3 72/SYSTEMS 22/~~239~~

MOMENTUM MASS FLOW CONTROLLER
FOR MK 2
AIR CONDITIONING SYSTEM

Aug. 29, 1958

AVRO AIRCRAFT LIMITED

MALTON – ONTARIO

TECHNICAL DEPARTMENT (Aircraft)

AIRCRAFT: ARROW MK 2

REPORT NO: 72/SYSTEMS 22/239

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TITLE:

REQUIREMENT FOR, AND FUTURE DEVELOPMENT OF AN ANGULAR MOMENTUM MASS FLOW CONTROLLER FOR MK 2 AIR CONDITIONING SYSTEM

PREPARED BY [signature] DATE 2/9/58

RECOMMENDED FOR APPROVAL [signature] DATE 2/9/58

APPROVED DATE

APPROVED FOR RELEASE [signature] DATE Sept 10/58.

AVRO AIRCRAFT LIMITED
MALTON – ONTARIO

TECHNICAL DEPARTMENT

REPORT NO. 72/SYSTEMS 22/239			
SHEET NO. 1			
AIRCRAFT: ARROW MK 2	AIR CONDITIONING SYSTEM	PREPARED BY: J. Dubury	DATE: Aug. 1958
		CHECKED BY:	DATE:

Requirement for, and future developement of an angular momentum mass flow controller for MK 2 Air Conditioning System.

Basic need for mass flow controller

It is required to maintain 27.5 ± 2.5 Lb./min. air flow through the cockpit. Deficiency of flow gives inadequate cooling while excessive flow would cause both crew discomfort and some loss in engine performance. Mass flow through the Mk2 system is modulated via the variable nozzle guide vanes in the expansion turbine.
A mass flow sensing unit is needed to transmit modulating signals to the pneumatic jack operating these guide vanes.
No currently available unit appears capable of controlling the mass flow within the required limits. The reasons for this are fundamental i.e. the pressure difference across a venturi is proportional to m^2/ρ, a velocity measuring device detects m/ρ.
Thus such devices are subject to density variation errors, i.e. pressure and temperature errors. The pressure range experienced at the cockpit entry is about 6 to 16 P.S.I.A., so that these errors result in a most unsatisfactory control system.
The bleed pressures available from the P.S.13 engine are appreciably less than from a J75 so that it is most important that MK2 system pressure drops are kept to a minimum. This

imposes the additional requirement that the pressure drop though the controller should be small.

The angular momentum mass flow controller (briefly described below) fulfills both these requirements, i.e. it detects mass flow (being completely unaffected by pressure or temperature) and causes very little pressure drop.

Principle of Operation

If the flow of fluid through an elemental annulus initially having zero angular momentum is spun up to a known angular velocity then the torque required to accomplish this is given by

$$\frac{dQ}{dr} = 2\pi \rho \omega V r^3 \qquad \text{(1)}$$

Where Q is torque (Lb. Ft.)

r is radius (Ft.)

ρ is fluid density (Slugs/Ft.^{3})

V is axial velocity (Ft./Sec.)

ω is the angular velocity (Rad./Sec.)

Now, assuming that ρ, V, and ω are independent of radius equation (1) can be integrated with respect to radius. Giving;

$$Q = 2\pi \rho \omega V \int_{r_1}^{r_2} r^3 dr$$

$$= \frac{\pi}{2} \rho \omega V \left(r_2^4 - r_1^4\right) \quad \text{(LB. FT)} \qquad \text{(2)}$$

Where r_1 and r_2 inner and outer radii of the boundaries of the annular duct respectively.

Now on the basis of the flow uniformity previously mentioned.

The total mass flow,

$$m = \pi \rho V (r_2^2 - r_1^2) \quad \text{(SLUGS/SEC)}$$

$$\therefore \rho V = \frac{m}{\pi (r_2^2 - r_1^2)} \quad \text{———} \quad (3)$$

Substitution of equation (3) in equation (2) gives,

$$Q = \frac{m\omega}{2} (r_2^2 + r_1^2) \quad \text{(LB. FT)} \quad \text{———} \quad (4)$$

Thus if the angular velocity is maintained constant,

$$Q = k m \quad \text{———} \quad (5)$$

where $k = \frac{\omega}{2}(r_2^2 + r_1^2)$.

Radial maldistribution of velocity would not necessarily invalidate equn. (5) if this flow pattern was independant of pressure and temperature. This is likely to be so since Reynolds No. is independant of pressure at a given mass flow.

Test Equipment and Results to Date

The test aparatus so far constructed and tested was for the sole purpose of confirming equation (4).

The angular velocity was inparted to the air by a rotor consisting of 16 blades of 1 inch chord and .05 inches thick. The inner radius was 1 inch and the outer 2 inches. The blades were unshrouded and had a tip clearance to the outer case of about .005 inch. The leading edges of the blades were radiused and the trailing edges left square. The blade spacing was decided on the basis of cascade theory (Ref. 1)

Power was supplied by a small Globe Industries synchronous motor running on 110V 400~ supply at a synchronous speed of 24,000 rpm. A small 18.78:1 reduction gear box produced a rotor speed of 1,278 rpm.

The motor case was mounted on bearings and restrained by a spring, the springs angular deflection then being a measure of the rotor torque.

The motor case was also attached to a potentiometer so that a spring deflection potentiometer output relationship could be determined.

All swirl was removed from the air by a honeycomb upstream of the rotor.

The only test run completed to date is shown in Fig. 1. The tests were conducted with air, the flow being measured on a Flowrator upstream of the test unit.

The results were extremely satisfactory when considered in relation to the possible errors in the Flowrator, voltmeters etc.

Application to MK2 System

The apparatus described above was found to suffer the following defects.

(i) Some device such as a group of slip rings is needed to supply current to the motor.

(ii) Starting torque tends to wind the spring up with a considerable jerk.

(iii) The inertia of the impeller motor combination is large and since this could tend to oscillatory instability in operation, is undesirable.

The above objection can be obviated if the power and torque detection units are separated (Fig. 2). The principle being that the torque required to straighten the flow is equal to the torque required to spin it up. The need for an upstream honeycomb is eliminated since the angular velocity of the flow is controlled by the impellor.

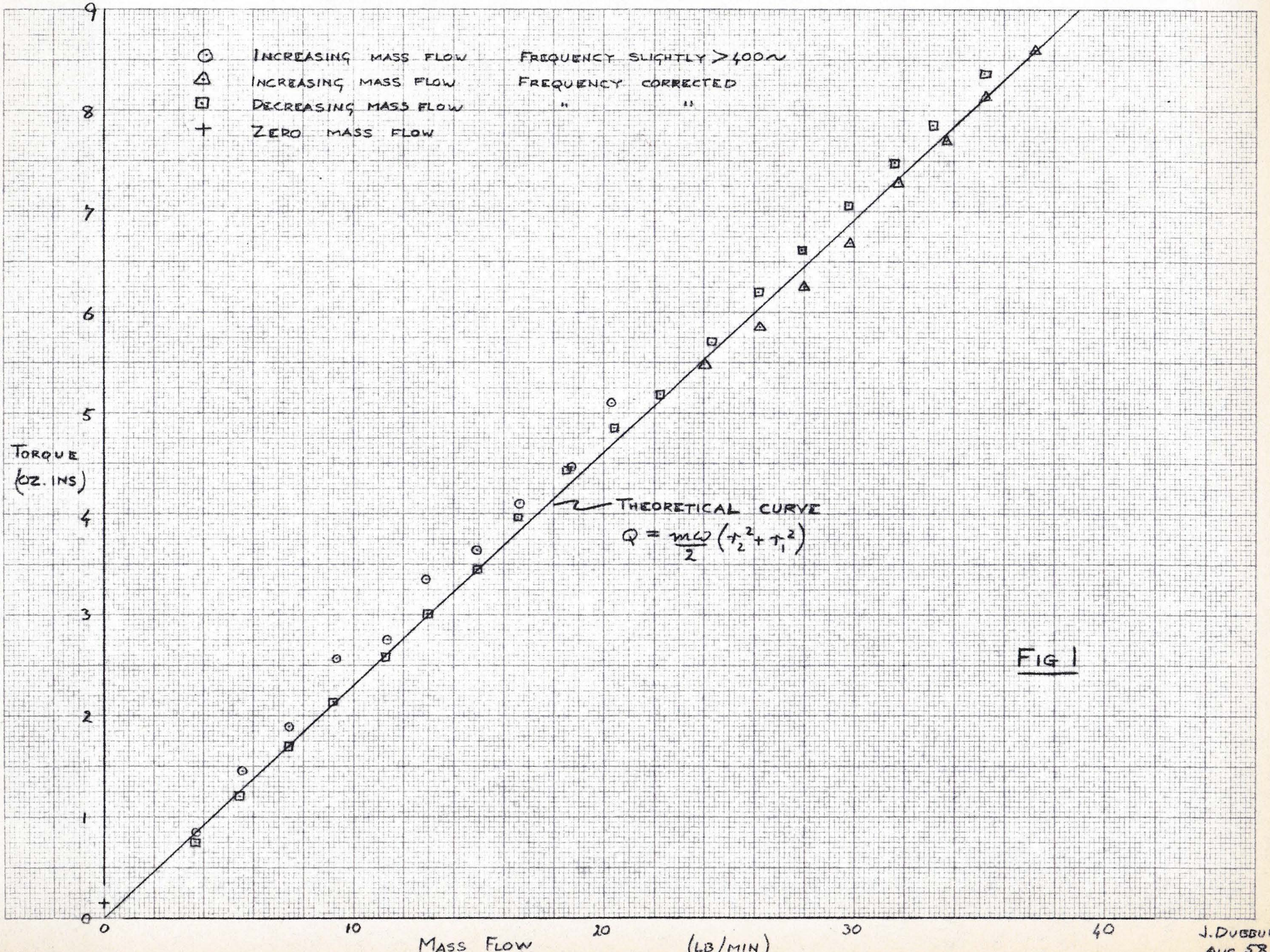
A preliminary design of such a unit has been made and manufacture of an experimental unit could begin immediately in the simulator lab. The unit would be about 12.75 inches long including connecting flanges. The diameter would be 5 inches max locally over flanges.

The pneumatic valve (controlling flow to the nozzle guide vane jack) is operated directly by the turbine. This provides a simple reliable rate control system which involves no electronics, and should be stable over a very wide range. The gear box is spring loaded internally to prevent back lash. Calculations show flow errors due to friction should be negligible. Provision is made for adjusting the control point of the unit while it is in operation with no need to dismantle anything. A small potentiometer in tandem with the valve gives a method of quickly ground checking the controllers functioning.

Reference

1. Report No. 72/Systems 22/144

   Modification of the mass flow controller theory to the concept of complete guidance by the rotor.



J. DUBBURY
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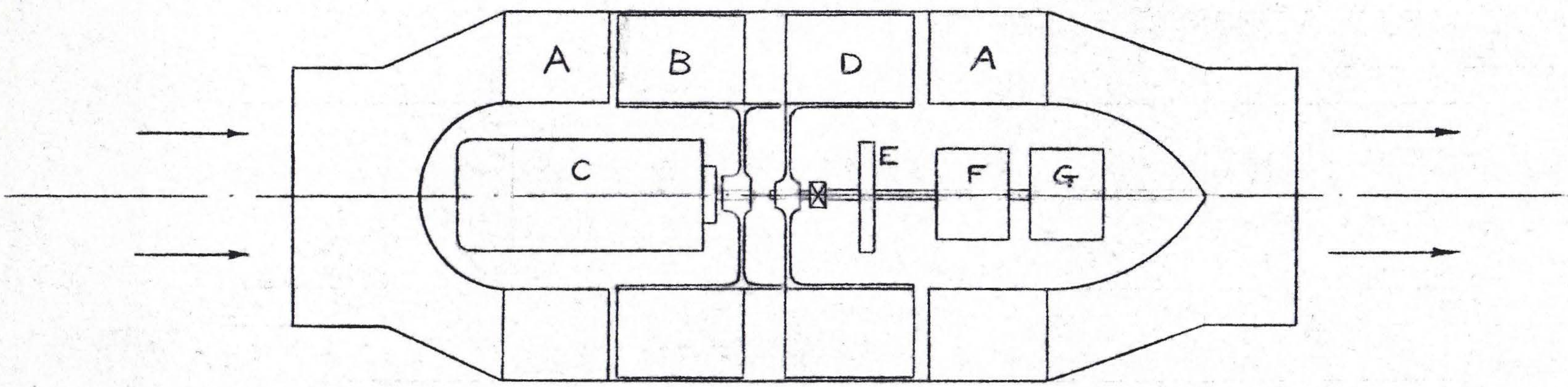
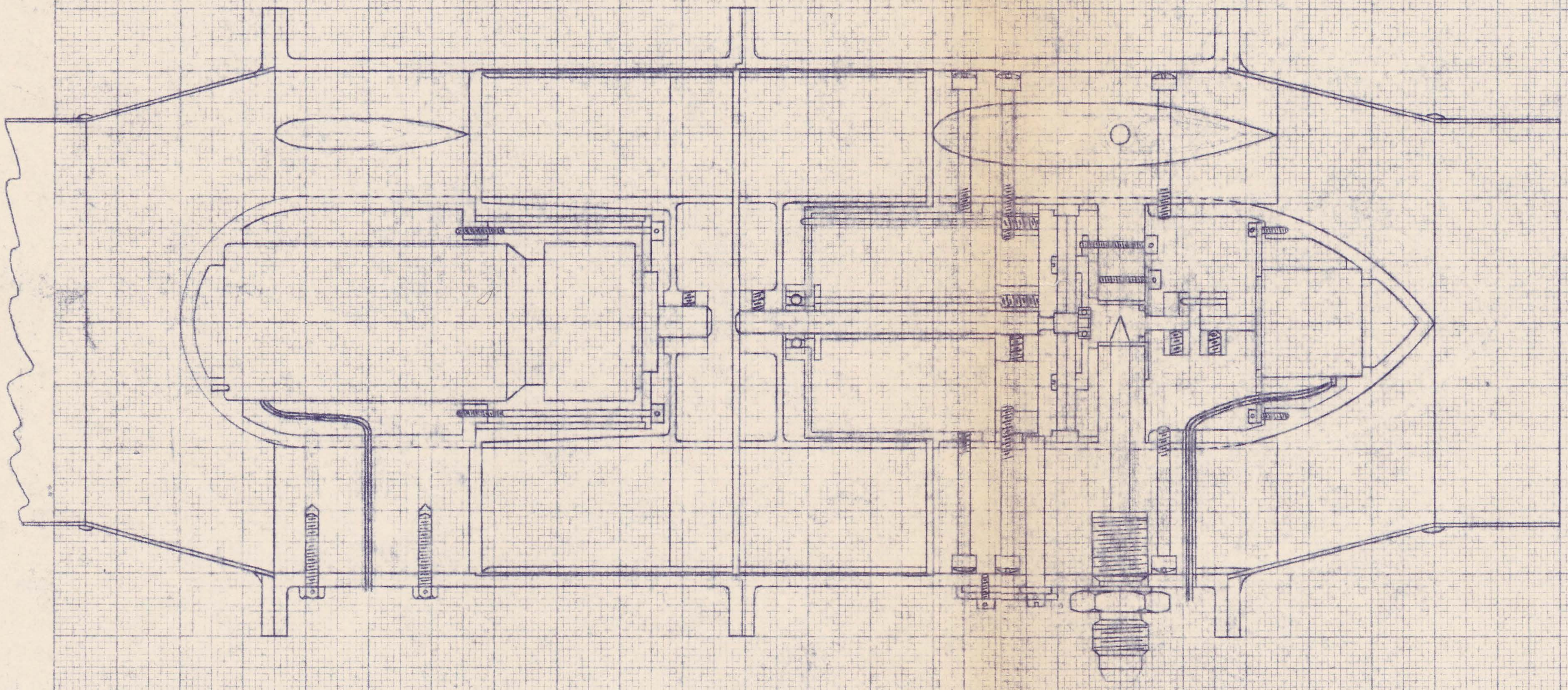
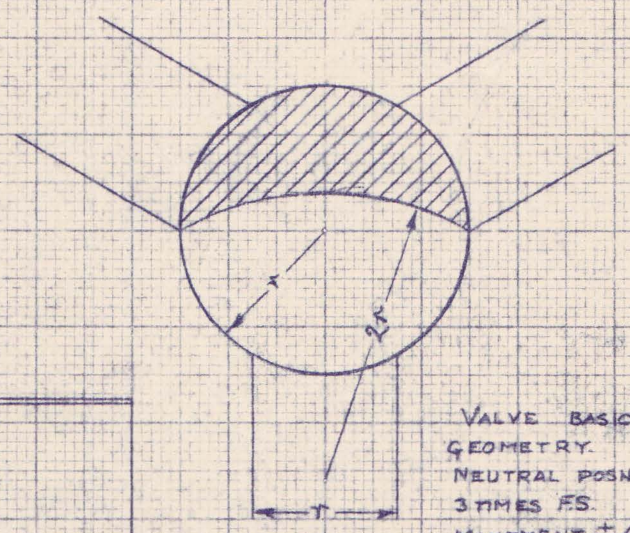
DIAGRAMMATIC LAYOUT OF MK 2 MASS FLOW CONTROLER



A. SUPPORT VANES.
B. IMPELLOR.
C. SYNCHRONOUS MOTOR AND GEARBOX TO DRIVE IMPELLOR.
D. TORQUE MEASURING TURBINE.
E. SPIRAL SPRING TO RESTRAIN TURBINE.
F. REDUCTION GEAR BOX
G. PNEUMATIC VALVE TO OPERATE NOZZLE GUIDE VANE JACK.

FIG 2.





VALVE BASIC GEOMETRY.
NEUTRAL POSN.
3 TIMES F.S.
MOVEMENT ± 60°

MASS FLOW CONTROLER MK 2

FULL SIZE

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MOTOR - GEARBOX   GLOBE INDUSTRIES   C - 33A - 504 - 1   1/4" SHAFT

BALL BEARINGS   NEW HAMPSHEAR BEARINGS   MICRO BEARINGS SR3 AND SR4

ADAPTORS   MS 21923 - 4

STD. AN BEADS.

HELIPOT POTENTIOMETER

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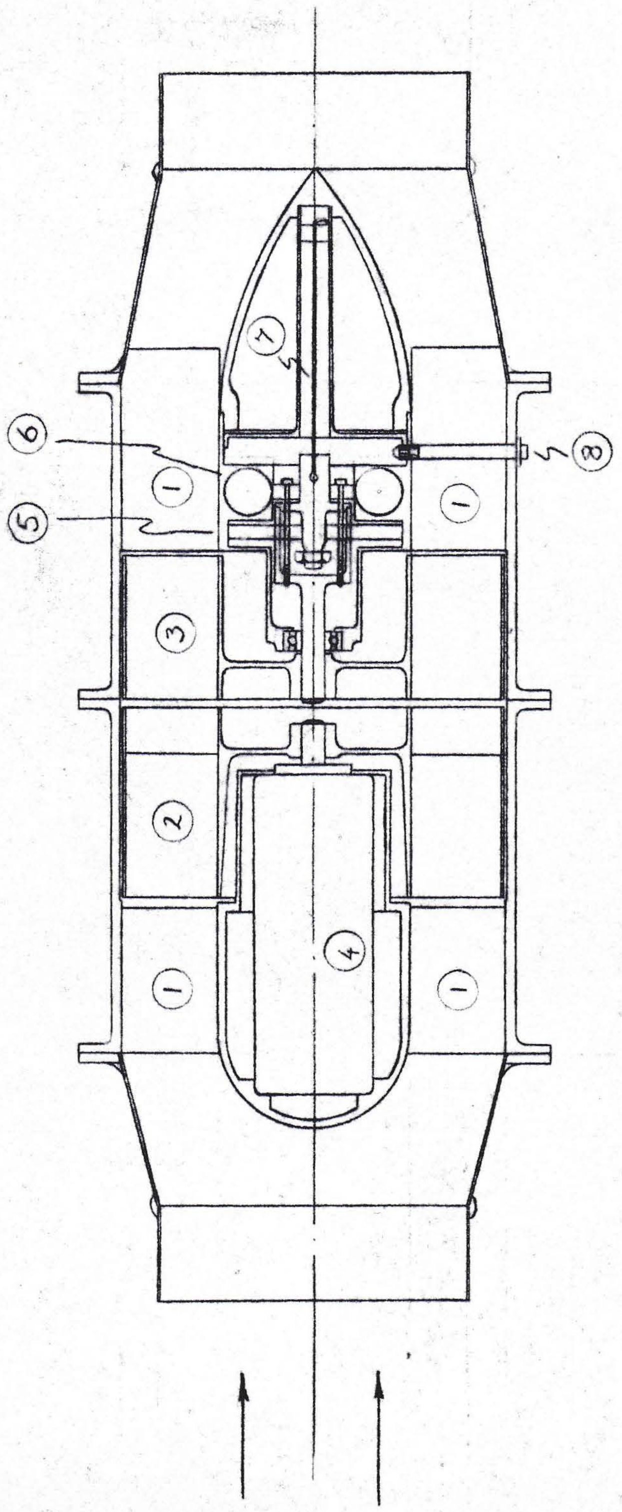
AIRCRAFT: ARROW MK2	COCKPIT MASS FLOW DETECTOR	REPORT NO.	SHEET NO.
		PREPARED BY: J. DUBBURY	DATE: DEC. 58
		CHECKED BY	DATE

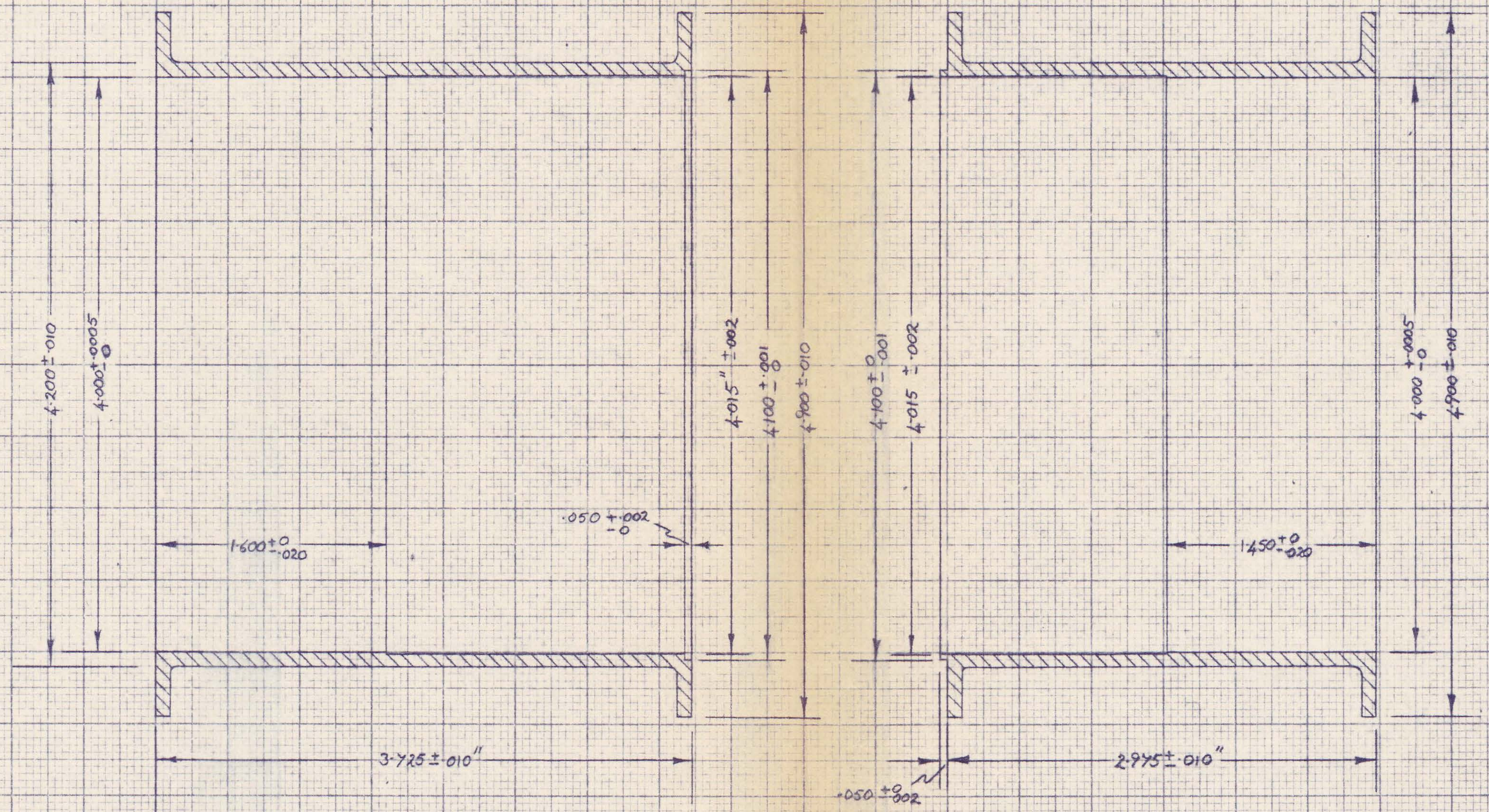


① SUPPORT VANES.
② ROTOR
③ TURBINE
④ MOTOR - GEARBOX COMBINATION.

⑤ MAIN SPRING.
⑥ DIFFERENTIAL TRANSFORMERS.
⑦ TORSION BAR TRIMMING SPRING.
⑧ EXTERNAL TRIMMING ADJUSTMENT.

RM 1319A

MASS FLOW DETECTOR CASING



TURNED FROM L A BAR QQ-A-277 COND. T6

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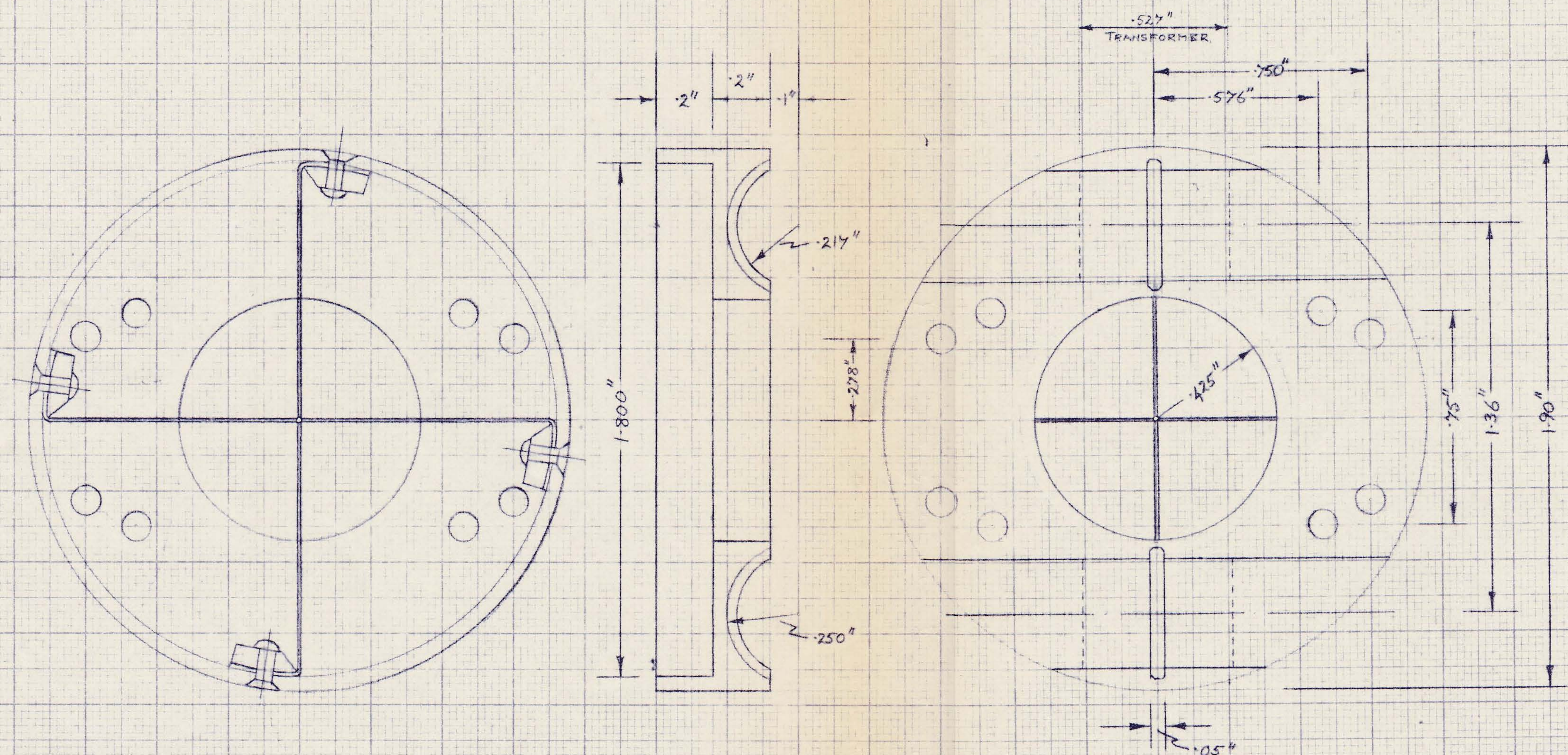

MAIN SPRING AND DIFFERENTIAL TRANSFORMER MOUNTING

TWICE FULL SIZE

BOLT HOLES 4/40 (SNUG FIT)

INNER BOLTS FOR INITIAL ASSEMBLY

OUTER BOLTS FOR RETENTION TO BODY

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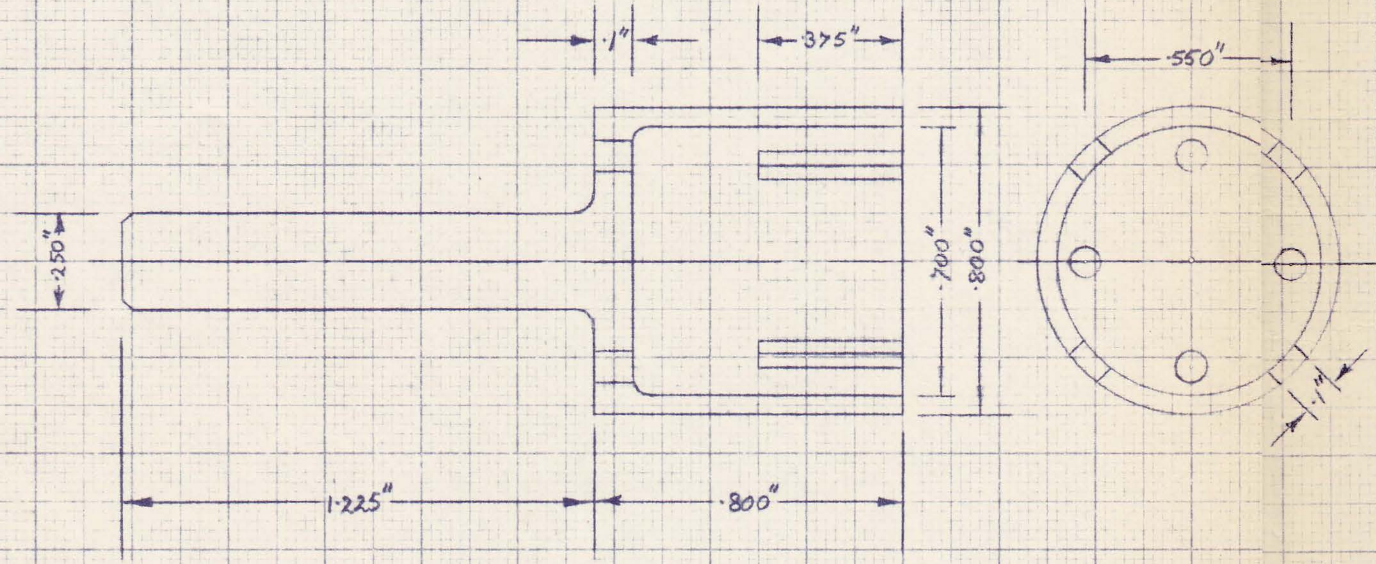
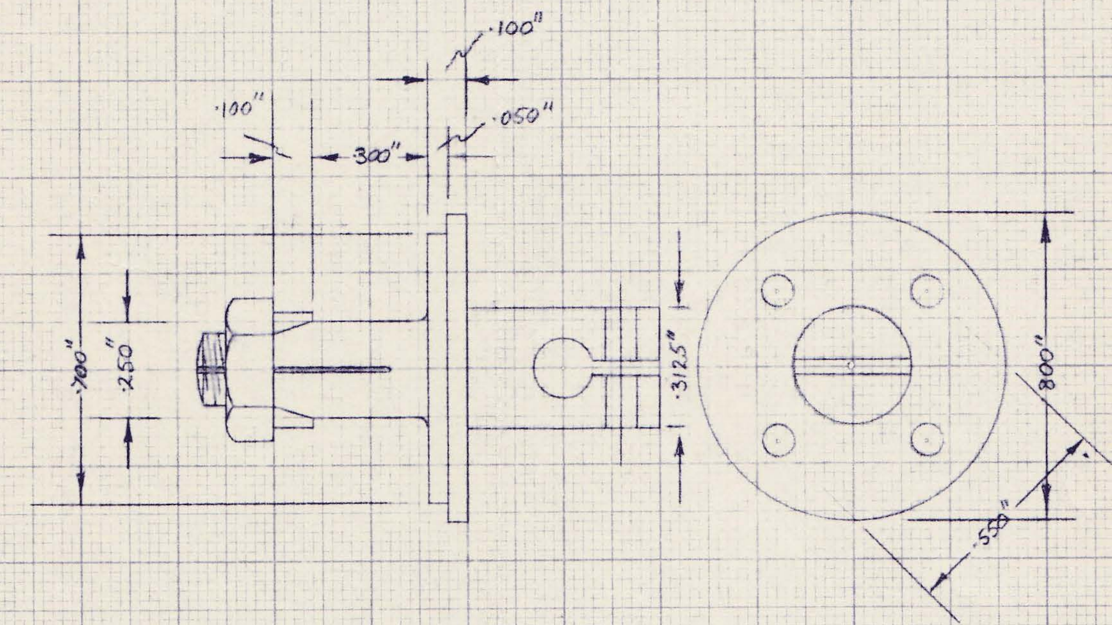


FORWARD SECTION OF SHAFT.

TWICE FULL SIZE.

BOLT HOLES TAPPED 2/56



AFT SECTION OF SHAFT.

TWICE FULL SIZE

FORWARD CLAMPING NUT 10/32

BOLT HOLES 2/56

AFT TORSION BAR CLAMPING BOLT HOLE HALF TAPPED 2/56

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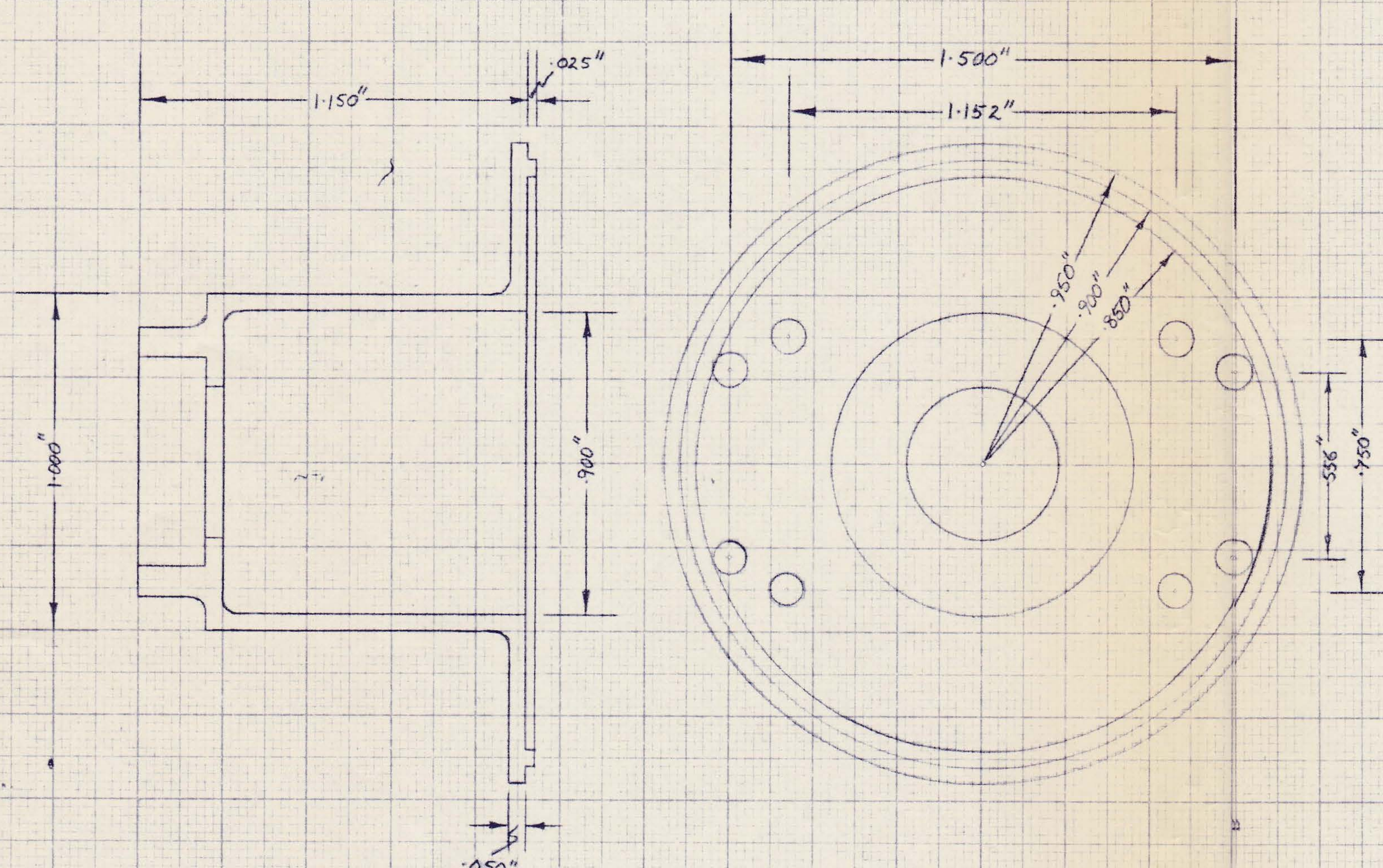


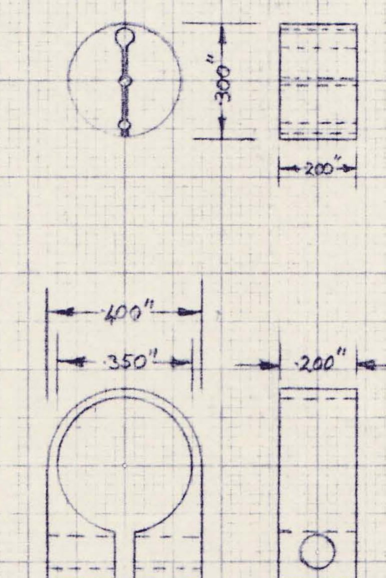
Bearing mounting

Twice full size

Any light bearing with ·25" bore can be used.

Four inner bolt holes countersunk on forward face
to accept flat head initial assembly bolts.

All bolt holes 4/40.



Aft torsion bar clamp

Twice full size

Clamping bolt hole half tapped 2/56.

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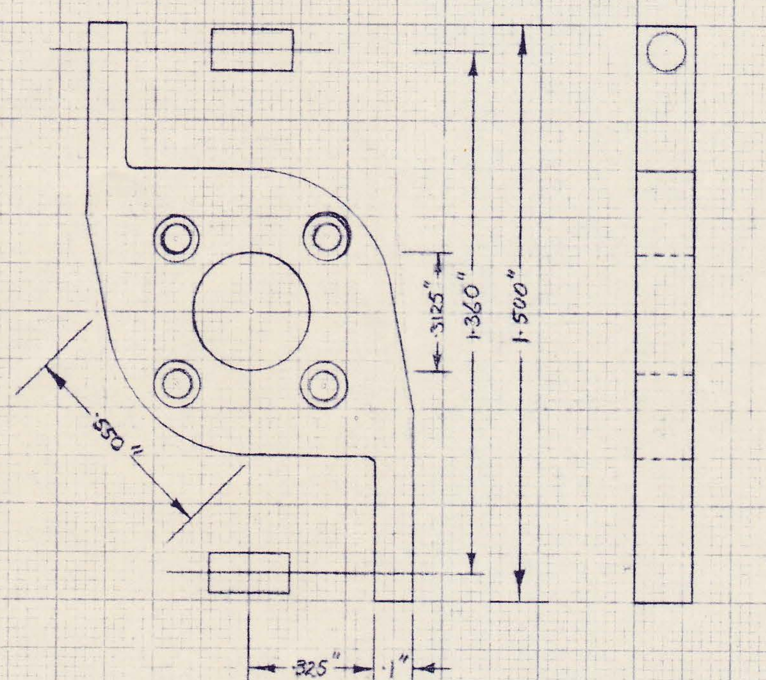

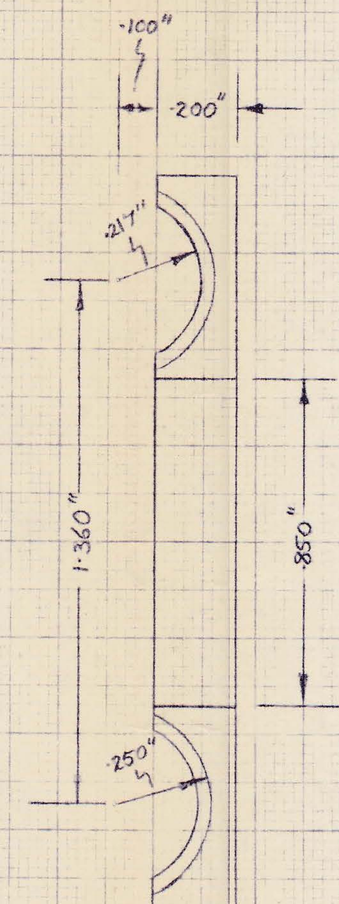

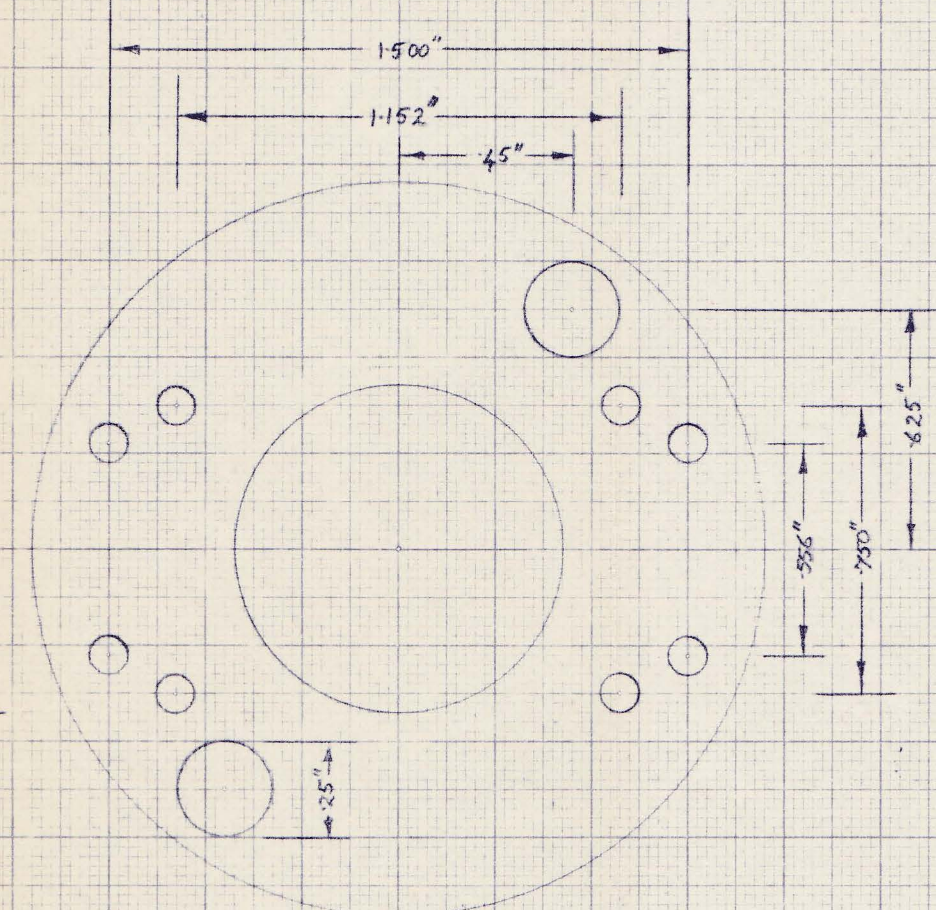

CORE MOUNT

TWICE FULL SIZE

BOLT HOLES 2/56 (SNUG FIT) SHAMFERED TO GIVE POSITIVE SEATING OF BOLT HEADS.

DIFFERENTIAL TRANSFORMER RETAINING CAP

TWICE FULL SIZE

BOLT HOLES TAPPED 4/40.

THE ·25" DIA. HOLES ARE TRANSFORMER LEAD OUTLETS.

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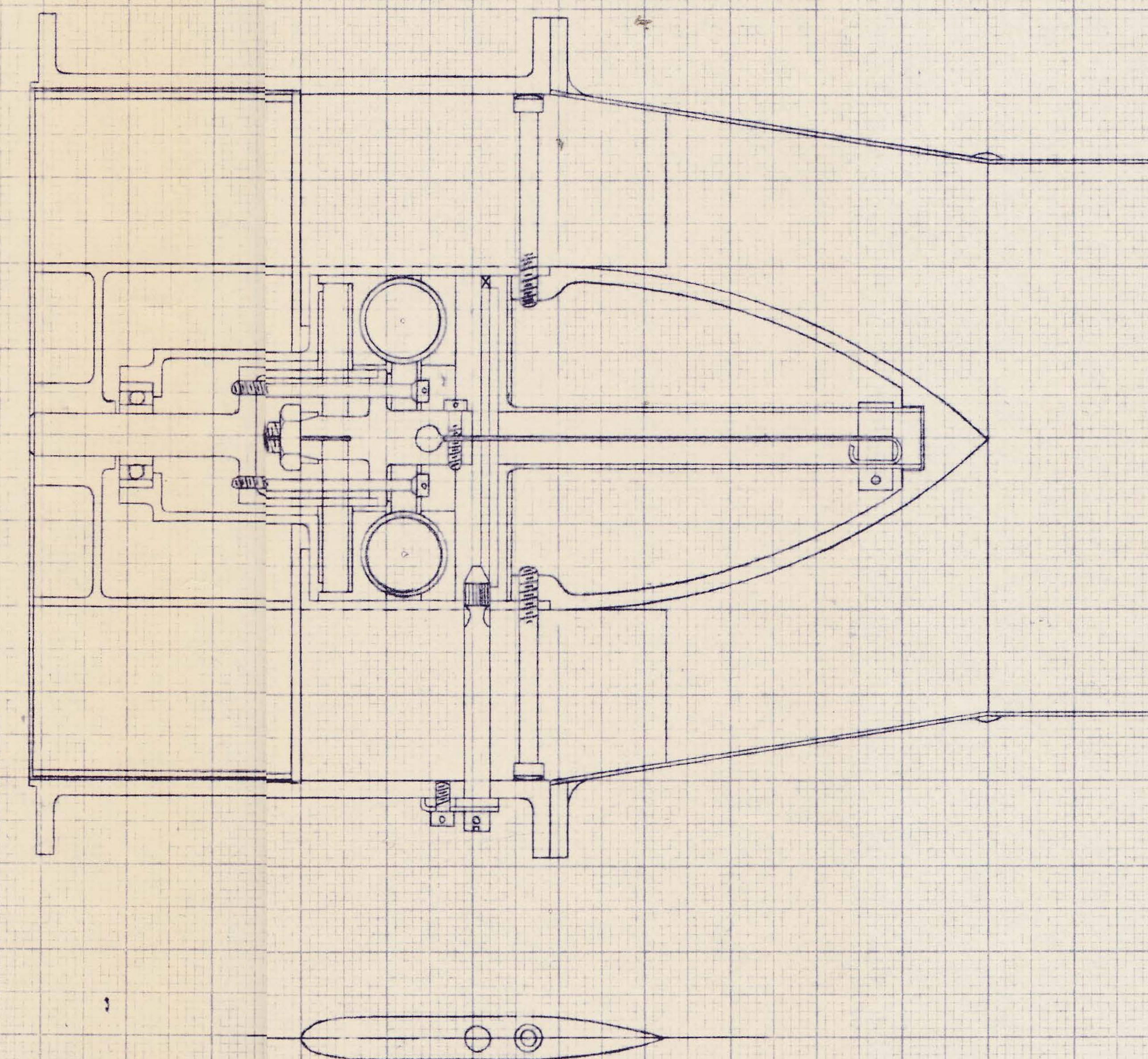

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