EXPERIMENTAL FLIGHT INSTRUMENTS

TUNIS SCHOUTEN

FOREWORD

This is one of a series of reports presenting the results achieved in the continuing investigation in the field on control-display technology being conducted under Project 6190, "The Air Force Control-Display Integration Program", with Mr. John H. Kearns as Project Engineer. The work described herein was conducted under Task 619008 with Mr. Eldon M. Bobbett as Task Engineer.

This report was prepared by the Instrument Division of Lear Siegler, Inc., Grand Rapids, Michigan. The report covers the work performed by the Instrument Division under Contract AF33(615)-4271 with Mr. T. Hainsworth serving as program manager.

The time period covered by this report extends from 1 July 1966 to 30 April 1967. Manuscript was released by the author in April 1967 for publication. The contractor's report number is GRR-67-1329.

This technical report has been reviewed and is approved.

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ABSTRACT

The tasks associated with this program were a portion of Air Force Project 6190 whose goal is to develop and improve flight instrumentation for Air Force aircraft. The specific twofold aim of the Instrument Division effort was to deliver attitude director indicators with an advanced display format, and to develop both an attitude director indicator and a vertical type indicated airspeed indicator utilizing gearless servo techniques. The final results of this portion of Project 6190 remain to be evaluated. Generally, the theory of gearless servo drives is well developed. This is confirmed by the relative ease with which the "gearless" indicators were designed and built.

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SECTION I

INTRODUCTION AND PROGRAM OBJECTIVES

Under the basic charter of the Control Systems Research Branch of the Air Force Flight Dynamics Laboratory, a research program was initiated to update mechanization techniques as applied to aircraft flight instruments. The mechanization program was initiated as a parallel program for the improvement of the display format on attitude director indicators. The technique chosen was a DC torquer used in a "gearless" application. Preliminary information revealed that there would be a weight, power and size reduction. As evidenced by the results in this report, there was nearly a one-half pound reduction in weight and a 13.5 watt reduction in power required. Although no specific attempt was made under this program to reduce the size, space is available within the indicator.

The only requirement specified for the indicated airspeed indicator was that it be "gearless". The indicator is a vertical scale indicator and was fabricated to demonstrate another application of the DC torquer. The use of the torquer in this type of indicator is not as promising as was hoped due to the high load produced by the tape in the configuration fabricated. However, other applications exist for the DC torquer which would create tremendous advantages over conventional servo-driven indicators.

The objective of the program was to design and fabricate an attitude director indicator employing a gearless direct-drive servo in both the roll and pitch axes, and a gearless servo-driven vertical scale indicated airspeed indicator to be used in "in-house" simulation and flight research programs.

SECTION II

GEARLESS ATTITUDE DIRECTOR INDICATOR

The aim of this portion of the program, conducted under AF/LSI Contract AF33(615)-4271, was to develop and build a gearless attitude director indicator incorporating the latest attitude sphere design as delineated in Contract AF33(615)-203. Basically, this task involved modifying a standard ARU-2B/A attitude director indicator to the gearless servo configuration without the standard flight path angle tape. Figure 1 shows a demonstration model of this indicator. To permit viewing the internal construction, the case of this demonstration model was build with transparent plastic windows.

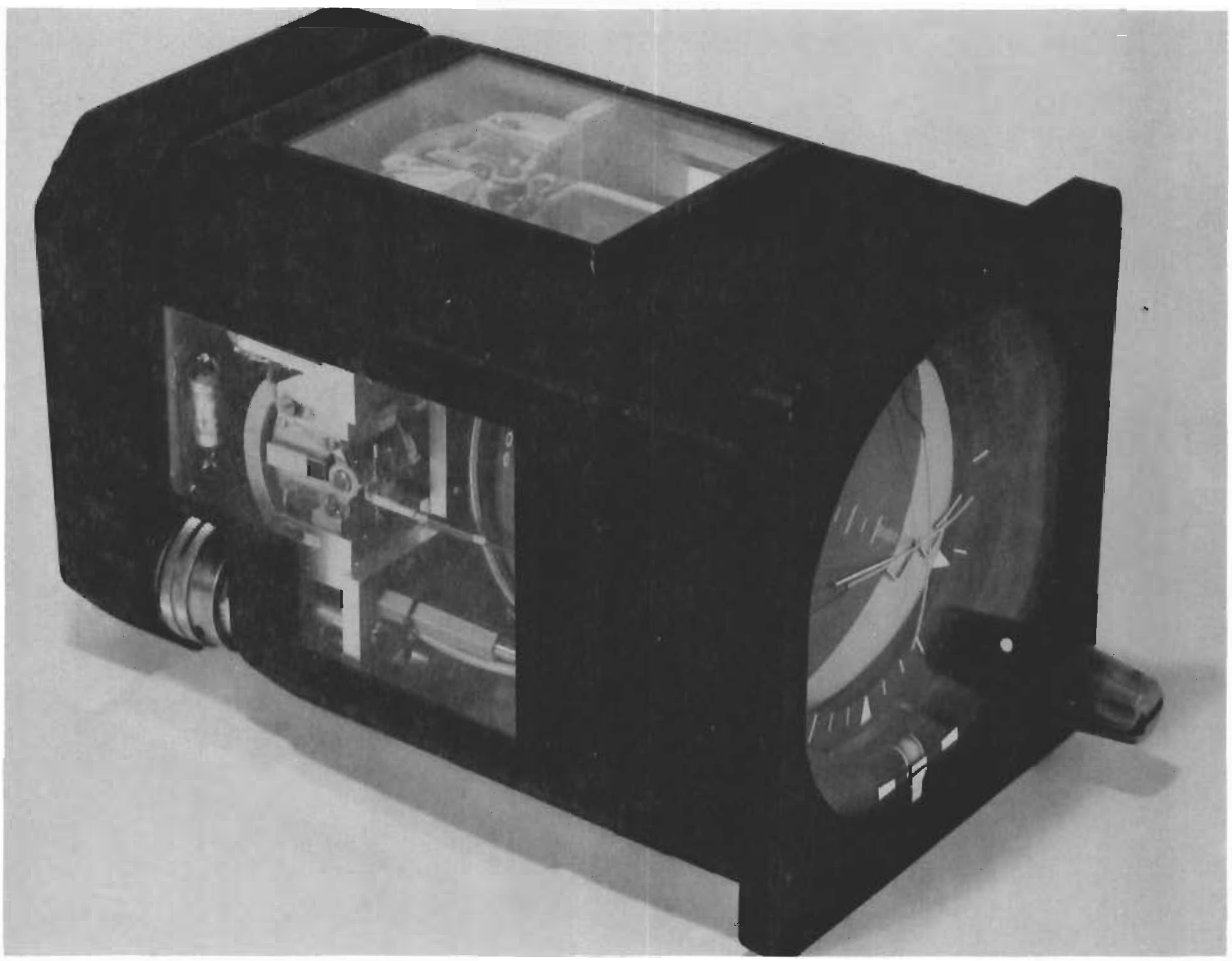


Figure 1. Experimental Attitude Indicator, Demonstration Model

DESIGN APPROACH

The DC torque motor is well suited for attitude indicator applications. Its "doughnut" shape is readily adapted to the typical pitch and roll axes of attitude indicators. When the DC torquer is used in conjunction with a "pancake" synchro follow-up, the design becomes relatively straightforward.

The pitch and roll axis servo mechanisms of the experimental attitude indicator are shown in Figure 2 while an assembly drawing is presented in Figure 3. Both of these figures illustrate the design approach.

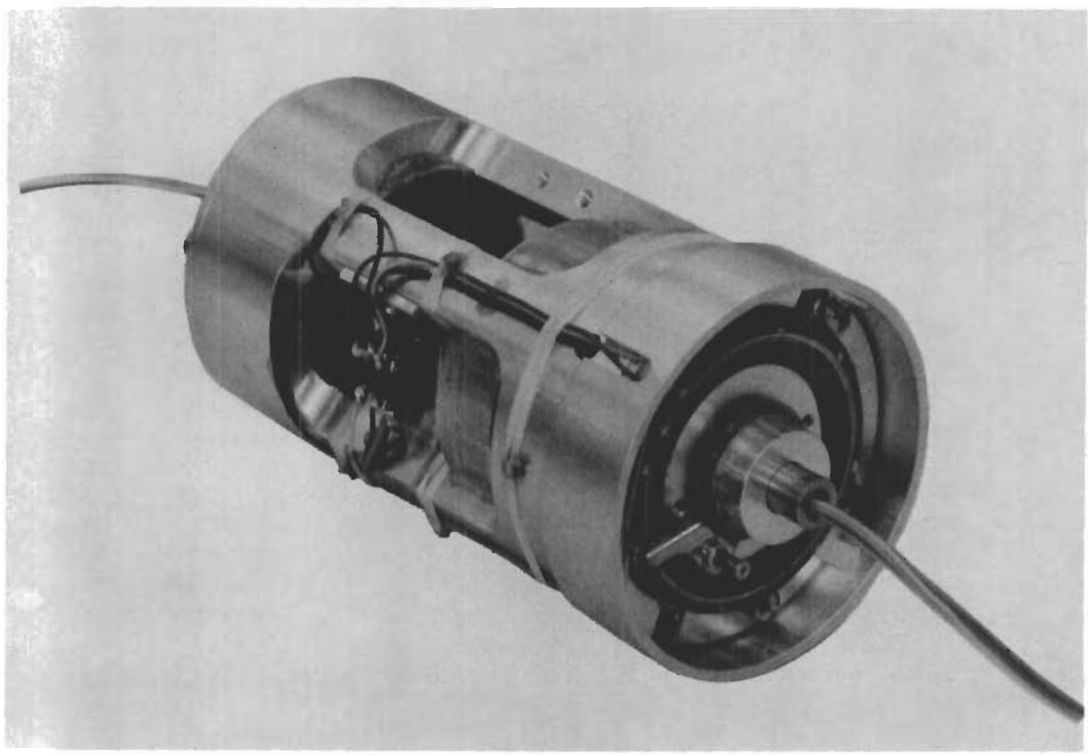


Figure 2. Pitch and Roll Axis Servo Mechanism, Experimental Attitude Indicator

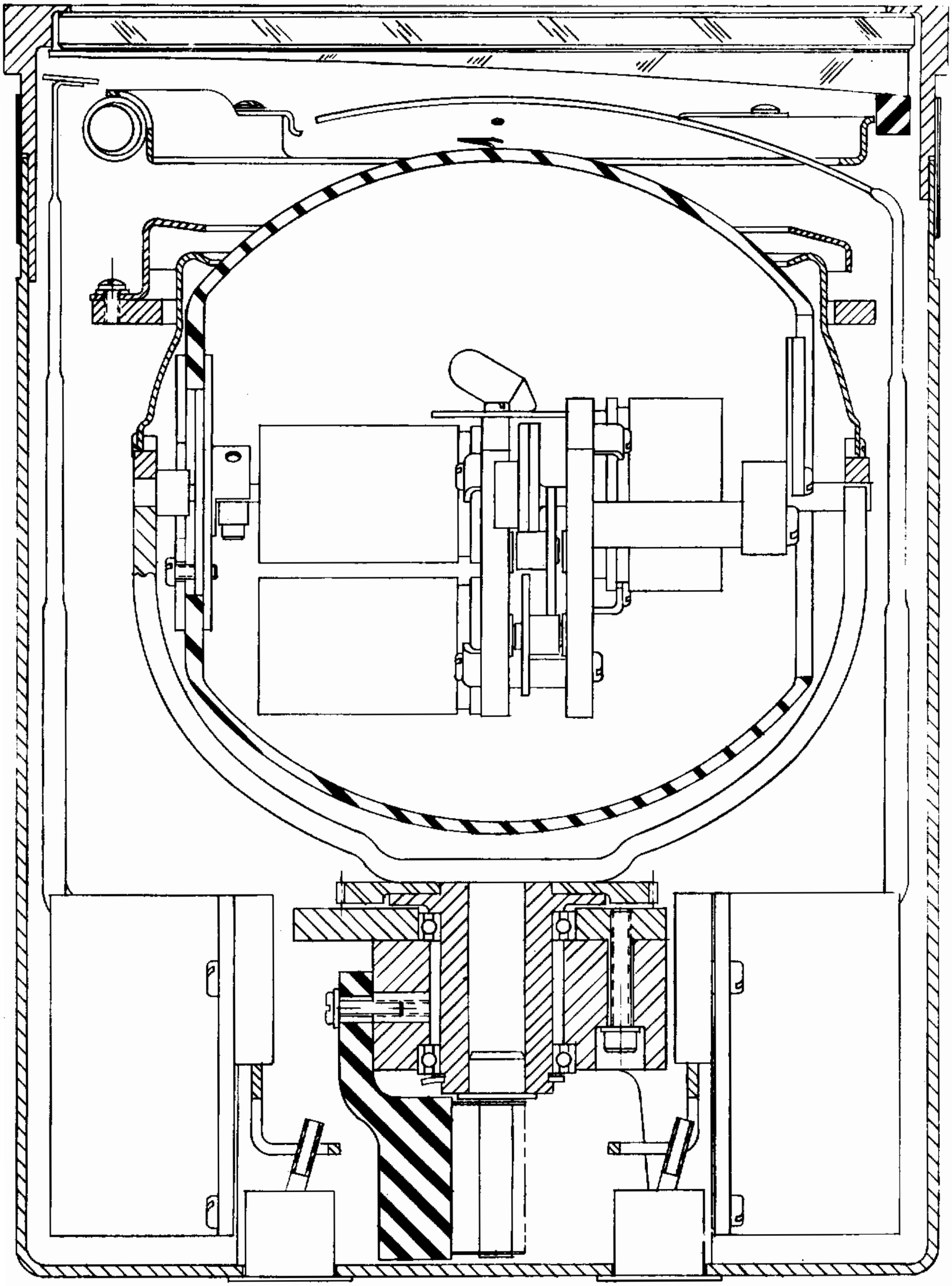


Figure 3. Indicator Assembly Drawing

Basically, the DC torque motor and the "pancake" synchro follow-up are mounted on the same shaft. This shaft is parallel to the pitch or roll axis, depending upon the mechanism under consideration. The package, consisting of the torque motor and its associated follow-up, is partially enclosed in a rotatable structure. The lack of gearing eliminates a common cause of servo error and instability.

Of the two mechanized axes, the roll axis represents the greater load to the torque motor. However, even the roll axis load is well within the capability of the DC torque motor which is utilized in the mechanism. Experimental values of the "break-away" torque required by the roll axis of the experimental indicator at room temperature average 0.375 inch-ounces. For comparison purposes, the stall torque output of the roll axis torquer is 13.5 inch-ounces. Thus, there is a substantial amount of excess torque available for providing performance.

DISPLAY APPROACH

Inasmuch as the sphere for the "gearless" attitude indicator which was developed under this program was specified by the contract, no evaluation of the indicator display has been performed by the Instrument Division. This display evaluation will be performed by the procuring activity.

SECTION III

GEARLESS INDICATED-AIRSPEED INDICATOR

The indicated-airspeed indicator developed and built as a part of this program displays IAS in the conventional manner, i.e., a marked tape moves vertically relative to a fixed index or lubber line. Because of the conventional display approach utilized in this instrument, only the mechanization technique is of interest.

The primary purpose of this indicator is to evaluate "gearless" mechanization techniques as applied to a typical "tape" instrument. Requirements pertaining to the Indicated Airspeed Indicator are contained in Exhibit "A" (Statement of Work) of Air Force RFP #35328002, dated 1 February 1966, included as Appendix I.

DESIGN APPROACH

The primary consideration in the design of the vertical scale IAS indicator was to eliminate all gears. This consideration essentially determined the design approach; i.e., the tape would be attached to a "reel" which permits full scale travel in approximately 340° of rotation. The 340° limitation results from the "lost rotation" of the reel caused by the need for tape "take-off" rollers and a mechanical stop.

Full scale tape travel of 13.75 inches and a "reel" rotation of approximately 340° required a "reel" diameter of approximately 4.5 inches. (Actual "reel" diameter is 4.633 inches.) This reel dimension is within the size confines of the specification.

To eliminate all gearing (and associated servo problems) a DC torquer, which was chosen as the "prime mover," and a "pancake" synchro were mounted concentric with and inside the tape "reel." Also mounted concentric with and within the reel were two ball bearing sets which served as supports for the moving elements of the mechanism package.

The tape reel, which is made of transparent plastic for demonstration purposes, is used to connect and support all movable elements of the mechanism. The stationary elements of the mechanisms are mounted to a metal side plate which also serves as the main frame member of the indicator.

Electrical accessibility to the motor and follow-up is attained through a hole in the side support plate. The necessary wiring is accommodated within a groove in the outside supporting plate surface.

The design approach, which utilizes 340° of synchro rotation, results in a possible ambiguity problem. Whenever the indicator follow-up synchro is displaced more than 180° from its synchro transmitter, the servo will drive to its stop and "hang-up" until the error becomes less than 180°. This problem is most likely to occur if the instrument is inactivated while the transmitter rotor continues to rotate. The rapid response of the DC torque motor precludes, for all practical purposes, the error exceeding 180° when the indicator is being operated. A possible "hang-up" problem is eliminated in the design by means of a false signal which commands the servo to its midposition when power is first applied to the indicator. When the mid-point is reached, a cam-switch-relay combination switches the servo to its normal input which is always at a distance of less than 180° of synchro (and reel) rotation away.

The above ambiguity problem could be prevented if synchro transmitter rotation is limited to some value less than 180°. However, a "gearless" indicator which could achieve equivalent tape travel (13.75 inches) in less than 180° of synchro (and reel) rotation would require a reel diameter of approximately 8.75 inches. A reel of this size would be too large for this application. In addition, servo stability would suffer because of the high inertia of the reel.

Tape tension is maintained by means of a spring-loaded tape roller mounted to the rear of the instrument bezel. All tape rollers are ball-bearing mounted in order to decrease tape friction.

Figure 4 shows the right side of the indicator with the transparent case removed. The mechanism package is located in front of the electronic circuitry. Two transformers are located behind the bezel on either side of the mechanism package.

TEST DATA

Two separate tests were run on the subject indicator. One test was made to evaluate the tape load as "seen" by the DC torque motor. The other test was made to check the operation and efficiency of the electronic circuitry in the indicator. The results of these tests have been tabulated and are presented as Tables I and II.

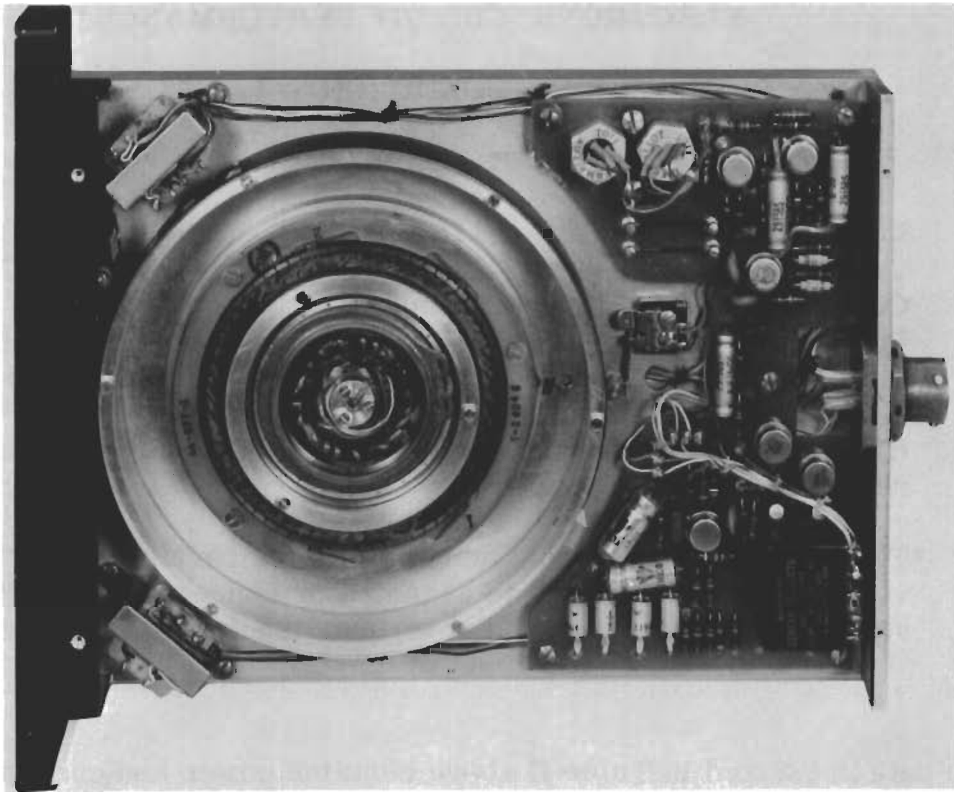


Figure 4. Indicated Airspeed Indicator Layout

TABLE I
INDICATOR BREAK-AWAY TORQUE REQUIREMENTS*

IAS Reading (KTS)	Break-Away Torque (In.-Ozs.)
100	3.65 - 4.06
150	3.65 - 4.06
200	3.65 - 4.06
250	3.65 - 4.06
300	3.65 - 4.06
325**	5.27**
350	3.65 - 4.06
400	3.65 - 4.06
450	3.65 - 4.06
500	3.65 - 4.06
550	3.65 - 4.06

*Room temperature
**Cam-switch position

TABLE II
ELECTRONIC CIRCUIT PERFORMANCE*

CONDITION

Parameter	Null	Saturated
Volts In, V_I	115 VAC	115 VAC
Volts Out, V_O	1.5 VDC	120 VDC
Current In, I_I	30 ma	70 ma
Power In, P_I	3.45 watts	8.05 watts
Power Out, P_O	.06 watts	3.8 watts

(DC Torquer is Inland Model T-2804-B. Torquer armature resistance is 38 ohms.)

*Tabular values were obtained at room temperature. "In" values are those measured at indicator connector. "Out" values are those measured at torquer input.

The data presented in Table II above contains power and current requirements of associated auxiliary components, among them:

2 power transformers
1 relay (20 V @ 500 ohms)
1 control transformer (follow-up)

Because of the "auxiliary" power "drain", the values presented in Table II can not be used to obtain the efficiency of the servo amplifier. The values presented in Tables I and II, however, are useful in evaluating the minimum torquer output, in inch-ounces, for a given power input, e.g., 3.8 watts.

SECTION IV

ARU-2B/A ATTITUDE DIRECTOR INDICATOR MODIFICATION

The final portion of this program involved modifying three standard ARU-2B/A attitude director indicators. The modification consisted of incorporating a flight path angle tape presentation in each indicator and replacing the standard sphere presentation by a sphere presentation by a sphere configured as shown in Figure 5.

No new design techniques were required to fulfill the subject requirements of the Work Statement, i.e., Exhibit "A" of Air Force RFP #35328002, dated 1 February 1966. Because of the similarity of these indicators to previously manufactured items, no additional information concerning their design will be included in this report. It should be noted that the aforementioned indicators are driven by conventional AC servo mechanisms.

Evaluation of the display will be accomplished by the procuring activity.

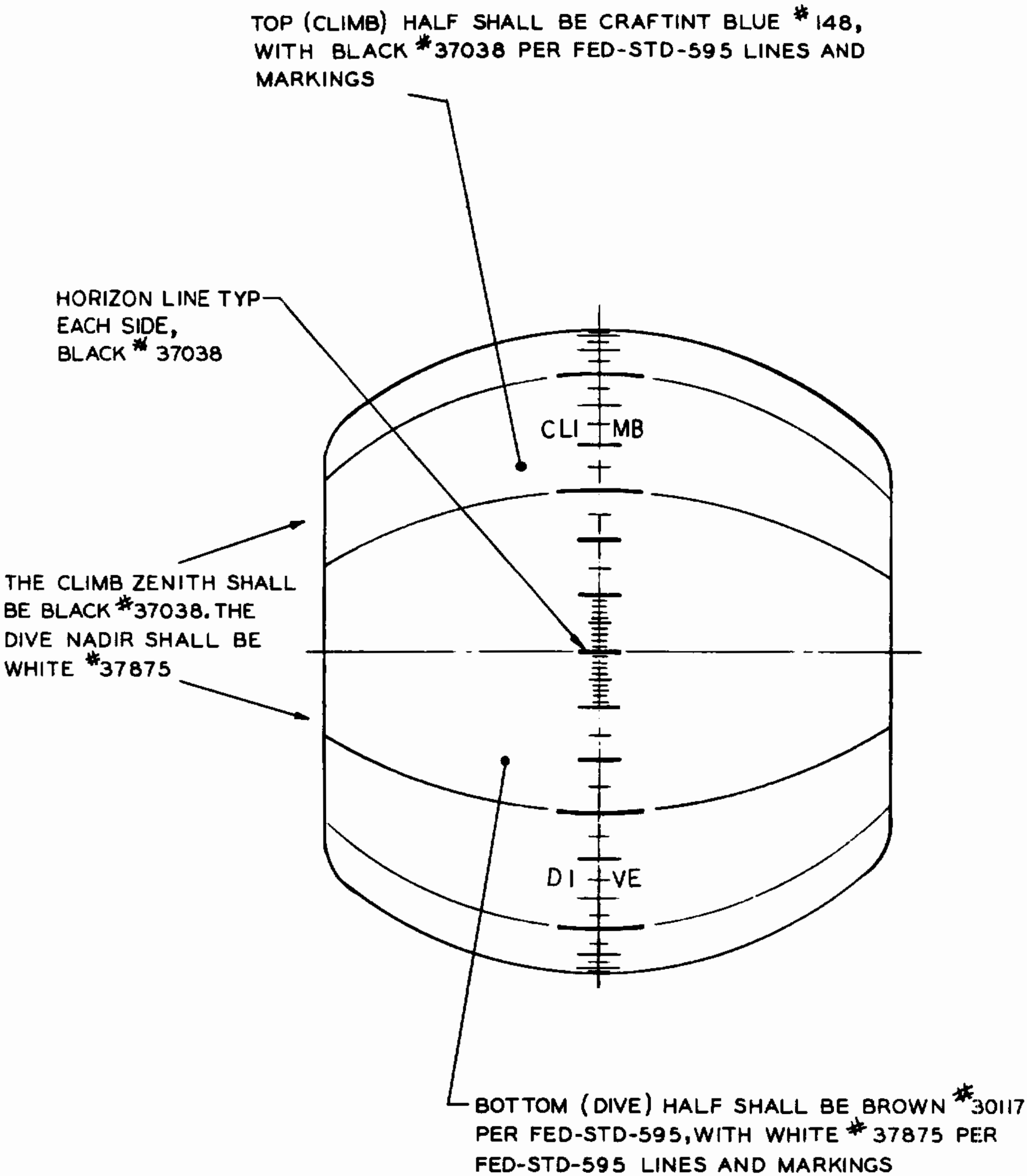


Figure 5. Modified ADI Sphere Configuration Drawing

SECTION V

CONCLUSIONS

The results of this program indicate that careful consideration should be given to the application, insofar as applicability of DC torque motors is concerned. It appears that under light-load conditions, as exemplified by the ADI developed during this program, the DC torque motor has many desirable characteristics. However, under relatively high-load conditions the DC torquer becomes much less attractive, mainly because in a "gearless" application "brute" power is required, i.e., no gears are available for torque multiplication. If gearing is used in conjunction with a DC torque motor as a torque multiplier, the torquer essentially substitutes for a much smaller motor and some gear stages. Under these conditions use of the torquer, with its relatively large weight and volume, is difficult to justify unless rapid response is of prime importance.

Judging from the results of this program, the gearless DC torque motor is well suited to attitude indicator applications. The use of design techniques which utilize gearless DC torquer-driven servo mechanisms in both the roll and pitch ADI axes results in a number of advantages over conventional "geared" AC servo-driven attitude indicators.

When compared with the typical geared AC servo mechanism-driven attitude indicator, the "gearless" indicator exhibits:

- Reduced weight,
- Reduced power requirements,
- Improved performance,
- Simplified design, and
- Cost reduction potential.

The conventional (AC driven) ARU-2B/A attitude director indicator weighs approximately 7 lbs. and 6 ounces. A similarly equipped "gearless" attitude director indicator weighs approximately 7 pounds. Thus, the "gearless" ADI exhibits a 6-ounce weight reduction over its conventional counterpart.

The power requirement of the standard ARU-2B/A attitude indicator is approximately 16 watts under static servo conditions. The power requirement of an equivalent gearless ADI is 2.5 watts under static conditions. The reduction in power requirements shown by the gearless

ADI can be attributed to the fact that the permanent magnet field of the DC torquer requires no electrical power at any time. Hence, the orginary fixed phase (field) current drain of the conventional AC servo motor is eliminated by use of the DC torque motor. An additional advantage of less heat build-up occurs because of the elimination of the need for field excitation in the DC torquer.

Performance of the gearless attitude director indicator is equal or superior to that of the conventional ARU-2B/A attitude indicator. The following rate of the gearless indicator is equal to the rate of the transmitting synchro, i. e., the lag is essentially zero. Servo stiffness is excellent because of the lack of gearing, with its associated problems, and the excellent torque multiplication of the DC torque motor.

The gearless attitude indicator is considerably simpler, design-wise, than the conventional ADI. This is due mainly to the elimination of gears and their associated shafts, offsets, etc. This feature of the gearless indicator accounts for the cost reduction potential of the unit.

Under some conditions, a tape indicator can be considered a "high-load" device. It was found that the gearless IAS indicator, developed as a part of this program, represents a rather significant load application. This load is caused by tape friction and inertia, as well as that energy which is required to "bend" the tape as it traverses the indicator. Although no tests were performed at low temperatures, it is expected that such conditions would represent a considerable hardship to the "direct-driving" torque motor.

Tape tension was found to be a critical parameter insofar as tape load is concerned. If the tape was too tightly tensioned, the torque motor was unable to actuate the display with the power available to it from its driving amplifier.

Vertical scale indicators that contain spring-loaded mechanisms which work directly against the direct-driving motor appear to be "borderline" applications of the gearless servo mechanism. This is true for two reasons: the motor must resist the full spring load without the benefit of gearing, and the motor is continuously exercised by the spring, i. e., power is continually required, thus negating one of the prime advantages of the direct-drive approach which is low null power expenditure.

APPENDIX I

EXHIBIT A

STATEMENT OF WORK

RFP 35328002

STATEMENT OF WORK

1. Program:

This procurement is a further step in the continuing program under Project 6190 to develop and improve flight instrumentation for Air Force aircraft. The Flight Control Division presently has underway, programs for the improvement of the display format on attitude director indicators, likewise it is felt that research should be undertaken for possible updating and improving mechanization techniques. Therefore, this procurement will examine the use of a gearless servo principle in two (2) types of indicators: attitude director and vertical tape indicated airspeed.

2. Objective:

The objective of this effort is to design and fabricate an Attitude Director Indicator employing a Gearless Servo on the roll axis, a Gearless Servo driven vertical tape indicated Airspeed Indicator and three (3) model 4058A Attitude Director Indicators to be used in "in-house" simulation and flight research programs.

3. Requirements:

3.1 The contractor shall modify one (1) standard Attitude Director Indicator (ARU-2B/A), resulting in an experimental attitude director combination without the flight path angle tape.

3.1.1 The pitch axis shall be driven by conventional A C servomechanisms with the roll axis employing a gearless servo drive.

3.1.2 The sphere shall have appropriate markings to comply with the latest design set forth by Contract AF33(615)-203.

3.1.3 The case shall be of transparent plastic.

3.2 The contractor shall design and fabricate an Indicated Airspeed Indicator employing gearless servomechanism techniques.

3.2.1 The dimensions of the instrument shall be a maximum of seven (7) inches long and one and one-eighth (1 1/8) inches wide with a depth not to exceed eight (8) inches behind the mounting plate.

3.2.2 The face of the instrument shall be glass with as thin a bezel as practicable.

3.2.3 Instrument lighting and "off" flags are not required in this instrument.

3.2.4 The instrument case shall not be hermetically sealed and shall be designed for front mounting.

3.2.5 The sides of the instrument case shall be of transparent plastic to expose the inner working components.

3.2.6 The connectors at the rear of the case shall be an Anthenol Plug AN3106A-20-27S. Pin connections to be used are shown in Figure 2.

3.2.7 Indicated air speed shall be presented by a moving tape under a lubber line. The tape width shall be three-fourths (3/4) inches when viewed head-on. The tape background shall be black with numerals and graduations white. The tape scale factor shall be one and one-fourth (1 1/4) inches per fifty (50) knots. Colors shall conform to FED-STD-595. Black, color number 37038 and white, color number 37875.

3.2.8 The lubber line shall be 0.030 inches, white and be located approximately two and one-half (2 1/2) inches from top of window as shown in Figure 1.

3.2.9 The range of air speed shall be fifty (50) to six-hundred (600) knots with graduations and numerals as shown in Figure 1.

3.2.10 Markings on air speed tape shall be as follows:

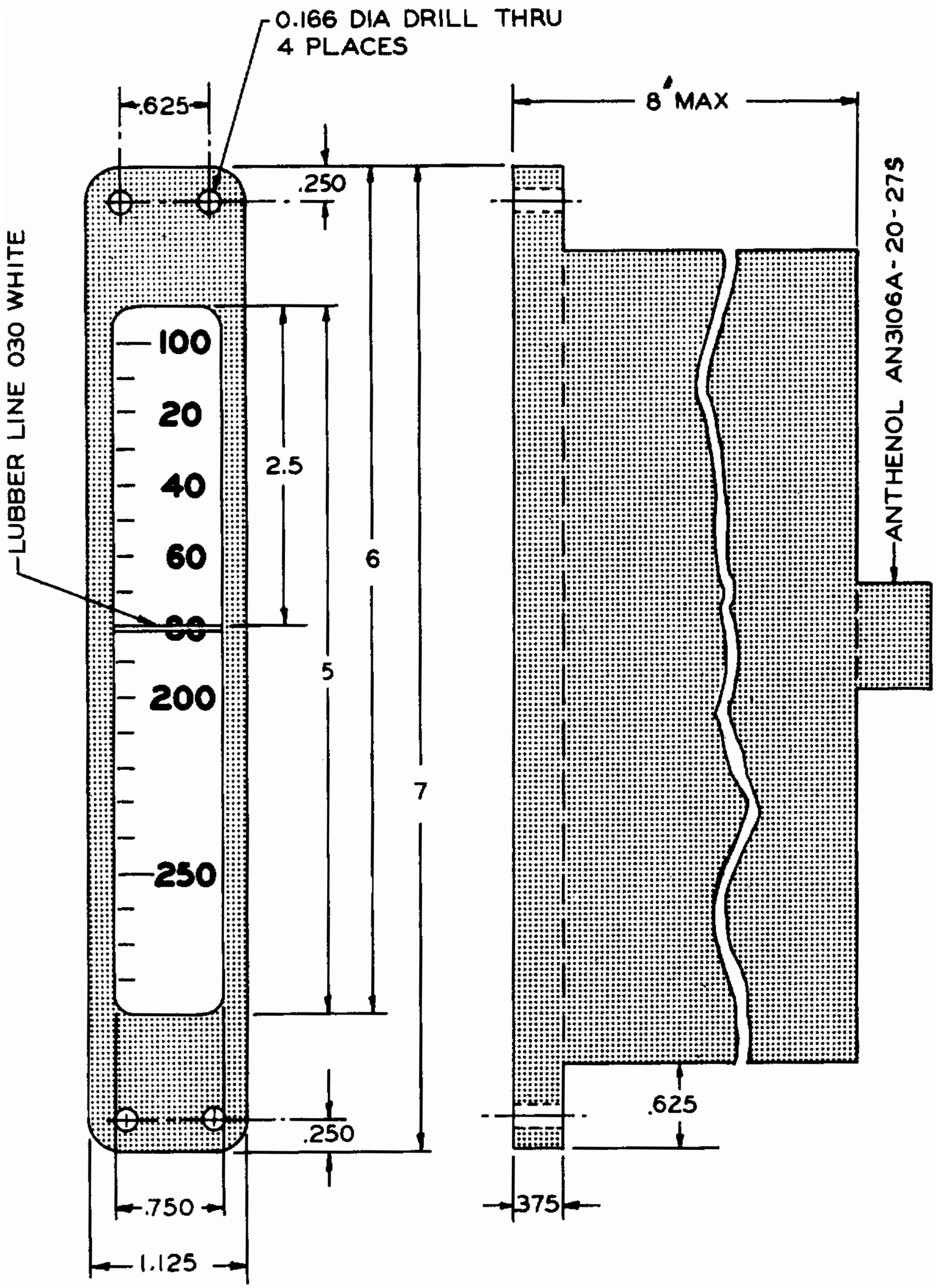
Major Numerals, 7/32 white
Minor Numerals, 5/32 white
Major Graduations, 3/16 white
Minor Graduations, 1/8 white

3.2.11 The unit shall accept positioning commands from an Eclipse Pioneer AY201-1 synchro or equivalent.

3.2.12 Power requirements shall be 115 volts, 400 cycles per second.

3.2.13 One degree of synchro rotation shall correspond to approximately 0.070 inch of tape travel. Step inputs of one-half (1/2) inch or more shall result in only one (1) overshoot of no more than 0.15 inch.

3.3 The contractor shall modify three (3) standard attitude director indicators (ARU-2B/A) with flight path angle tape presentation included. The sphere markings shall conform to the latest design as reflected in contract AF33(615)-203.


0.166 DIA DRILL THRU
4 PLACES
.625
8" MAX
.250
LUBBER LINE 030 WHITE
100
20
40
60
200
250
2.5
6
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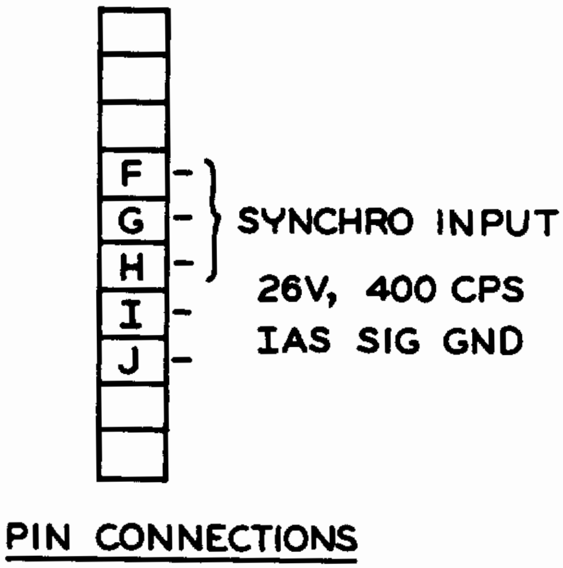
7
ANTHENOL AN3106A-20-27S
.625
.250
.750
1.125
.375

Figure 1



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13. ABSTRACT

The tasks associated with this program were a portion of Air Force Project 6190 whose goal is to develop and improve flight instrumentation for Air Force aircraft. The specific twofold aim of the Instrument Division effort was to deliver attitude director indicators with an advanced display format, and to develop both an attitude director indicator and a vertical type indicated airspeed indicator utilizing gearless servo techniques. The final results of this portion of Project 6190 remain to be evaluated. Generally, the theory of gearless servo drives is well developed. This is confirmed by the relative ease with which the "gearless" indicators were designed and built.

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	ROLE	WT	ROLE	WT	ROLE	WT
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