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TERMINATION REPORT ON THE
JG 168 MACH INDICATOR
AND THE
BG 94 MACH INDICATOR AMPLIFIER
CALIBRATOR FOR THE
ASTRA SYSTEM OF THE CF-105
AVRO ARROW.

CR-ED 1057 April 1959

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TERMINATION REPORT ON THE JG 168 MACH INDICATOR AND THE BG94 MACH INDICATOR AMPLIFIER CALIBRATOR FOR THE ASTRA SYSTEM OF THE CF-105 AVRO ARROW.

1 INTRODUCTION

This report was prepared in accordance with the requirements of Nucleus Contract 2-FF-8-13 as related to Astra Automatic Flight Control System of the Avro Arrow in general, and the Mach Indicator in particular.

At the time of cancellation, the first developmental models of this equipment were being evaluated with respect to specification, and reasonable justification of the basic design concept was being obtained. A program of redesign for production economy and improved maintainability had been initiated.

2 GENERAL

2.1 Part and Function in System

The Mach Indicator and associated Amplifier-Calibrator form part of the Astra I phase of the CF-105 Avro Arrow Electronic System.

Its function in the system is to portray Actual Mach, Command Mach and Mach Limit. It provides the pilot with numerical and comparative information on the Actual Mach at which he is flying, the optimum Mach at which he should fly to most efficiently perform any phase of his mission, and the maximum Mach attainable or permissible under the environmental conditions of the aircraft.

2.2 History of Development

2.2.1 Basic Form Concept

Preliminary studies into the optimum presentation for the Mach Indicator and Indicated Air Speed Indicator were conducted by Minneapolis Honeywell Human Engineering personnel in mid 1956. These studies were based on a requirement for actual, command and limit indication against the Mach scale.

Mach and Airspeed indication were separated on the basis that Actual Mach, being a computed function, exists as an electrical signal (as do Command Mach and Mach Limit) and hence is suited to remote indication by a servo system. Airspeed indication, on the other hand, may be derived directly from pitot pressures by suitable mechanization and therefore remains available in the event of power failure.

With separate instruments it was deemed advisable to make them individually distinctive to aid pilot recognition. Distinction could best be obtained by providing strongly characteristic forms of presentation. Since it was desirable to retain the established circular form of the conventional I.A.S. indicator, a new form of presentation for the Mach Indicator was necessary.

A series of tests was undertaken in which 5 different combinations of I.A.S. and Mach Indicator presentations were compared for speed and accuracy of interpretation. Of the Mach Indicator presentations, two were circular, two vertical rectilinear and one horizontal rectilinear. The tests showed the horizontal rectilinear presentation to have a significant speed and accuracy advantage over the others. The configuration of this presentation as evaluated is shown in Fig. 1-A.

2.2.2 Basic Mechanization Concept

For mechanization of the rectilinear presentation, considerations of tape, rack and pinion, leadscrew and nut and other forms of drive culminated in adoption of the leadscrew and nut principle. Tape drive showed considerable merit, but was rejected for the following reasons:

a) To ensure a true, stable motion of the pointers a full guide system would have to be provided, which would spoil any advantage of simplicity.

b) Excessive length of gear train would be required between the servo motor and winding drum.

c) The winding drums and idlers would not be economical space-wise and did not fit in with the integral lighting system then envisaged.

d) Difficulties were anticipated with stretching of the tape due to repeated flexing over small sheaves.

2.2.3 Basic Design Specification

From these preliminary studies a Technical Development Specification was drawn up. In outline this T.D.S., issued on October 1st, 1956, set the following conditions:

a) The unit should provide visual indication of three parameters, namely; Actual, Command, and Limit Mach.

b) It should contain the complete servo system to drive these indices except for the input potentiometers which would be remotely located.

c) The instrument case should be hermetically sealed and should contain the presentation, integral lighting, power failure indicator, and as many of the mechanical and electrical components of the servo system as practical.

d) The instrument should occupy a panel space approximately 4 1/2" wide by 2" high.

e) Its sole power supply should be 115 volts 400 cps.

f) The presentation should be as illustrated in Fig. 1-B, the actual scale length being 3".

g) Under normal operating conditions, the Command Mach index forming the base of the pentagonal form should slave from the Actual Mach index which forms the apex of the pentagon.

h) Operation of a function selector switch should cause the Command Mach index to move independently in response to signals from a data link system or from a potentiometer controlled by the navigator.

i) The Mach Limit pointer should be in the form of a striped bar travelling above the scale between the limits of 1.0 to 2.4 Mach. Its input signal would be supplied by a characterized potentiometer within the Air Data Computer, its voltage ratio being a function of altitude.

j) The slewing rate of the indices should be 12 Mach per minute minimum.

2.2.4 Major Changes During Development

During the development of this unit many changes have taken place from the original T.D.S. The most important of these are stated below:

a) The specification for the scale ranges changed several times, finally settling at 0.6 to 2.2 for Actual and Command Mach, and at 1.1 to 2.0 for Mach Limit.

b) The instrument bezel dimensions were increased to 5 1/4" wide by 2 1/2" deep.

c) The form, modes and disposition of the Function Selector switch were the subject of repeated discussion between R.C.A. and Minneapolis-Honeywell Controls Limited. The final decision was to eliminate the switch altogether and to provide only two modes of operation, "Normal" and "Data Link". Under "Normal" conditions, the Command Mach index is caused to run to its low position, where it is concealed behind a mask. In the "Data Link" mode, the Command Mach servo is energized by means of relays in the Mach Indicator Amplifier-calibrator. These relays are actuated by an enabling signal transmitted from Data Link when it is desired to guide the aircraft on an interception course or for any other requirement.

d) The presentation was subject to detail changes, the current form being illustrated in Figure 1-C. Three indices have been modified to improve their readability.

e) The original voltage for the illumination system was 28 volts. This was changed to 5 volts at too late a date for the change to be incorporated in the early "D" models but was scheduled for the 4th. "D" model onwards.

f) Originally, for accessibility and space economy, the instrument was to be front mounted to the panel and secured by a clamp that was adjustable from the front of the panel. A suitable clamp was designed, but was eliminated later in favour of front mounting by a flange secured directly to the panel by screws.

g) The original AN connectors were replaced by the considerably smaller Bendix Pygmy connectors when the latter gained military approval.

At an early stage in the development a requirement was raised for increased sensitivity in the Command Mach channel when the Actual Mach pointer approached coincidence with the Command Mach pointer. It was considered such a feature would enable the pilot to more accurately maintain a given Command Mach velocity. Severe problems in mechanization within the space available, and the belief that such a gain change in the equipment would cause the human operator element in the system to create an instability in the servo loop, forced abandonment of the proposal.

The Amplifier-calibrator, containing the three amplifiers and associated electrical components that could not be conveniently located in the Indicator, was originally intended to be a separate shock isolated unit. Later requirements called for it to be mounted on a common shock isolated tray with the Flight Director/Attitude Indicator and G-Limiter amplifier-calibrators.

3 RELEVANT SPECIFICATIONS

Design was predicated upon the following detail specifications and the various Military Specifications as referenced therein.

Document No.	Title	Dated:
	Astra I Standards, Rev. C	
RCA Spec. Dwg. #8954602	Astra I Environmental Specification (for Developmental Equipment)	May 20, 1958
RCA 8951057 Revision B	RCA Specification for Mach Indicator and Amp-Cal for Astra I System.	Feb. 3, 1958
R-ED 929	Comments to RCA Spec 8951057 Rev. B on the Mach Indicator and Amplifier-Calibrator.	Jan. 30, 1958
R-ED 873	Preliminary Detail Specification for the Type JG168A-1 Mach Indicator and the type BG94A-1 Amplifier for use in the Avro Arrow Aircraft.	Oct. 30, 1957
TDS 26266 Issue 2	Technical Developmental Specification for JG168A-1 Mach Indicator and BG94A-1 Amplifier-Calibrator.	March 28, 1957

4 DESCRIPTION OF UNITS

4.1 System

The Mach Indicator system comprises two separate units, the panel mounted instrument designated Mach Indicator DJG168A-1, and the remotely located Amplifier-calibrator DBG94A-1. These designations refer to the first 3 "D" models. The later "D" models were designated DJG168B-1 and DBG94B-1. The Mach Indicator and Amplifier-calibrator together form the DYG6000A-1 System. A "D" prefix before the designation denotes a model in the Development stage and is dropped at compliance acceptance release.

Drawing C-8024 provides a schematic of the system.

4.2 Mach Indicator

The Mach Indicator is an hermetically sealed and integrally illuminated instrument measuring 2.5 inches by 5.25 inches at the bezel and extending, less mating connector, approximately 4.5 inches behind the instrument panel to which it front mounts (Fig. 2 and Drawing D-JG168A-1 Sheet 2)

It contains all mechanization associated with the system including power failure indication, and provides visual indication of Actual, Command and Limit Mach. Calibration equipment is contained in a separate and relatively accessible compartment located at the back of the instrument.

General details of the overall assembly and various sub-assemblies are covered by the following drawings:

a) D-JG168A-1 Sheet 1, Mach Indicator Assembly

b) D-JG168A-1 Sheet 2 - Mach Indicator Installation.

c) DD480914 - Mechanism Assembly

d) DD480915 - Front Case Assembly

e) DD480916 - Back Case Assembly

f) DD480917 - Platform Assembly

g) DD480918 - Terminal Board Assembly

h) DD480919 - Lighting Terminal Board Assembly

i) DD480920 - Carriage Assembly

j) DD480922 - Lead Screw Assembly

k) DD481307 - Reflector Assembly

l) DD481309 - Lampholder Assembly

m) DD480176 - Power Failure Indicator Assembly

4.3 Amplifier-Calibrator

The Amplifier-calibrator measures 3.03 inches wide by 10.06 inches long (less connectors) and is 6.05 inches high. It contains the amplifiers, excitation transformer and relays as well as their associated circuitry and feedback network (Fig. 3 and Drawing D-BG94A-1 Sheet 2)

General details of the overall assembly and various sub-assemblies are covered by the following drawings:-

a) D-BG94A-1 Sheet 1 - Amplifier-calibrator Assembly.

b) D-BG94A-1 Sheet 2 - Amplifier-calibrator Installation

c) DD481195 - Terminal Board Assembly

d) DD481193 - Case Assembly

e) DD480948 - Base Assembly

5 PRINCIPLE OF OPERATION

5.1 General

The Mach Indicator, in conjunction with the Amplifier Calibrator and associated inputs, constitutes three separate servo loops.

Each Mach channel consists of a positional servo in which the input potentiometer (located in the Air Data Computer or the Data Link) forms one half of a bridge, the other half being a linear rebalance potentiometer contained in the Mach Indicator (Fig. 4). The wiper of the latter potentiometer is rigidly secured to its respective pointer and carriage and is caused to move by a 20 threads per inch lead screw, driven through a 16.6 to 1 reduction gear train (two stage) from a size 11 servo motor (Fig. 9).

The drive system requires power from the aircraft's 400 cps, 115 volt system. To minimize weight and to obtain a proper phase relationship it was found advantageous in this application to use two of the three phases of the 400 cps system for servo motor excitation. With minor modification but some weight penalty it can be designed for single phase operation. Twenty-eight volts D.C. is required for relay operation, and 28 volts A.C. is required for illumination.

System damping is inherent in the motor as characterized by the speed-torque curve. Time lag due to the amplifier is reduced by provision of negative feedback. The servo block diagram appears in Figure 5.

5.2 Calibration

To compensate for tolerance accumulation trimmer potentiometers have been series connected with one end of each rebalance potentiometer. Similar trimmer resistances located at the input potentiometers permit factory setting to provide identical voltage to Mach ratios relative to the instrument, hence obviating field adjustment.

The decision to locate these trimmers in close proximity to their relative potentiometers, rather than collecting them within the Amplifier Calibrator was predicated upon elimination of individual field calibration as mentioned above, and also on minimization of the adverse influence of temperature differentials.

5.3 Details of Individual Mach Channels

5.3.1 Mach Limit

The Mach Limit signal is a function of altitude and is derived from a characterized potentiometer located in the Air Data Computer. The scale range used, i.e. 1.1 to 2.0 Mach, necessitates shorting out of the input potentiometer below the 1.1 position.

5.3.2 Actual Mach

The Actual Mach signal is derived from a linear potentiometer located in the Air Data Computer. The scale range used, i.e. 0.6 to 2.2 Mach, again necessitates shorting out of the input potentiometer below the 0.6 position and further, to obtain the same potentiometer gain in terms of volts per inch of potentiometer length, the excitation voltage must be appropriately selected.

5.3.3 Command Mach

The Command Mach signal is derived from the Data Link Coupler and, in the first three "D" models, corresponds to a scale range of 0.8 to 2.2 Mach. The nature of the input was not clearly defined until very late in the program and as a result its method of accommodation in these three models represents a compromise in the interest of delivery. The ultimate system to be used in fourth and subsequent units is described in section 10.1.1.

It was originally assumed that all three channels would be identical, and the design evolved on this basis. Indeed early planning called for manual control of Command Mach input by the navigator and hence the nature of the input would have been stipulated by Honeywell. The input finally provided by R.C.A. consisted of a resistive digital to analogue conversion network (Fig. 6). The numbers above each relay are the binary Mach terms which, when summed, will give the desired Mach value. For example, operating the 1.28 and 0.32 relays to give 1.60 Mach, the circuit resolves into the configuration shown in Figure 7, where it can be seen that the correct relationship is obtained.

This type of network introduces non-linear variations of input and output impedances of which only the former is of importance to the application. The input impedance of the network varies from infinity at either extremity of the Mach range to 4 Kilohms in the middle range. This prohibits series connection of trimmer resistances.

When Data Link is not transmitting the Command Mach pointer is driven to the bottom of the scale where it is hidden by a mask. This is accomplished by having the ground lead of the amplifier connected to a tap on the bridge transformer corresponding to 0.60 Mach (Refer to schematic diagram C8024). When there is Data Link transmission, a ground controlled switch closes an energizing circuit to the enabling relay. The relay then switches the ground lead from the transformer tap to the signal output terminal of the Data Link Coupler, thus enabling command signals to be amplified. It was originally intended to have the Command Mach pointer slaved from the Actual Mach pointer when there is no command signal. However it was felt that relative lags in motion between the two indices or non-coincidence between them in the absence of perfect slaving would be very distracting to the observer, and could also lead to misinterpretation, as a result of which the pilot may try to chase the Command Mach pointer upscale or downscale. The better course was felt to be concealment of the Command Mach pointer when not in use.

The voltage from the Data Link Coupler has possible outputs from 0 to 2.56 Mach, whereas the Mach Indicator has a suppressed zero scale with a range from 0.60 to 2.20. This introduced a problem in matching the ranges. Various means to accomodate the greater range of the Data Link Coupler over the Instrument range were considered and rejected. These were:

a) Condensing the scale to cover the range 0 to 2.56. This was counter to the original Human Engineering concept in that the useful length of travel is reduced from 3 inches to 1.875 inches with sacrifice in readability.

b) Characterizing the rebalance pot so that the scale factor (Mach per inch travel) at either end is considerably more than in the central portion. Space limitations rendered this method impractical.

The method adopted provided fixed precision wire-wound resistors in series to both ends of the rebalance potentiometer to absorb the excess Mach range. This would allow satisfactory operation for input signals within the range of the instrument; but, for signals outside the display range of the instrument, the motor would drive against the clutch at either end, and the clutch would be slipping continuously as long as the command signal is outside the instrument range. This situation may exist for long periods, for example, when the aircraft is on the ground in the Alert condition, or undergoing system test.

The harmful effects of continuous clutch slippage are these: -

a) The clutch was not designed for continuous slippage; accelerated wear would soon cause it to lose its effectiveness.

b) Particles worn off would be detrimental to other parts.

c) Excessive gear wear would result from running continuously loaded.

d) Unbalanced voltages would exist at the amplifier input, driving it to saturation.

e) Large temperature rise and possible motor overheating.

It was realized at the time that the problem was not completely solved, but had to be lived with temporarily until R.C.A., who was advised of this implication of their network, would so modify their equipment as to restrict their output to the Mach Indicator range. The suggestion that limit switches be installed within the Indicator to confine the indices travel was found impractical to implement, both because of space limitation and the complicated electrical circuitry that would ensue. Later, a completely satisfactory solution to all parties concerned was arrived at and is discussed in section 10.1.1.

6 DESCRIPTION OF PARTS

6.1 Mach Indicator

6.1.1 Main Assembly

Although originally intended to be of rectangular cross section to permit clamp mounting to the panel, the case was later changed to octagonal section to permit direct front mounting and yet economize on panel space. Although initially fabricated by investment casting the case design was slanted to ultimate die casting in production.

Further design requirements involving the case were:-

a) To ensure an hermetic enclosure all joints were to be soldered.

b) The final joint was to be capable of separation and re-closure to permit overhaul.

c) The final joint was to be as remote as possible from the header and bezel glass, and was to be capable of progressive soldering to prevent undue elevation of overall temperature and resultant damage to the glass, header, and instrument mechanism.

d) A flat tape rather than a round "filler wire" should be used to combat the adverse influence of case flexure under pressure differentials.

e) Mechanical rigidity necessitated a spigot and recess joint, the tape merely serving as the seal.

f) Case draw and the joint position was to provide maximum internal width at the location of the servo motors.

g) A silicone rubber gasket was required to preclude entry of solder to the m chanism.

Three Bourns "Trimpots" type 220L and one Ace Electronic X-500 "Ace Trim" are mounted externally to the hermetic seal on the back case. These are for scale calibration and illumination intensity adjustment respectively, and are contained in a separate sealed compartment to discourage tampering. Connections are made through a fused glass header.

6.1.2 Front Case Sub Assembly

The front case assembly consists of the front case and the bezel glass. The bezel glass is soldered into a .010" thick "U" section copper expansion ring which is in turn soldered to the case (Fig.8). The front case is an Alcan 135 aluminum investment casting, this material being chosen for its excellent castability, good machining and dense structure (freedom from porosity). This is discussed further in Section 7.3. The front case may be considered as a major structural member, as it transmits loadings from the back case and the mechanism sub-assemblies to the instrument panel.

6.1.3 Back Case Sub Assembly

This assembly consists of the back case casting, the electrical connector, the header and the evacuation and sealing tube which are all soldered in place. Comments made concerning the front case material also apply to the back case.

Internal lugs on each side of the back case casting are slotted to engage flanges on the capacitor platform, thus reducing case flexure under differential pressures and improving thermal conduction and heat dissipation. A boss on the inside of this cover takes the ground lug, the lead from which is brought out through the connector. Two slots on the trim potentiometer compartment cover permit drainage of condensate.

6.1.4 Mechanism Assembly

6.1.4.1 General

The Mechanism Assembly contains all the mechanical and electrical components located within the hermetically sealed instrument case. The main frame, an Alcan 135 investment casting, accommodates the three servo motors and associated gear trains, the rebalance potentiometers and bus bars, the leadscrew and carriage assemblies, guides for the carriages, and a mounting base for the scale and lighting system. Also mounted thereon, as a separate sub-assembly, is the capacitor platform which supports the electrical ancillaries and terminal boards.

Much design attention in the mechanism assembly was given to the conflicting demands for space. It was originally intended that the main frame should be built up from three separate portions, i.e., two gear plates which would be screwed and dowelled to a bridge piece which would in turn be screwed to the front case. Unavailability of space for four mounting screws necessitated fabrication of the main frame from a single investment casting.

6.1.4.2 Drive System

The lead screw drive system used in this instrument, (Fig. 9) while possessing many favourable features, gave rise to some severe design problems. Calculations and tests of the breadboard model confirmed that, for optimum performance, backlash between the motor and the rebalance potentiometer contacts had to be minimized. In such a reduction system the adverse influence of a given amount of backlash increases with remoteness from the motor, and hence some form of lost motion take up was essential at the carriage and leadscrew and desirable at the intermediate gear of the two stage train.

By using a lead screw of 20 threads per inch a gear reduction of 16.6 to 1 could be used instead of 1200 to 1 (approximately) as required by a tape drive. This small reduction caused the moment of inertia of the output, as reflected back into the motor, to be of more severe consequence as regards stability, and necessitated minimization of the screw diameter. Further, the relatively large bearing area under shear at the carriage and lead screw caused abnormally high coulomb friction for such a servo system, the retardation torque increasing as the square of the lead screw diameter for a given depth of thread engagement. Conversely, a certain minimum diameter had to be maintained if, under vibration, transverse resonance was to be avoided and the helix angle of the screw maintained at an acceptable level.

The thread form ultimately adopted was also the result of several conflicting requirements. To minimize backlash (and hence instability) it was realized that close fitting and/or preloading would be necessary both axially and radially. To reduce radial clearance, and hence possible "rocking" motion of the carriage, short cylindrical sections were provided at each extremity of the carriage. These were bored to be a relatively close fit on the outside diameter of the screw, the threads of which were truncated to provide an acceptable bearing area. It was further realized that positive axial positioning was required, and yet that precise maintenance of close pitch line clearance, besides being exorbitantly expensive, could cause severe variation in retardation torques due to minute inequalities along the screw, or as a result of wear. To circumvent this an axial loading spring and loading nut having relatively large clearance were provided, angular motion of the latter relative to the carriage being prevented by a tab washer. A standard 60° thread form in this installation would have acted as a conical clutch, tending to increase the drag of the system, and hence was eliminated. Under these considerations a square form of thread should, ideally, be used, but the difficulty of grinding or otherwise providing a smooth surface on the flank of such a thread caused its rejection. On the basis of the foregoing a modified 3/16" 20 T.P.I. Stub Acme thread form of 14 1/2° flank angle and relatively large root diameter was selected.

Each lead screw was in turn mounted to the carriage through flanged ball bearings, the inner race of one bearing being constrained between a shoulder on the screw and the clutch and gear assembly. To provide restraint against shock and vibration and to compensate for thermal expansion differentials the alternate bearing, free to slide axially on the screw, was thrust loaded to one pound by a compression spring. A small spacer bushing further restricted any possible motion to 0.007 inches (nominal) to safeguard the gears.

Extensive experimentation was carried out and serious consideration given to the selection of lubricants. In view of the high bearing area under shear and the extreme temperature range, as well as the small reduction stage used, it was realized that a low viscosity lubricant of minimum temperature viscosity characteristic was essential. Tests confirmed that normal petroleum and diester base oils causes sluggish response at low temperature and instability at high temperatre. Molybdenum disulphide in liquid suspension possessed the same disadvantage, and dry film lubricants, while having satisfactory characteristics, were eliminated on the basis of the dry environment pertaining and the danger of flaking and contamination of the closely adjacent potentiometers. Of the various silicones tested General Electric Versilube F-50 was selected as providing optimum performance, and the axial loading nut was fabricated from dry sintered bronze, vacuum impregnated with the above lubricant to maintain a constant film. This F-50 lubricant has a temperature viscosity coefficient of 0.60 and a viscosity of 40 to 60 centistokes at 38°C.

Type 303 stainless steel was originally selected for the lead screws from consideration of its free-machining, non-magnetic and non-corrosive properties. Subsequent tests showed 431 hardenable stainless to have considerably better wear characteristics when run with the phosphor bronze carriage and sintered bronze loading nut, and the material specification was correspondingly altered.

The 16.6 to 1 gear train was designed as a two stage reduction. Lack of space and restrictions on availability of optimum centre distances precluded the use of anti-backlash gears and optimum gear ratio steps. This, plus manufacturing tolerances, eccentricities, clearance, differential thermal expansion between gears and gear plate, and wear, could cause considerable backlash even on the basis of statistical overall error. By careful tolerancing, the use of precision 2 gears in the second reduction, and material selection to minimize wear, a satisfactory backlash condition was achieved. All gears were of 120 diametral pitch, 20° pressure angle.

On the experimental model no lateral spring loading was provided for the carriages in the guide slots but tests showed that even with close tolerances on the widths of the slots and carriages, which allowed a maximum play of only .004", the lateral movement of the indices, which was magnified to .007" at their reading surfaces, was very noticeable and disconcerting. A leaf spring was therefore incorporated on one side of the carriage so as to load the carriage on one side of the slot only (Fig.10)

This also allowed the tolerances on both the width of the carriages and the width of the slots to be increased.

The indices are located on top of the carriages by means of two bosses raised on the face of each carriage which locate in holes in the base of each index. In the case of the Actual and Command Mach indices the holes are slotted to allow adjustment parallel to the lead screw. A curved leaf spring located beneath the index fastening screws prevents disturbance of the index setting during the clamping operation. Adjustment is facilitated by providing a pin at the index where a tool can be applied using another pin projecting from the face of the carriage as a fulcrum. A similar means of adjustment is also provided for the scale.

In addition to the 3 inches required for the excursion of the carriages, a nominal 1/32" of overtravel was allowed at each end to allow for manufacturing tolerances. In addition to this overrun, allowance had to be made for a system failure which would cause the motor to run continuously in one direction, causing the carriage to jam up against the gear plate and stall the motor. To prevent this, a clutch was interposed in the drive system. This clutch, which will begin to slip at a torque of approximately 0.6 oz. in., consists of the gear on the end of the lead screw held in contact with the face of the clutch plate by means of a Belleville type washer. The clutch plate is a press fit on the leadscrew while the gear is a running fit.

6.1.4.3 Rebalance Potentiometers

Material selection herein, and the method of securing, was predicated upon minimization of thermal expansion differentials between scale and potentiometer.

To obtain best indicator accuracy it was essential to locate the potentiometers close to the leadscrews and to locate the carriage guide slots as close to the indices as possible, so as to restrict loose pivotal motion of the indices about the leadscrew. The windings and bus bars of the potentiometers were, therefore, located on the back of the main frame bridge where they were cemented to glass epoxy laminate supports (Fig. 10).

The rebalance potentiometers were sub-contracted to Helipot Corporation, Toronto. They are wound with .0025" diameter Karma (equivalent to Evanohm) wire with resistivity of 800 ohms per cir. mil-ft. on a quadruple Formvar insulated copper core .070" dia. Resolution is 300 turns per inch and linearity specified is 0.25 per cent maximum. The windings and a coin silver bus bar are cemented in V-grooves cut in opposite sides of a support strip made from fibreglas epoxy laminate. The wipers are made of precious metal alloy (Paliney #7) strips which are mounted on the carriage nut. One strip contacts the winding and the other contacts the bus bar. Wiper pressure is adjusted on assembly to 5 ± 3/4 grams for minimum wear and noise.

6.1.4.4 Power Failure Indicator

The power failure indicator is also mounted on the main frame. This consists of a U shaped electro magnet with a hinged clapper which pulls in toward a shaded pole. The flag is driven by a spindle extending up from the pivot of the clapper through a small bearing in the bridge piece of the main frame. Application of 115V, 400 cycle power causes the flag to retract from view. A small leaf spring causes the device to fail safe, i.e., to return the flag to its visual position, upon removal of the 400 cycle power.

6.1.4.5 Lighting System

The lighting system was designed to meet MIL-L-25467A Amendment 1, the principal requirements of which are:

a) the indicia shall be illuminated by light in the Aviation Red spectrum as specified in MIL-C-25050.

b) The brightness of the white portions of the indices shall be between 0.5 and 1.5 foot lambers.

c) the black portions shall reflect between 0.02 and 0.10 foot lamberts.

d) stray light shall not exceed 0.20 foot lamberts in the upper half of the instrument and 1.50 foot lamberts from the lower half of the instrument.

The first illumination system exploited the ability of methyl methacrylate indices and "U" shaped channels to conduct and emit light at predetermined areas (Fig. 11). A model constructed on this basis gave satisfactory results, but was very sensitive to dimensional variation accruing from either fabrication error or heat distortion. A subsequent increase in the specified high temperature test to 71°C, coupled with a calculated 30°C rise above ambient internal to the case, precluded the use of acrylics which have virtually no mechanical strength above 100°C.

The light conduction principle was therefore abandoned in favour of light "wedges" (Fig. 12). Initial testing with a plane surfaced wedge disclosed striation in illumination intensity across the dial, whereas a wedge having one plane and one hyperbolic surface gave excellent results. As a concession to producability the hyperbolic surface was reduced to cylindrical with very minor degredation in performance. Such a system will, unfortunately, emit light from both faces of the wedge, and, to minimize the frontal emission (spillage) of light, a second wedge has been provided. This absorption wedge, placed in front of the active wedge, has a higher refractive index which, in conjunction with its geometry, causes it to "capture" and retain spilled light.

The position of the bulbs and the angle of entry of the light into the wedge were critical. To permit sufficient distance between the lamps and the wedge, and yet maintain the proper angle of entry, a "light pipe" was introduced (Fig. 13A). It was intended that this device should be glass, but exhaustive search failed to disclose a supplier willing to undertake the job. Plastics were then tried as follows:

a) Transparent Epoxy - not sufficiently transparent and resulted in spectral contamination.

b) Allymer HT-CR-39 - gave satisfactory performance for about 100 hours at 120°C, after which minor cracks and some discoloration developed and seemed progressive.

c) Polypenco Q-200.5 - performance almost identical to b) above.

In the complete absence of any satisfactory alternative material the use of a "light pipe" was therefore abandoned, and a metallic reflector, painted white to provide some diffusion, was substituted at the cost of slightly lowered efficiency (Fig. 13).

Discussion of the various lamps suited to this application is contained in Appendix A. Four type 327 bulbs (28 volts, .04 amp) were used per instrument. These were the "baseless" type in the interest of space economy, the glass envelopes being identical to those used with the mid-flange base bulbs. In the case of plastic light "pipes" these were to be cemented to the plastic, but when used in conjunction with the reflector they were secured by "potting" the lower section into an epoxy strip. The terminal wires were then connected through to a printed circuit strip. Clear glass bulbs were used, the chromaticity being obtained through use of a separate filter. In the interest of extended life the voltage applied to the bulbs was limited to 24 volts by means of a resistor. Failure of any one of the four bulbs resulted in a detectable, but not serious, diminution in light intensity over a portion of the dial.

6.1.4.6 Capacitor Platform

The capacitor platform carries the main terminal board, the servo motor control phase tuning capacitors, the Command Mach rebalance potentiometer padding resistors, the illumination system voltage dropping resistor, and the wire ducts for the potentiometer leads. The platform, through flanges which engage matching lugs, also provides flexural bracing for the sides of the case.

6.1.4.7 Servo Motors

The servo motor is a standard Kearfott

R119-22A, size 11 frame, and is available in equivalent types from several manufacturers. It has two 57.5 volt control phase windings which are series connected when used with the EG129 amplifier. Teflon lead terminations afford convenience in wiring. It is provided with a 13-tooth 20° pressure angle involute pinion shaft.

The mode of operation of the servo motor is through excitation from two phases of the three-phase system. The motor fixed phase is supplied from phase A which is 120° lagging phase C from which the reference or bridge voltage is supplied. There is approximately a 30° phase lag through the amplifier, resulting in a control phase voltage that is close to 90° with respect to the fixed phase. Thus, there is no loss of output torque and the motor time constant, which is equal to

$$T_m = \frac{\text{rotor inertia x no-load speed,}}{\text{Stall Torque}} \quad \text{is not impaired.}$$

This mode of operation is superior to using a series capacitor in the fixed phase for phase shifting, since it dispenses with the additional capacitor per motor (a total of three in the instrument). Also, with capacitor phase shifting there is a resonant rise in voltage which must be counteracted in some way to avoid motor overheating. A method used earlier was to reduce the motor fixed phase voltage by tapping the primary winding in the bridge excitation transformer. By using the three-phase supply, a significant weight saving accrues from the great reduction in transformer size.

A capacitor is connected across the control phase to improve the power factor. The null characteristic (output vs input voltage at small voltages) of the amplifier is affected by the value of the capacitor, and its choice of value was dictated primarily by the sharpness of the null obtained.

The Minneapolis-Honeywell size 11 "Tape" motor was once considered for the application. The nomenclature "tape" refers to the fact that the stator magnetic circuit is made from a wound tape coil - a construction which lends itself to low cost manufacture. It is, however, relatively short in relation to its diameter and hence its torque to inertia ratio is low. Analysis showed that there would be insufficient damping provided by the motor, and auxiliary compensation networks would be required for stability. The added circuitry required was not a desirable feature and would also nullify its original cost advantage.

Space did not allow use of a motor-velocity generator combination.

6.1.4.8 Wiring

Internal wiring within the instrument consists of #26 gauge extruded teflon insulated wires.

6.2 Amplifier Calibrator

6.2.1 General

The Amplifier-calibrator houses the amplifiers, amplifier feedback transformers and gain controlling resistors, the bridge excitation transformer, the enabling relay for Command Mach, and the voltage dropping resistor for the power failure indicator.

Components that are not hermetically sealed are in all cases chosen so as to inherently be moisture and fungus-resistant, so that varnish and fungicidal treatments are not required. Under conditions of high humidity, degradation of component quality can occur due to absorbed moisture from the varnish itself. Thus the terminal board material is of fibreglas epoxy composition, the resistors are moulded high-stability deposited carbon, and the feedback transformers are epoxy coated being manufactured to MIL-T-27A, Grade 5, Class S standards.

As shown in Installation Drawing D-BG94A-1 Sheet 2, the dimensions of the amplifier-calibrator are 2 7/8" high x 10 1/8" long x 6" high and the weight is 4.4 lbs. The three amplifiers, being the heaviest components, are mounted on a base, terminal side down, so as to present an overall low centre of gravity. Above the amplifiers is the terminal board assembly where small components such as resistors, feedback transformers and terminals for wiring tie-points are mounted. On the base beside the amplifiers are the bridge excitation transformer, the enabling relay, and two grommets for feed through wiring. Four small holes at the corners of the base act as drain holes for accumulated condensate. Two Bendix Pygmy PT bayonet type connectors are back-mounted on one end wall. The front L-shaped cover provides for ready access, while a bottom cover protects the wiring at the underside of the base. The wiring within the Amplifier-calibrator is #22 gauge extruded teflon insulated copper wire.

It was found possible to use unshielded wires with the Amplifier-calibrator. Only the three input signal leads coming to the Amplifier-calibrator need to be shielded. There is no coupling between the three Mach channels. Noise pickup is minimized in the design by keeping potentiometer resistances low (approximately 2000 ohms). Quadrature voltages due to the capacitance to the shield wire were calculated to be well within acceptable limits and quadrature error was deemed negligible especially in view of the high quadrature rejection characteristics of the amplifier.

In the equipment, a constant aim was to design for reliability. Honeywell co-operated with R.C.A. in a reliability programme. Part of the programme of reliability control is to accumulate test data on component failure rates and also to predict equipment mean life from existing knowledge of component failure rates. As much as possible, electrical and mechanical parts were chosen from the Astra I Standards Handbook, the parts listed therein having been selected as being the most suitable for the Astra environment.

6.2.2 Amplifier

The amplifier is the type EG129A-1 developed by Minneapolis-Honeywell. It consists of a transistorized pre-amplifier, discriminator, and magnetic-amplifier output stage. It is packaged in a hermetically sealed unit approximately 2 3/16" cube and weighing 11.5 oz.

This amplifier was selected for the following reasons: It is transistorized, with attendent advantages in miniaturization, ruggedness, reliability and low power consumption. It was available, and well along in development, and to our knowledge the smallest amplifier on the market to do the job. It was also advisable from the point of view of standardization, since it was to be used in other portions of the Astra system.

This amplifier has more than sufficient power for the application. A new design using power transistors could be developed giving a smaller output but the EG129's power availability permitted the use of standard servo motors.

A study of the amplifier transfer function will show the relationships that govern the choice of external gain setting resistor values in the amplifier circuit.

The amplifier has a time lag due to its magnetic circuit and the electrical time constant $\frac{L}{R}$ of the control windings. It has two feedback loops which affect the gain and time constant. Negative voltage feedback exists around the transistorized pre-amplifier stages to stabilize against transistor parameter variations. The external resistor in this circuit (connected between pins 6 and 8) is R_g. There is also overall negative feedback to control gain, linearity, and time constant. Thus, the amplifier may be represented as in Figure 14a.

$$\frac{e_3}{e_1} = \frac{A_1}{1 + A_1 \frac{K_1 R_g}{R + R_g}} \cong \frac{1}{K_1}\left[1 + \frac{R}{R_g}\right] \text{if } A_1 \text{ is large}$$

$$= A_2$$

Fig. 14a reduces to Fig. 14b,

$$\frac{e_o}{e_1} = \frac{A_2 \frac{K_2}{1 + T_1 S}}{1 + A_2 K_3 \frac{K_2}{1 + T_1 S}} = \frac{1}{\frac{1}{A_2 K_2} + K_3} \times \frac{1}{1 + \frac{T_1}{1 + A_2 K_2 K_3} S}$$

A_2K_2 is large, thus gain is controlled mainly by K_3, but A_2 and K_3 have comparable effects on the time constant.

6.2.3 Bridge Excitation Transformer

Each of the servo bridges is excited by a secondary winding of the bridge excitation transformer. The secondaries are [illegible] but an electrostatic shield minimizes coupling between the primary and secondary windings. Hermetically sealed construction to MIL-T-27A Grade 4, Class S is used.

6.2.4 Enabling Relay

The enabling relay is an Allied Controls Incorporated subminiature D.P.D.T. relay type MSB-6D. Quality level is for a life expectancy of 100,000 operations. It is rated to +125°C. Low level ("dry") contacts are specified. For increased reliability, contacts are paralleled to provide redundancy.

7 CONSTRUCTION PROBLEMS

The following describes difficulties encountered during manufacture of the early "D" models, and remedial action undertaken.

7.1 Bezel Glass

As a protection against shock and thermal expansion differentials the bezel glass was separated from the aluminum case by a copper expansion ring (Fig. 8). To this end the edges of the glass were platinized by vapour deposition and then tinned. The glass and expansion ring were then positioned in the case with flux and a solder preform, and the assembly was slowly preheated in an oven to just below the melting point of the solder. The assembly was then transferred to an induction heater to accomplish the final seal in the minimum time, and after slow cooling the front case assembly was tested for leaks on a helium mass spectrometer.

Considerable difficulty was encountered in the procurement of satisfactory pre-tinned bezel glasses. While American suppliers could provide a satisfactory platinized surface, they could not maintain dimensional accuracy. Conversely, while Canadian suppliers would maintain tolerances, they had little background knowledge in the vapour deposition of platinum. As a result, leakage in excess of the required 1 x 10-7 cc per second maximum occurred due to poor solder flow.

In the interest of developing Canadian availability very fine co-operation was received from the American Optical Company of Belleville, Ontario, with progressive improvement. The last batch received from this supplier exhibited marked improvement in quality and adherence.

Thermal expansion differentials, especially during the soldering phase, continued to cause serious stress distributions in the rectangular glass, particularly compressive stress along the length due to disproportionate shrinkage of the expansion ring. This resulted in occasional cracking of the glass when the bezel ring was secured to a bowed glass. Partial alleviation was obtained by using thicker and softer rubber gasket material. It was planned to try a tougher and softer grade of glass and to revert to a soft steel expansion ring having a coefficient of expansion nearer to that of glass to eliminate the problem altogether. It was felt that this combination would eliminate the risk of failure. However, the project was

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cancelled before tests could be commenced.

7.2 Header

Original plans called for a header with integral evacuation tube. This tube proved too small to permit satisfactory evacuation of such a large case, and further some instances of cracking the glass and destroying the seal occurred during seal off.

The problem was circumvented by using a plain header and a separate larger evacuation tube. This also, incidentally, was advantageous from a repair and overhaul standpoint.

7.3 Front and Back Cases

Due to the extensive soldering required these were electrotinned on all surfaces.

Repeated opening of the cases due to failure of the bezel glasses or headers resulted in deterioration of the tinned surface and necessitated stripping and re-tinning of the castings. This stripping tended to etch away the aluminum and copper portions of the alloy, hence increasing the silicone content and degrading the quality of the seal.

It was intended that Alcan 143 would be used in place of Alcan 135 to minimize the difficulty on future units.

7.4 Intermediate Gear Seizure

Failure due to seizure of the intermediate gear on its shaft was encountered. This was rectified by slightly increasing the clearance on the shaft and by increasing the chamfer on the inner face of the gear hub (Fig. 15)

7.5 Carriage Jamming

The most serious problem associated with the design arose during cold tests (-30°F) in the evaluation of the first "D" model.

During the low temperature tests jamming of the pointers at the ends of the travel occurred. This was first manifested when, due to defective amplifiers, hard-over signals were applied to the motors. (The fault in the amplifiers was found to be insufficient clearance between the case and the printed circuit board terminals. At low temperatures, the differential pressure between atmosphere and the fixed mass of the enclosed gas caused enough deflection of the case wall to short circuit the terminals. This fault existed only in the early models and was corrected by interposing an insulating piece between the terminals and the case).

On examination after dis-assembly, one cause of jamming was due to intermediate gear seizure as described above, but another pointer showed evidence of jamming of the carriage between the frame and the inclined plane (helix) of the lead screw.

After modification of the intermediate gear was carried out, the instrument was re-assembled and a thorough investigation of the jamming problem was made. The test equipment was modified so that inputs could be applied to cause the carriages to drive against the frame at either end of their travel.

The unique circumstances that will result in jamming were: an excess signal beyond the normal range, driving the carriage against the ends at -30°F; de-energizing the instrument leaving the carriage in that position; then bringing the instrument up to room temperature. The instrument then resisted attempts to run the carriage off the stops, and would not release until cooled again.

An analysis of these results led to the conclusion that jamming was being caused by differential expansion of the frame, carriage and lead screw. The low initial force on the carriage when first wedged against the frame by the lead screw would build up to a much higher force when the temperature rose and the parts expanded, causing the carriage to lock securely. Then, when the instrument was cooled again, contraction of the parts would release the carriage.

Another contributing factor was undoubtedly the change in viscosity of the lubricant between gear and clutch with temperature. This resulted in a high slipping torque of the clutch at a low temperature, which aided the tendency for the carriage to jam. Then, at a higher temperature and lower viscosity, the clutch would slip before the carriage could be backed off its stop.

In practice, jamming can only occur in case of an amplifier failure, or when an excess Command Mach input signal is applied, at sub-zero temperature, with the fault remaining until warmup to room temperature. The latter possibility is removed with Command Mach limiting in the later models (See Section 10.1.1). However, it was decided to redesign the clutch assembly to include an anti-jamming device. One such device is shown in Figure 16. Pins extend out from both ends of the carriage. On the clutch end of the travel the pin goes through a hole in the main frame, hitting a flat spring, which moves out to engage one of three dogs on the inner face of the clutch on the lead screw shaft. The lead screw rotation is thus stopped before the carriage hits the frame, and further running of the motor results only in slippage of the gear on the clutch. At the other end of travel, the carriage pin engages one of three slots in a steel disc which rotates with the lead screw. This engagement stops lead screw rotation before the carriage hits the frame, and the clutch can then slip as before. At either end, as soon as rotation is reversed, the pin is withdrawn from the stop by the motion of the carriage, and the lead screw is again free to rotate.

Some lead screw assemblies were thus modified and tested for jamming by the same methods used before. The tests were successful in preventing jamming.

Another anti-jamming method which was tried with success was to attach a .020 inch silicone rubber washer to the main frame, at the end of the lead screw. The carriage would then butt up against the washer instead of the frame itself. Differential expansion would then merely compress the washer slightly, preventing a large jamming force from being applied to the carriages.

In the interest of prompt delivery, neither of these devices was installed in the first "D" model. It was, however, proposed to employ one of these anti-jamming methods, probably the second, in the succeeding instruments.

8 PERFORMANCE

8.1 Requirements

8.1.1 Accuracy

Repeater accuracy of the Indicator for all three Mach Indices was to be ± .01 Mach or better. Absolute accuracy, of course, depended upon the additional inaccuracies contributed by the source of the Mach signals. It was a design aim to request and limit the input signal tolerances to ± .017 Mach. On this basis the maximum absolute error based on root-sum-square computation would be ± .02 Mach.

Possible contributing errors in the instrument were potentiometer non-linearity, manufacturing and assembly tolerances, differential coefficients of expansion of potentiometer and scale, null offset and quadrature errors in the amplifier, and dead zone due to frictional causes (lead screw coulomb friction, motor friction and slot effect voltages).

8.1.2 Reponse

The slewing rate of the three indices was to be a minimum of 9 Mach per minute. Overshoot of the pointers should be a minimum with one overshoot allowable.

8.1.3 Environmental

The Indicator and Amplifier-calibrator were designed to meet the environmental conditions given in detail in Engineering Specifications E.S. 0101-1 and E.S. 0101-2

8.2 Predicted Performance

The transfer function of the amplifier was taken from frequency response tests, and the motor transfer function,

$$\frac{K_m}{S\ (T_m\ S+1)} = \frac{17.0}{S(.032S + 1)}$$ was derived

from actual characteristic curves. The analytical results of the servo system plotted on a Bode diagram and Nichols chart yielded, for an amplifier gain of 450, a phase margin of 48 degrees and a gain margin of 19 db. A peak of 2db existed at ω = 20 rads/sec for the closed loop response.

The calculated dead zone, using maximum specified friction and slot effect voltages for the motor and a value of coulomb friction at the leadscrew of 0.12 oz.-in., was 0.0023 inch, which is less than one wire step of the potentiometer. The error on a ramp input when the aircraft is accelerating at the rate of 1.5g or 3 Mach per minute is 0.004 inch or 0.002 Mach.

8.3 Actual Performance

Transient and frequency responses were taken on a breadboard servo. The results for the same amplifier gain agreed closely with the calculated values. The comparison of the closed loop frequency responses is given in Figure 21.

The transient response showed one overshoot of about 15% obtaining at a gain of 450; the time to reach the peak being about 0.20 seconds. In the 'D' model instrument the gain was finally adjusted to a somewhat lower level of 260.

In order to obtain an accurate representation of the motor transfer function it was necessary to use those portions of the motor characteristic curves near the operating point. These are at low speeds and low control phase voltages. As an indication of the error that would be made in using rated values for the motor, the transfer function would be

$$T.F. = \frac{6.28}{S(.021S + 1)}$$ compared with the more accurate

$$T.F. = \frac{17.0}{S(.032S + 1)}.$$

The first 'D' Model Indicator was not subjected to the full evaluation tests per the E.S. before the project was terminated. However, the calibration and response tests per section 4.2.2.3.1 and 4.2.2.3.2 of E.S. 0101-1 were performed at room temperature and passed. The altitude test on the Indicator was also passed. When the instrument was tested for low temperature, failure occurred at a certain phase of the cold test. This is covered in detail in Section 7.5

Some quantitative results were obtained in an experimental "X" model using the mechanism of the regular "D" Models, using a steel rule graduated in 1/100th of an inch instead of the Mach scale to facilitate measurement. A General Radio Decade Voltage Divider Type 1454A (± .05 Per cent accuracy) was used as the reference input.

8.3.1 Accuracy

Twenty readings were taken along the scale comparing the output indication with the reference input ratio. A maximum error of .008 inch (=0.27% or .005 Mach) occurred for the Actual Mach indication, and a maximum error of .004 inch (.002 Mach) occurred for the Command Mach indication. There was good repeatability with negligible difference between up scale and down scale readings.

8.3.2 Response

Slewing speeds for the Actual and Command Mach indices were 11.5 and 11.0 Mach per minute, respectively, as compared with the T.D.S. requirement of 9 Mach per minute minimum.

8.3.3 Sensitivity

Smooth operation existed. Each .001 change in input ratio produced movement in the pointer. This corresponded approximately to each turn of the rebalance potentiometer.

8.3.4 Stability

One overshoot was barely perceptible on step inputs.

8.4 Internal Heating

In addition to these performance tests, a temperature survey was made of nine selected spots within the Indicator to determine local ambient data for reliability prediction and to confirm design estimates for temperatures. These tests are of interest because of the technique used in obtaining temperatures in a sealed instrument containing the proper nitrogen-helium mixture (since the mixture ratio affects heat transfer).

Thermistors, Keystone Carbon Co., Type L0503-33.3K-125-S1, .05 diameter x .03 thick, were used. They were cemented with epoxy at the appropriate spots and their leads brought out through spare pins in the connector and pins made available through not exciting the control phases of the motors (heat contribution from the control phase normally being relatively small). Temperature values were obtained indirectly by measurement of the thermistor resistances using a resistance bridge with a low battery voltage (to avoid errors due to thermistor self-heating). Accuracies within ± 2°C. can be easily obtained using uncalibrated thermistors of ± 10% resistance tolerance, while ± 1°C accuracy can be obtained using calibrated thermistors. Thermistors are more suitable in this application than are thermocouples, the latter having disadvantages of size, and errors due to lead conduction losses and thermoelectric EMF at the connector connections.

9 PRESENT STATUS

9.1 Equipment

At the time of cancellation the first "D" model had been assembled and was undergoing evaluation. Due to repeated opening of the case the leak rate was somewhat in excess of specification, and late in the testing it was found that a stress crack had occurred in the bezel. It had been the intent to pursue evaluation to gain as much knowledge as possible, and then re-encapsulate the device and spot check it. This unit does not have the anti-jamming feature described in section 7.5.

The second "D" model had been dismantled for incorporation of the anti-jamming system, and, with the exception of cases, the parts necessary to an additional two instruments are on hand.

Concerning the Amplifier-Calibrator, the first "D" model had passed evaluation testing, the second had passed 50% of the tests, and the third was 95% through assembly.

9.2 Design

Once the basic layout of the equipment had been achieved any changes, whether internally generated or forced by alterations in associated equipment, had to be accomplished within the existing framework. This quite naturally prohibited an optimum overall design. In the realization of this a revised and very fluid layout program was maintained in parallel with the general development program in anticipation of a general redesign for ultimate production economy.

The indicator illumination system was being redesigned as was the front case and bezel arrangement (Fig. 17). The main frame was being extensively revised in the interest of cost and weight reduction, and the Allard power failure indicator was being incorporated. Technical details are discussed in section 10.

Advancement of delivery dates for the pre-production models, received just prior to cancellation, had forced abandonment of such a broad program and only the more essential elements were consequently being carried forward.

10 FUTURE PROGRAM

As previously mentioned an extensive program for improving the overall system was being considered and some initial planning had been proceeding. These changes had been brought about by:-

a) Inadequacies in the original design as discovered during construction and testing.

b) Changes necessitated by outside influences.

c) Advancements in the state of the art making more suitable equipment available.

10.1 Limited Changes

These changes were to be incorporated on number 4 and subsequent "D" models, which would become the DJG168B-1 Mach Indicator and the DBG94B-1 Amplifier-Calibrator. The change from A to B in the suffix letter indicates non-interchangeability of equipment.

10.1.1 Command Mach Channel

As mentioned in section 5.3.3, the input for the Command Mach Channel was the responsibility of R.C.A. and was not defined until late in the program. This forced an interim compromise on the first three "D" models.

For the subsequent units R.C.A. requested a proposal as to how the Command Mach signals could be handled in the Mach Indicator system to avoid difficulties arising from signals outside the scale range of the Indicator. We submitted two proposals - One approached the problem by confining all changes to the Mach Indicator system as requested by R.C.A., with no modification to the Data Link Coupler. It required the following added equipment: two channels of amplitude comparison, phase sensitive amplifiers and demodulators, limiters and relays. In all, the changes were rather extensive and would entail a change in scope of the project. The other solution required R.C.A. to make very minor modifications to their Coupler. It is simple, will act positively and precisely, and the relative merits over the other proposal are quite obvious. Approval was finally obtained to proceed with this method of Command Mach signal limiting.

In this latter solution, the manner of operation is thus. Referring to Figure 6, it is seen that any signal greater than 0.64 will have either or both of the 0.64 and 1.28 relays closed; and that any signal greater than the display range of the Indicator will have either the 1.28, 0.64 and 0.32 relays all closed or the 2.56 relay closed. These relations enable a logic circuit to be devised, taking advantage of the relays already there and adding contacts where required, to reject or pass signals to the Mach Indicator instrument.

The control circuit is shown in Figure 19. Relays K1 and K2 serve as low-signal and high-signal cutouts respectively and function as shown in Figure 18. On a signal from Data Link below 0.64M, relay K1 is unenergized and the ground connection of the amplifier is made to a tap on the transformer corresponding in voltage ratio to 0.62M (one increment less than 0.64). The servo then drives the indicator pointer to the bottom end of the scale where it is hidden from view. If the command signal is equal to or exceeds 2.24M (=1.28 + 0.64 + 0.32), K2 is energized and the ground is made to a tap corresponding to 2.22M and the indicator finger is driven to the top end of the scale. For command signals equal to and between 0.64 and 2.22M, the signal has a path to the amplifier and the Indicator command pointer follows the command signal.

The changes required in the Amplifier-calibrator were the addition of relay K2, suppressor diodes across the relay coils of K1 and K2 to protect the contacts of the relays in the Data Link Coupler, and a new bridge transformer.

Changes required in the Indicator were an adjustment to the scale factor since the top indication is now 2.22 instead of the original 2.20, a change of resistor values for the rebalance potentiometer fixed resistors, and an adjustment to the Mach Limit rebalance potentiometer as the limits on this potentiometer have shifted slightly on the new scale.

10.1.2 Illumination Voltage

The 28 volt bulbs were to be changed to

similar style 5 volt bulbs because of the latter's heavier and more rugged filaments. Associated changes were the removal of the voltage dropping resistor and a change in value of the variable resistor in the lighting circuit. A possible compromise arrangement between this and the full (Fig. 20) revision is shown (Fig.17).

10.1.3 Power Failure Indication on 2 phases

The weakness of the original method of tying the warning flag device with its series voltage dropping resistor across the two phases was that although the flag would drop in case of power failure in both phases, the flag may not drop if a single phase to ground fault occurs, at which time the line to line voltage drops to $1/\sqrt{3}$ of the normal value, because the drop-out voltage of the device is too marginal to this value.

The remedy was to use an A.C. relay with the warning flag device, connecting the relay coil across one phase, and routing the other phase from which the warning device is excited through the relay contacts. The voltage dropping resistor is incidentally eliminated.

10.2 Extensive Changes

While the modifications noted in section 10.1 could be accommodated fairly readily, there existed quite a number of improvements which would necessitate extensive redesign. These were held pending decision to proceed on the basis of production economy.

10.2.1 Illumination System

The illumination system was still based upon the wedge principle but was of modular design and was to be mounted into the front case and not directly onto the mechanism assembly (Fig. 20). It was found possible to use plane faced wedges having an angle of only 2 1/2° between the faces. The original difficulty in using such a small angle was that it was not possible to obtain good emission from the wedge at points adjacent to the light source, but the combination of inclining the receiving edge 45°, spilling some light directly onto the indices and the use of smaller lamps which could be positioned more conveniently, gave a solution. The wedges in this design were to be pre-assembled with the mask and cemented into a frame consisting of two identical pressings which embraced the wedges on all four corners and three edges. The frame had four lugs for mounting to the front case and two others for securing the lamp holder.

The lamp holder was to be an investment casting to which the Aviation Red filter is cemented and into which the lamps are secured by staking. This lamp holder design was chosen for the following reasons. The CM682 lamps have an extremely long life when operated at 5 volts (approx. 60,000 hours) and are unaffected by the temperatures, vibrations or shocks that are likely to occur in a panel instrument, and hence are not likely to requre replacement during the life of the instrument. It was, therefore possible to dispense with the complication and the spatial handicap of providing removable retaining and contact pressure devices for the lamps. The centre contacts of the lamp were to be paralleled by a soldered jumper wire.

The variable resistor for the illumination system was no longer a requirement hence its mounting lug on the back case was to be removed.

10.2.2 Bezel

The bezel redesign was prompted by the troubles encountered with the use of a screwed-on bezel. The new bezel wasto be soldered in place, a solder-ring being placed in a recess prior to positioning the bezel. The bezel was then to be placed within an induction heating coil and pressed lightly down on the window glass during the heating cycle. The expansion ring was to be changed from copper to soft steel.

10.2.3 Wiring

It was found during assembly of the "D" models that the Teflon insulated leads were susceptible to breakage at the soldered joints if flexed a few times. The capacitor platform was therefore redesigned to incorporate an internal connector and the electrical components were re-disposed to allow a large cabling radius, thus minimizing lead flexing during assembly. The internal connector simplified testing of the mechanism assembly before fitting into the case, and also served as a terminal board thus releasing space for the rectifying circuit for the D-C operated Allard power failure indicator. This design also had a small eyeleted printed circuit board for making common ground connections; this was a neater and more convenient method than that of making numerous connections to and jumpering several terminal posts, as used in the "D" models.

10.2.4 Power Failure Indicator

The change to the Allard power failure indicator involved slight changes to the main frame and the addition of a simple clip and rectification circuitry. The change would save in overall cost and improve the reliability of the power failure warning system.

10.2.5 Mechanism Assembly

Considerable attention was given to the main frame and mechanism assembly as described in section 6.1.4.

The first and foremost requirement was for the rebalance potentiometers to become more accessible. This was to be achieved by mounting them on a separate demountable member (Fig. 20). This member was to be a pressing into which carriage guide slots were to be cut and from which lugs were to be extended at each end for mounting of the mechanism assembly to the front case. The bridge arrangement is thus the inverse of the original concept, with the capacitor platform now forming the span.

Two alternative forms of construction of this new main frame had been laid out: one being a casting, the other a pressed sheet metal fabrication. Stampings offered greater production economy, but maintenance of accuracy in manufacture must be proven.

The fabricated frame was to be made from four separate major parts which were to be hot staked together in an assembly fixture. The great advantage of this design lies in the reduction of rejects and inspection time in production. Reject stampings would be a rarety once tooling had been perfected and would possibly involve only one part of the frame. Cast frames, on the other hand, would require a considerable amount of machining which must be done by jig borer and must be inspected 100%.

One machining error could cause rejection, wasting all previous manufacturing time on that part.

The rebalance potentiometers and busbars were to be cemented to simplified glass-epoxy laminate supports which in turn were to be cemented to the mounting plate. Terminals for the pots and busbars would consist of small headed pins pressed into the supports and mounting plate. The ends of the potentiometer windings would be resistance welded to the heads of the pins, the projecting ends of the terminals would then be soldered into holes in a flexible printed circuit, cemented to the top of the mounting plate. The printed circuitry would terminate at eyelet in a glass-epoxy laminate panel affixed to a flange on the side of the mounting plate. From here, wire leads would run to an internal connector mounted at the back of the mechanism assembly.

10.2.6 Weight Reduction

Recent developments in amplifiers and motors indicated that a considerable reduction in weight could be achieved during redesign.

As a first step, the EG129A-1 amplifier could be replaced with the 481363 transistor power amplifier developed for the D-DG6000G-1 Three Axis Repeater. This amplifier design uses two Transitron 2N547 silicon transistors which in push-pull can supply 4 watts to drive a size 11 servo motor. It uses the EG113C-1 for the pre-amplifier, which essentially is an improved version of the pre-amplifier and discriminator portion of the EG129A-1 transistor-magnetic amplifier.

Considering a reduction of 3 ounces in the weight of each amplifier, and the improved compactness of the Amplifier-Calibrator resulting therefrom, a total weight reduction of 1.2 pounds would be anticipated.

Again, a size 11 motor could be operated directly from an EG113C-1 amplifier which has a rated output of 1 watt. The motor would be run using unbalanced phases. Some reduction in stall torque results (unbalanced phases stall torque about 70% of balanced phases stall torque), but is not too serious. The

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weight of this amplifier is only 3.25 ounces.

A recently developed size 8 servo motor, the Helipot Corporation model 8SM420 appears well suited to the Mach Indicator, and presents many advantages besides weight economy. Its outstanding characteristics are: stall torque 0.25 oz. in., no load speed 7,000 rpm, rotor inertia 0.1 gm-cm^2, acceleration at stall 170,000 rads/sec^2, weight 1.1 oz., power per phase 2.3 watts, ambient temperature 130°C. These characteristics, especially in rotor inertia and acceleration at stall, are considerably better than other size 8 motors. If used in the instrument, a weight saving of 3.4 ounces per motor or 0.64 lbs. per instrument will result. Its small rotor inertia more than compensates for the smaller stall torque when compared with a size 11 motor, so that the dynamic performance is, in fact, somewhat improved if it is used with an amplifier capable of supplying full control phase power or if used with an EG113C-1 amplifier and operating with unbalanced phases.

With this ultimate combination of EG113C-1 amplifier and Helipot 8SM420 motors, it is possible to reactivate an approach considered at the beginning of the project two years ago. This is the possibility of including the amplifiers within the instrument, and deleting the separate Amplifier-calibrator. Since the instrument is sealed the headers and cases for the EG113C-1's will disappear. The two connectors on the Amplifier-calibrator and associated cabling will be eliminated as well as the parasitic weight associated with the joint mounting tray. It is estimated that this move will require an increase in the case depth of about 3 1/2".

Other combinations using other size 8 motors with one or the other of the amplifiers mentioned may be considered, but some degradation in present performance must be expected because of the low torque to inertia ratios.

If an EG113C-1 amplifier is used with a size 11 motor, or a Helipot size 8 motor not utilizing unbalanced phases, some degradation in dynamic response will also result. The no load speed of the motor will be reduced in the ratio of the power output from the amplifier to the rated control phase power. The gear ratio must, therefore, be decreased and since the load inertia referred to the motor shaft varies inversely as the square of the gear ratio, more sluggish behaviour of the servo is evident.

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11 CONCLUSIONS

11.1 General

The continued evolution of high performance aircraft has increased the complexity of panel instrumentation confronting the pilot and has also increased the rate at which he must correctly assimilate and react to the information presented. Human engineering studies have repeatedly shown that a distinctive and if possible symbolic form of instrumentation provides improved observer reaction, and further, that mechanization of the instrument to permit ready comparison of actual and desired conditions aids in the rapid evaluation of overall performance.

While, then, the advantages accruing from the use of rectangular instruments seem to be well substantiated, the mechanical complexity involved in achieving such devices necessitate careful consideration as to the relative merits. Among other applications where the merits of multiple presentation of rectilinearly-driven indices are advantageous are:

a) An altimeter - where such data as desired altitude, actual altitude (gross and sensitive), terrain clearance, rate of climb may be presented.

b) Fuel management gauge - where the fuel levels of several tank units can be instantly compared.

c) Engine performance indicator - % thrust or rpm, for multi-engined aircraft.

Among the major points of mechanical complexity imposed by the rectilinear presentation are:

a) It is more difficult to provide integral illumination. Whereas the round instrument can be readily illuminated by peripheral lighting or back lighting, the whole area of the rectangular face must be illuminated and back lighting is impossible because of the open slots required for movement of the indices. The recourse to wedge lighting has several drawbacks. The dial is set back behind several layers of glass, causing loss of viewing angle, reflections, and impairment of visibility under daylight at high altitudes (because of lack of diffused light at high altitudes). The wedges themselves are a source of light scatter.

b) Differential coefficients of expansion problems are encountered, angular displacement being non-dimensional, whereas rectilinear displacement involves length.

c) The greater number and area of bearing surfaces increase frictional loading so that servos are required even for non-critical indications.

d) The rectangular case must be made more rugged to withstand flexure under differential pressures.

e) The rectangular case is more difficult to seal, more costly to machine for sealing, and gives rise to non-uniform stresses in the window glass.

f) The round instrument is more economical of panel space for the same scale length.

The development of the Mach Indicator has shown that the above problems can be solved, although the instrument will be more expensive to manufacture than a circular one.

The Mach Indicator is, as far as is known, the first aircraft instrument to be developed having a rectilinear presentation with multiple leadscrew driven indices. Its design incorporates features for field interchangeability, and for harmonization with related input equipment.

The Mach Indicator has demonstrated good accuracy and response characteristics as a servo repeater. It appears capable of meeting the severe environmental conditions of present day aircraft.

11.2 Knowledge and Experience Gained

The specific knowledge and experience gained were mainly as follows:

11.2.1 Hermetic sealing of instrument package

The most reliable and widely used technique for preparing window glasses for soldering is to platinize the sealing edge by a firing process and to dip-tin this surface. Techniques for this process have been developed by the American Optical Company at Belleville, Ontario.

The expansion ring into which the glass is soldered should be of a material having a coefficient of expansion closer to that of the glass than to the case into which it is soldered. The soldering technique used for the front case assembly, namely, to insert fluxed solder preforms in the assembly and then preheat in an oven to 50°F of the melting point of the solder, followed by an immediate soldering operation in an induction heater, was found to be the best way of minimizing stresses in the glass.

The use of tear strip, which may be applied and removed by local heating, and a silicone rubber ring in a gap beneath the tear strip to prevent solder running into the joint between the case halves, is a feasible method of sealing.

Investment castings in Alcan 135 aluminum alloy approximately 0.10 thick proved to be impervious to helium when subjected to high vacuum without impregnation. However, this alloy was found to be almost impossible to re-tin after stripping. Alcan 143 is a more suitable material for electro-tinning and should have reasonable casting qualities.

The evacuation tube should not be a glass header type, as apart from the tendency for the glass to crack if lateral forces are inadvertently applied the tube is of inadequate cross sectional area.

11.2.2 Designing for extreme temperatures

The instrument was designed to operate under all conditions within the ambient temperature range -65°F to 160°F. A maximum internal working temperature of 200°F was allowed for. Lubrication of moving parts was effected by G.E. Versilube F50 silicone oil having a viscosity-temperature co-efficient of 0.60 and low volatility. Tests showed that this lubricant was superior to all others tested.

The effect of differential expansion on reading accuracy was minimized as far as possible by maintaining a reasonable similarity between the coefficients of thermal expansion of the scale and the rebalance potentiometers. The scale was made of aluminum alloy while the potentiometer core was copper. Aluminum was not used for the core because of the difficulty of obtaining aluminum rod with a good insulated coating; however, the differential expansion between the aluminum and copper was responsible for a shift of only slightly more than .001" over a 3" length between ambient and maximum or minimum temperature. The potentiometers were mounted on glass epoxy laminate supports having a coefficient of expansion very close to that of copper.

The stainless steel leadscrews were located by the bearings at one end only, the other bearing being allowed to slide on the shaft and loaded axially by a spring.

The window glass was soldered to a flexible "U" section expansion ring, which was in turn soldered to the aluminum front case.

11.2.3 Integral Illumination

Considerable knowledge has been gained concerning all aspects of integral illumination of aircraft instruments, particularly those phases pertaining to the wedge principle. The first method tried, that of piping light through transparent plastic indices (Fig. 11) was workable, but was abandoned because the plastic material could not withstand the high temperatures encountered within the instrument. Since that time, new transparent plastic materials have been developed of which the best but most expensive is Sierracin 880 which will withstand approximately 300°F.

The latest form of wedge system developed for the pre-production models (Fig,17) appeared from tests on a prototype model using plastic wedges to be highly successful and suitable for production.

Much knowledge was gained on the subject of miniature lamps and the measurement of light intensity particularly that of coloured light. Those subjects are covered in Appendices A and B respectively.

11.2.4 Leadscrew Wear

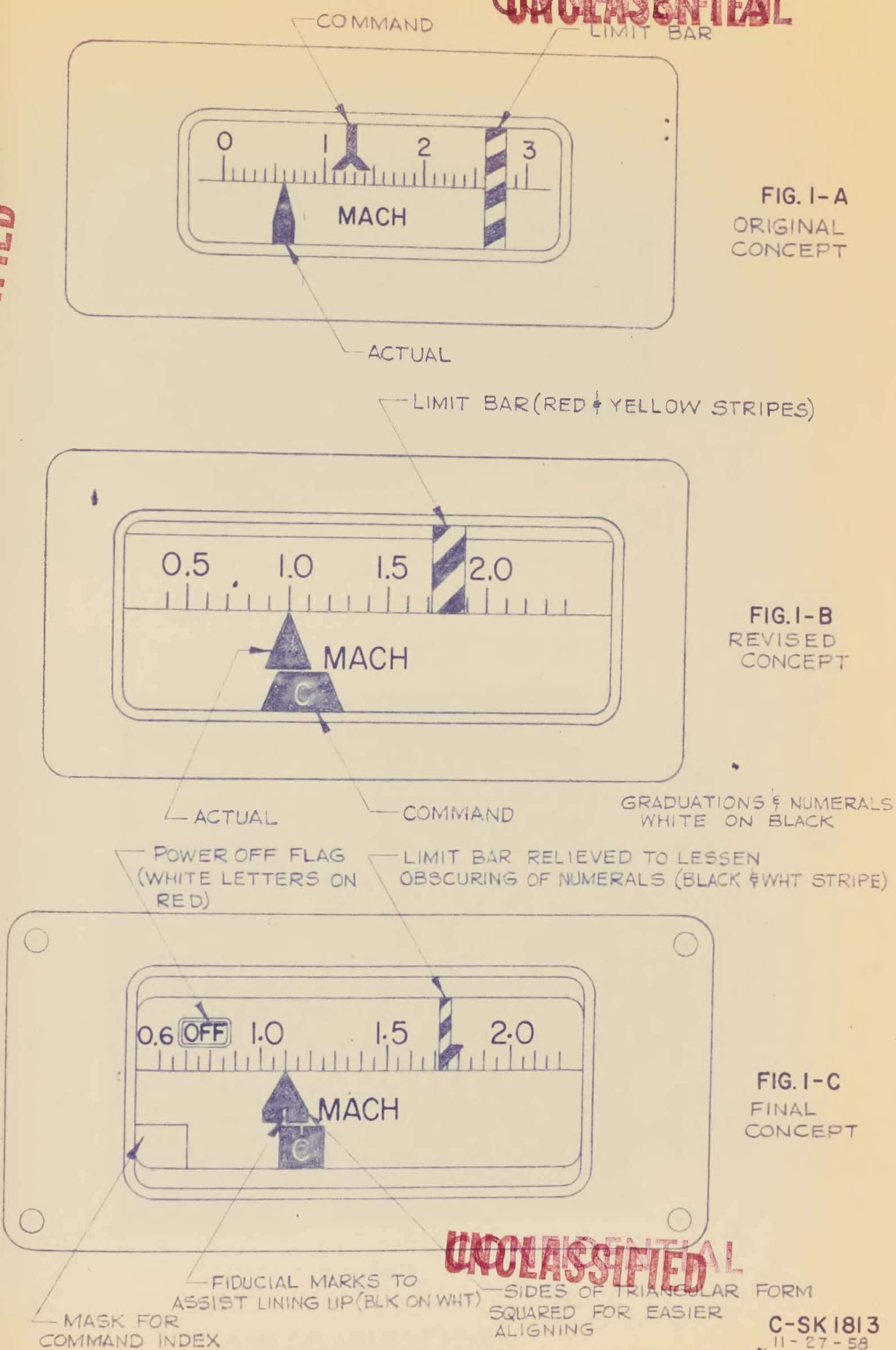
A wear test program was carried out on the leadscrew and carriage system to determine the optimum material, surface finish and lubrication for the leadscrews to give longevity.

Best wear results were obtained with a hardened Type 431 stainless steel leadscrew running in a leaded tin bronze investment cast carriage and lubricated with Versilube F50 silicone oil. The lubricant was retained by impregnation of a sintered bronze carriage loading nut. The surface finish of these leadscrews was better than 16 micro inches.

11.3 Integral Packaging

Recent developments in components have indicated that greater compactness in packaging with resultant weight reduction can be achieved, to a degree that a completely integrated indicator with self-contained amplifiers is feasible.

The ultimate in compactness at the present state of the art, and with no sacrifice in performance, would be the use of Minneapolis-Honeywell's EG113C-1 amplifier, together with the Helipot 8SM420 Size 8 servo motor wound for unbalanced phase operation.



MACH INDICATOR DIAL PRESENTATION - FIG 1

C-SK 1813
11-27-58
(SCALE 1:1)

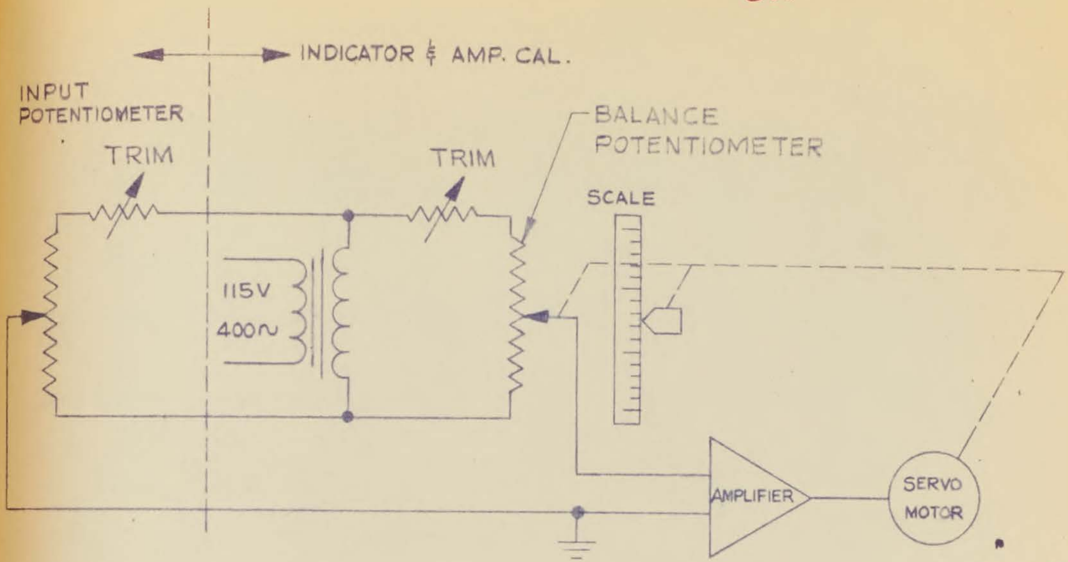


FIG. 4 BASIC SERVO SYSTEM

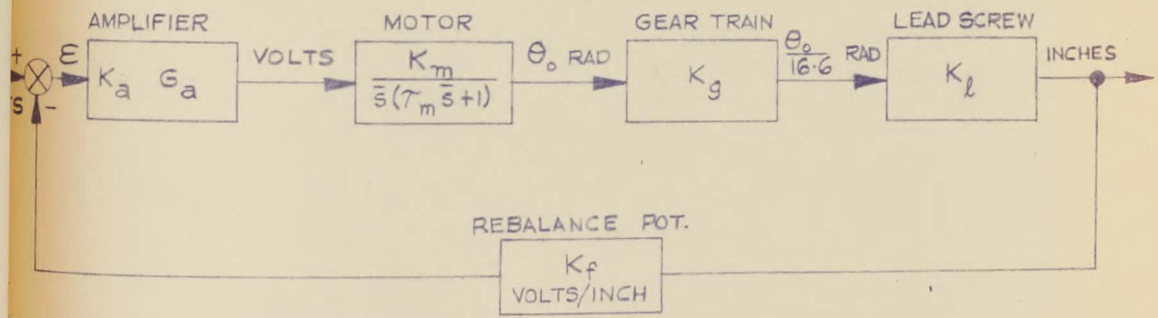


FIG. 5 SERVO SYSTEM BLOCK DIAGRAM

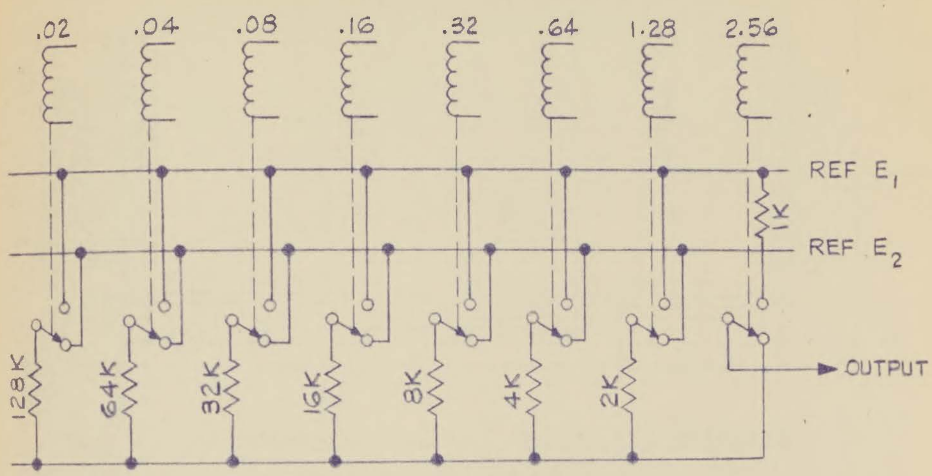
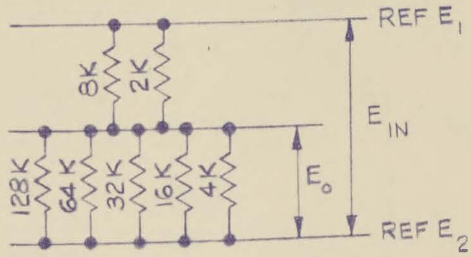


FIG. 6

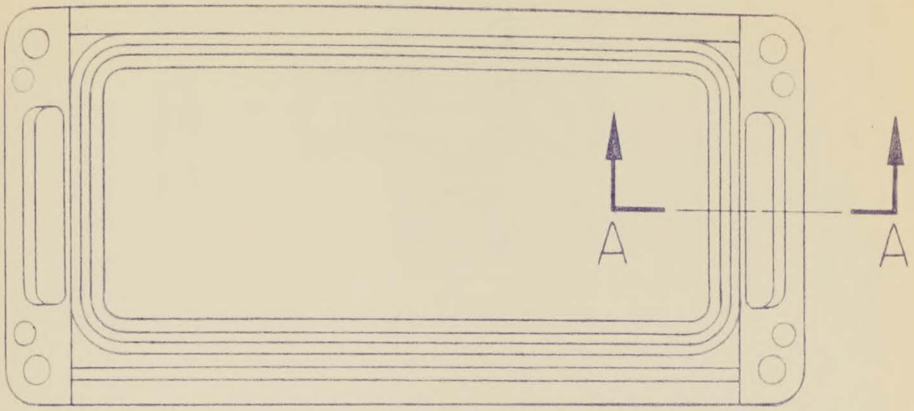
R.C.A. DATA LINK NETWORK FOR COMMAND MACH



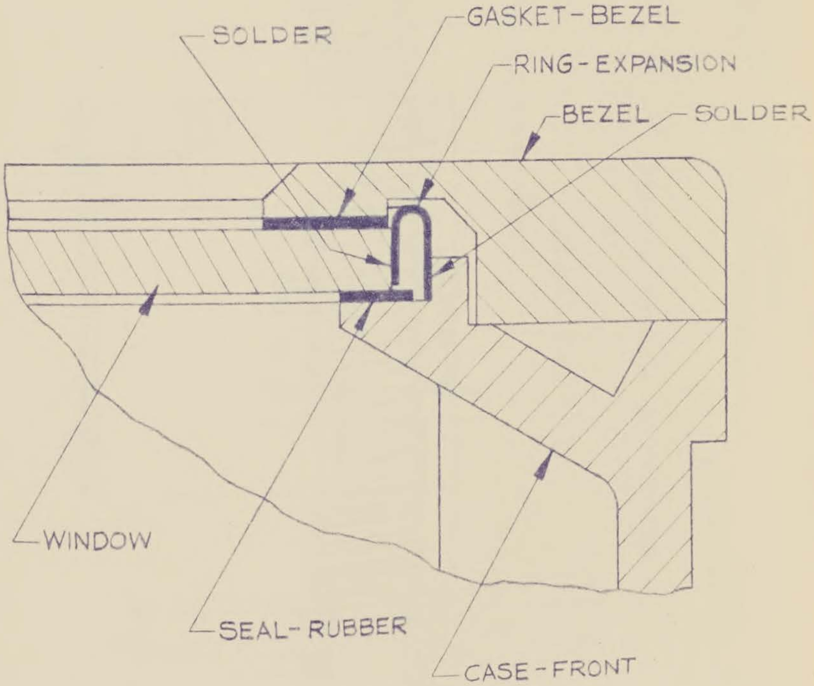
$$\frac{E_o}{E_{IN}} = \frac{2.725K}{4.325K} = 0.63 = \frac{1.6M}{2.54M}$$

FIG. 7

CIRCUIT REDUCTION FOR EXAMPLE OF 1.60 M.



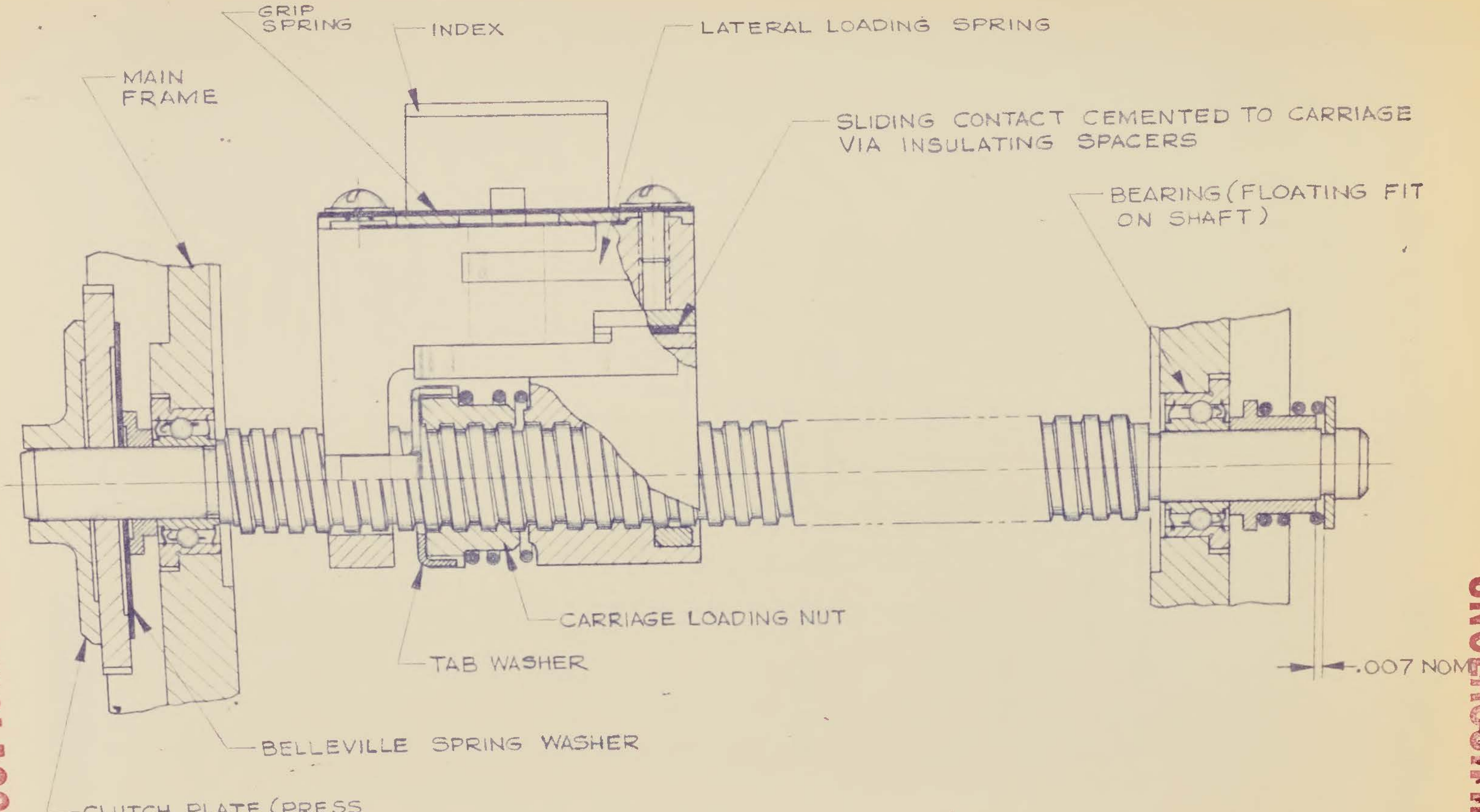
FRONT VIEW - GASKET AND BEZEL REMOVED
SCALE - FULL SIZE



SECTION A-A
SCALE - 4 X SIZE

C-SK1808
11-25-58

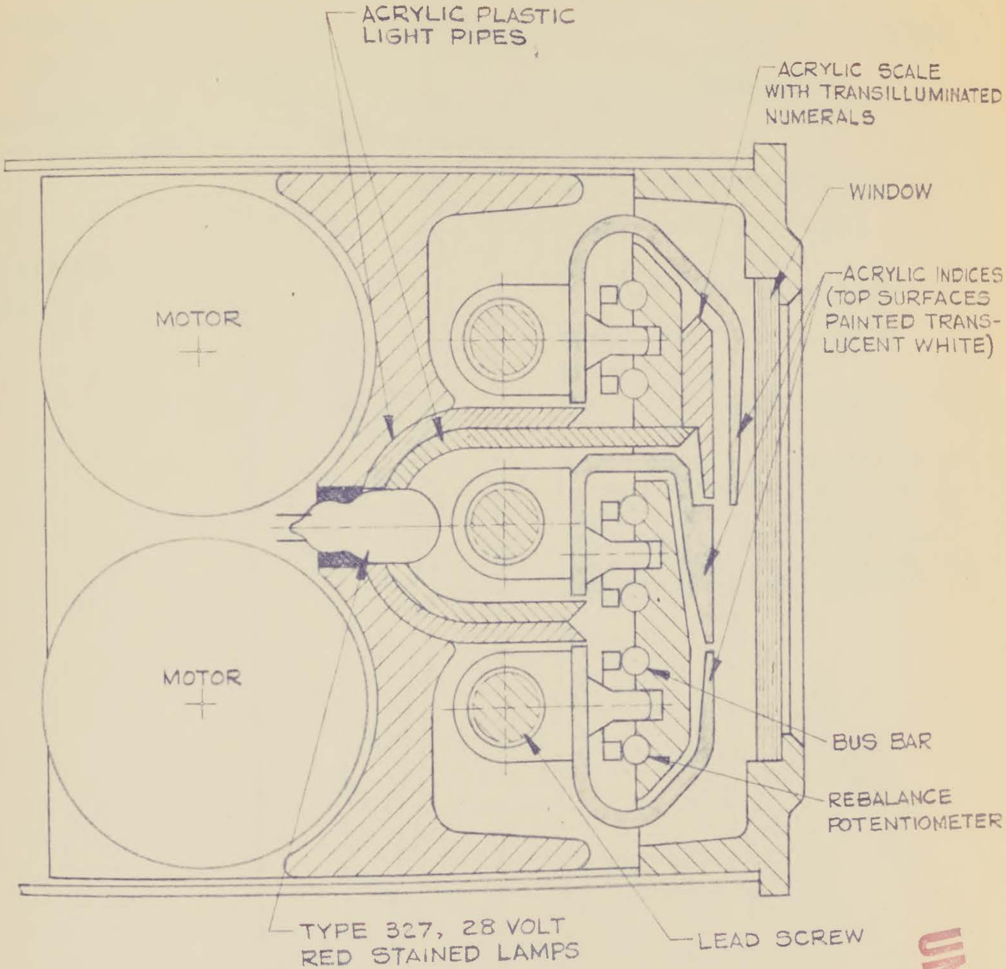
FIG 8



TYPICAL SECTION - LEAD SCREW & CARRIAGE
MACH INDICATOR - "D" MODEL DESIGN

FIG 9

SCALE 4:1
DEC 19-58

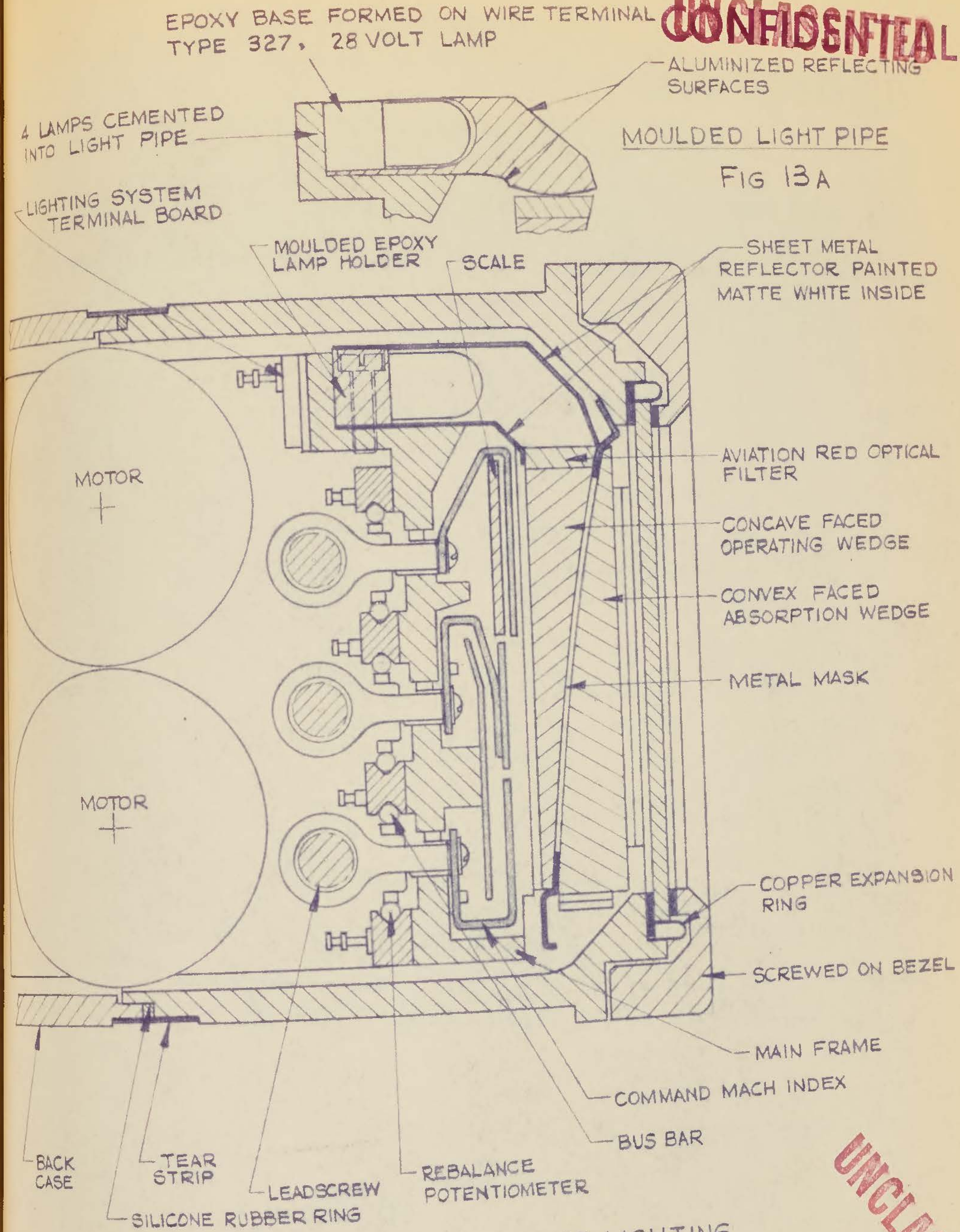


TYPICAL SECTION SHOWING LIGHTING ARRANGEMENT

MACH INDICATOR - PRELIMINARY DESIGN
(SCALE 2X SIZE)

C-SK1810
11-26-58

FIG 11



MOULDED LIGHT PIPE

FIG 13A

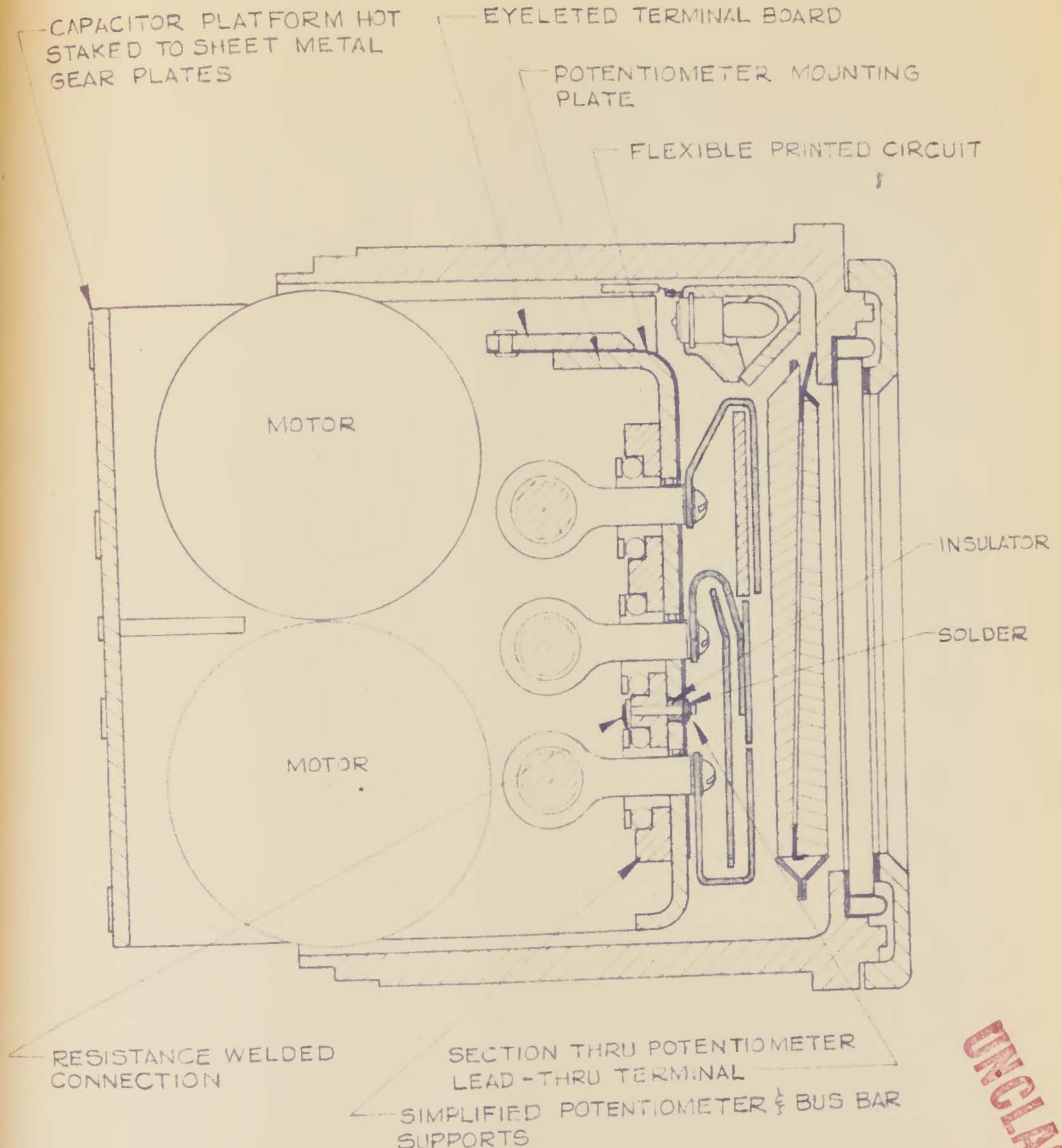
TYPICAL SECTION SHOWING LIGHTING ARRANGEMENT

MACH INDICATOR - "D" MODEL

(SCALE 2X SIZE)

C-SK1811
11-26-58

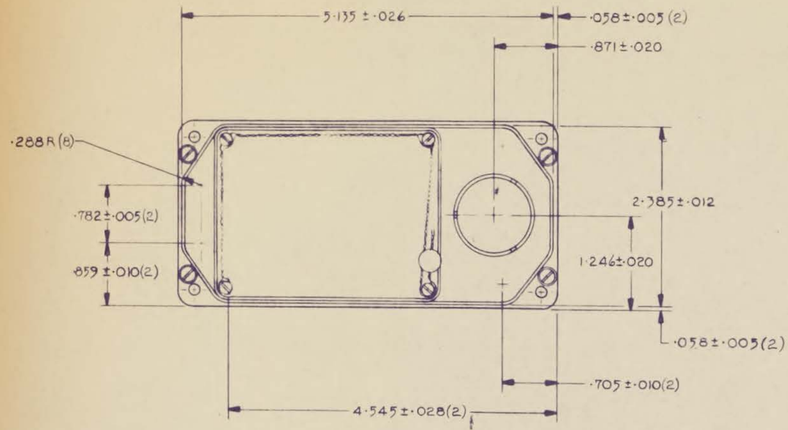
FIG 13

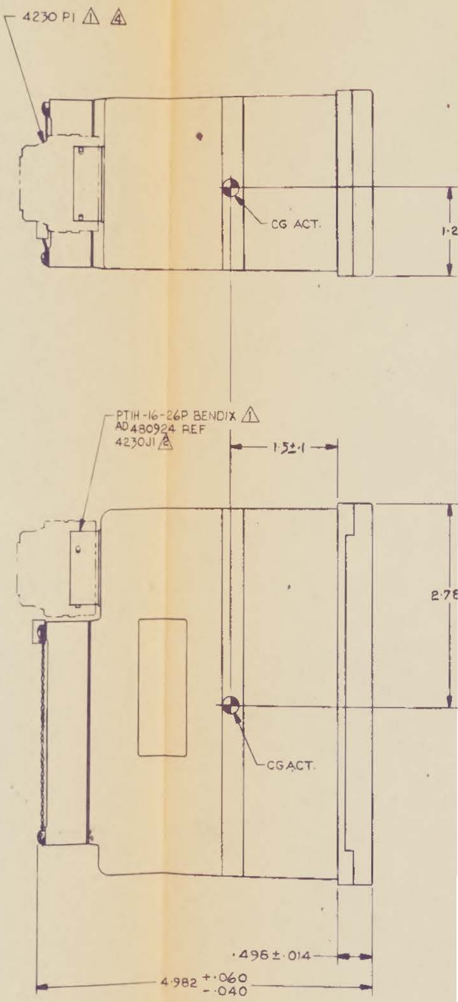


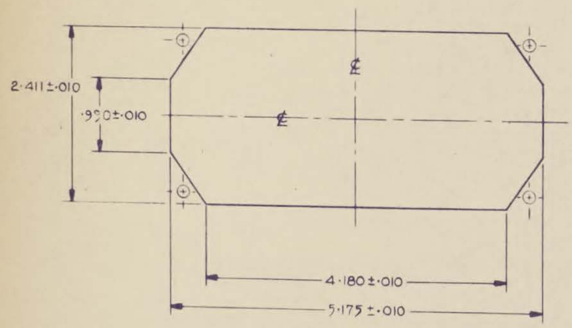
MACH INDICATOR - TYPICAL SECTION THRU FRONT CASE AND MECHANISM ASSY - ADVANCED PRE PRODUCTION DESIGN
(SCALE 2:1)

C-SK1814
11-28-58

FIG 20

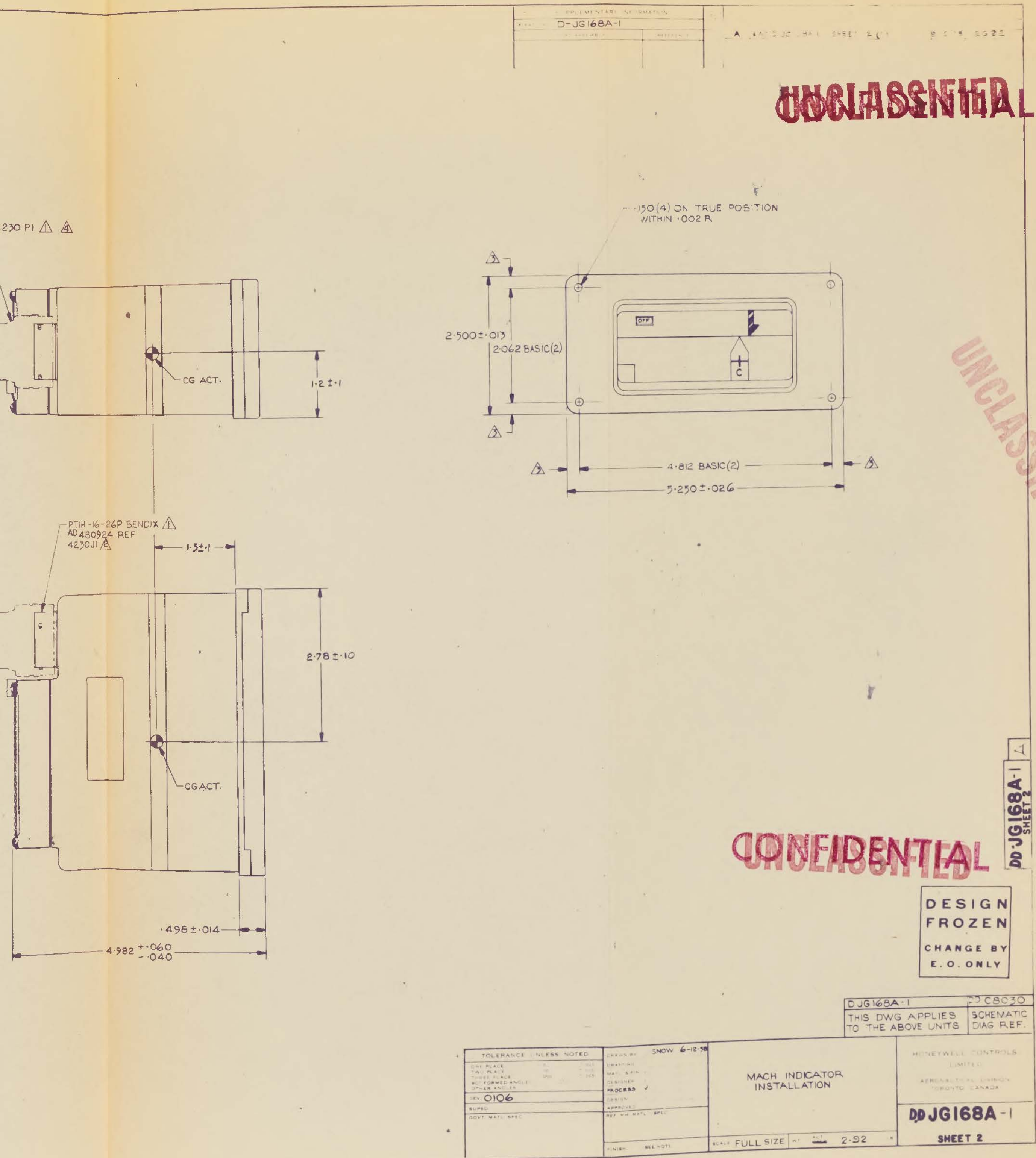






RECOMMENDED PANEL CUT-OUT

△4 - REF DESIGNATION PER SYSTEM SCHEMATIC DIAGRAM UD H 4702
△3 - THESE DIMENSION PAIRS ARE EQUAL WITHIN ·006 REF
△2 - REF DESIGNATION PER SCHEMATIC DIAGRAM AD C 8030
△1 - RECOMMENDED MATING CONNECTOR BENDIX PYGMY PT06P-16-26S REF NOT FURNISHED BY MH



D-JG168A-1
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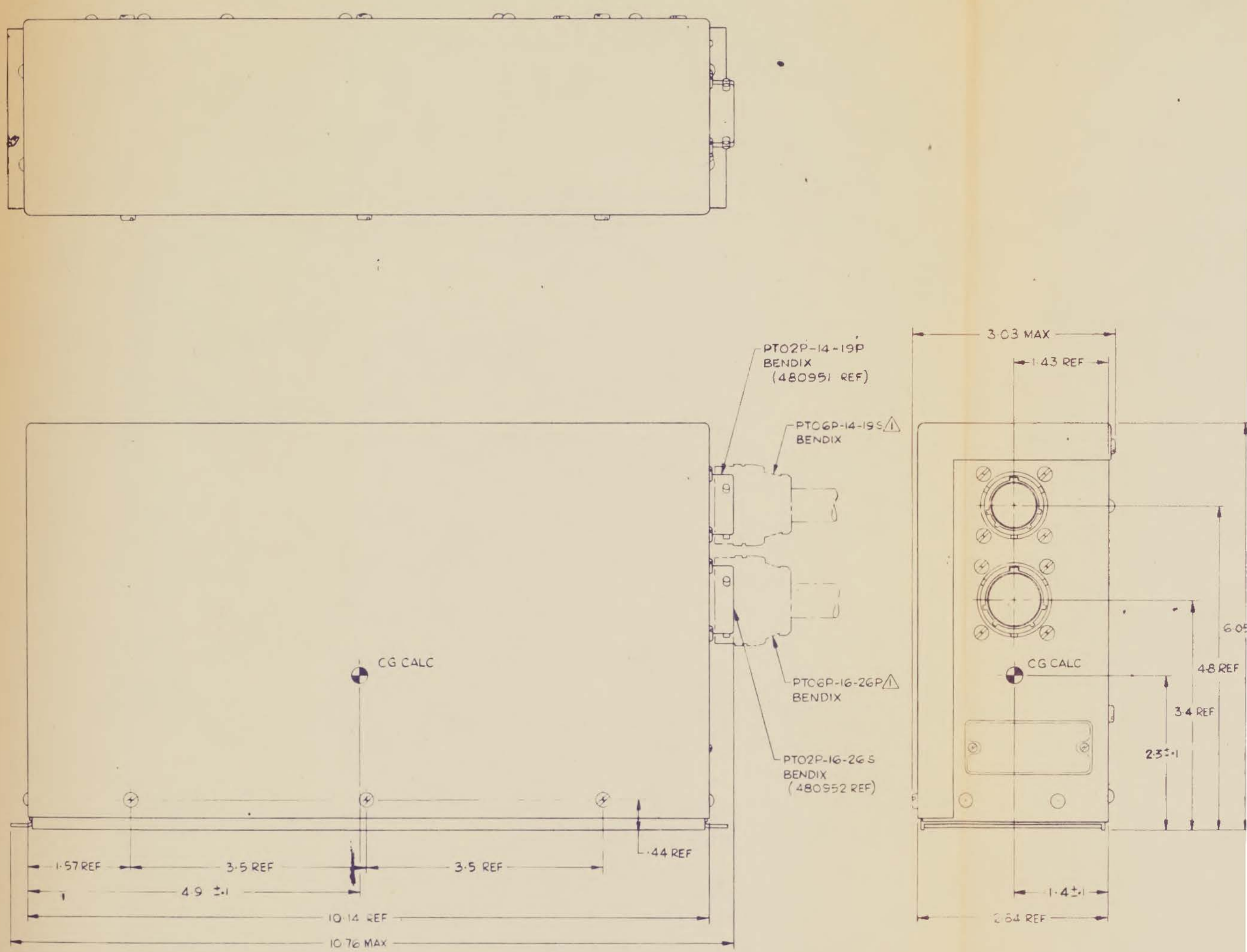
CONFIDENTIAL
.150 (4) ON TRUE POSITION WITHIN .002 R
2.500±.013
2.062 BASIC(2)
OFF
C
4.812 BASIC(2)
5.250±.026
230 P1
CG ACT.
1.2±.1
PTIH-16-26P BENDIX
AD480924 REF
4230J1
1.5±.1
2.78±.10
CG ACT.
.498±.014
4.982 +.060 -.040
DD-JG168A-1 SHEET 2
DESIGN FROZEN
CHANGE BY E.O. ONLY
DJG168A-1
DC8030
THIS DWG APPLIES TO THE ABOVE UNITS
SCHEMATIC DIAG REF.
TOLERANCE UNLESS NOTED
0106
SNOW 6-12-58
PROCESS
MACH INDICATOR INSTALLATION
HONEYWELL CONTROLS LIMITED
AERONAUTICAL DIVISION TORONTO CANADA
DD JG168A-1
SHEET 2
FULL SIZE
2.92



⚠1 - NOT FURNISHED BY HONEYWELL

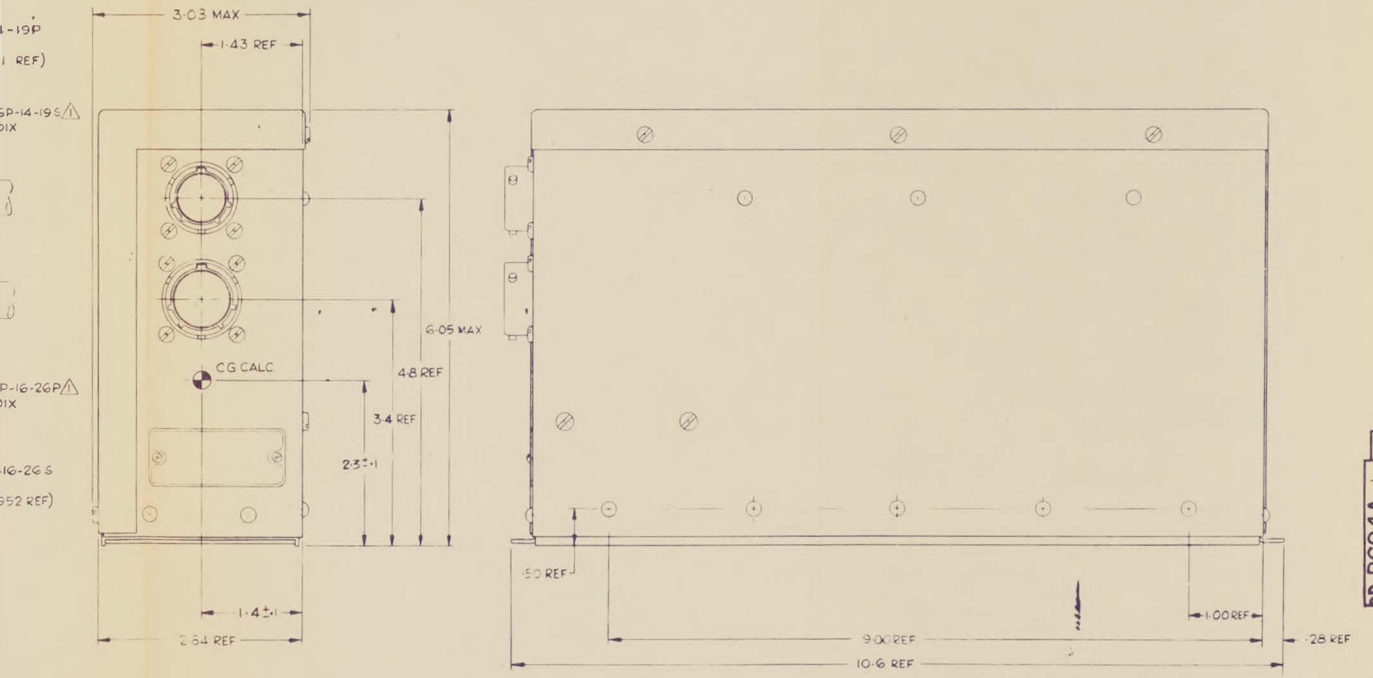
SUPPLEMENTARY INFORMATION	
FIRST USED D-BG 94 A-1	
NEXT ASSEMBLY	REFERENCE

FIRST CLASS.

REVISIONS			
SYM	DESCRIPTION	DATE	APPROVAL
A	WAS DD-BG 94A-1 SHEET 2 (2)	9-12-58	2692

CONFIDENTIAL

UNCLASSIFIED



UNCLASSIFIED

DD-BG94A-1 SHEET 2 | A

DESIGN FROZEN
CHANGE BY E.O. ONLY

CONFIDENTIAL

UNCLASSIFIED

D-BG94A-1 (ALL)	C8029
THIS DWG APPLIES TO THE ABOVE UNITS	SCHEMATIC DIAG REF

TOLERANCE UNLESS NOTED	
ONE PLACE ·0	± ·020
TWO PLACE ·00	± ·010
THREE PLACE ·000	± ·005
90° FORMED ANGLES	
OTHER ANGLES	
DEV. 0106	
SUPSD	
GOVT MATL SPEC	

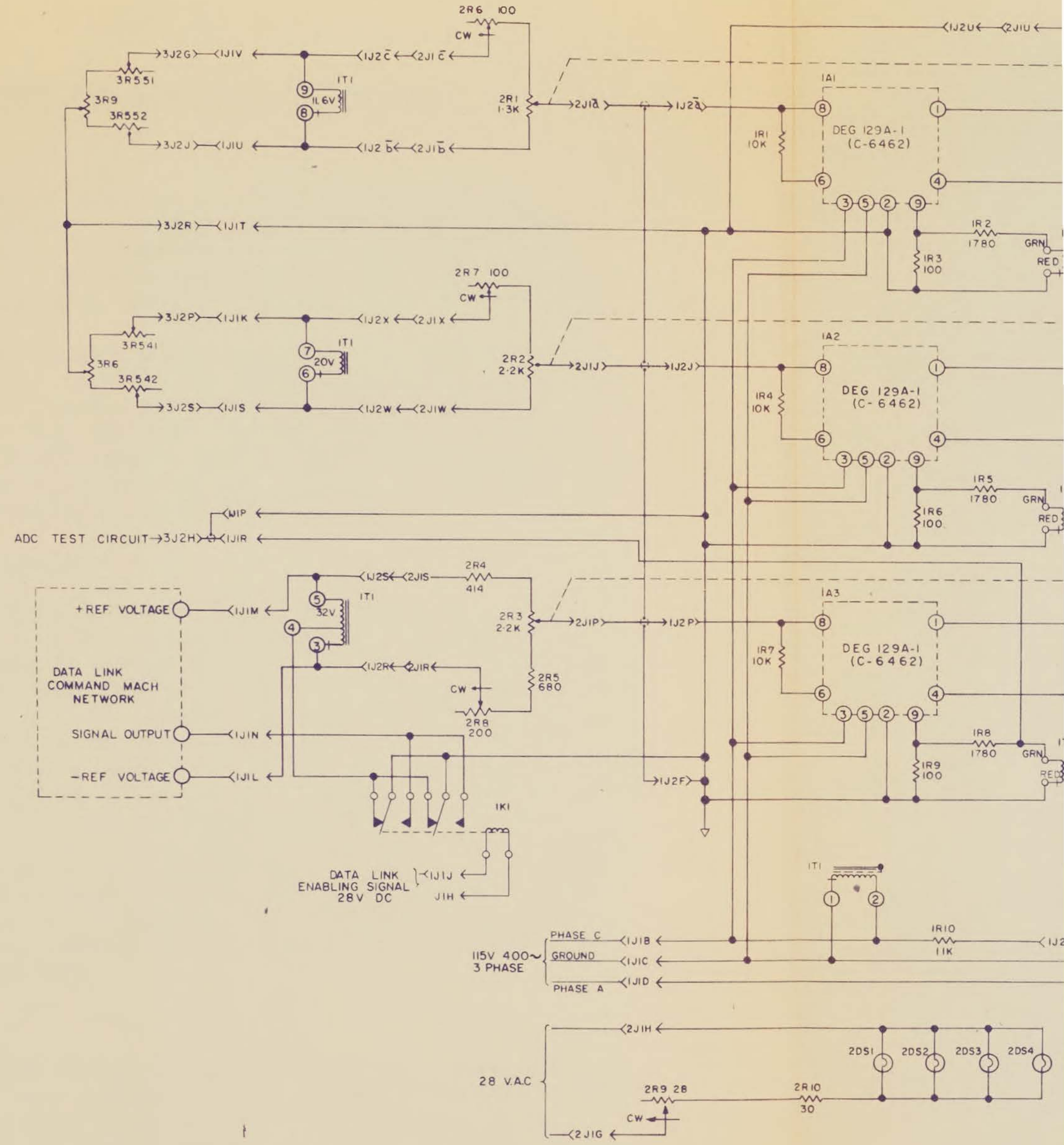
DRAWN BY P. HOLMES 7-10-58
DRAFTING
MATL & FIN
DESIGNER
PROCESS
DESIGN
APPROVED
REF MH MATL SPEC
FINISH SEE NOTE

AMPLIFIER CALIBRATOR INSTALLATION

SCALE FULL SIZE | WT CALC 4·1 LB

HONEYWELL CONTROLS LIMITED
AERONAUTICAL DIVISION
TORONTO CANADA

DD-BG94A-1
SHEET 2



3 — FOR INTERCONNECTING DIAGRAM SEE DWG[DD] H 4702

2 — WHEN USED IN A.E.S SYSTEM, PREFIX 1 IN REF DESIGNATION IS REPLACED BY 4240
PREFIX 2 IN REF DESIGNATION IS REPLACED BY 4230
PREFIX 3 IN REF DESIGNATION IS REPLACED BY 4310
FOR EXAMPLE, 1J2W IS 4240J2W

1 — ALL RESISTANCES ARE IN OHMS & ALL CAPACITANCES ARE IN UF UNLESS OTHERWISE SPECIFIED

DYG 6000A-1

D YG 6000A-1 S1 THRU DD C8024

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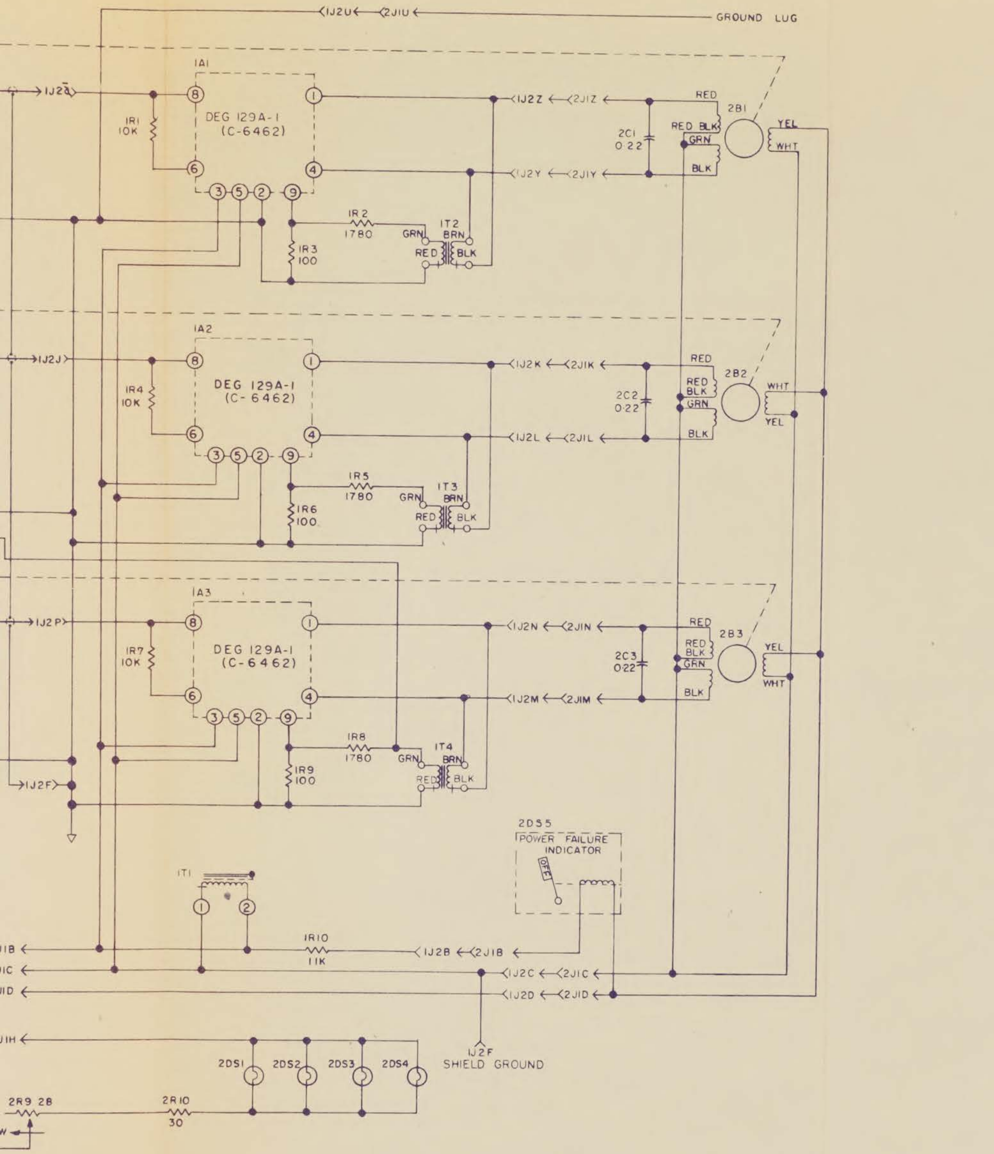
CONFIDENTIAL



UNCLASSIFIED

DD C8024

DESIGN FROZEN

CHANGE BY E.O. ONLY

0106	PROCESS	SNOW 7-14-58 SCHEMATIC DIAGRAM-MACH INDICATOR SYSTEM NONE	DD C8024

1.4 Light Intensity Tolerance

To achieve the accuracy of light intensity of instrument illumination systems demandee by MIL-L-25467A Amendment 1, it is necessary to use lamps having a light output within a tolerance of ± 15% of the nominal mean spherical candle power at rated voltage. Lamps held to such a tolerance are not yet commercially available but Chicago Miniature Lamp Works have set up a facility by which they will select lamps to this tolerance on demand.

APPENDIX B

1 LIGHT INTENSITY MEASUREMENT

A factor which hindered the development of the illumination system for the Mach Indicator was the lack of a suitable means of making photometric and colorimetric measurements in the red region of the visible spectrum. Much time was spent in trying to use what are now known to be inadequate measuring instruments and techniques.

Our Minneapolis measurements personnel were greatly concerned by this problem and by going into it very thoroughly and in co-operation with the United States National Bureau of Standards they have achieved a workable solution. The method involves the use of the best commercial photometer, the Spectra Brightness Spot Meter, supplied with a specially selected, red sensitive photomultiplier tube. Special calibration and operation procedures have been worked out to determine the colour ratio versus correction factor curve for the combination of photomultiplier tube and lens system in use. The dominant wavelength of the red light emitted by the instrument dial to be calibrated is then determined and the correction factor taken from the curve. By this means, and with periodic checking of the standard brightness source against a primary brightness standard, consistency of readings within 20% between photometers can be achieved. Low as this accuracy may seem it is many times better than anything previously achieved with commercially available equipment.

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APPENDIX C

ENGINEERING SPECIFICATION NO. ES-0101-1

DJG168A-1

MACH INDICATOR

Design Requirements

1.1 General Description

1.1.1 Function

This device is an hermetically sealed and integrally illuminated voltage rebalance servo driven instrument intended to provide visual information on Actual, Command and Limit Mach by the straight line motion of indicia relative to a linear scale.

1.1.2 Associated Equipment

The instrument is to be used in conjunction with the BG94A-1 Amplifier to transduce signals received from the Air Data Computer and Data Link outputs of the Avro Arrow.

1.1.3 Adjustment

Provision is made for factory adjustment and calibration. Calibration equipment is contained within a separate compartment, safety wired to discourage tampering.

It is not intended that the device shall be re-calibrated in the field.

1.1.4 Mounting

The indicator front mounts to the instrument panel and is of basically rectangular form. It occupies a panel space of 2.5 inches vertically by 5.26 inches horizontally and extends approximately five inches behind the panel.

1.1.5 Connection

The instrument is provided with an hermetically sealed Bendix Pygmy connector, bayonet lock, type PT1H-16-26P. The mating plug is a Bendix Pygmy PT06 type with 16-26S socket assembly.

Specific Ratings

.1 Electrical

1.1 Input

The instrument is designed to operate from two phases of a 115 volt/200 volt A.C., 400 cps three phase system. The illumination system requires 28 volts A.C., 400 cps. Motor phases are rated at 115 volts, 400 cps.

Unless otherwise specified the following voltages and tolerances shall be used for calibrating and testing the instrument.

1.1.1 115 $\pm$ 3 volt A.C. 400 $\pm$ 5 cycles at 0° (reference) phase angle applied to connector pin 'D'.

1.1.2 115 $\pm$ 3 volt A.C. 400 $\pm$ 5 cycles at 120° leading phase applied to connector pin B.

1.1.3 The A.C. supply shall have a harmonic content less than 5%.

.1.1.4 28 $\pm$ 0.5 volts A.C., 400 $\pm$20 cycle, no specified phase applied to the illumination system.

.1.1.5 Voltages of 11.6, 20 and 32 volts (nominal) derived via the DB694A-1 Amplifier Calibrator from the 120° leading phase are supplied to the Mach Limit, Actual Mach, and Command Mach rebalance potentiometer respectively.

.1.2 Output

The output consists of signal voltages derived from the rebalance potentiometers under excitation as listed in 1.2.1.1.4.

The voltage between the wiper of any rebalance potentiometer and signal ground, ie., the error voltage shall be substantially zero when the instrument is in operation. This is also manifested by a substantially zero voltage across the control phase of the respective servo motor.

1.2.2 Mechanical

1.2.2.1 Output

The output consists of visual presentation of data by indicia position over the range noted.

.1.1 Mach Limit, over the range 1.1 to 2.0 Mach.

.1.2 Actual Mach, over the range 0.6 to 2.2 Mach

.1.3 Command Mach, over the range 0.8 to 2.2 Mach.

.1.4 Indication of Power Failure.

Detail Requirements

Applicable Specifications

The instrument has been designed in conformance with R-ED 873 "Preliminary Detail Specification for the type JG168A-1 Mach Indicator and Type BG94A-1 Amplifier Calibrator for use in the Avro Arrow Aircraft," and in conformance with the specifications listed therein.

Response

The minimum response speed of all three indicia is 9 Mach units per minute.

PROCESS REQUIREMENTS

Honeywell Process E.S. Involved

.1 The unit shall be identified in accordance with ES 9019.

.2 All soldering shall be per ES 4824.

.3 The trim pot compartment cover shall be lockwired in accordance with M.S. 33540.

Specific Processes

.1 General

.1.1 All parts are to be thoroughly cleaned in chlorothene to M.H. Spec. 7506 prior to lubrication or assembly and shall subsequently be stored in clean dust tight containers.

.1.2 Clutch components and gears shall be coated with a light file of silicone oil to M.H. Spec. 6895 by dipping and allowed to drain for at least 30 minutes on a wire screen in a covered glass dish before assembly.

.2 Ball Bearings

All ball bearings, and sub-assemblies containing ball bearings, shall be processed in accordance with E.S. 4046.

.3 Potentiometers

Potentiometers shall be processed in accordance with E.S. 4826 as applicable.

2.4 Light Bulbs

2.4.1 Preburning

All light bulbs used in the integral illumination system shall, in an ambient temperature of 50°C., be preburned for 50 hours at 28 volts A.C., ± 1 volt, and shall be subject to five over voltages surges in accordance with Figure 1 of MIL-E-7894A prior to selection for brilliance.

2.4.2 Selection

All bulbs surviving 2.2.4.1 shall be checked for relative brightness by placing a hooded exposure meter over each individual bulb and recording the light emission obtained with 24 volts ± 0.5 volts across the bulb. Bulbs giving readings varying by more than ± 15% from the mean batch emission shall be rejected (Odd bulbs of extremely high or low emission may be neglected in calculating the mean if they unduly affect the balance.)

No bulb used in any one instrument shall be more than 15% brighter than the dullest bulb used in that instrument.

2.5 Front Case Sub-Assembly

The bezel glass and expansion ring are to be soldered into the front case casting using solder to MS6570 and MS6334 flux. The procedure is as follows:

a) Assemble expansion ring and glass into recess in front case. Brush flux into joint and place .010 x .100 section solder preforms over joint.

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APPENDIX C

ENGINEERING SPECIFICATION NO. ES-0101-1

DJG168A-1

MACH INDICATOR

1 Design Requirements

1.1 General Description

1.1.1 Function

This device is an hermetically sealed and integrally illuminated voltage rebalance servo driven instrument intended to provide visual information on Actual, Command and Limit Mach by the straight line motion of indicia relative to a linear scale.

1.1.2 Associated Equipment

The instrument is to be used in conjunction with the BG94A-1 Amplifier to transduce signals received from the Air Data Computer and Data Link outputs of the Avro Arrow.

1.1.3 Adjustment

Provision is made for factory adjustment and calibration. Calibration equipment is contained within a separate compartment, safety wired to discourage tampering.

It is not intended that the device shall be re-calibrated in the field.

1.1.4 Mounting

The indicator front mounts to the instrument panel and is of basically rectangular form. It occupies a panel space of 2.5 inches vertically by 5.26 inches horizontally and extends approximately five inches behind the panel.

1.1.5 Connection

The instrument is provided with an hermetically sealed Bendix Pygmy connector, bayonet lock, type PT1H-16-26P. The mating plug is a Bendix Pygmy PT06 type with 16-26S socket assembly.

1.2 Specific Ratings

1.2.1 Electrical

1.2.1.1 Input

The instrument is designed to operate from two phases of a 115 volt/200 volt A.C., 400 cps three phase system. The illumination system requires 28 volts A.C., 400 cps. Motor phases are rated at 115 volts, 400 cps.

Unless otherwise specified the following voltages and tolerances shall be used for calibrating and testing the instrument.

1.2.1.1.1 115 ± 3 volt A.C. 400 ± 5 cycles at 0° (reference) phase angle applied to connector pin 'D'.

1.2.1.1.2 115 ± 3 volt A.C. 400 ± 5 cycles at 120° leading phase applied to connector pin B.

1.2.1.1.3 The A.C. supply shall have a harmonic content less than 5%.

1.2.1.1.4 28 ± 0.5 volts A.C., 400 ±20 cycle, no specified phase applied to the illumination system.

1.2.1.1.5 Voltages of 11.6, 20 and 32 volts (nominal) derived via the DBG94A-1 Amplifier Calibrator from the 120° leading phase are supplied to the Mach Limtt, Actual Mach, and Command Mach rebalance potentiometer respectively.

1.2.1.2 Output

The output consists of signal voltages derived from the rebalance potentiometers under excitation as listed in 1.2.1.1.4.

The voltage between the wiper of any rebalance potentiometer and signal ground, ie., the error voltage shall be substantially zero when the instrument is in operation. This is also manifested by a substantially zero voltage across the control phase of the respective servo motor.

1.2.2 Mechanical

1.2.2.1 Output

The output consists of visual presentation of data by indicia position over the range noted.

2.2.1.1 Mach Limit, over the range 1.1 to 2.0 Mach.

2.2.1.2 Actual Mach, over the range 0.6 to 2.2 Mach

2.2.1.3 Command Mach, over the range 0.8 to 2.2 Mach.

2.2.1.4 Indication of Power Failure.

3 <u>Detail Requirements</u>

3.1 <u>Applicable Specifications</u>

The instrument has been designed in conformance with R-ED 673 "Preliminary Detail Specification for the type JG168A-1 Mach Indicator and Type BG94A-1 Amplifier Calibrator for use in the Avro Arrow Aircraft," and in conformance with the specifications listed therein.

3.2 <u>Response</u>

The minimum response speed of all three indicia is 9 Mach units per minute.

PROCESS REQUIREMENTS

1 <u>Honeywell Process E.S. Involved</u>

1.1 The unit shall be identified in accordance with ES 9019.

1.2 All soldering shall be per ES 4824.

1.3 The trim pot compartment cover shall be lockwired in accordance with M.S. 33540.

2 <u>Specific Processes</u>

2.1 <u>General</u>

2.1.1 All parts are to be thoroughly cleaned in chlorothene to M.H. Spec. 7506 prior to lubrication or assembly and shall subsequently be stored in clean dust tight containers.

2.1.2 Clutch components and gears shall be coated with a light file of silicone oil to M.H. Spec. 6895 by dipping and allowed to drain for at least 30 minutes on a wire screen in a covered glass dish before assembly.

.2 **Ball Bearings**

All ball bearings, and sub-assemblies containing ball bearings, shall be processed in accordance with E.S. 4046.

2.3 **Potentiometers**

Potentiometers shall be processed in accordance with E.S. 4826 as applicable.

2.4 **Light Bulbs**

2.4.1 Preburning

All light bulbs used in the integral illumination system shall, in an ambient temperature of 50°C., be preburned for 50 hours at 28 volts A.C., ± 1 volt, and shall be subject to five over voltages surges in accordance with Figure 1 of MIL-E-7894A prior to selection for brilliance.

2.4.2 Selection

All bulbs surviving 2.2.4.1 shall be checked for relative brightness by placing a hooded exposure meter over each individual bulb and recording the light emission obtained with 24 volts ± 0.5 volts across the bulb. Bulbs giving readings varying by more than ± 15% from the mean batch emission shall be rejected (Odd bulbs of extremely high or low emission may be neglected in calculating the mean if they unduly affect the balance.)

No bulb used in any one instrument shall be more than 15% brighter than the dullest bulb used in that instrument.

2.5 **Front Case Sub-Assembly**

The bezel glass and expansion ring are to be soldered into the front case casting using solder to MS6570 and MS6334 flux. The procedure is as follows:

a) Assemble expansion ring and glass into recess in front case. Brush flux into joint and place .010 x .100 section solder preforms over joint.

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b) Preheat sub-assembly in air circulating oven at 350°F until temperature is stabilized.

c) Transfer sub-assembly to previously set up inducation heater and, with minimum delay, apply heat until solder has run into joints. Should additional solder be required in the corners extreme care shall be exercised to avoid excess coating on the glass.

d) As much flux as possible shall be removed by immersion in a hot tri-chlorethelene bath. Any flux residue shall be de-activated by heating as per ES 4824.

2.2.6 Preliminary Sealing Check

The front and back case sub-assemblies shall be tested for quality of hermetic seal prior to further assembly. The leak rate when tested in accordance with M.H. Process S.S. 4863 shall not exceed 1 x 10^{-8} c.c. per second.

2.2.7 General Assembly Sequence

The recommended assembly sequence is as follows:

a) With the main frame secured to the assembly fixture mount the bus bar and potentiometer assemblies, with leads attached, to the main frame. Secure the leads from the potentiometer terminals under the wire clamps held by the next fixing screw toward the centre of the potentiometer support. Smear a thin film of Helilube grease onto the potentiometers and bus bars using a clean brush or lint free cloth.

b) Assemble compound gear studs to the main frame.

c) Instal the lead screw sub-assemblies and carriages and set and/or check wiper tension at 5 grams ± 3/4 gram. This check shall be made with the carriage at mid travel and transversely loaded to ensure contact between the carriage pad and the guide slot. Secure the lead screw, selecting the spacer bush to provide .005 to .008 axial freedom.

d) Solder lamp wires and leads to terminals on illumination system terminal board using the lighting system soldering fixture. Remove all surplus flux with chlorothene and transfer sub-assembly to main frame. Add clips to secure lead wires.

e) Instal servo motors.

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f) Fit compound gears to studs and check backlash as per Section 4.2.1.3.

g) Attach Power Failure Indicator sub-assembly to main frame.

h) Lightly screw wire duct assembly to condenser platform sub-assembly and thread leads from motors, pots, bus bars and power failure indicator through their respective holes as shown on the wiring diagram. Lightly screw condenser platform sub-assembly to main frame.

i) Instal power failure indicator flag, pointers with their associated springs, and the scale in the order given. Only the screws holding the Mach Limit pointer shall be secured with glyptol at this stage. The scale, shield and indicia shall be tested for contrast in accordance with Section 4.2.1.7 prior to assembly.

j) Complete connector to header and ground lug wiring in the back case and wire up trim potentiometers and variable resistor to header. Solder all leads from the mechanism to the terminal board and wire up to the header and connector using the wiring fixture. Clean off all surplus flux and solder splatter with chlorothene, holding the mechanism in an inverted position while cleaning the main terminal board to avoid dropping of chlorothene into the mechanism.

k) Test for potentiometer noise as per Section 4.2.1.6.

l) Fit mechanism into test fixture and run in on appropriate input. Run in Actual and Command Mach drive systems for 30 minutes; Mach Limit for 20 minutes.

m) Check slewing, sensitivity and overshoot as per section 4.2.2.3.1 paragraphs b), c), f), h), and i); backlash as per section 4.2.1.3 and the power failure indicator as per section 4.2.1.2.

n) Adjust then calibrate as per section 3.3 and secure scale and pointer retaining screws with glyptol.

o) Run Actual and Command Mach pointers to stops at high end of scale and fit shield. Check dial for cleanliness and assemble wedges and mask.

p) Temporarily instal mechanism within the front case. Slacken off screws holding wire ducts and adjust capacitor platform relative to the front case using the lining up fixture. Remove mechanism from case and centralize wire ducts relative to carriages. Check wedges and inside of case for cleanliness and finally secure mechanism into front case. Check position of condensor platform relative to case before securing screws with glyptol.

q) Temporarily close back case on front case and test and adjust the illumination system as per Section 3.4.

r) Make checks as per section 4.2.1.4 and section 4.2.1.5

s) Seal off instrument as per Section 2.2.8

8 Sealing and Evacuation

8.1 Remove all loose particles from the mechanism and inspect the dial face, indicia, and glass wedges for cleanliness. The inside of the cases and bezel glass shall similarly be cleaned prior to sealing the instrument case.

8.2 Fit sealing gasket and fix instrument assembly into soldering fixture. With front and back cases held snugly on the sealing gasket, clean soldering surfaces with chlorothene and solder the tear strip per E.S. 4824, overlapping the ends approximately 1/2 to 1". Care shall be exercised to minimize heat transfer into the case.

8.3 Evacuate, fill, seal and test per MH Process 4863 exercising care that solder does not drip into the case during the final sealing-off of the evacuation tube.

ADJUSTMENT & CALIBRATION REQUIREMENTS

1 Equipment

1.1 Test harness as depicted in the attached schematic Figure 1 (CSK 1643) and including:-

a) A four stage 10K decade voltage divider with ± 0.1% accuracy (General Radio type 1454-A or equivalent)

within 0.010 inches.

b) By means of the Actual Mach Position potentiometer position the Actual Mach pointer at the 2.2 Mach graduation within 0.003 inches. Set the decade box to 0.9902 to bring the Command Mach pointer up scale. Using the adjusting tool now alter the position of the Command Mach pointer on its carriage until the marks on the Actual and Command pointers align to within 0.003 inches. Secure the Command Mach pointer.

c) Align the Actual Mach pointer with the 0.8 Mach graduation within 0.003 inches. With a decade box setting of 0.0660 adjust the Command Mach trimpot to bring the marks on the Actual and Command pointers into alignment within .003 inches.

d) Recheck at the 0.9902 setting, and if necessary repeat (b) and (c) above.

Illumination Intensity Adjustment

Using the Spectra Brightness Spot Meter and with 28 volts ± 0.5 volts applied, adjust the illumination intensity potentiometer until the mean of 12 readings taken over various white portions of the dial as per Figure 2 falls within the range of 0.5 to 1.5 foot-lamberts, (CBK 1655).

INSPECTION AND TEST REQUIREMENTS

1 General Tests

1.1 Check and supervise all processes, adjustments and calibration.

1.2 Check for proper workmanship and general appearance.

1.3 Inspect all sub-assemblies in quantities sufficient to maintain desired quality control.

1.4 Check for proper packaging and labelling.

2 Specific Tests

All tests listed shall be conducted at normal room temperature (20°C to 30°C) unless otherwise specified.

2.1 Construction Tests

2.1.1 Indicator Travel

inspect to ensure that all pointers are [illegible] at least 0.015 inches overtravel at each extremity of their normal range. The potentiometer wipers shall remain in continuous contact with their respective bus bars and potentiometers throughout the entire available range of the carriage.

4.2.1.2 Power Failure Indicator

With the Power Switch at "OFF" the Failure Warning Flag shall move into the field of view; it shall retract from view when the switch is moved to "ON".

4.2.1.3 Backlash

With the output gear fixed the maximum accumulated backlash as measured at the input (motor) pinion shall not be in excess of 30 degrees

4.2.1.4 Dielectric Strength

The instrument shall be checked for dielectric strength in the assembled condition prior to hermetic sealing in accordance with E.S. 4184 by applying test voltages for 5 seconds between the ground pin U and the grouped pins as follows:-

between pins B, C, D, and pin U, 900 volts RMS 60 cycles

between pins G, H, J, K, L, M, N, P, R, S, W, X, Y, Z, a, b, c, and pin U, 500 volts RMS.

4.2.1.5 Resistance to Ground

The resistance to ground shall be checked between the ground pin U and all the remaining connector pins grouped. This resistance shall not be less than 20 megohms when tested with an applied potential of 250 volts.

4.2.1.6 Potentiometer Noise

The potentiometers shall be tested for noise in accordance with E.S. 4826 (ES 2059 section II, C, 9, (e)) using the test circuit depicted in Figure 3 (CSK1656) and with the amplifiers not energized. The equivalent noise resistance shall not exceed 300 ohms.

4.2.1.7 Scale and Indicia Contrast

With the equipment subjected to uniform diffuse, white north sky illumination, and with no glass interposed between the equipment and the testing device, the contrast between white and [illegible] portions of the scale and indicia shall be 12 [illegible]. Contrast shall be defined as:

The chamber temperature shall then be reduced to 43°C (110°F) and the equipment turned on at specified voltage. The equipment shall be operated in this condition for four hours. Performance in accordance with section 4.2.1.2 and sub-sections a), e), g), h), and i) of section 4.2.2.3.1 shall be checked while at this temperature and after return to room temperature. The illumination system shall NOT be energized during this test.

Altitude

The indicator shall be subjected to a pressure altitude of 40,000 feet in the unenergized state for five minutes. There shall be no visible evidence of damage to the bezel glass or seal.

Low Temperature

The indicator shall be subjected to an ambient temperature of -34°C (-30°F) in an off condition and maintained at this temperature for three hours after stabilization has been achieved. Performance shall be checked in accordance with section 4.2.1.2 and sub-sections a), b), c), e), f), g), and h) of section 4.2.2.3.1 both at the end of the soak period at -30°F and at return to room temperature. The illumination system shall not be energized during this test.

Vibration

"The instrument shall be mounted to the vibration table with the dial at an inclination of 45° to the vertical, the normally horizontal transverse axis being maintained in the horizontal plane and the dial facing up. While in this position the instrument shall be subjected to a resonant frequency scan of 15 minutes cycle time over the range 5 to 50 cps., using a circular vibrational motion of .018 to .020 inches diameter applied in the vertical plane containing the transverse axis. Performance shall be checked in accordance with section 4.2.1.2 and sub-sections a), e), g), h), and i), of section 4.2.2.3.1 during the scan and at the completion of the test. Resonant points shall be recorded and operation at the resonant frequencies shall be checked.

[illegible]	DECADE VOLTAGE DIVIDER SETTING		
	MACH LIMIT	ACTUAL MACH	COMMAND MACH
0.6	--	.0014 to .0108	--
0.8	--	--	.0560 to .0760
1.1	.0238 to .0400	--	--
1.5	.4494 to .4656	.5570 to .5664	.5180 to .5380
2.0	.9814 to .9976	--	--
2.2		.9891 to .9985	.9802 to 1.0000

TABLE 1

CALIBRATION TEST RANGES

FUNCTION	TEST RANGE
MACH LIMIT	.0030
ACTUAL MACH	.0020
COMMAND MACH	.0020

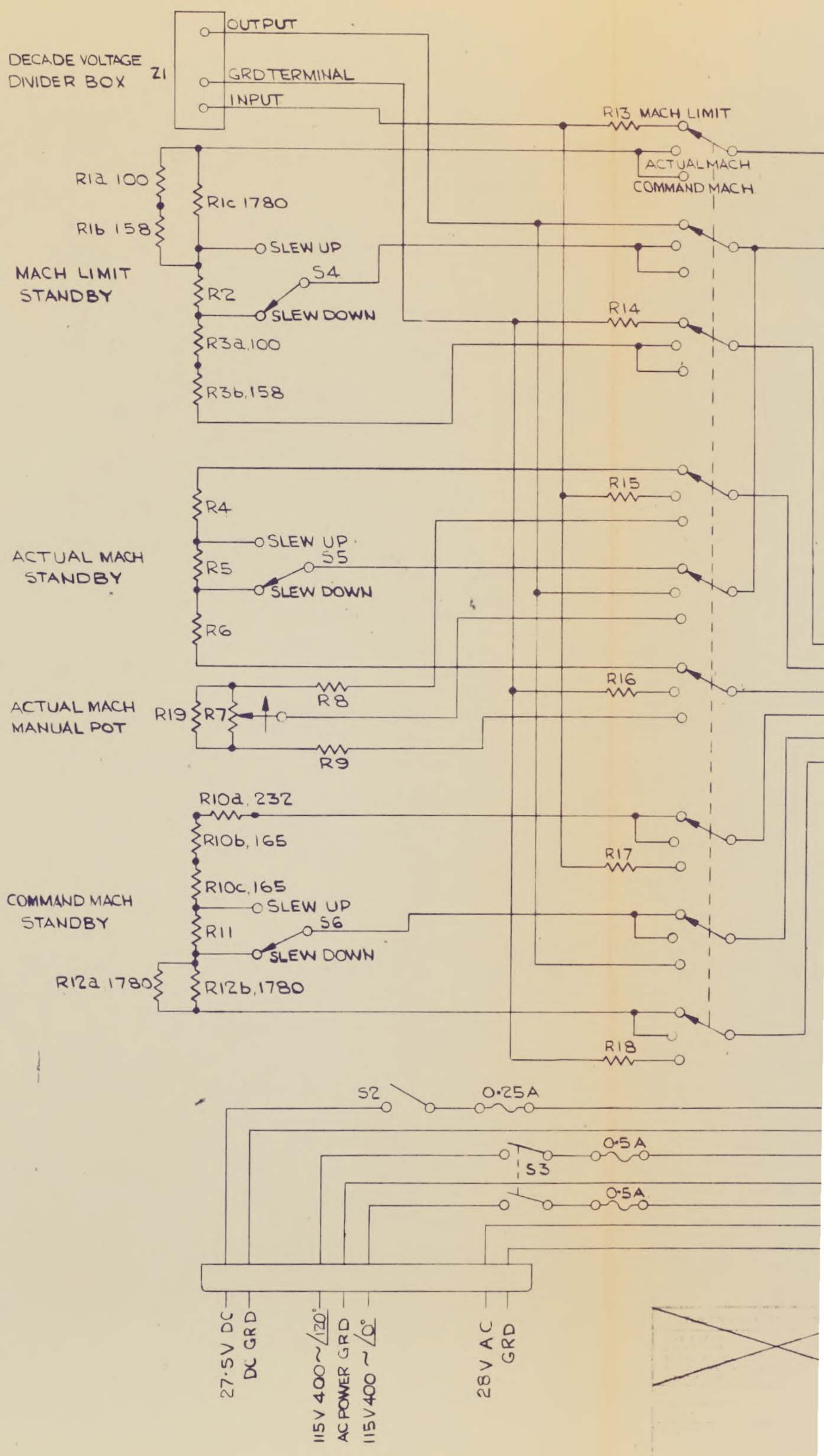
TABLE 2
SENSITIVITY TEST RANGES

RESISTOR VALUES

MOLDED DEPOSITED CARBON ±1% VALUE IN OHMS	
R1	225
R2	1780
R3	258
R4	232
R5	1780
R6	158
R8	100
R9	165
R10	562
R11	1780
R12	890
R19	SELECTED TO GIVE PARALLEL COMBINATION OF R7 & R19 = 2,000 ±1% = 2490 NOMINAL

WIREWOUNDS ±0.1% VALUE IN OHMS	
R13	437
R14	390
R15	467
R16	97
R17	2146
R18	4620

R7	10,000 OHMS ±5% WIREWOUND POTENTIOMETER



1-BOND AMP CAL CASE TO POWER GRD.

YG6000A-1

CSK 1645

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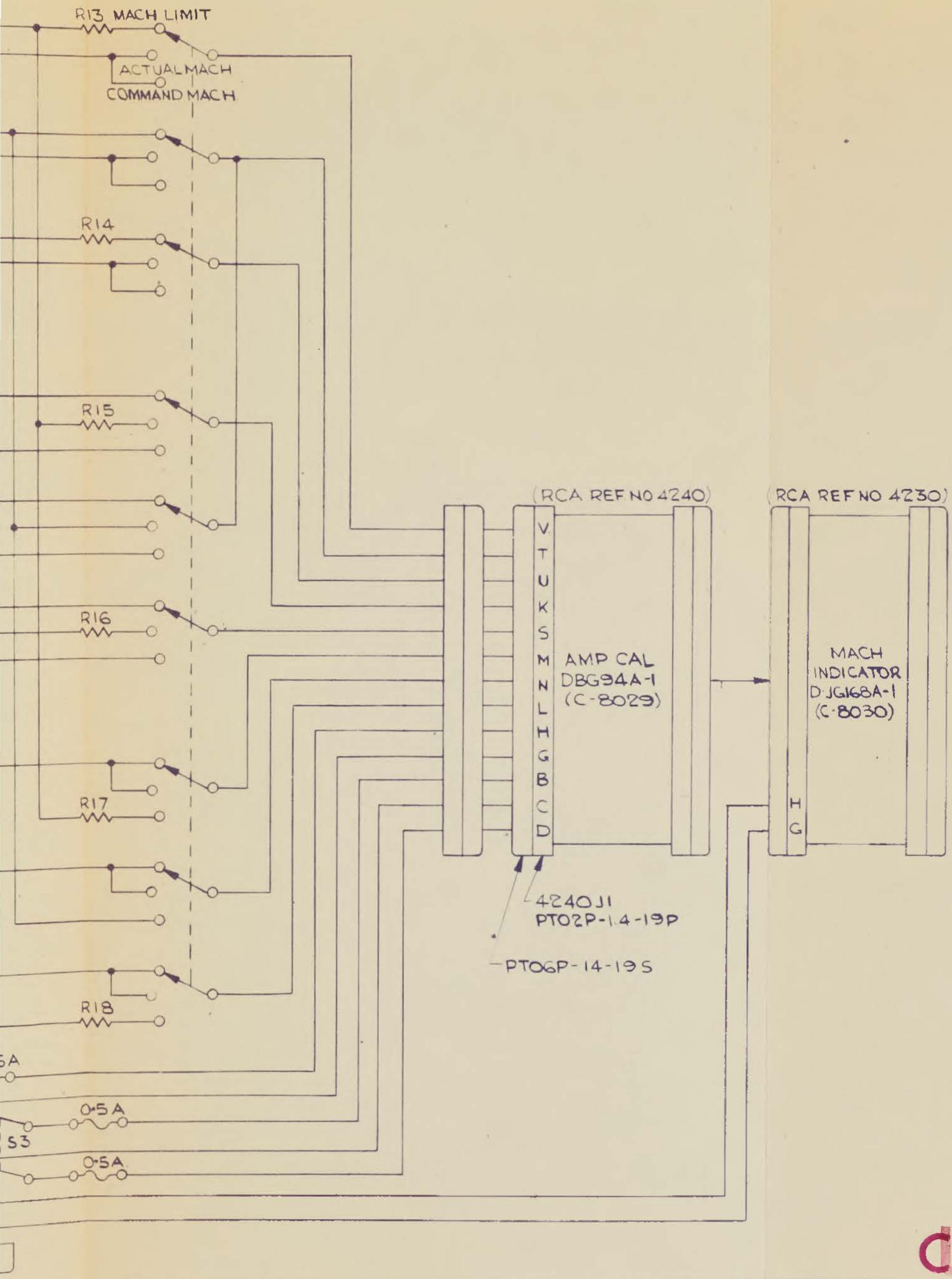

CSK-1643

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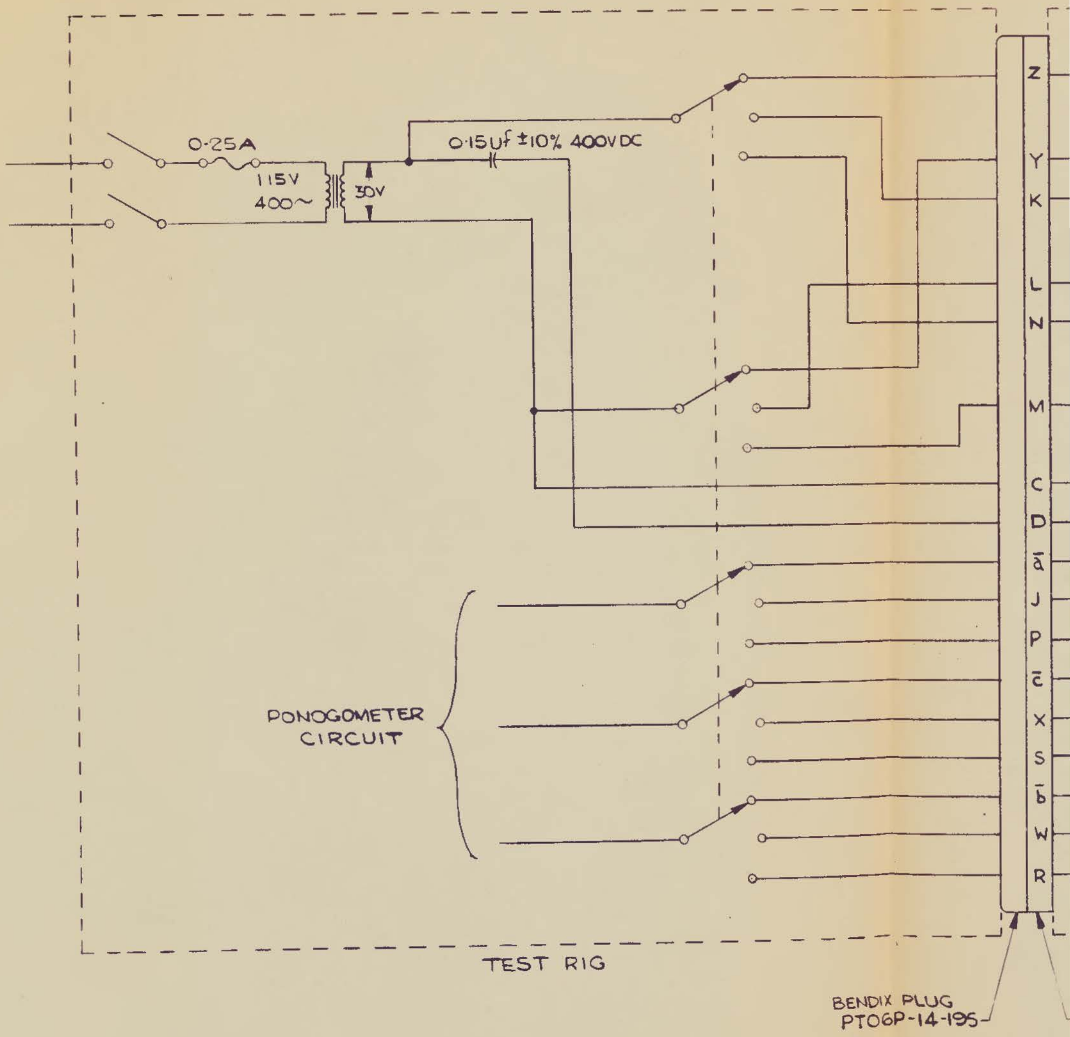
RATTRAY 6-1958

FIG 1
PROPOSED TEST RIG
FOR MACH INDICATOR
AND AMP CAL

NONE

CSK-1643


0·25A
115V
400~
30V
0·15uf ±10% 400VDC
Z
Y
K
L
N
M
C
D
ā
J
P
c̄
X
S
b̄
W
R
PONOGOMETER
CIRCUIT
TEST RIG
BENDIX PLUG
PT06P-14-19S

0106

REVISIONS

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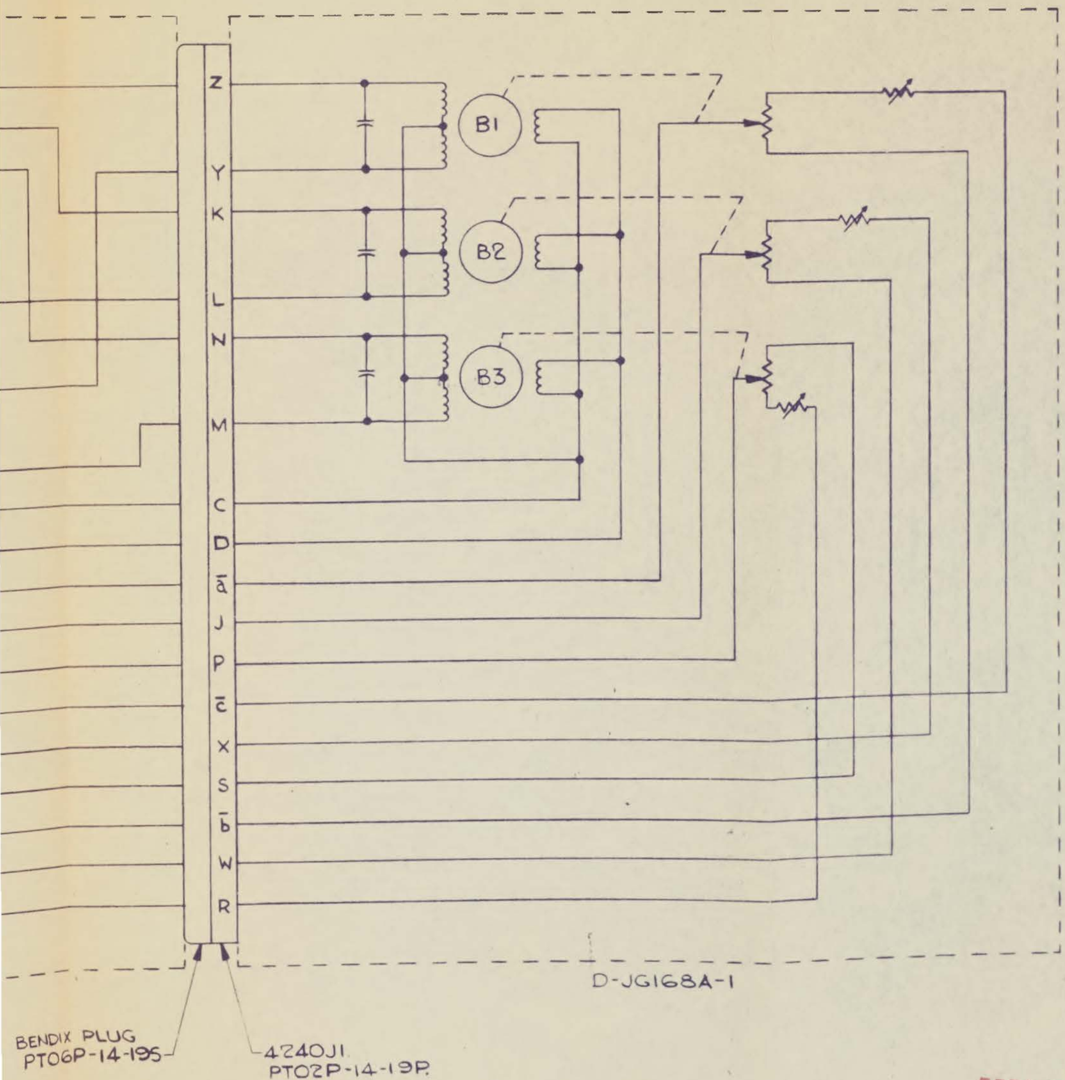

CSK-1656

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TOLERANCES UNLESS NOTED

0106

DRAWN BY W RATTRAY

7-8-55

FIG. 3
PROPOSED TEST RIG
FOR POTENTIOMETER
NOISE TEST

HONEYWELL CONTROLS
LIMITED

AERONAUTICAL DIVISION
TORONTO, CANADA

CSK-1656

SCALE NONE.

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APPENDIX D

ENGINEERING SPECIFICATION NO. [illegible]

BG94A-1

AMPLIFIER-CALIBRATOR FOR MACH INDICATOR.

1. DESIGN REQUIREMENTS

1.1 General Description

1.1.1 Function

This amplifier-calibrator is intended for use with the JG 168A-1 Mach Indicator. It provides voltage amplification for the three similar positional servos associated therewith and also excitation voltages for the respective potentiometers used therein. It also contains the enabling relay used to energize the Command Mach channel.

1.1.2 Associated Equipment

The device is to be used in conjunction with the Air Data Computer and the Data Link outputs of the Avro Arrow to provide signals to the JG 168A-1 Mach Indicator.

1.1.3 Adjustment

All adjustment and calibration equipment is contained in the associated Mach Indicator.

1.1.4 Mounting

The amplifier-calibrator is designed for mounting to a common shock isolated platform in conjunction with the BG 114A-1 Amplifier Calibrator for the Flight Director/Altitude Indicator and the BG 128A Calibrator for the "G" Limiter.

1.1.5 Connection

The device is provided with two Bendix Pygmy bayonet lock box mount receptacles, the input being a PT02P-14-19P and the output a PT02P-16-26S. These are intended to mate with a PT06P-14-19S and a PT06P-16-26P respectively.

1.2 Specific Ratings

1.2.1 Input

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1.2.1.1 115 volts, 400 cps power is required (amplifiers and bridge excitation transformer) and is applied to pins B and C (ground) of connector J1.

1.2.1.2 115 volts, 400 cps power of a phase 120 degrees lagging that of 1.2.1.1 is routed through the unit for motor fixed phase power and for the power failure indicator in the JG168A-1.

1.2.1.3 28 volts nominal d-c is required for relay operation. Power consumption is approximately 2.2 watts.

1.2.2 <u>Output</u>

1.2.2.1 The unit supplies phase sensitive power that is approximately 90 degrees apart with respect to the servomotors fixed phases in the JG168A-1.

1.2.2.2 The excitation voltages for the Mach Limit, Actual Mach, and Command Mach bridges are 11.6, 20 and 32 volts (nominal), respectively

1.2.2.3 Upon actuation of the relay K1, the Command Mach signal is removed from a reference position on a tap of the bridge transformer and is enabled to be amplified.

1.3 <u>Detail Requirements</u>

1.3.1 <u>Applicable Specifications</u>

The amplifier-calibrator has been designed in accordance with R-ED 873 "Preliminary Detail Specification for the Type JG168A-1 Mach Indicator and Type BG 94A-1 Amplifier Calibrator for use in the Avro Arrow Aircraft" and in conformance with the specifications listed therein.

2.2 PROCESS REQUIREMENTS

2.1 <u>Honeywell Process E.S. Involved</u>

2.1.1 The unit shall be identified in accordance with E.S. 9019.

2.1.2 All soldering shall be per MS 4824.

3. ADJUSTMENT AND CALIBRATION REQUIREMENTS

No adjustments or calibrating means is built into the unit.

4. INSPECTION & TEST REQUIREMENTS

4.1 General

4.1.1 Check or supervise all processes.

4.1.2 Check for proper workmanship and general appearance.

4.1.3 Check for proper packaging and labelling.

4.2 Specific

4.2.1 Test Facilities

4.2.1.1 All amplifier a-c voltages shall be measured with a full wave rectifying, average-sensitive, RMS calibrated VTVM with a minimum of $\pm$ 3% full scale accuracy and an input impedance of 10 megohms minimum.

4.2.1.2 Tests are to be performed with the test circuit of Figure 1 (CSK 1652)

4.2.1.3 The load for each of the amplifiers contained herein shall be a Kearfott R119-22A or electrically equivalent servo motor, running at no-load on the shaft.

4.2.1.4 Power supply

For test purposes, the voltages shall be held to 115 $\pm$ 2 volts and 400 cps $\pm$ 1%. The maximum current consumption for the amplifier phase (leading phase) under test conditions is approximately 250 ma. The motor fixed phase requires about 53 ma.

4.2.1.4.1 The A-C supply shall have a harmonic content less than 5%.

4.2.2 Performance Tests

4.2.2.1 Amplifier

Connect amp-cal to test set. Allow amplifiers to warm up for 15 minutes. Throw selector switch S1 to test A1 Amplifier. Check 4.2.2.1.1 to 4.2.2.1.6 inclusive. Repeat for amplifiers A2 and A3.

4.2.2.1.1 Zero Signal Output

Throw switch S2 to short amplifier input to signal ground. The amplifier output voltage shall not exceed 10 volts.

4.2.2.1.2 Stability

Apply a small input voltage. The output waveform shall exhibit stability and the output voltage shall be controllable for any given input. If the output tends to run away, the probability is that the feed back transformer is incorrectly connected.

4.2.2.1.3 Gain

Determine the gain by taking the average of the in-phase and out-of-phase signals required to produce 30 volts output. Gain shall be 260 ± 15% at room temperature ambient.

4.2.2.1.4 Null Offset

Determine the null offset by taking one-half of the difference of the in-phase and out-of-phase signals required to produce 30 volts output. The null offset shall not exceed 10 millivolts.

4.2.2.1.5 Phasing

An in-phase signal to the amplifier shall cause clockwise rotation of the motor shaft, when viewed from the shaft end.

4.2.2.1.6 Max, input Signal

Apply 20 volts to the amplifier input by switching S3. Output voltage shall be 185 ± 15 volts. Hold for 5 seconds.

4.2.2.2 Transformer T1 voltages

Test voltages with the loads shown in Figure 1 shall be within limits shown in Table 1. Relay K1 is unenergized for this test.

TABLE I

Test Points	volts
V-K	11.6 ± 1
K-S	20 ± 1.5
S-L	32 ± 2
V-L	64 ± 4
L-T	7.5 ± 0.5
V-J1B	58 ± 5

4.2.2.3 Relay Operation

With switch S4 in "OFF" position, test points T and N shall show an open circuit. Throw S4 to "OPERATE" position, applying 20 volts d.c. to relay coil. Test points T and N shall show continuity.

4.2.2.4 Resistance Checks

Remove power from the amp-cal. A resistance check across points J1B and J2B shall indicate 11 ± 1 kilohms. Continuity shall be indicated between J2U and signal ground.

4.3 Test Specifications

4.3.1 General

The tests listed herein are excerpted from Appendix A of Aero Engineering Document R-ED 873, "Preliminary Detail Specification for the Type JG168A-1 Mach Indicator and Type BG94A-1 Amplifier Calibrator for use in the Avro Arrow Aircraft," dated Oct. 30, 1957, and from Attachment II 'Minimum Preshipment Tests (Flight worthiness Tests) for M-H Equipment R & D portion of Arrow Electronic System" dated April 21, 1958 and forming a portion of memo C.A. Swenson to Arrow Project Engineers entitled "Arrow Electronics System R & D Environmental Specifications.

Where performance testing is called up hereafter the equipment shall be tested in accordance with and shall pass the tests detailed in sections 4.2.2.1.1, 4.2.2.1.3., 4.2.2.1.4., with gain tolerances specified for the particular temperature, 4.2.2.1.6, 4.2.2.2 and 4.2.2.3.

4.3.2 Specific

4.3.2.1 High Temperature

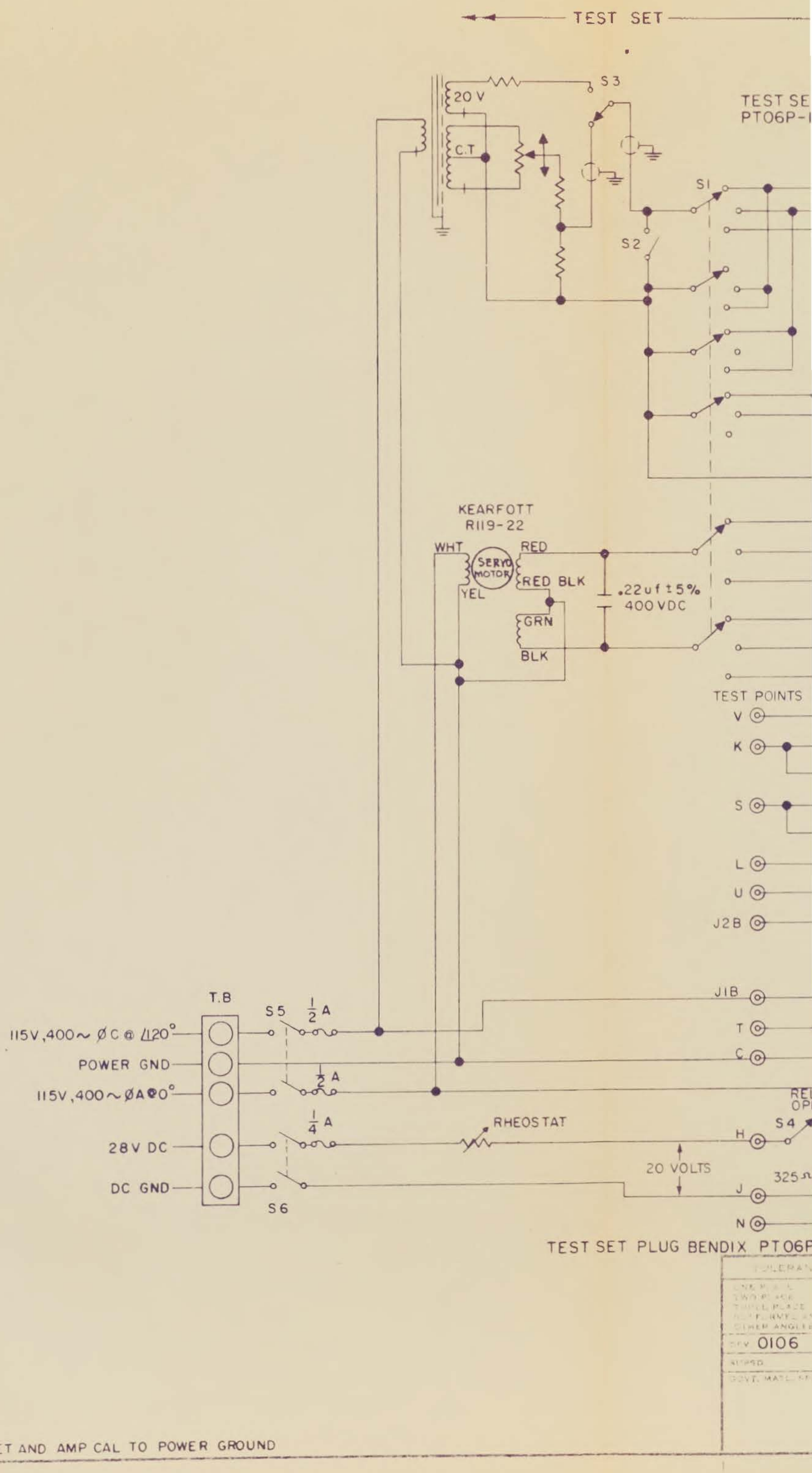
The amplifier calibrator shall be energized and subjected to a temperature of 71°C (160°F) and maintained in this environment for a period of three hours after stabilization has been achieved. Performance shall be checked in accordance with the tests listed in Section 4.3.1 while at this temperature and after return to room temperature. The gain at the high temperature shall be 260 ± 20%.

4.3.2.2 Low Temperature

The amplifier-calibrator shall be subjected to an ambient temperature of -34°C (-30°F) in an off-condition and maintained at this temperature for three hours after stabilization has been achieved. It shall then be turned on and performance shall be checked in accordance with the tests listed in section 4.3.1 while at this temperature and after return to room temperature. The gain at the low temperature shall be 260 + 15%, -30%.

4.3.2.3 Vibration

The amplifier calibrator shall be energized and subjected to a resonant frequency scan of 15 minutes duration over the range 5 to 500 cps with a double amplitude of .020 inches or a maximum acceleration of 2g, whichever is the limiting value, in each of the three mutually perpendicular major axes. The resonant points shall be recorded. The equipment shall be tested for an additional 15 minutes in each axis at the most severe resonant point. Performance shallbe checked in accordance with the tests listed in section 4.3.1 at these resonant points and at the completion of the test.



1 – CONNECT CASES OF TEST SET AND AMP CAL TO POWER GROUND

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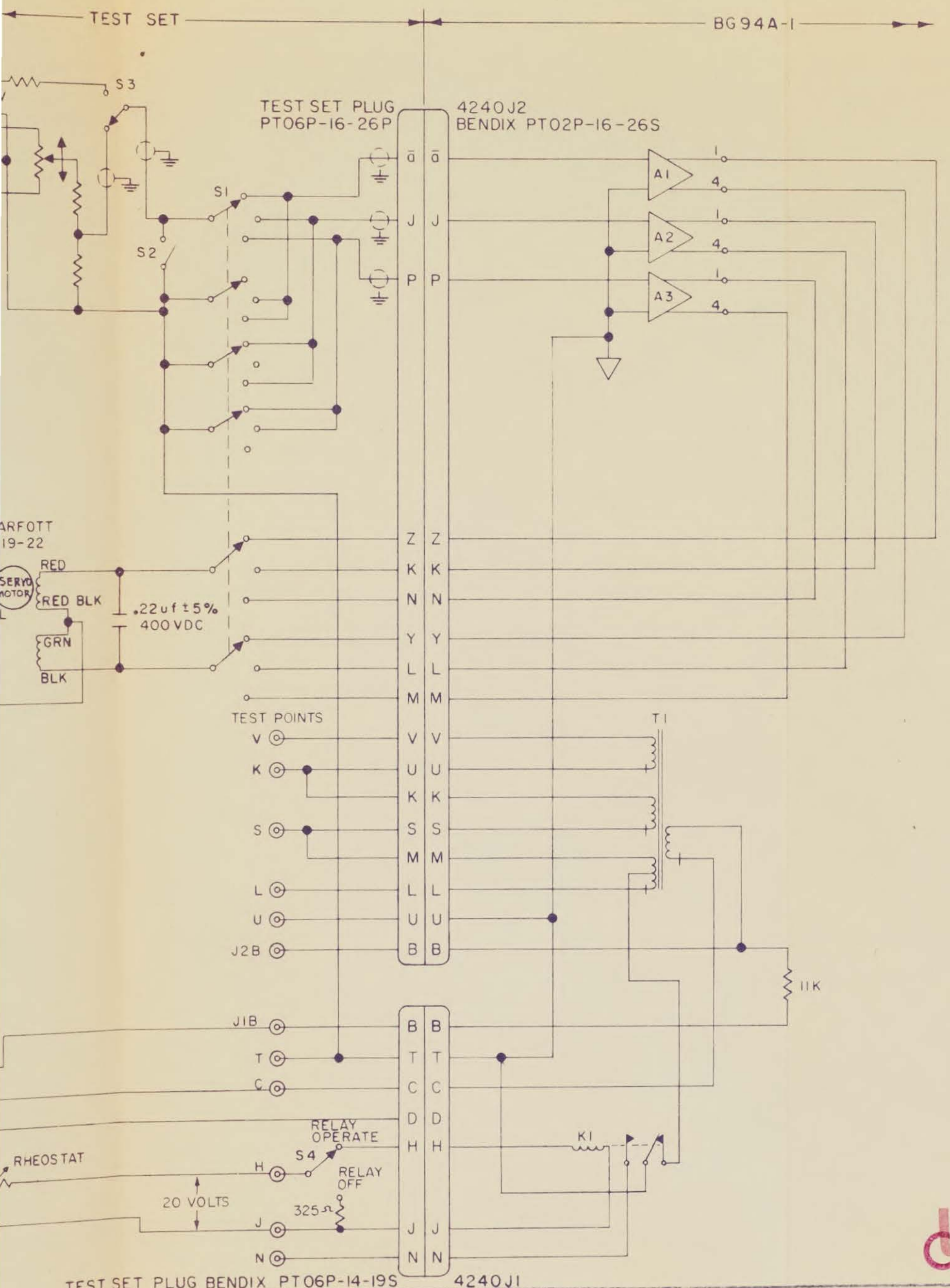

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TOLERANCE UNLESS NOTED	DRAWN BY ARTHUR 6-19-58	FIG.1 PROPOSED TEST RIG FOR BG94A-I AMPLIFIER-CALIBRATOR	HONEYWELL CONTROLS LIMITED AERONAUTICAL DIVISION TORONTO, CANADA
DEV 0106	PROCESS		C-SK1652
		SCALE NONE	