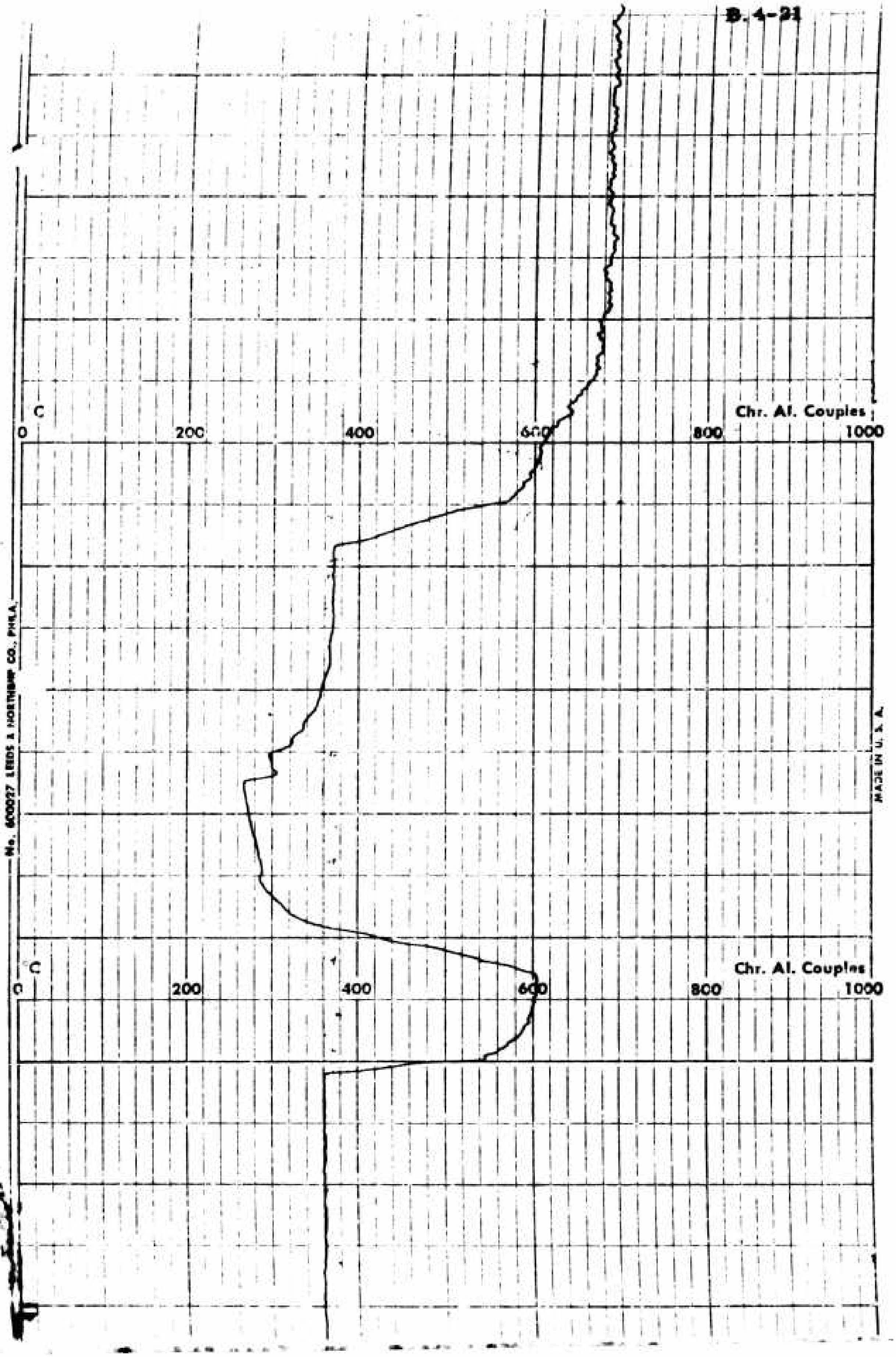
MADE IN U.S.A.

B. 4-21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No. 600027 LEEDS & NORTHRUP CO., PHILA.
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APPENDIX C

METHOD OF CALCULATION; AREA AND MASS WEIGHTED PARAMETERS

C. 1 AREA WEIGHTED VELOCITY

It is assumed that the velocity profile is a body of revolution determined graphically in a nondimensional form $\left(\frac{v}{v_c}\right) = f\left(\frac{r}{r_p}\right)$ where v_c designates the velocity measured in the center of pipe, and r_p is the inside radius of the pipe. From the definition of the area weighted velocity,

$$v_{\text{area weighted}} = \frac{v_c}{A_p}\int_0^{A_p}\left(\frac{v}{v_c}\right)dA = \frac{v_c}{r_p^2}\int_0^{r_p}\left(\frac{v}{v_c}\right)2\pi r\,dr$$

or in a nondimensional form

$$v_{a.w.} = \frac{v_c}{\pi}\int_0^{r_p}\left(\frac{v}{v_c}\right)2\pi\left(\frac{r}{r_p}\right)d\left(\frac{r}{r_p}\right) = 2v_c\int_0^{1}\left(\frac{v}{v_c}\right)\left(\frac{r}{r_p}\right)d\left(\frac{r}{r_p}\right) \qquad (1)$$

the integral $\int_0^1 \left(\frac{v}{v_c}\right)\left(\frac{r}{r_p}\right) d\left(\frac{r}{r_p}\right)$ is found by measuring the area under the curve $\left(\frac{v}{v_c}\right) = f\left(\frac{r}{r_p}\right)$ shown on Figures 5. 1-8 and 5. 1-9.

C. 2 MASS WEIGHTED TOTAL PRESSURE $\overline{P_T}$.

By definition, the mass weighted total pressure is $\overline{P_T} = \frac{1}{W}\int_0^r P_t \, dW$. (1)

At M 0. 3, an equation for incompressible flow can be used with fair accuracy. This simplification leads to conservative solution.

$$P_T = P + \rho \frac{v^2}{2g} \quad (2)$$

Also, the weight flow is

$$W = \int_0^{r_p} \rho v (2 \pi r) \, dr. \quad (3)$$

Substituting (2) and (3) into (1)

$$\overline{P_T} \approx P + q \frac{\int_0^{r_p} v^3 \, r dr}{\int_0^{r_p} v r dr}.$$

Expressed in nondimentional form, where $q_c = \frac{\rho v_c^2}{2g}$

$$\overline{P_T} = P + q_c \frac{\int_0^1 \left(\frac{v}{v_c}\right)^3 \left(\frac{r}{r_p}\right) d\left(\frac{r}{r_p}\right)}{\int_0^1 \left(\frac{v}{v_c}\right)\left(\frac{r}{r_p}\right) d\left(\frac{r}{r_p}\right)} \quad (4)$$

Both integrals in the above equation can be solved graphically as shown on Figures 5. 1-8 and 5. 1-9.

APPENDIX D

THERMODYNAMIC CALCULATION PROCEDURE; NON-ROTATING COMPONENTS

The various pressure and temperature measuring stations are shown in Figure D-1. Details of the various rakes are given by Figure D-2. The basic equations used in conjunction with these instrumentation locations are given in Reference 3.4-2 and the computer equation flow scheme is presented herein (see Appendix F for nomenclature).

Due to the length of this calculation, the flow scheme follows steps e, a, b, c, d, f, g, h, i, j, k, l, m, n. Step "e" is misplaced as it was initially intended as part of an iterative procedure to determine the effect of water injection on γ and R which required the output of Steps "a" through "f" based on initially assumed values of γ and R. Since virtually all running was done without water injection, the iterative procedure is unnecessary when the output of Step "e" (no water injection) is used as input for Steps "a", "b", etc. The hub area weighted total pressure values of Steps "h" and "i" are used only for reference since the distortion of the velocity profile at that station does not permit accurate area weighted pressure values with the instrumentation provided. These values do provide a useful reference, however, and together with the results of Reference 3.4-2 help in determining the loss coefficients C_I' and C_{II}'.

FIGURE D-1

VERTICAL DUCTS SHOWING LOCATION OF FLOW MEASURING AND HUB STATIONS

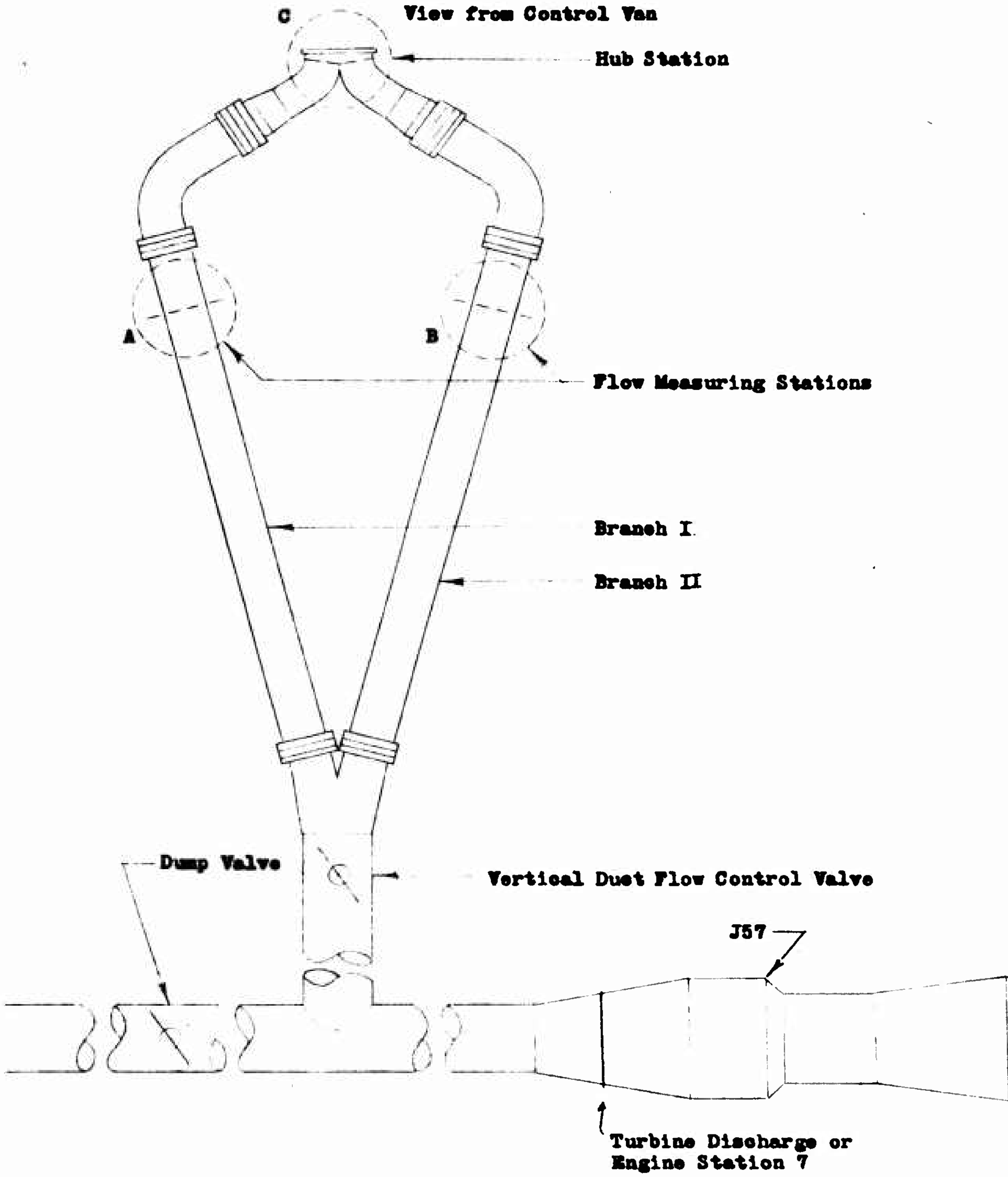
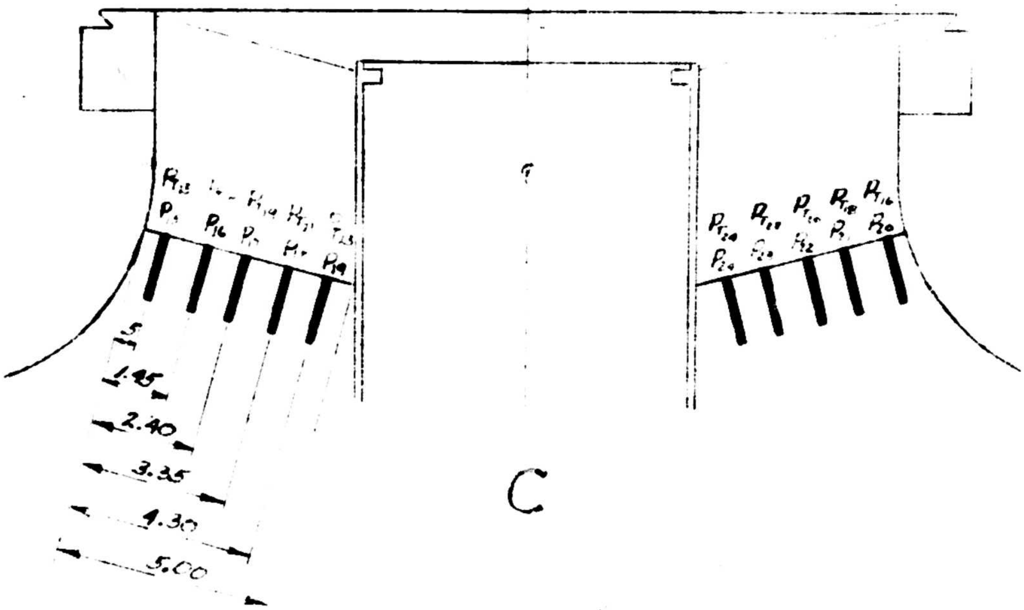
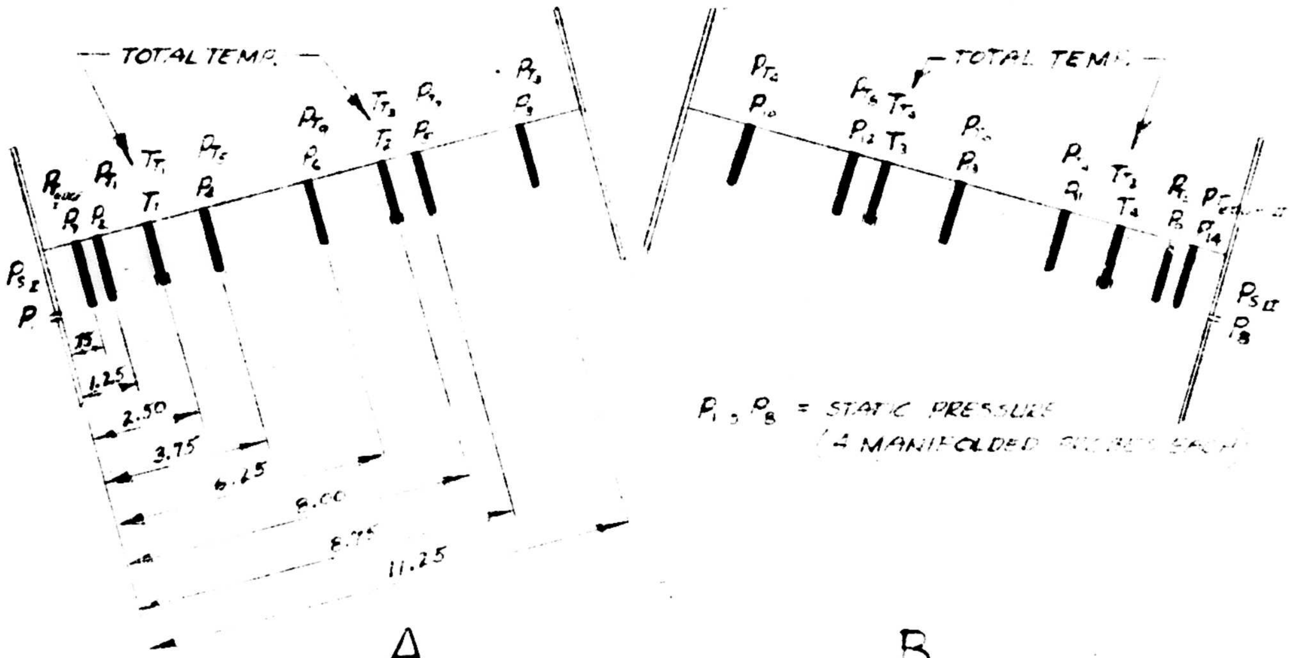


FIGURE D-2

IDENTIFICATION OF PROBE LOCATIONS AT FLOW MEASURING AND HUB STATIONS

1. ALL PROBES ARE TOTAL PRESSURE EXCEPT AS NOTED
2. UPPER SYMBOLS USED IN ANALYSIS, CORRESPONDING LOWER SYMBOLS APPEAR IN READOUT.





P_1, P_8 = STATIC PRESSURE (4 MANIFOLDED PROBES EACH)

Step a). Flow Rate - Branch I

Input: γ, R, from Step "e."

$g = 32.17$ ft/sec^2

T_1 (°F), T_2 (°F), P_{res} (in-Hg), P_1 (in-TBE), P_6 (in-TBE)

Calculation:

1. $T_{T_{fs_I}} = \frac{T_1 + T_2}{2} + 460$; °R

2. $P_{ref} = P_{res}\,(70.721)$; psfa

3. $P_{fs_I} = P_1\,(15.365) + ②$; psfa

4. $P_{T_{fs_{max}}} = P_6\,(15.365) + ②$; psfa

5. $M_{fs_{I_{max}}} = \sqrt{\frac{2}{\gamma - 1}\left[\left(\frac{④}{③}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}$; dimensionless

6. $T_{fs_{I_{max}}} = \frac{①}{1 + \frac{\gamma-1}{2}\,⑤^2}$; °R

7. $a_{fs_{I_{max}}} = \sqrt{\gamma g R\,⑥}$; ft/sec

8. $v_{fs_{I_{max}}} = ⑦⑤$; ft/sec

9. $\rho_{fs_{I_{max}}} = \frac{③}{R⑥}$, #/ft^3

10. $\mu_{fs_{I_{max}}} = [1.937348 + 1.780448 \times 10^{-2} \times ① - 4.170257 \times 10^{-6} \times ①^2 + 5.805605 \times 10^{-10} \times ①^3 - 2.156955 \times 10^{-14} \times ①^4]\,[4.32 \times 10^{-5}]$; #/hr ft

11. $Re_{fs_{I_{max}}} = \dfrac{(9)(8)(1.021)(3.6\times10^{3})}{(10)}$; dimensionless

12. $v_{fs_{I_{avg}}} = Z_1 \times (8)$; ft/sec

13. $M_{fs_{I_{avg}}} = \dfrac{(12)(5)}{(8)}$; dimensionless

14. $T_{fs_{I_{avg}}} = \dfrac{(1)}{1+\frac{\gamma-1}{2}(13)^2}$; °K

15. $\rho_{fs_{I_{avg}}} = \dfrac{(3)}{R\,(14)}$; #/ft^3

16. $a_{fs_{I_{avg}}} = \sqrt{\gamma g R\,(14)}$, ft/sec

17. $\left(v_{fs_{I_{avg}}}\right)_{corrected} = (16)(13)$; ft/sec

18. $w_{fs_I} = (15)(17)(0.818)$; #/sec

Step 6). Flow Rate - Branch II

Input: γ, R from Step "e"

$g = 32.17$ ft/sec^2

T_3(°F), T_4(°F), P_8(in-HgA), P_{13}(in-HgA)

Calculation:

19. $T_{T_{fs_{II}}} = \dfrac{T_3+T_4}{2} + 460$; °K

20. $P_{fs_{II_{max}}} = P_8(15.365) + (2)$; psfa

21. $P_{T_{fs_{II\,max}}} = P_{13}\,(15.365) + (2)$; psfa

22. $M_{fs_{II\,max}} = \sqrt{\frac{2}{\gamma-1}\left[\left(\frac{(21)}{(20)}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}$; dimensionless

23. $T_{fs_{II\,max}} = \frac{(19)}{1+\frac{\gamma-1}{2}(22)^2}$; °R

24. $a_{fs_{II\,max}} = \sqrt{\gamma g R\,(23)}$; ft/sec

25. $v_{fs_{II\,max}} = (24)\,(22)$; ft/sec

26. $\rho_{fs_{II\,max}} = \frac{(20)}{R\,(23)}$; #/ft^3

27. $\mu_{fs_{II\,max}}$ = Eq. 10 with (1) replaced by (19) therein

28. $Re_{fs_{II\,max}} = \frac{(26)\,(25)\,(1.021)(3.6\times 10^{3})}{(27)}$; dimensionless

29. $v_{fs_{II\,avg}} = Z_2 \times (25)$; ft/sec

30. $M_{fs_{II\,avg}} = \frac{(29)\,(22)}{(25)}$; dimensionless

31. $T_{fs_{II\,avg}} = \frac{(19)}{1+\frac{\gamma-1}{2}(30)^2}$; °R

32, 33. } Not Used

34. $\rho_{fs_{II\,avg}} = \frac{(20)}{R\,(31)}$; #/ft^3

35. $a_{fs_{II_{avg}}} = \sqrt{\gamma g R \text{ (31)}}$; ft/sec

36. $\left(v_{fs_{II_{avg}}}\right)_{corrected}$ = (35) (30) ; ft/sec

37. $w_{fs_{II}}$ = (32) (36) (0.818) ; #/sec

38. w_{TOT} = (18) + (37) ; #/sec

Step c). Velocity Profile - Branch I

Input: P_2 (in-TBE), P_3 (in-TBE), P_4 (in-TBE), P_5 (in-TBE), P_6 (in-TBE), P_7 (in-TBE)

Calculation:

39. $P_{T_{1_I}}$ = P_2(15.365) + (2) ; psfa

40. $P_{T_{3_I}}$ = P_3 (15,365) + (2) ; psfa

41. $P_{T_{5_I}}$ = P_4 (15.365) + (2) ; psfa

42. $P_{T_{7_I}}$ = P_5 (15.365) + (2) ; psfa

43. $P_{T_{9_I}}$ = P_6 (15.565) + (2) ; psfa

44. $P_{T_{E_I}}$ = P_7 (15.365) + (2) ; psfa

45. $M_{1_I} = \sqrt{\frac{2}{\gamma-1}\left[\left(\frac{(39)}{(3)}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}$; dimensionless

46. $M_{3_I} = \sqrt{\frac{2}{\gamma-1}\left[\left(\frac{(40)}{(3)}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}$; dimensionless

47. $M_{5_I} = \frac{(41)}{(3)}$ etc ″

48 $M_{7_I} = \frac{(42)}{(3)}$ ″

49. $M_{9_I} = \frac{(43)}{(3)}$ ″

50. $M_{E_I} = \frac{(44)}{(3)}$ ″

51. $\left(\frac{v_1}{v_{max}}\right)_I = \frac{(45)}{(49)}$ ″

52. $\left(\frac{v_3}{v_{max}}\right)_I = \frac{(46)}{(49)}$ ″

53. $\left(\frac{v_5}{v_{max}}\right)_I = \frac{(47)}{(49)}$ ″

54. $\left(\frac{v_7}{v_{max}}\right)_I = \frac{(48)}{(49)}$ ″

55. $\left(\frac{v_9}{v_{max}}\right)_I = \frac{(49)}{(49)}$ ″

56. $\left(\frac{v_{E_I}}{v_{max}}\right)_I = \frac{(50)}{(49)}$ ″

Step d). Velocity Profile - Branch II

Input: P_9 (in-TSE), P_{10} (in-TSE), P_{11} (in-TSE), P_{12} (in-TSE), P_{13} (in-TSE); P_{14} (in-TSE)

57. $P_{T_{2_{II}}} = P_9\,(15.365) + \textcircled{2}$; psfa

58. $P_{T_{4_{II}}} = P_{10}\,(15.365) + \textcircled{2}$; psfa

59. $P_{T_{6_{II}}} = P_{11}\,(15.365) + \textcircled{2}$; psfa

60. $P_{T_{8_{II}}} = P_{12}\,(15.365) + \textcircled{2}$; psfa

61. $P_{T_{10_{II}}} = P_{13}\,(15.365) + \textcircled{2}$; psfa

62. $P_{T_{E_{II}}} = P_{14}\,(15.365) + \textcircled{2}$; psfa

63. $M_{2_{II}} = \sqrt{\frac{2}{\gamma-1}\left[\left(\frac{(57)}{(20)}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}$; dimensionless

64. $M_{4_{II}}$ $\qquad \frac{(58)}{(20)}$ etc "

65. $M_{6_{II}}$ $\qquad \frac{(59)}{(20)}$ "

66. $M_{8_{II}}$ $\qquad \frac{(60)}{(20)}$ "

66.a $M_{10_{II}}$ $\qquad \frac{(61)}{(20)}$ "

67. $M_{E_{II}}$ $\qquad \frac{(62)}{(20)}$ "

68. $\left(\frac{v_2}{v_{max}}\right)_{II} = \frac{(63)}{([illegible])}$ "

69. $\left(\frac{v_4}{v_{max}}\right)_{II} = \frac{(64)}{(66a)}$; dimensionless

70. $\left(\frac{v_6}{v_{max}}\right)_{II} = \frac{(65)}{(66a)}$ "

71. $\left(\frac{v_8}{v_{max}}\right)_{II} = \frac{(66)}{(66a)}$ "

72. $\left(\frac{v_{10}}{v_{max}}\right)_{II} = \frac{(66a)}{(66a)}$ "

73. $\left(\frac{v_{E_{II}}}{v_{max}}\right)_{II} = \frac{(67)}{(66a)}$ "

Step e). Engine Parameters

Input: w_f (#/sec) ; T_{T_2} (°K), T_{T_7} (°K)

74. for $500°K < T_{T_2} \leq 1000°K$

$h_{T_2} = 120.42 + (0.2477)(T_{T_2} - 500)$; Btu/#

75. ⓐ for $500°K < T_{T_7} \leq 1000°K$

$h_{T_7} = 120.42 + (0.2477)(T_{T_7} - 500)$; Btu/#

ⓑ for $1000°K < T_{T_7} \leq 1500°K$

$h_{T_7} = 244.25 + (0.2627)(T_{T_7} - 1000)$; Btu/#

ⓒ for $1500°K < T_{T_7} \leq 2250°K$

$h_{T_7} = 375.62 + (0.2819)(T_{T_7} - 1500)$; Btu/#

76. $w_7 = \left(\frac{17{,}664 - (75)}{(75) - (74)}\right) w_f$; #/sec

77. $w_f/w_a = \dfrac{w_f}{(76) - w_f}$; dimensionless

78. $\% \text{ Air} = \dfrac{0.0677 \times 100}{(77)}$; %

79. $R = \left[0.0095\,(77) + 53.34\right]$; ft/°R

80. (a) for $360°R < T_{T_7} \le 990°R$

$$c_p = \left(0.2430 - 0.08\,(77)\right) - \left(0.00343 - 0.115\,(77)\right)\left(\frac{5\,T_{T_7}}{900}\right) + \left(0.0008 - 0.008\,(77)\right)\left(\frac{5\,T_{T_7}}{900}\right)^2 \text{ ; Btu/\#°R}$$

(b) for $990°R < T_{T_7} \le 1530°R$

$$c_p = \left(0.2170 + 0.157\,(77)\right) + \left(0.0057 + 0.0267\,(77)\right)\left(\frac{5\,T_{T_7}}{900}\right) \text{ ; Btu/\#°R}$$

(c) for $1530°R < T_{T_7} \le 6300°R$

$$c_p = \left(0.3340 + 0.5\,(77)\right) - \left\{\frac{0.834 + 7.6\,(77) + 10\,(77)^2}{\frac{5\,T_{T_7}}{900} + 3.65 + 20\,(77)}\right\} \text{ ; Btu/\#°R}$$

81. for $T_{T_7} < 2700°R$

$$c_v = c_p - 0.06855$$

82. $\gamma = \dfrac{(80)}{(81)}$

Step f). Flow Measuring Station Mass Weighted Mean Total Pressure; Branch I

Input: All values are taken from previous steps

Calculation:

83. $\overline{P}_{T_{fs_I}} = ③ \left\{ 1 + X_1 \left[1 + \frac{1}{2(㉜ - 1)} \left(\frac{①}{⑥} - 1 \right) \right] \frac{⑧^2}{32.17 \, (79)(6)} \right\}$; psfa

Step g). Flow Measuring Station Mass Weighted Mean Total Pressure, Branch II

Input: All values are taken from prior steps

Calculation:

84. $\overline{P}_{T_{fs_{II}}} = (20) \left\{ 1 + X_2 \left[1 + \frac{1}{2((82) - 1)} \left(\frac{(19)}{(25)} - 1 \right) \right] \frac{(29)^2}{32.17 \, (79)(23)} \right\}$; psfa

Step h). Hub Station Area Weighted Total Pressure; Branch I

Input: P_{15} (in-TBE), P_{16} (in-TBE), P_{17} (in-TBE), P_{18} (in-TBE)

P_{19} (in-TBE)

Calculation:

85. $P_{T_{15}} = P_{15}(15.365) + ②$; psfa

86. $P_{T_{17}} = P_{16}(15.365) + ②$; psfa

87. $P_{T_{19}} = P_{17}(15.365) + ②$; psfa

88. $P_{T_{21}} = P_{18} (15.365) + ②$; psfa

89. $P_{T_{23}} = P_{19} (15.365) + ②$; psfa

90. $\left(P_{T_{hub_I}}\right)_{aw} = 0.298 ⑧⑤ + 0.192 ⑧⑥ + 0.169 ⑧⑦$
$+ 0.146 ⑧⑧ + 0.195 ⑧⑨$; psfa

Step i) Hub Station Area Weighted Total Pressure, Branch II

Input: P_{20} (in-TBE), P_{21} (in-TBE), P_{22} (in-TBE), P_{23} (in-TBE),
P_{24} (in-TBE), P_{T_7} (in-Hg)

Calculation:

91. $P_{T_{16}} = P_{20} (15.365) + ②$; psfa

92. $P_{T_{18}} = P_{21} (15.365) + ②$; psfa

93. $P_{T_{20}} = P_{22} (15.365) + ②$; psfa

94. $P_{T_{22}} = P_{23} (15.365) + ②$; psfa

95. $P_{T_{24}} = P_{24} (15.365) + ②$; psfa

96. $\left(P_{T_{hub_{II}}}\right)_{aw} = 0.298 ⑨① + 0.192 ⑨② + 0.169 ⑨③$
$+ 0.146 ⑨④ + 0.195 ⑨⑤$; psfa

97. $\left(P_{T_{hub}}\right)_{aw} = \dfrac{⑨⓪ + ⑨⑥}{2}$; psfa

98. $P_{T_7} = P_{T_7}(70.721)$; psfa

98a. $C_I = \dfrac{\overline{P_{T_{fs_I}}} - (P_{T_{hub_I}})_{aw}}{P_{T_7}} = \dfrac{(83) - (90)}{(98)}$; dimensionless

98b. $C_{II} = \dfrac{\overline{P_{T_{fs_{II}}}} - (P_{T_{hub_{II}}})_{aw}}{P_{T_7}} = \dfrac{(84) - (96)}{(98)}$; dimensionless

Step j) Hub Station Total Pressure; Mass Weighted; Calculated, Branch I

Input: C_I', assumed value based on prior run values of C_I above plus results of full scale mock up test

Calculation:

99. $\overline{P_{T_{hub_I}}} = (83) - C_I' (98)$, psfa

Step k). Hub Station Total Pressure, Mass Weighted; Calculated; Branch II

Input: C_{II}', assumed value based on prior run values of C_{II} above plus results of full scale mock up test

Calculation

100. $\overline{P_{T_{hub_{II}}}} = (84) - C_{II}' (98)$; psfa

Step l) Hub Station Parameters for Input to Rotating Component Subroutine

Input: δ_1, δ_2

Calculation:

100a. $\overline{P}_{T_{hub}} = \frac{(99) + (100)}{2}$; psfa

100b. $\overline{T}_{T_{hub}} = \frac{(1) + (19)}{2}$; °K

100c. Not Used

100d. $T_{T_{TIP}} = (100b) - 5$; °K

Step m). Total Pressure Loss Parameters; Branch I

Input: All values are taken from previous steps

Calculation:

101. $\frac{P_{T_7} - \overline{P}_{T_{FS_I}}}{P_{T_7}} = \frac{(98) - (83)}{(98)}$; dimensionless

101a. $\frac{\overline{P}_{T_{FS_I}} - \overline{P}_{T_{hub_I}}}{P_{T_7}} = \frac{(83) - (99)}{(98)}$, dimensionless

102. $\frac{P_{T_7} - \overline{P}_{T_{hub_{II}}}}{P_{T_7}} = \frac{(98) - (99)}{(98)}$; dimensionless

Step n). Total Pressure Loss Parameters; Branch II

Input: All values are taken from previous steps

Calculation:

103. $\frac{P_{T_7} - \overline{P}_{T_{FS_{II}}}}{P_{T_7}} = \frac{(98) - (84)}{(98)}$. dimensionless

103a. $$\frac{\overline{P}_{T_{TS_{II}}} - \overline{P}_{T_{hub_{II}}}}{P_{T_7}} = \frac{(84) - (100)}{(98)}$$; dimensionless

104. $$\frac{P_{T_7} - \overline{P}_{T_{hub_{II}}}}{P_{T_7}} = \frac{(98) - (100)}{(98)}$$; dimensionless

APPENDIX E

SUMMARY OF STRAIN GAGE AND THERMOCOUPLE LOCATIONS

E. 1 INTRODUCTION

Table E. 2-1 following lists all strain gage locations, and the type of gage and the data desired at each location. Table E. 2-2 is a compilation of the thermocouple locations.

TABLE E.2-1

TABULATION OF STRAIN GAGE INSTALLATIONS

Bridge Name	Bridge Number	Gage Type	No. of Gages	Bridge Type	Wiring Configuration	Gage Location Part Name	Gage Location Part No.	Station
Pitch Arm	1	ABD-13	4	Bending	Normal	Feathering Arm	285-0140	23.00
Flapwise Bending	4	ABD-13	8	Bending	Parallel	Front Spar	285-0170	62.50
Flapwise Bending	5	ABD-13	8	Bending	Parallel	Aft Spar	285-0170	62.50
Flapwise Bending	6	ABD-13	8	Bending	Parallel	Front Spar	285-0170	73.40
Flapwise Bending	7	ABD-13	8	Bending	Parallel	Aft Spar	285-0170	73.40
Flapwise Bending	8	ABD-13	8	Bending	Parallel	Front Spar	285-0170	53.50
Flapwise Bending	9	ABD-13	8	Bending	Parallel	Aft Spar	285-0170	53.50
Flapwise Bending	10	ABD-13	8	Bending	Parallel	Front Spar	285-0170	78.30
Chordwise Bending	11	ABD-13	4	Tension	Normal	Front Spar	285-0170	83.50
Flapwise Bending	12	ABD-13	8	Bending	Parallel	Aft Spar	285-0170	78.30
Chordwise Bending	13	ABD-13	4	Tension	Normal	Aft Spar	285-0170	103.00*

*Moved from Station 83.5 after addition of aft spar doubler

TABLE E.2-1 (Continued)

Bridge Name	Bridge Number	Gage Type	No. of Gages	Bridge Type	Wiring Configuration	Gage Location Part Name	Part No.	Station
Flapwise Bending	17	ABD-13	8	Bending	Parallel	Aft Spar	285-0170	138.30
Flapwise Bending	23	ABD-13	8	Bending	Parallel	Aft Spar	285-0170	164.50
Flapwise Bending	24	ABD-13	8	Bending	Parallel	Front Spar	285-0170	206.00
Flapwise Bending	25	C6-142-350B	8	Bending	Parallel	Aft Spar	285-0170	206.00
Flapwise Bending	29	C6-142-350B	8	Bending	Parallel	Aft Spar	285-0170	270.00
Thrust	30	ABD-13	8	Tension	Parallel	Shaft Assembly	285-0534	W.L. -1.4
Thrust	30X	ABD-13	8	Tension	Parallel	Shaft Assembly	285-0534	W.L. -1.4
In-plane Bending	31	ABD-13	8	Bending	Parallel	Shaft Assembly	285-0534	W.L. -1.4
90° to In-plane Bending	32	ABD-13	8	Bending	Parallel	Shaft Assembly	285-0534	W.L. -1.4
Hub Gimbal	33	ABD-13	4	Bending	Normal	Hub Gimbal Beam	285-0529	W.L.+4.25
Hub Gimbal	34	ABD-13	4	Bending	Normal	Hub Gimbal Beam	285-0529	W.L.+4.25
Blade Torsion	36	ABD-13	4	Shear	Normal	Blade Structure	285-0166	Top. Skin 38.0

TABLE E. 2-1 (Continued)

Bridge Name	Bridge Number	Gage Type	No of Gages	Bridge Type	Wiring Configuration	Gage Location Part Name	Gage Location Part.No.	Station
Blade Torsion	37	ABD-13	4	Shear	Normal	Blade Structure	285-0166	Bottom Skin 38.00
Blade Torsion	38	ABD-13	4	Shear	Normal	Blade Structure	285-0138	Top Skin 82.00
Blade Torsion	39	ABD-13	4	Shear	Normal	Blade Structure	285-0138	Bottom Skin 82.00
Horizontal Shear	40	ABD-13	4	Shear	Normal	Blade Structure	285-0127	23.50
Vertical Shear	41	ABD-13	4	Shear	Normal	Blade Structure	285-0127	23.50
Swashplate Drag Link		ABD-13	4	Tension	Normal	Swash Plate Drag Link	285-0332	Shown on 285-0300 W.L. -57.2
Flapping Angle Pickup		ABD-13	4	Bending	Normal	Flapping Angle Pickup	285-0947	Hub 19.00
Strap Wind-up Pickup		ABD-13	4	Bending	Normal	Feathering Angle Pickup	285-0948	Hub 19.00
Hub Tilt Pickup		ABD-13	4	Bending	Normal	Hub Tilt Pickup	285-0956	Hub 6.00
Blue Blade Duct Torsion 1.		ABD-13	8	Bending	Parallel	Duct Gimbal Ring Gages Installed per 285-0995	285-0178	Shaft Assy. 19.00

TABLE E.2-1 (Continued)

Bridge Name	Bridge Number	Gage Type	No. of Gages	Bridge Type	Wiring Configuration	Gage Location Part Name	Gage Location Part No.	Station
2.		ABD-13	8	Bending	Parallel	Duct Gimbal Ring Installed per 285-0955	285-0178	Shaft Assy. 19.00
Red Blade Duct Torsion								
1.		ABD-13	8	Bending	Parallel	Duct Gimbal Ring Gages Installed per 285-0955		Shaft Assy. 19.00
2.		ABD-13	8	Bending	Parallel	Duct Gimbal Ring Gages Installed per 285-0955		Shaft Assy. 19.00
Yellow Blade Duct Torsion								
1.		ABD-13	8	Bending	Parallel	Duct Gimbal Ring Gages Installed per 285-0955		Shaft Assy. 19.00
2.		ABD-13	8	Bending	Parallel	Duct Gimbal Ring Gages Installed per 285-0955		Shaft Assy. 19.00
For and Aft Horizontal Force Pickup		ABD-13	4	Tension	Normal	Upper Truss	285-0523-1	W.L. -43.00
Lateral Horizontal Force Pickup		ABD-13	4	Tension	Normal	Upper Truss	285-0523-1	W.L. -43.00
Pylon Thrust	A	ABD-13	4	Tension	Normal*	Lower Truss	285-0523-3	W.L. -52.00

*All eight tubes of the lower truss were strain gaged and diametrically opposed tubes were wired in parallel at the plug to cancel side loads. The configuration of these gages are A and E, B and F, C and G, and D and H.

TABLE E. 2-1 (Continued)

Bridge Name	Bridge Number	Gage Type	No. of Gages	Bridge Type	Wiring Configuration	Gage Location Part Name	Gage Location Part No.	Station
Pylon Thrust	B	ABD-13	4	Tension	Normal	Lower Truss	285-0 0523-3	W.L. -52.00
" "	C	"	"	" "	"	" "	"	" "
" "	D	"	"	" "	"	" "	"	" "
" "	E	"	"	" "	"	" "	"	" "
" "	F	"	"	" "	"	" "	"	" "
" "	G	"	"	" "	"	" "	"	" "
" "	H	"	"	" "	"	" "	"	" "
Control Force	1	AB-19	4	Tension	Normal	Rod End	285-0326-3	W.L. -57.00
Control Force	2	AB-19	4	Tension	Normal	Rod End	285-0326-3	W.L. -57.00
Control Force	3	AB-19	4	Tension	Normal	Rod End	285-0326-3	W.L. -57.00

TABLE E.2-2

THERMOCOUPLE SUMMARY

General Location	Thermocouple Identification	Number Thermocouples Involved	Blade Station or HUB W. L.	Blade	Specific Location
1. Coupling	BC-2, #1 thru 4	4	103.5	Blue	Coupling No. 2, Dwg. 285-1002
	BC-4, #1 thru 4	4	128.5	Blue	Coupling No. 4, Dwg. 285-1002
	BC-6, #1 thru 4	4	153.5	Blue	Coupling No. 6, Dwg. 285-1002
	BC-8, #1 thru 4	4	178.5	Blue	Coupling No. 8, Dwg. 285-1002
	BC-10, #1 thru 4	4	203.5	Blue	Coupling No. 10, Dwg. 285-1002
	BC-12, #1 thru 4	4	228.5	Blue	Coupling No. 12, Dwg. 285-1002
	BC-14, #1 thru 4	4	253.5	Blue	Coupling No. 14, Dwg. 285-1002
	BC-16, #1 thru 4	4	278.5	Blue	Coupling No. 16, Dwg. 285-1002
	BC-18, #1 thru 4	4	303.5	Blue	Coupling No. 18, Dwg. 285-1002
	RC-2, #1 thru 4	4	103.5	Red	Coupling No. 2, Dwg. 285-1002
	RC-18, #1 thru 4	4	303.5	Red	Coupling No. 18, Dwg. 285-1002
	YC-2, #1 thru 4	4	103.5	Yellow	Coupling No. 2, Dwg. 285-1002
	YC-18, #1 thru 4	4	303.5	Yellow	Coupling No. 18, Dwg. 285-1002
2. Mast	#1	1	WL-34	------	Lower Bearing Housing Dwg. 285-0937
	#2	1	WL-13	------	Mast Structure, Dwg. 285-0937

TABLE E.2-2 (Continued)

THERMOCOUPLE SUMMARY

General Location	Thermocouple Identification	Number Thermocouples Involved	Blade Station or HUB W.L.	Blade	Specific Location
2. Mast	#3	1	WL-8	-----	Mast Structure, Dwg. 285-0937
	#4	1	WL-1.0	-----	Mast Structure, Dwg. 285-0937
	#5	1	WL-6.5	-----	Spoke, Inboard Section, Dwg. 285-0937
	#6	1	WL-6.5	-----	Spoke, Station 7.0 (half-way out), Dwg. 285-0937
	#7	1	WL-6.5	-----	Spoke Station 14.0 (at tip), Dwg. 285-0937
	#8	1	WL-2.5	-----	Outer Skirt of Gimbal fitting, Dwg. 285-0937
3. Misc.	BBJ-1	1	21.88	Blue	Inner Surface ball joint, at top, Dwg. 285-0949
	BHD-1	1	15.50	Blue	Outer Surface of inboard articulated Duct seal housing at top, Dwg. 285-0951
	H-1	1	-------	-----	Hub cooling air near spoke
4. Ribs	BR-1	1	33.25	Blue	Inner surface closest to duct at top, Rib at Sation 33.25, Dwg. 285-0949
	BR-2	1	63.0	Blue	Inner surface closest to duct at top, Rib at Station 63.0, Dwg. 285-0950

TABLE E.2-2 (Continued)

THERMOCOUPLE SUMMARY

General Location	Thermocouple Identification	Number Thermocouples Involved	Blade Station or HUB W.L.	Blade	Specific Location
4. Ribs	BR-3	1	73.0	Blue	Inner surface closest to duct at top, Rib at Station 73.0, Dwg. 285-0950
5. Segments	BS-1, #1 thru 6	6	10B	Blue	On Rib No. 9, Segment No. 1, Dwg. 285-1002
	BS-1, #1 thru 10	4	97	Blue	Ribs, outer surface of skin, Segment No. 1, Dwg. 285-1002
	BS-1, #11 thru 14	4	97	Blue	Between ducts on Rib No. 5, Segment No. 1, Dwg. 285-1002
	BS-18, #1 thru 6 and No. 11	7	321	Blue	Segment No. 18, Rib No. 5, Dwg. 285-1002
	BS-18, #7 thru 10	4	321	Blue	Segment No. 18, outer skin, Rib No. 5, Dwg. 285-1002
6. Spars	BFS-1	1	83.1	Blue	Front spar, Neutral Axis
	BFS-2	1	135.38	Blue	Front spar, Neutral Axis
	BFS-3	1	206	Blue	Front spar, Neutral Axis
	BRS-1	1	83.3	Blue	Rear spar, Neutral Axis
	BRS-2	1	135.38	Blue	Rear spar, Neutral Axis
	BRS-3	1	206	Blue	Rear spar, Neutral Axis

TABLE E.2-2 (Continued)

THERMOCOUPLE SUMMARY

General Location	Thermocouple Identification	Number Thermocouples Involved	Blade Station or HUB W.L.	Blade	Specific Location
6. Spars	C13	1	206	Blue	Front spar, top
	C14	1	206	Blue	Front spar, bottom
	C15	1	78.3	Blue	Front spar, top
	C16	1	78.3	Blue	Front spar, bottom
	C17	1	270	Blue	Aft spar, top
	C18	1	270	Blue	Aft spar, bottom
	C19	1	206	Blue	Aft spar, top
	C20	1	206	Blue	Aft spar, bottom
	C21	1	135.3	Blue	Aft spar, top
	C22	1	135.3	Blue	Aft spar, bottom
	C23	1	78.3	Blue	Aft spar, top
	C24	1	78.3	Blue	Aft spar, bottom
7. Cooling Ducts	BCD-1	1	330	Blue	Probe, front spar cooling duct
	BCD-2	1	321	Blue	Probe, rear spar cooling duct
	BCD-5	1	78	Blue	Probe, main duct cooling space outboard of Station 73 near exit hole in upper skin

TABLE E.2-2 (Continued)

THERMOCOUPLE SUMMARY

General Location	Thermocouple Idendification	Number Thermocouples Involved	Blade Station or HUB W.L.	Blade	Specific Location
7. Cooling Ducts	Cooling Air	1	57	Blue	Probe, main duct cooling space near exit hole in bottom skin
	RCDF	1	325	Red	Probe, front spar cooling duct
	RCDR	1	325	Red	Probe, rear spar cooling duct
	Cooling Air	1	78	Red	Probe, main duct cooling space near exit hole in upper skin
	Cooling Air	1	57	Red	Probe, main duct cooling space near exit hole in lower skin
	YCDF	1	325	Yellow	Probe, front spar cooling duct
	YCDR	1	325	Yellow	Probe, Aft spar cooling duct
	Cooling Air	1	78	Yellow	Probe, main duct cooling space near exit hole in upper skin
	Cooling Air	1	57	Yellow	Probe, main duct cooling space, near exit hole in lower skin
8. Primary Ducts	C1	1	325	Blue	Probe, centered in aft duct 1" upstream of rotor tip nozzle cascade
	C2	1	325	Blue	Probe, centered in forward duct 1" upstream of rotor tip nozzle cascade

TABLE E.2-2 (Continued)

THERMOCOUPLE SUMMARY

General Location	Thermocouple Identification	Number Thermocouples Involved	Blade Station or HUB W.L	Blade	Specific Location
9. Seal Gimbal Ring	Gimbal Ring	1	19	Blue	Duct Gimbal ring, Dwg. 285-0178
	Gimbal Ring	1	19	Red	Duct Gimbal ring, Dwg. 285-0178
	Gimbal Ring	1	19	Yellow	Duct Gimbal ring, Dwg. 285-0178

APPENDIX F

NOMENCLATURE AND COMPUTER PROGRAM FORMATS

F.1 INTRODUCTION

This section provides the nomenclature, input and output format, and computer program listing for the thermodynamics and aerodynamics of the hot cycle system. This information is included in this appendix for convenience and is introduced and discussed further in Section 5.1.5 and Appendix D.

F. 2 Nomenclature

Analysis	Fortran Program	Definition
a	A	Velocity of sound; Slope of lift curve in radians
A	BAD	Total duct cross-section area - square feet
A_D		Duct cross-section area per blade - square feet
A_N	ANT	Total nozzle area at blade tips - square feet
b	B	Number of blades
B		Tip loss factor (assumed = 0.97)
c	C	Blade chord - inches
c_p	CP	Specific heat at constant pressure - BTU/pound-°F
c_v	CV	Specific heat at constant volume - BTU/pound-°F
C	CORR	Profile power increase
C_I		Calculated hub pressure loss coefficient based on hub area - weighted total pressure, Branch I
C_{II}		Calculated hub pressure loss coefficient based on hub area - weighted total pressure, Branch II
C'_I	C1	Estimated turning pressure loss coefficient through hub, Branch I
C'_{II}	C2	Estimated turing pressure loss coefficient through hub, Branch II
C_i	C1	Power correction factor for blade twist
C_f		Nozzle thrust coefficient
C_p	CA	Nozzle power coefficient $= \frac{RHP \times 550}{\rho \pi R^2 V_t^3}$

Analysis	Fortran Program	Definition
C_T	CT	Rotor thrust coefficient = $\frac{T}{\rho \pi R^2 V_t^2}$
C_{V_e}, C_{V_f}	CF	Nozzle velocity coefficient
C_w		Nozzle flow coefficient
dr		Increment of blade length - feet
D		Duct hydraulic diameter - $\frac{4 \times A_D}{\text{wetted perimeter}}$
E		Number of gas generators
f	F	Duct friction coefficient
g		Acceleration due to gravity - 32.2 feet/seconds^2
GN1, GN2, GN3	GN1, GN2, GN3	$T_g/T = GN1 + GN2\left(\frac{C_T}{\delta}\right) + GN3\left(\frac{C_T}{\delta}\right)^2$
h_{T_2}		Compressor inlet total enthalpy
h_{T_7}		Turbine discharge total enthalpy
J		Mechanical equivalent of heat - 778 feet-pound/BTU
M	AM	Mach number
n		Blade station index number for 100 step computation, n = 0, 1, 2, 3, ... 99.
N_1		Low pressure compressor rpm
N_2		Low pressure compressor rpm
P_{amb}	PAMB	Ambient pressure - in Hg

ANALYSIS
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Analysis	Fortran Program	Definition
P_o		Ambient pressure - pound/feet^2
P_t	PT	Gas total pressure - pound/feet^2 (absolute)
P_{T_7}		Turbine discharge total pressure
P_{T_c} or P_c	PT or P	Total and static pressures described by Figure D-2, P_{1-24} readout
r		Gas total pressure ratio, P_T/P_o.
r_3/r_2	R3R2	Static duct pressure ratio
R		Gas constant
R	RAD	Blade radius, feet
Re		Reynolds number
t/c	TCR	Blade thickness ratio
T	T	Rotor thrust - pounds
T_{amb}	TAMB	Ambient Temperature
$T_{t_{1-4}}$		Total temperatures described by Figure D-2, T_{1-24} readout
T_T	TT	Gas total temperature - ^oR
T_{T_7}	TT7	Turbine discharge total temperature
Tg/T	TGTi	Ground effect parameter = $\frac{\text{T in ground effect}}{\text{T out of ground effect}}$
U	U	Duct utilization = $\frac{\text{duct area}}{\text{blade cross - section area}}$
v	V	Velocity
V_j	Vj	Jet velocity at blade tip - foot/second

Analysis	Fortran Program	Definition
V_T	VT	Blade tip speed - feet/second
W		Flow rate
W_7		Turbine discharge flow rate
W_f	WF	Fuel flow rate
W	WG	Total gas flow, pound/second = EXW_g
W_g	WG	Gas flow per engine, pound/second
X_1	X1	$\frac{\text{Mass weighted total pressure}}{\text{max. total pressure}}$, flow measuring Sta. I
X_2	X2	$\frac{\text{Mass weighted total pressure}}{\text{max. total pressure}}$, flow measuring Sta. II
Z_1	Z1	$\frac{\text{Area weighted velocity}}{\text{max. velocity}}$, Branch I
Z_2	Z2	$\frac{\text{Area weighted velocity}}{\text{max. velocity}}$, Branch II
γ	GAMMA	Ratio of specific heats - c_p/c_v
δ	DEL	Temperature droop of gas at blade tip below temperature of gas or blade root
δ_i		Coefficients of NASA drag polar
μ	MU	Absolute viscosity
ρ	RHO	Density
σ		Blade solidity ratio
ω		Rotor angular velocity - radius/second

SUPERSCRIPTS

—		Mass weighted value

SUBSCRIPTS

0		Ambient air away from engine
1		Face of gas generator

Analysis	Fortran Program	Definition
2		Hub measuring station
3		Blade root
4		Blade tip and nozzle inlet
5		Nozzle exit
I		Branch I
II		Branch II
aw		Area weighted value
e		Position at edge of flow station rake
f_s		Flow measuring station
hub		Hub station below rotating seal
max		Maximum value at center of duct
ref		Reference value
res		Reservoir value
tot		Total or summation
T		Total or stagnation

FIGURE F. 3-1 INPUT FORMAT

HUGHES TOOL COMPANY-AIRCRAFT DIVISION

MODEL | REPORT NO 285-16 (62-16) | PAGE F. 3-1

ANALYSIS

PREPARED BY

CHECKED BY

HOT CYCLE HELICOPTER -
WHIRL TEST DATA
INPUT TO COMPUTER PROGRAM

DATE		2/28/62
RUN NO.		35
1	Z_1	.935
2	Z_2	.927
3	X_1	.442
4	X_2	.440
5	C_1	.01
6	C_2	.01
7	P_{amb}	30.17
8	RPM	240
9	W_f	6500
10	T_{T2}	54
11	P_{T7}	71.37
12	T_1	1143
13	T_2	1143
14	T_3	1142
15	T_4	1137
16	P_{res}	68.61
17	T_{T7}	665
18	P_1	-20.90
19	P_2	-4.70
20	P_3	-7.80
21	P_4	-3.60
22	P_5	-5.70
23	P_6	-4.30
24	P_7	-6.15
25	P_8	-25.50
26	P_9	-11.10
27	P_{10}	-11.40
28	P_{11}	-9.30
29	P_{12}	-8.70
30	P_{13}	-8.60
31	P_{14}	-12.50
32	P_{15}	-5.90
33	P_{16}	-6.40
34	P_{17}	-7.70
35	P_{18}	-10.10
36	P_{19}	-13.60
37	P_{20}	-11.10
38	P_{21}	-13.90
39	P_{22}	-17.00
40	P_{23}	-11.20
41	P_{24}	-11.80
42	RAD	27.5
43	C	31.5
44	B	3.

9704

ANALYSIS

PREPARED BY

CHECKED BY

MODEL

REPORT NO

HOT CYCLE HELICOPTER -
WHIRL TEST DATA
INPUT TO COMPUTER PROGRAM

DATE		
RUN NO.		35
45	TOR	.18
46	RAD	1.1417
47	R3R2	.98
48	F	1.004
49	CF	.955
50	ANT	.7375
51	GM1	1.21
52	GM2	-3.0
53	GM3	12.5
54	CORR	1.0

FIGURE F. 3-2 INPUT FORMAT - LISTING OF INPUT DATA CARDS

```
 275   315 3   18     114166   98      004     955     7375
 121    -3      125        935     927     442     440    1
 3017   240     0  6500    54   7137 1143 1143 1142 1137  6861  665
-2090  -470   -780  -360   -570   -430   -615 -2550 -1110 -1140  -930  -870
 -860 -1250   -590  -640   -770 -1010 -1360 -1110 -1390 -1700 -1120 -1180
  35    01          01
```

1

FIGURE F.3-3 PRINTOUT

```
     XEQ

ENTRY POINTS TO SUBROUTINES REQUESTED FROM LIBRARY,
   (FPT)     (TSHM)     (RTN)     (STHM)     (FIL)     SQRT)     EXP(

     EXECUTION  TIME  1659
   RAD = 27.5   CHORD = 31.5   NO. BLADES =3.   T/C =0.18   TOTAL DUCT AREA = 1.1
   G = 0.00400   CF = 0.95500   TOTAL NOZZLE AREA = 0.73750
   T6/TI =  1.2100  +  -3.0000 X CT/S + 12.5000 X CT/S X CT/S,    Z1 = 0.9350   Z2
  K1 = 0.4420   X2 = 0.4400   PROFILE CORR. = 1.0000
   TEST =   35    C1 =  0.01000   C2 =  0.01000
   PAMB =  30.17   RPM = 240.   DEL =   0.   WF LB/HR =  6500.   TAMB F =   54.
  FLOW ST. TEMP F =  1143.  1143.  1142.  1137.   PRES =  68.61
  FROW ST. PRESS = -20.90  -4.70  -7.80  -3.60  -5.70  -4.30  -6.15 -25.90 -11.10
 -8.60 -12.50  -5.90  -6.40  -7.70 -10.10 -13.60 -11.10 -13.90 -17.00 -11.20 -11.8
  ET7 =   665.
   WF =     0.10202E 03    WF/WA =     0.18017E-01    O/O AIR =     0.37576E 03    RN
   QR =     0.27748E-00    CV =     0.20893E-00    GAMMA =     0.13281E 01
   FLOW MEASURING STATION
      BRANCH              1                  2                   BRANCH            1
      TT              0.16030E 04       0.15995E 04              PMAX           0.4531
      PTMAX           0.47861E 04       0.47200E 04              MMAX           0.2881
      TMAX            0.15815E 04       0.15773E 04              AMAX           0.1898
      VMAX            0.54704E 03       0.55539E 03              RHOMAX         0.5371
      MUMAX           0.95087E-01       0.94958E-01              REMAX          0.1135
      VAVG            0.51148E 03       0.51484E 03              MAVG           0.2694
      TAVG            0.15841E 04       0.15804E 04              RHOAVG         0.5362
      AAVG            0.19000E 04       0.18978E 04              (VAVG)CORR     0.5119
      W               0.22454E 02       0.22305E 02
      TOTAL GAS FLOW  =      0.44759E 02
   FLOW MEASURING STAT. MASS WEIGHTED MEAN TOTAL PRESSURE
   BRANCH 1 =      0.47565E 04     BRANCH 2 =      0.46888E 04
   HUB STATION TOTAL TEMP =     0.16012E 04
   VELOCITY PROFILE FLOW MEASURING STATION
   VELOCITY PROFILE BRANCH 1
   PT1 =     0.47800E 04     PT3 =     0.47323E 04     PT5 =     0.47969E 04     PT7 =
   PT9 =     0.47861E 04     PTE =     0.47577E 04      M1 =     0.28473E-00      M3 =
    M5 =     0.29404E-00      M7 =     0.27597E-00      M9 =     0.28815E-00      ME =
  V1/VMAX =     0.98812E 00    V3/VMAX =     0.89026E 00    V5/VMAX =     0.10204E 01
  V7/VMAX =     0.95772E 00    V9/VMAX =     0.10000E 01    VE/VMAX =     0.93370E 00
   VELOCITY PROFILE BRANCH 2
   PT2 =     0.46816E 04     PT4 =     0.46770E 04     PT6 =     0.47093E 04     PT8 =
  PT10 =     0.47200E 04     PTE =     0.46601E 04      M2 =     0.27082E-00      M4 =
    M6 =     0.28693E-00      M8 =     0.29209E-00     M10 =     0.29294E-00      ME =
  V2/VMAX =     0.92451E 00    V4/VMAX =     0.91500E 00    V6/VMAX =     0.97950E 00
  V8/VMAX =     0.99710E 00   V10/VMAX =     0.10000E 01    VE/VMAX =     0.89919E 00
   HUB STATION AREA WEIGHTED TOTAL PRESSURE BRANCH 1 =     0.47229E 04
   PT15 =     0.47615E 04     PT17 =     0.47538E 04     PT19 =     0.47339E 04     PT21
   HUB STATION AREA WEIGHTED TOTAL PRESSURE BRANCH 2 =     0.46557E 04
   PT16 =     0.46816E 04     PT18 =     0.46386E 04     PT20 =     0.45910E 04     PT22
   HUB STATION TOTAL PRESSURE, MASS WEIGHTED, CALCULATED
   BRANCH 1 =     0.47060E 04     BRANCH 2 =     0.46383E 04     AVERAGE =     0.46722E
  C1 = 0.00666    C2 = 0.00656    101 = 0.05763    101A = 0.01000    102 = 0.0676
  103 = 0.07103    103A = 0.01000    104 = 0.08103
   DESIGN M3 = 0.4245    PRESS RATIO = 0.95765    R4 = 2.05507    CT/SOLID = 0.080780
   ROTOR THRUST =     20192.    DISC LOADING =     8.5033    R2 =    2.1898
   CP =     0.57326E-03     CPO =     0.12907E-03     CT =     0.69932E-02
```

```
ED FROM LIBRARY,
     (STHM)       (FIL)        SQRT)        EXP(3

BLADES =3.   T/C =0.18   TOTAL DUCT AREA = 1.14166   R3/R2 = 0.980
AL NOZZLE AREA = 0.73750
/S + 12.5000 X CT/S X CT/S,    Z1 = 0.9350   Z2 = 0.9270
LE CORR. = 1.0000
C2 =  0.01000
=   0.   WF LB/HR =  6500.   TAMB F =   54.   PT7 =  71.37
1142.  1137.   PRES =  68.61
7.80  -3.60  -5.70  -4.30  -6.15 -25.80 -11.10 -11.40  -9.30  -8.70
-10.10 -13.60 -11.10 -13.90 -17.00 -11.20 -11.80

 0.18017E-01   O/O AIR =    0.37576E 03    RN =     0.53340E 02
.20893E-00   GAMMA =    0.13281E 01

    2                     BRANCH              1              2
  0.15995E 04             PMAX           0.45310E 04    0.44604E 04
  0.47200E 04             MMAX           0.28815E-00    0.29294E-00
  0.15773E 04             AMAX           0.18984E 04    0.18959E 04
  0.55539E 03             RHOMAX         0.53714E-01    0.53015E-01
  0.94958E-01             REMAX          0.11358E 07    0.11397E 07
  0.51484E 03             MAVG           0.26942E-00    0.27155E-00
  0.15804E 04             RHOAVG         0.53623E-01    0.52912E-01
  0.18978E 04             (VAVG)CORR     0.51191E 03    0.51535E 03
  0.22305E 02
9E 02
ED MEAN TOTAL PRESSURE
NCH 2 =     0.46888E 04
012E 04
STATION

 0.47323E 04    PT5 =     0.47969E 04    PT7 =     0.47646E 04
 0.47577E 04     M1 =     0.28473E-00     M3 =     0.25653E-00
 0.27597E-00     M9 =     0.28815E-00     ME =     0.27193E-00
K =     0.89026E 00   V5/VMAX =     0.10204E 01
K =     0.10000E 01   VE/VMAX =     0.98370E 00

 0.46770E 04    PT6 =     0.47093E 04    PT8 =     0.47185E 04
 0.46601E 04     M2 =     0.27082E-00     M4 =     0.26804E-00
 0.29209E-00    M10 =     0.29294E-00     ME =     0.25755E-00
K =     0.91500E 00   V6/VMAX =     0.97950E 00
K =     0.10000E 01   VE/VMAX =     0.81919E 00
PRESSURE BRANCH 1 =    0.47229E 04
  0.47538E 04    PT19 =    0.47339E 04    PT21 =    0.46970E 04    PT23 =    0.4643
PRESSURE BRANCH 2 =    0.46557E 04
  0.46386E 04    PT20 =    0.45910E 04    PT22 =    0.46801E 04    PT24 =    0.4670
 WEIGHTED, CALCULATED
NCH 2 =    0.46383E 04    AVERAGE =    0.46722E 04
01 =  0.05763    101A =  0.01000   102 =  0.06763
  104 =  0.08103
 = 0.95765   R4 = 2.05507   CT/SOLID = 0.080780   RHP =   1972.
 LOADING =   8.5033    R2 =   2.1898
0.12907E-03    CT =    0.69932E-02
```

```
C       HOT CYCLE TEST DATA REDUCTION
        READINPUTTAPE3,100,RAD,C,B,TCR,BAD,R3R2,F,CF,ANT
        READINPUTTAPE3,101,GN1,GN2,GN3,Z1,Z2,X1,X2,CORR
        WRITEOUTPUTTAPE2,102,RAD,C,B,TCR,BAD,R3R2,F,CF,ANT,GN1,GN2,GN3,Z1,
       1Z2,X1,X2,CORR
1       READINPUTTAPE3,103,PAMB,RPM,DEL1,WF,TT2,PT7,T1,T2,T3,T4,PRES,TT7
        READINPUTTAPE3,104,P1,P2,P3,P4,P5,P6,P7,P8,P9,P10,P11,P12
        READINPUTTAPE3,104,P13,P14,P15,P16,P17,P18,P19,P20,P21,P22,P23,P24
        READINPUTTAPE3,106,TEST,C11,C21
        WRITEOUTPUTTAPE2,107,TEST,C11,C21
        WRITEOUTPUTTAPE2,105,PAMB,RPM,DEL1,WF,TT2,PT7,T1,T2,T3,T4,PRES,P1,
       1P2,P3,P4,P5,P6,P7,P8,P9,P10,P11,P12,P13,P14,P15,P16,P17,P18,P19,P2
       20,P21,P22,P23,P24,TT7
        VT=(RPM*6.28*RAD)/60.
        DR=(17.32*PAMB)/(TT2+460.)
        P=70.721*PAMB
        CALL ENPR(WF,TT2,TT7,R,GAMMA,CP)
        CALL FLRAT(GAMMA,R,T1,T2,PRES,P1,P6,T3,T4,P8,P13,Z1,Z2,X1,X2,WTOT,
       1PREF,P1M,P2M,PT1B,PT2B,TTHUB)
        CALL VELPR(P2,P3,P4,P5,P6,P7,PREF,P1M,P2M,GAMMA,P9,P10,P11,P12,P13
       1,P14)
        CALL EXTRA(PREF,P15,P16,P17,P18,P19,P20,P21,P22,P23,P24,PT7,PT1B,P
       1T2B,PTHB,C11,C21)
        CALL POWER(RAD,C,B,VT,GAMMA,TCR,BAD,DR,WTOT,TTHUB,PTHB,R3R2,F,CP,C
       1F,P,ANT,DEL1,GN1,GN2,GN3,CORR)
        WRITEOUTPUTTAPE2,110
        GOTO1
100     FORMAT(2F5.1,F2.0,6F7.5)
101     FORMAT(8F7.4)
102     FORMAT( 9H    RAD =F5.1,10H   CHORD =F5.1,15H   NO. BLADES =F2.0,8
       1H   T/C =F4.2,20H   TOTAL DUCT AREA =F8.5,10H   R3/R2 =F6.3/7H
       2F =F8.5,7H   CF =F8.5,22H   TOTAL NOZZLE AREA =F8.5/11H   TG/TI =
       3F8.4,4H  + F8.4,9H X CT/S +F8.4,23H X CT/S X CT/S,   Z1 =F7.4,7H
       4  Z2 =F7.4/7H   X1 =F7.4,7H   X2 =F7.4,18H   PROFILE CORR. =F7.4)
103     FORMAT(F6.2,2F5.0,F6.0,F5.0,F6.2,4F5.0,F6.2,F5.0)
104     FORMAT(12F6.2)
105     FORMAT(10H    PAMB =F7.2,8H   RPM =F5.0,7H  DEL =F5.0,13H   WF LB/
       1HR =F7.0,11H   TAMB F =F6.0,8H   PT7 =F7.5/20H   FLOW ST. TEMP F =
       24F7.0,9H   PRES =F7.2/19H   FLOW ST. PRESS =12F7.2/12F7.2/8H   TT7
       3 =F7.0)
110     FORMAT(1H1)
106     FORMAT(I5,2F8.5)
107     FORMAT(10H    TEST =I5,8H    C1 =F9.5,8H    C2 =F9.5)
111     FORMAT(8F9.0)
112     FORMAT(8H   RPM =F6.0,9H   PAMB =F6.2,9H   TAMB =F4.0,7H   WG =F6.
       12,9H   THUB =6.0,9H   PHUB =F7.0,7H   CP =F6.4,10H   GAMMA =F7.3)
110     FORMAT(1H /1H /1H /)
```

```
      SUBROUTINE ENPR(WF1,TT21,TT71,R,GAMMA,CP)
      WF=WF1/3600.
      TT2=TT21+460.
      TT7=1.8*(TT71+17.8)+460.
      HT2=120.42+.2477*(TT2-500.)
      IF(TT7-1000.)1,1,2
1     HT7=120.42+.2477*(TT7-500.)
      GOTO5
2     IF(TT7-1500.)3,3,4
3     HT7=244.25+.2627*(TT7-1000.)
      GOTO5
4     HT7=375.62+.2819*(TT7-1500.)
5     W7=((17664.-HT7)*WF)/(HT7-HT2)
      WFWA=WF/(W7-WF)
      PAIR=6.77/WFWA
      R=.0095*WFWA+53.34
      TT7C=TT7/180.
      IF(TT7-990.)6,6,7
6     CP=(.243-.08*WFWA)-(.00343-.115*WFWA)*TT7C+(.0008-.008*WFWA)*TT7C*
     1TT7C
      GOTO10
7     IF(TT7-1530.)8,8,9
8     CP=(.217-.157*WFWA)+(.0057+.0267*WFWA)*TT7C
      GOTO10
9     CP=(.334+.9*WFWA)-((.834+7.6*WFWA+10.*WFWA*WFWA)/(TT7C+3.65+20.*WF
     1WA))
10    CV=CP-.06855
      GAMMA=CP/CV
      WRITEOUTPUTTAPE2,100,W7,WFWA,PAIR,R,CP,CV,GAMMA
100   FORMAT(8H     WF =E15.5,11H     WF/WA =E15.5,13H     O/O AIR =E15.5,8
     1H    RN =E15.5/8H     CP =E15.5,8H     CV =E15.5,11H     GAMMA =E15.5
     2)
      RETURN
```

```
      SUBROUTINE FLRAT(GAMMA,R,T1,T2,PRES,P1,P6,T3,T4,P8,P13,Z1,Z2,X1,X2
     1,WTOT,PREF,P1M,P2M,PT1B,PT2B,TTHUB)
      A=1.937348
      B=1.780448 E-02
      C=-4.170257 E-06
      D=5.805605 E-10
      E=-2.156955 E-14
      F=4.32 E-03
      TT1=(T1+T2)/2.+460.
      PREF=PRES*70.721
      P1M=P1*15.365+PREF
      PT1M=P6*15.365+PREF
      CO1=(GAMMA-1.)/GAMMA
      CO2=(GAMMA-1.)/2.
      AM1M2=(1./CO2)*((PT1M/P1M)**CO1-1.)
      AM1M=SQRT1F(AM1M2)
      T1M=TT1/(1.+CO2*AM1M*AM1M)
      A1M2=GAMMA*32.17*R*T1M
      A1M=SQRT1F(A1M2)
      V1M=A1M*AM1M
      RH1M=P1M/(R*T1M)
      AMU1M=(A+B*TT1+C*(TT1**2)+D*(TT1**3)+E*(TT1**4))*F
      RE1M=(RH1M*V1M*1.021*3600.)/AMU1M
      V1A=Z1*V1M
      AM1A=(V1A*AM1M)/V1M
      T1A=TT1/(1.+CO2*AM1A*AM1A)
      RH1A=P1M/(R*T1A)
      A1A2=GAMMA*32.17*R*T1A
      A1A=SQRT1F(A1A2)
      V1AC=A1A*AM1A
      W1=RH1A*V1AC*.818
      TT2=(T3+T4)/2.+460.
      P2M=P8*15.365+PREF
      PT2M=P13*15.365+PREF
      AM2M2=(1./CO2)*((PT2M/P2M)**CO1-1.)
      AM2M=SQRT1F(AM2M2)
      T2M=TT2/(1.+CO2*AM2M*AM2M)
      A2M2=GAMMA*32.17*R*T2M
      A2M=SQRT1F(A2M2)
      V2M=A2M*AM2M
      RH2M=P2M/(R*T2M)
      AMU2M=(A+B*TT2+C*(TT2**2)+D*(TT2**3)+E*(TT2**4))*F
      RE2M=(RH2M*V2M*1.021*3600.)/AMU2M
      V2A=Z2*V2M
      AM2A=(V2A*AM2M)/V2M
      T2A=TT2/(1.+CO2*AM2A*AM2A)
      RH2A=P2M/(R*T2A)
      A2A2=GAMMA*32.17*R*T2A
      A2A=SQRT1F(A2A2)
      V2AC=A2A*AM2A
      W2=RH2A*V2AC*.818
      WTOT=W1+W2
      WRITEOUTPUTTAPE2,100
      WRITEOUTPUTTAPE2,101,TT1,TT2,P1M,P2M,PT1M,PT2M,AM1M,AM2M,T1M,T2M,A
     11M,A2M,V1M,V2M,RH1M,RH2M,AMU1M,AMU2M,RE1M,RE2M,V1A,V2A,AM1A,AM2A,T
     21A,T2A,RH1A,RH2A,A1A,A2A,V1AC,V2AC,W1,W2,WTOT
  100 FORMAT(26H     FLOW MEASURING STATION/97H          BRANCH           1
     1                         2                        BRANCH          1
     2     2)
      CO3=1./(2.*(GAMMA-1.))
```

```
      CO4=(V1M*V1M)/(32.17*R*T1M)
      PT1B=P1M*(1.+X1*(1.+CO3*(TT1/T1M-1.))*CO4)
      CO5=(V2M*V2M)/(32.17*R*T2M)
      PT2B=P2M*(1.+X2*(1.+CO3*(TT2/T2M-1.))*CO5)
      WRITEOUTPUTTAPE2,102,PT1B,PT2B
      TTHUB=(TT1+TT2)/2.
      WRITEOUTPUTTAPE2,103,TTHUB
103   FORMAT(28H    HUB STATION TOTAL TEMP =E15.5)
102   FORMAT(58H    FLOW MEASURING STAT. MASS WEIGHTED MEAD TOTAL PRESSU
     1RE/14H    BRANCH 1 =E16.5,14H    BRANCH 2 =E16.5)
101   FORMAT(18H            TT          2E16.5,22H           PMAX          2E16.5
     1/18H          PTMAX       2E16.5,22H           MMAX          2E16.5/18H
     2          TMAX        2E16.5,22H           AMAX          2E16.5/18H
     3VMAX          2E16.5,22H           RHOMAX        2E16.5/18H           MUMAX
     4     2E16.5,22H           REMAX         2E16.5/18H           VAVG          2E
     516.5,22H           MAVG          2E16.5/18H           TAVG          2E16.5,2
     62H          RHOAVG        2E16.5/18H           AAVG          2E16.5,22H
     7          (VAVG)CORR   2E16.5/18H           W             2E16.5/25H           TO
     8TAL GAS FLOW  =E16.5)
      RETURN
```

```
      SUBROUTINE VELPR(P2,P3,P4,P5,P6,P7,PREF,P1M,P2M,GAMMA,P9,P10,P11,P
     112,P13,P14)
      PT11=P2*15.365+PREF
      PT31=P3*15.365+PREF
      PT51=P4*15.365+PREF
      PT71=P5*15.365+PREF
      PT91=P6*15.365+PREF
      PTE1=P7*15.365+PREF
      G1=2./(GAMMA-1.)
      G2=(GAMMA-1.)/GAMMA
      AM112=G1*((PT11/P1M)**G2-1.)
      AM312=G1*((PT31/P1M)**G2-1.)
      AM11=SQRT1F(AM112)
      AM31=SQRT1F(AM312)
      AM512=G1*((PT51/P1M)**G2-1.)
      AM712=G1*((PT71/P1M)**G2-1.)
      AM912=G1*((PT91/P1M)**G2-1.)
      AME12=G1*((PTE1/P1M)**G2-1.)
      AM51=SQRT1F(AM512)
      AM71=SQRT1F(AM712)
      AM91=SQRT1F(AM912)
      AME1=SQRT1F(AME12)
      V1VM1=AM11/AM91
      V3VM1=AM31/AM91
      V5VM1=AM51/AM91
      V7VM1=AM71/AM91
      V9VM1=1.
      VE1VM1=AME1/AM91
      PT22=P9*15.365+PREF
      PT42=P10*15.365+PREF
      PT62=P11*15.365+PREF
      PT82=P12*15.365+PREF
      PT102=P13*15.365+PREF
      PTE2=P14*15.365+PREF
      AM222=G1*((PT22/P2M)**G2-1.)
      AM22=SQRT1F(AM222)
      AM422=G1*((PT42/P2M)**G2-1.)
      AM622=G1*((PT62/P2M)**G2-1.)
      AM822=G1*((PT82/P2M)**G2-1.)
      AM1022=G1*((PT102/P2M)**G2-1.)
      AME22=G1*((PTE2/P2M)**G2-1.)
      AM42=SQRT1F(AM422)
      AM62=SQRT1F(AM622)
      AM82=SQRT1F(AM822)
      AM102=SQRT1F(AM1022)
      AME2=SQRT1F(AME22)
      V2VM2=AM22/AM102
      V4VM2=AM42/AM102
      V6VM2=AM62/AM102
      V8VM2=AM82/AM102
      V10VM2=1.
      VE2VM2=AME2/AM102
      WRITEOUTPUTTAPE2,102
      WRITEOUTPUTTAPE2,100,PT11,PT31,PT51,PT71,PT91,PTE1,AM11,AM31,AM51,
     1AM71,AM91,AME1,V1VM1,V3VM1,V5VM1,V7VM1,V9VM1,VE1VM1
      WRITEOUTPUTTAPE2,101,PT22,PT42,PT62,PT82,PT102,PTE2,AM22,AM42,AM62
     1,AM82,AM102,AME2,V2VM2,V4VM2,V6VM2,V8VM2,V10VM2,VE2VM2
  100 FORMAT(29H     VELOCITY PROFILE BRANCH 1/9H     PT1 =E15.5,9H     PT3
     1 =E15.5, 9H     PT5 =E15.5,9H     PT7 =E15.5/9H     PT9 =E15.5,9H
     2PTE =E15.5,9H     M1 =E15.5,9H     M3 =E15.5/9H     M5 =E15.5,9H
```

```
     3   M7 =E15.5,9H      M9 =E15.5,9H      ME =E15.5/12H    V1/VMAX =E15.
     45,12H    V3/VMAX =E15.5,12H    V5/VMAX =E15.5/12H    V7/VMAX =E15.5,1
     52H    V9/VMAX =E15.5,12H    VE/VMAX =E15.5)
101  FORMAT(29H     VELOCITY PROFILE BRANCH 2/9H     PT2 =E15.5,9H     PT4
     1 =E15.5,9H     PT6 =E15.5,9H     PT8 =E15.5/9H    PT10 =E15.5,9H     P
     2TE =E15.5,9H      M2 =E15.5,9H      M4 =E15.5/9H      M6 =E15.5,9H
     3  M8 =E15.5,9H     M10 =E15.5,9H      ME =E15.5/12H    V2/VMAX =E15.5
     4,12H    V4/VMAX =E15.5,12H    V6/VMAX =E15.5/12H    V8/VMAX =E15.5,12
     5H  V10/VMAX =E15.5,12H    VE/VMAX =E15.5)
102  FORMAT(43H    VELOCITY PROFILE FLOW MEASURING STATION)
     RETURN
```

```
      SUBROUTINE EXTRA(PREF,P15,P16,P17,P18,P19,P20,P21,P22,P23,P24,PT7,
     1PT1B,PT2B,PTHB,C11,C21)
      PT15=P15*15.365+PREF
      PT17=P16*15.365+PREF
      PT19=P17*15.365+PREF
      PT21=P18*15.365+PREF
      PT23=P19*15.365+PREF
      PTH1AW=.298*PT15+.192*PT17+.169*PT19+.146*PT21+.195*PT23
      WRITEOUTPUTTAPE2,100,PTH1AW,PT15,PT17,PT19,PT21,PT23
      PT16=P20*15.365+PREF
      PT18=P21*15.365+PREF
      PT20=P22*15.365+PREF
      PT22=P23*15.365+PREF
      PT24=P24*15.365+PREF
      PTH2AW=.298*PT16+.192*PT18+.169*PT20+.146*PT22+.195*PT24
      WRITEOUTPUTTAPE2,101,PTH2AW,PT16,PT18,PT20,PT22,PT24
      PTHAW=(PTH1AW+PTH2AW)/2.
      PT7A=PT7*70.721
      C1=(PT1B-PTH1AW)/PT7A
      C2=(PT2B-PTH2AW)/PT7A
      PTH1B=PT1B-C11*PT7A
      PTH2B=PT2B-C21*PT7A
      PTHB=(PTH1B+PTH2B)/2.
      PLF1=(PT7A-PT1B)/PT7A
      PLFH1=(PT1B-PTH1B)/PT7A
      PLH1=(PT7A-PTH1B)/PT7A
      PLF2=(PT7A-PT2B)/PT7A
      PLFH2=(PT2B-PTH2B)/PT7A
      PLH2=(PT7A-PTH2B)/PT7A
      WRITEOUTPUTTAPE2,102,PTH1B,PTH2B,PTHB
      WRITEOUTPUTTAPE2,103,C1,C2,PLF1,PLFH1,PLH1,PLF2,PLFH2,PLH2
  103 FORMAT(7H    C1 =F9.5,7H    C2 =F9.5,8H    101 =F9.5,9H    101A =F9.5,
     18H    102 =F9.5/8H    103 =F9.5,9H    103A =F9.5,8H    104 =F9.5)
  100 FORMAT(55H    HUB STATION AREA WEIGHTED TOTAL PRESSURE BRANCH 1 =E
     115.5/10H    PT15 =E15.5,10H    PT17 =E15.5,10H    PT19 =E15.5,10H
     2    PT21 =E15.5,10H    PT23 =E15.5)
  101 FORMAT(55H    HUB STATION AREA WEIGHTED TOTAL PRESSURE BRANCH 2 =E
     115.5/10H    PT16 =E15.5,10H    PT18 =E15.5,10H    PT20 =E15.5,10H
     2    PT22 =E15.5,10H    PT24 =E15.5)
  102 FORMAT(57H    HUB STATION TOTAL PRESSURE, MASS WEIGHTED, CALCULATE
     1D/14H    BRANCH 1 =E15.5,14H    BRANCH 2 =E15.5,13H    AVERAGE =E1
     25.5)
      RETURN
```

```
      SUBROUTINE POWER(RAD,C,B,VT,GAMMA,TCR,BAD,DR,WG,TTHUB,PTHB,R3R2,F,
     1CP,CV,P,ANT,DEL1,GN1,GN2,GN3,CORR)
      R2=PTHB/P
      TT=TTHUB-DELI
      SOLID=(B*C)/(37.68*RAD)
      UR=(BAD*144.)/(B*TCR*C*C*.68)
      WAR=WG/BAD
      WTAP=(WAR*SQRT1F(TTHUB))/(P*R2*R3R2)
      GA1=(GAMMA-1.)/2.
      GA2=(GAMMA+1.)/(2.*(GAMMA-1.))
      ROOT=SQRT1F(.603*GAMMA)
      AM3T=.35
1     AM3=(WTAP*(1.+GA1*AM3T*AM3T)**GA2)/ROOT
      IF(ABSF(AM3-AM3T)-.0009)3,3,2
2     AM3T=AM3
      GOTO1
3     AM3D=AM3
      FGLDR=((1.1*SQRT1F(1.34*TCR*TCR+UR*UR)+TCR)*F*B*.5723)/(UR*TCR*SOL
     1ID)
      DO4I=1,100
      CON=I-1
      DM=(.01*FGLDR*AM3*AM3*AM3*(1.+GA1*AM3*AM3))/(1.-AM3*AM3)-((VT*VT*.
     10001)*(2.*CON+1.)*AM3*(1.+GA1*AM3*AM3)**2.)/(3438.96*TT*(1.-AM3*AM
     23))
4     AM3=AM3+DM
      PR=((AM3D/AM3)*((1.+GA1*AM3*AM3)/(1.+GA1*AM3D*AM3D))**GA2)
      R4=R2*R3R2*PR
      XX1=(GAMMA-1.)/GAMMA
      AET4=CP*(1.-(1./R4)**XX1)
      VJ=224.*CV*SQRT1F(AET4*TT)
      RHPWG=((VJ-VT)*VT)/17710.
      RHP=RHPWG*WG
      CPA=(RHP*550.)/(.002378*DR*3.14*RAD*RAD*VT*VT*VT)
      BT=.97
      CTT=(CPA*BT*1.414141)**.66667
9     CTST=CTT/SOLID
      TGTI=GN1+GN2*CTST+GN3*CTST*CTST
      CTOGT=CTT*TGTI
      C1=1.02+.15*CTST*TGTI
      CPO=(.00127238*SOLID-(.00294031*CTOGT)/(BT*BT)+(.05701598*CTOGT*CT
     1OGT)/(SOLID*BT*BT))*CORR
      CPI=CPA/C1-CPO
      CT=(CPI*BT*1.41414)**.66667
      IF(ABSF(CT-CTT)-.000005)10,10,13
13    CTT=CT
      GOTO9
10    CTS=CT/SOLID
      TGTI=GN1+GN2*CTS+GN3*CTS*CTS
      CTSG=CTS*TGTI
      TR=CTSG*VT*VT*RAD*RAD*.0074707*DR*SOLID
      DL=TR/(3.14*RAD*RAD)
      WRITEOUTPUTTAPE2,100,AM3D,PR,R4,CTSG,RHP,TR,DL,R2
      WRITEOUTPUTTAPE2,101,CPA,CPO,CT
101   FORMAT(8H    CP =E15.5,9H    CPO =E15.5,8H    CT =E15.5)
100   FORMAT(15H    DESIGN M3 =F7.4,16H    PRESS RATIO =F8.5,7H   R4 =F8.
     15,13H   CT/SOLID =F9.6,8H    RHP =F8.0/18H    ROTOR THRUST =F10.0,1
     28H    DISC LOADING =F9.4,8H    R2 =F9.4)
      RETURN
```

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