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TERMINATION REPORT
ON THE
HG32 AIR DATA COMPUTER
FOR THE
ASTRA SYSTEM
OF THE
CF-105 ARROW AIRCRAFT

CF-ED 1061 May 1959

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TERMINATION REPORT

ON THE

HG32 AIR DATA COMPUTER

FOR THE

ASTRA SYSTEM

OF THE

CF-105 ARROW AIRCRAFT

May 1959

Honeywell Controls
Systems Engineering & Military Products
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TERMINATION REPORT ON THE HG32 AIR DATA COMPUTER FOR THE ASTRA SYSTEM OF THE CF-105/ARROW AIRCRAFT

1 GENERAL

The HG32A-2 Air Data Computer was the main component of the YG719 Air Data Computer System, which was, in turn, part of the Astra Weapons System designed for the Avro CF-105 aircraft.

The Air Data Computer (Fig. 1) accepts inputs from the angle of attack sensor, the temperature sensor and the pitot-static system. It computes and corrects, as required, and provides air data outputs as needed by the Automatic Flight Control System, the Fire Control System, the Navigation System, the Cockpit Instruments and other aircraft sub-systems.

The earliest air data instruments used in aircraft were altimeters and airspeed indicators operating from the static pressure and total pressure lines respectively. Both were adaptations of the simple aneroid barometer and were subject to many errors.

As aircraft became more complex, it was necessary to know other air data such as rate of climb and descent, Mach Number etc. Other aircraft systems, navigational computers, fire control systems and automatic pilots required specific functions of certain air parameters. Each sub-system had, incorporated within it, computers to calculate the functions desired. Often the same function was computed in the same way from the same original data in each of the sub-systems. This, of course, was duplication of effort and hence uneconomical from several viewpoints. The realization of this redundancy led to the concept of a central air data computer which measures, computes, corrects and supplies air data functions to all of the aircraft sub-systems. The HG32A follows this concept.

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2 RELEVANT SPECIFICATIONS

Specification R-ED 875 "Preliminary Detail Specification for the YG719 Air Data Computer" outlines the general requirements for the A.D.C. The following Engineering Specifications (E.S.) which are internal documents used by Minneapolis-Honeywell define the component parts of the A.D.C. in greater detail.

a) ES 2032-1-A2 Air Data Computer System

b) ES 2032-2-A2 Air Data Computer

c) ES 2032-3-A2 Pressure Data Computer

d) ES 2032-4-A2 True Airspeed Computer.
Total Temperature Converter.
Air Density Computer.

e) ES 2032-5-A2 Angle of Attack Converter

f) ES 2032-6-A2 Chassis specification

g) ES 2032-7-A2 Potentiometer stacks.

3 DESCRIPTION OF THE UNIT

3.1 General

The HG32 Air Data Computer is designed as a completely self-contained system. It is a compact light weight unit having a high degree of accuracy. It was designed to fit in the electronics bay of the CF-105 ARROW Aircraft.

3.1.1 Physical

The HG32 Air Data Computer measures 12 1/2" long, 16" wide and 8 1/2" high and weighs 47 1/4 pounds.

3.1.2 Electrical

3.1.2.1 Inputs

Primary power is furnished to the Air Data Computer by the Aircraft electrical system as follows:

102 to 124V 400 cps $\pm$ 20 cps single phase using 82 Volt-Amperes.

25 to 29V D.C. for energizing the clutches in the Air Data Computer. This power is obtained from the sub-system requiring the output.

3.1.2.2 Outputs

The following potentiometer outputs are provided:

a) Mach Number (M)
b) Static Pressure (P_s)
c) Log P_s
d) Altitude (h)
e) True Airspeed (V)
f) Air Density (ρ)
g) Total Temperature (T_{Ti})
h) Angle of Attack (αi)

Synchro outputs are provided for differential pressure (q_c), Δ log P_s and Δ log R.

The functions of log R and ρ are provided as servo operated switches. Rate

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outputs of $\frac{d(\log P_S)}{dt}$ and $\frac{d(\log R)}{dt}$ are provided.

The potentiometers and synchros are energized by the sub-system requiring the signal. This eliminates phasing problems.

3.1.3 Mechanical

3.1.3.1 Inputs

Mechanical inputs to the Air Data Computer are in the form of air pressures, temperature detected by resistance wires, or angles and are as follows:

a) Total Pressure (P_T)

b) Static Pressure (P_S)

c) Angle of Attack (α)

d) Total Temperature (T_i)

3.1.3.2 Outputs

No purely mechanical outputs are provided.

3.2 Component Parts

The HG32 Air Data Computer consists of a chassis containing interconnecting cables, magnetic amplifiers and motor capacitors and mounting the following five modules.

a) Pressure Data Section

b) Air Density Computer

c) Total Temperature Computer

d) True Airspeed Computer

e) Angle of Attack Repeater.

4. DESCRIPTION OF PARTS

4.1 General Description

Modular construction is used throughout this device. The modules simplify maintenance and provide adaptability of design to changing aircraft applications because it is possible to adapt a module to a new requirement with relatively minor changes. Each module is complete in itself, and most modules can be replaced without readjusting other modules. Replacements may be made with the use of simple wrenches and screw drivers only; no soldering or special tools are required. Two of the modules in the Pressure Data Section require phasing and are preadjusted before being assembled in the final assembly. All other units require only proper internal gear meshing. Interconnection between sections is purely electrical.

4.2 Pressure Data Section

The pressure Data Computer (Fig. 2) is a mechanical analogue computer which converts pitot-pressure (P_T) and indicated static pressure (P_S) obtained from the aircraft pitot-static system, into the desired electrical outputs from these parameters. This section consists, functionally, of the pitot and indicated static pressure transducers and servo loop, a static pressure error corrector servo loop, a mechanical computer, and the pressure data output devices. The converting, computing, and output functions are combined into one continuous mechanism for optimum performance.

The pitot and indicated static pressure transducers sense pitot (ram air pressure) and static pressure (altitude) by means of servoed rebalance mechanisms. The outputs of these transducers are shaft rotations proportional to log P_T and log P_S. Static pressure error is computed and the proper correction applied by the Static Error Corrector servo loop. (The static pressure error versus Mach number relationship is a characteristic of the particular nose boom and pitot sensor combination).

A typical pressure transducer is shown diagramatically in Figure 3. Two bellows, one sensing and one reference (evacuated) are mounted in opposition to each other. The outer bellows headers are mounted to the transducer structure and the inner headers are joined by a rigid link. The differential force from the bellows is transmitted to a reed suspended sense beam by means of a flexible tape which is always in tension. The sense beam serves as a direct motion multiplier to the highly sensitive inductive signal pick-off. One end of a torsion bar rebalance spring is coupled to the sense beam at its pivot point through a coaxial tube which also serves as part of the beam mounting in the X-reed suspension. The cam follower is mounted on the other end of the torsion bar spring and is rotated by a contoured cam which, in this case, generates a logarithmic function. The log cam is on the output shaft of an adjustable cam.

A change in pressure in the sense bellows results in an unbalance of forces on the sense beam and a consequent slight rotation. The resulting movement of the slug in the inductive pick-off generates a signal which is fed to a phase sensitive amplifier which causes a servo motor to drive a mechanical linkage to restore the slug to its null position by rotating the torsion bar. The mechanical linkage consists of a gear train which drives through an adjustable cam which corrects any repeatable errors due to cam contours, gear irregularities etc. The output of the adjustable cam connects to the log-cam which imparts a non-linear (logarithmic) rotation through the follower arm to the torsion bar spring and sense beam to restore the beam and inductive pick-off to its null position.

The P_S and the P_T transducers are identical with the exception of the torsion bar rebalance springs. The torsion bar springs, which do not have a changing centre of gravity to produce a shift in static balance, have spring rates to match P_T and P_S pressure ranges. The pressure ranges of the two units are scaled to make the log cams identical.

To compensate for the sensitivity of the sense beams to angular accelerations, a second beam with the same polar moment of inertia is coupled to it in phase opposition. The whole system is also carefully statically balanced to reduce position error to a minimum. Materials have been selected to minimize the effects of temperature, and further compensation is accomplished by means of a bimetallic element acting on the sense beam.

The Mechanical computer receives as inputs shaft rotations proportional to the logarithms of P_T and P_s from the pressure transducers, and angle of attack information from the angle of attack repeater. In addition, an internal loop, the static pressure corrector, stores data relating P/P_s to indicated pressure ratio P_T/P_s, and supplies the correction necessary to provide a true static pressure P_s as a shaft rotation, (P is a function of pressure obtained as an intermediate computation stage). Outputs are provided as follows:

a) P_s, log P_s, and h - The output of the static pressure corrector is a shaft rotation proportional to the logarithm of $(1 + P/P_s)$. When this shaft rotation is combined with the shaft rotation proportional to log P_s by means of a differential gear, the output shaft rotates as a function of log P_s. By means of an adjustable cam the log P_s shaft rotation is converted to a shaft rotation proportional to h (Pressure altitude). Further, by the use of a solid cam and an adjustable cam, the log P_s shaft rotation is converted to a shaft rotation proportional to P_s. Shaft rotations of log P_s, h and P_s are available simultaneously.

b) Log R and Mach Number - The combination of shaft rotations proportional to log P_s and P_T by means of a differential gear results in an output shaft rotation proportional to log R. This shaft rotation may be converted to a shaft rotation proportional to Mach number by use of an adjustable cam. Shaft rotations proportional to log R and Mach number are available simultaneously.

c) Impact Pressure - As mentioned above, the cam-follower shaft of the transducer has a rotation proportional to the sensed pressure. A transmitting synchro attached to this shaft on the total pressure transducer provides an electrical signal proportional to total pressure as an input to a differential synchro whose rotor is positioned by the P_s shaft. The electrical output of this differential synchro is the difference between P_T and P_s, and is proportional to q_c.

d) Rate Signals - Electrical rate signals are available from the velocity generator sections of the P_T and P_s loop servo motors. These voltages are proportional to

$\frac{d \log P_s}{dt}$ and $\frac{d \log P_T}{dt}$. The two voltages may be summed to provide $\frac{d \log R}{dt}$ or may be used separately. The sum provides the rate portion of the Mach Hold signal and $\frac{d \log P_s}{dt}$ provides the rate portion of the Altitude Hold signal.

4.3 Air Density Computer

The Air Density Computer (Fig. 4) accepts potentiometer voltage input signals proportional to Mach number (M), altitude (P_s) and total temperature T_{Ti} and supplies signals proportional to air density to the using sub-systems.

The computation of air density is based on the following equations:

$$\rho = \frac{P_s}{R'T}$$

$$= \frac{1}{R'} \left[\frac{P_s \, (1 + 0.2M^2)}{T_T} \right]$$

$$= \frac{P_s \, (1 + 0.2 \, KT_s \, M^2)}{1716.5 \, T_{Ti}}$$

where:

ρ is air density in slugs per ft.^{3}

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P_s is static pressure in psf

M is true Mach number

T_{Ti} is indicated total temperature in °R.

R' is gas constant for air.

4.4 Total Temperature Computer

The Total Temperature Computer (Fig. 5) accepts a variable resistance signal proportional to indicated total temperature from the remote temperature sensor. It repeats this signal and supplies signals proportional to indicated total temperature to the Air Density Computer, the True Airspeed Computer and to using sub-systems.

The computation of total temperature is based upon the characteristic equation of the probe used. The TG4A-1 temperature probe has a platinum resistance element which follows the Callendar-Van Dusen equation:

$$\frac{R_t}{R_o} = 1 + \alpha \left[t - \delta\left(\frac{t}{100-1}\right)\left(\frac{t}{100}\right) - \beta\left(\frac{t}{100-1}\right)\left(\frac{t}{100}\right)^3 \right]$$

where:

R_t is probe resistance at temperature t in °C.

R_o is probe resistance at 0°C = 50 ohms.

α is 0.003925

δ is 1.45

β is zero for temperature above 0°C., and 0.10 for temperatures below 0°C.

4.5 True Airspeed Computer

The True Airspeed Computer (Fig. 6) accepts potentiometer voltage input signals proportional to Mach number (M) and Total Temperature (T_{Ti}) and supplies signals proportional to true airspeed to the using sub-systems.

The computation of true airspeed is based on the following equation:

$$V = M\,C_s$$

$$= MC_{so}\sqrt{\frac{T}{T_o}}$$

$$= 29.05M\sqrt{\frac{T_{T_i}}{1 + 0.2\,K_{T_s}\,M^2}}$$

where:

V is true airspeed in knots

T_{T_i} is indicated total temperature in degrees. Rankine

M is true Mach number

K_{T_s} is temperature sensor recovery factory (assumed constant at 0.98)

C_s is speed of sound in knots.

C_{so} is speed of sound at zero °R.

4.6 Angle of Attack Repeater

The Angle of Attack Repeater (Fig. 7) accepts an electrical synchro input signal representing indicated angle of attack from the alpha vane (α) mounted on the nose boom of the aircraft. It repeats this signal and supplies signals proportional to the indicated angle of attack to the using sub-systems.

4.7 Self Test Feature

The "Self Test" feature was added to the HG32 Air Data Computer circuitry to cause all the output devices to rotate to positions corresponding to the following air data conditions:

P_s = 242.2 psf (h = 50,000 ft.)

V = 500 yds/sec (Mach = 1.550)

ρ = .000362 slugs/ft^3 (T = 573.6°R)

α = 0 degrees.

The self test feature is actuated by applying

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28v d.c. to a test relay inside the A.D.C. Access to the relay is obtained through the test connector on the chassis. Connections to one output potentiometer on each of the output shafts (P_s log P_s, h, M, V, ρ, T_{Ti} and α) are also accessible at the test connector so that measurements may be made of potentiometer ratios under the test conditions (Fig. 7). This test feature checks the circuit operation of the entire A.D.C., with the exception of the pressure transducers. Upon removal of the 28V on the test relay all outputs will return to the ambient values so that transducer faults may be determined.

Test conditions are imposed upon the circuitry by the relay switching out the normal inputs from the transducers and substituting for them circuits of fixed value components. The circuit values correspond to the outputs that would be expected from the transducers when the transducers themselves are tested.

5 PERFORMANCE

5.1 Ranges

5.1.1 Operating Ranges

The operating range of the HG32 Air Data Computer was based on the assumed flight envelope of the aircraft.

a) Indicated Static Pressure (P_s) Transducer: 40 to 2420 p.s.f.

b) Total Pressure (P_T) Transducers: 80 to 4840 p.s.f.

c) Ram Temperature (T_i) Transducer: 350° R to 1000°R.

d) Angle of Attack (α) Transducer: -5° to +20°.

e) Static Error Corrector: Ps/P_s may vary from 1.055 to .99.

5.1.2 Output Ranges

a)	Static Pressure (P_s)	57.3 to 2194 p.s.f.
b)	Total pressure (P_T)	80 to 4840 p.s.f.
c)	Differential pressure (q_c)	0 to 4783 p.s.f.
d)	Mach number (M)	0.2 to 2.4 Mach
e)	True Airspeed (V)	100 to 1500 knots
f)	Ram Temperature (T_i)	350° to 1000°R.
g)	Air Density (ρ)	33 x 10^{-4} to .65 x 10^{-4} slugs/ft.^{3}
h)	Angle of Attack (α)	-5° to +20°
i)	Log R	.012111 to .897457 (0.2 to 2.4 Mach)
j)	Δ Log R	$\pm$ 0.05 Mach / $\pm$ 70° shaft rotation at Mach 0.8.

k) Log P_s — 1.7579866 to 3.341201 (57.3 to 2194 p.s.f.)

l) Δ Log P_s — $\pm$ 500 ft./$\pm$ 70° shaft rotation at 36,089 ft.

m) Pressure altitude (h) -1000 to 80,000 ft.

5.2 Threshold Sensitivities

5.2.1 Inputs

Threshold sensitivity is defined as the minimum amount that the input must be changed to produce a recognizable usable output.

a) Indicated Static Pressure Transducer - Assumed to be less than .001 inch mercury independent of measured pressure.

b) Total Pressure Transducer - Assumed to be less than .001 inch mercury independent of measured pressure.

c) Ram Temperature Transducer - Theoretically infinite.

d) Angle of Attack Transducer - Theoretically infinite.

e) Static Error Corrector - Less than .001 inch of mercury

5.2.2 Outputs

a) P_s — 0.1% of full range = 2,137 p.s.f.

b) P_T — less than .001 inch mercury

c) q_c — 0.1% of full range = 4.78 p.s.f.

d) M — 0.1% of full range = 0.0022 Mach

e) V — 0.1% of full range = 1.4 knots

f) T_i — 0.1% of full range = 0.650°R

g) ρ — 0.1% of full range .032 x 10^{-4} slugs/ft3

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h) α — 0.1% of full range = 0.025°

i) Log R — 0.1% of full range .000885 log 10 units.

j) Δ Log R — 0.1% of full range = .0001 Mach at .8 Mach.

k) Log P_s — equivalent to P_s threshold

l) Δ Log P_s — 0.1% of full range = 1 ft. at 36,089 ft.

m) h — 0.1% of full range = 81 ft.

5.3 Accuracy

Accuracies have been estimated on the basis of known or estimated capabilities. Errors have been combined on a root-sum-square basis.

a)	Static Pressure	.07% of indication at sea level, 1.06% indication at 80,000 ft. (Includes pot linearity.)
b)	Total Pressure	2% of indication
c)	Mach Number	1% of indication
d)	Differential Pressure	2 to 3% of indication
e)	Air Density	1% of indication
f)	True Airspeed	1% of indication
g)	Total Temperature	0.5% of indication
h)	Angle of Attack	0.5 degrees or better
i)	Log R	same as Mach Number
j)	Δ Log R	2% of full displacement
k)	Log P_s	same as static pressure
l)	Δ Log P_s	2% of full displacement
m)	Pressure Altitude	0.25% h + 20 ft.

5.4 Actual Performance

The development program was cancelled before a full evaluation of performance characteristics could be made. However, some of the modules were

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given rather extensive, although informal, tests. The results of these informal tests led the designers to believe that no difficulty would be encountered in meeting the full requirements.

6 PRESENT STATUS

Two complete HG32A-2 Air Data Computers have been produced. These units are now in Minneapolis and are awaiting shipping instructions. In addition, several modules have been completely assembled and tested, and parts for several others have been manufactured. These modules, partial assemblies, parts, and components have been gathered together and are in storage in Minneapolis, awaiting disposal instructions from the contracting agencies.

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7 PROPOSED FUTURE PROGRAM

The specific future of the HG32 Air Data Computer design is not known. However, the experience gained in the design and development of this first known central air data system will be applied to other existing and future air data systems. Sufficient information has been gained, in spite of the untimely and rather unfortunate demise of the project, to prove that the basic concepts and methods of instrumenting them are very sound.

The two completed systems are believed to be available to the National Research Council for evaluation purposes. This document has been prepared to aid N.R.C. in such an evaluation. The experience obtained by the Canadian engineers working on the project is also available to aid N.R.C., should such be desired.

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8 CONCLUSIONS

The HG32 Air Data Computer was specifically designed to meet the requirements of the Astra Electronics System. The unit, therefore, represents a design starting with first principles rather than a modification of an existing device. Such a design concept has several advantages. The central packaging approach permits a unified design which provides:

a) Space and weight saving - The additional weight and volume of repeaters and correctors and their packaging is not imposed upon the total system.

b) Better reliability - Fewer components, interconnections and less handling means a large gain in reliability.

c) Ease of maintenance - The single unit concept means easier and faster servicing, testing, and repair. Mounting, handling and cabling problems are greatly reduced.

d) Better accuracy and resolution - A single unit gives the greatest possible accuracy and resolution of output functions as there is no loss due to the repeating of functions from unit to unit.

During the development of this Air Data Computer, several important advances were made in component design.

Foremost is the pressure transducer with torsion bar rebalance and reed suspension. This component is fully described in Section 4.2 of this report. Also developed was a basic high linearity potentiometer. These potentiometers are of an inch diameter and of very short axial length making them excellent for stacking purposes in computers. Accuracy is 0.3 per cent.

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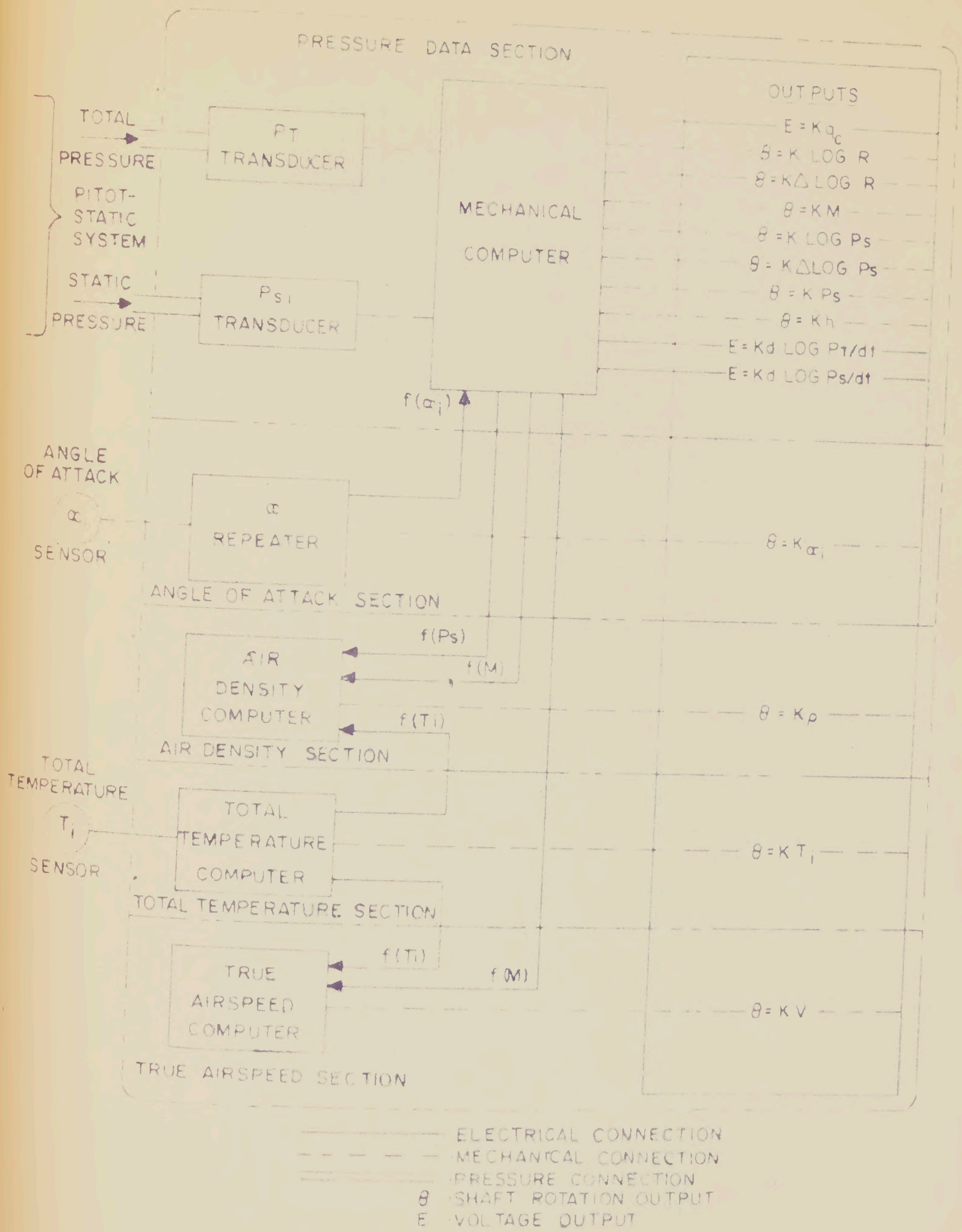

Air Data Computer General Block Diagram

Figure 1

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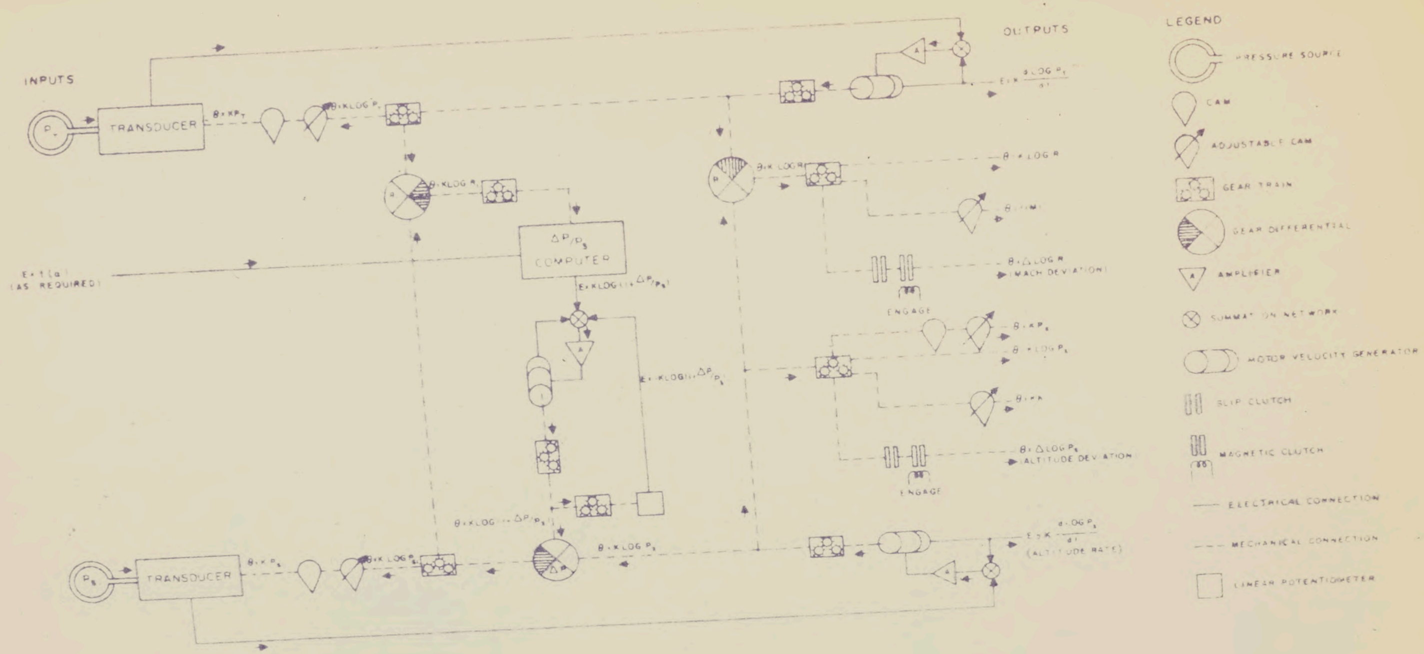

Detail Schematic Diagram of Pressure Data Section

Figure 2

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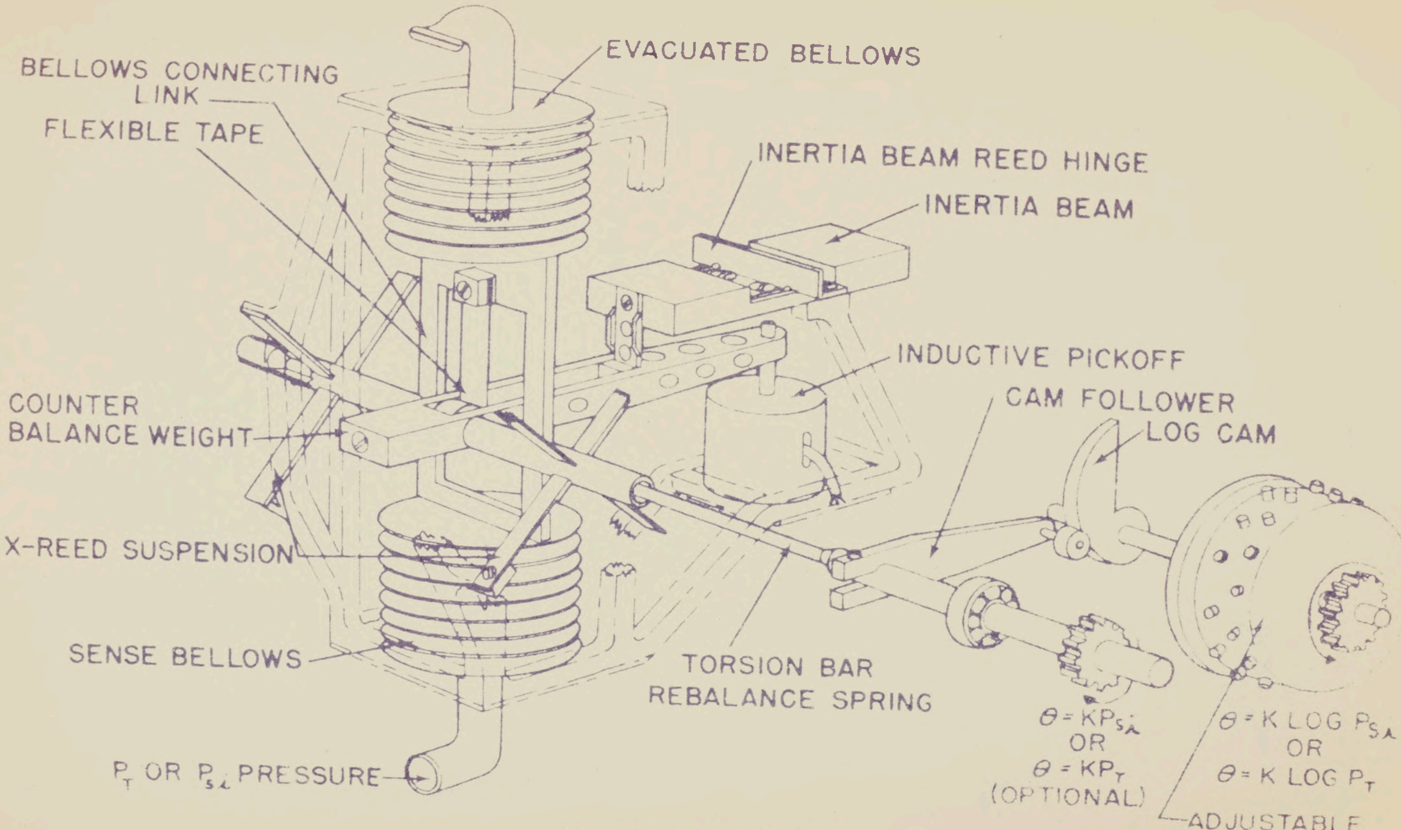
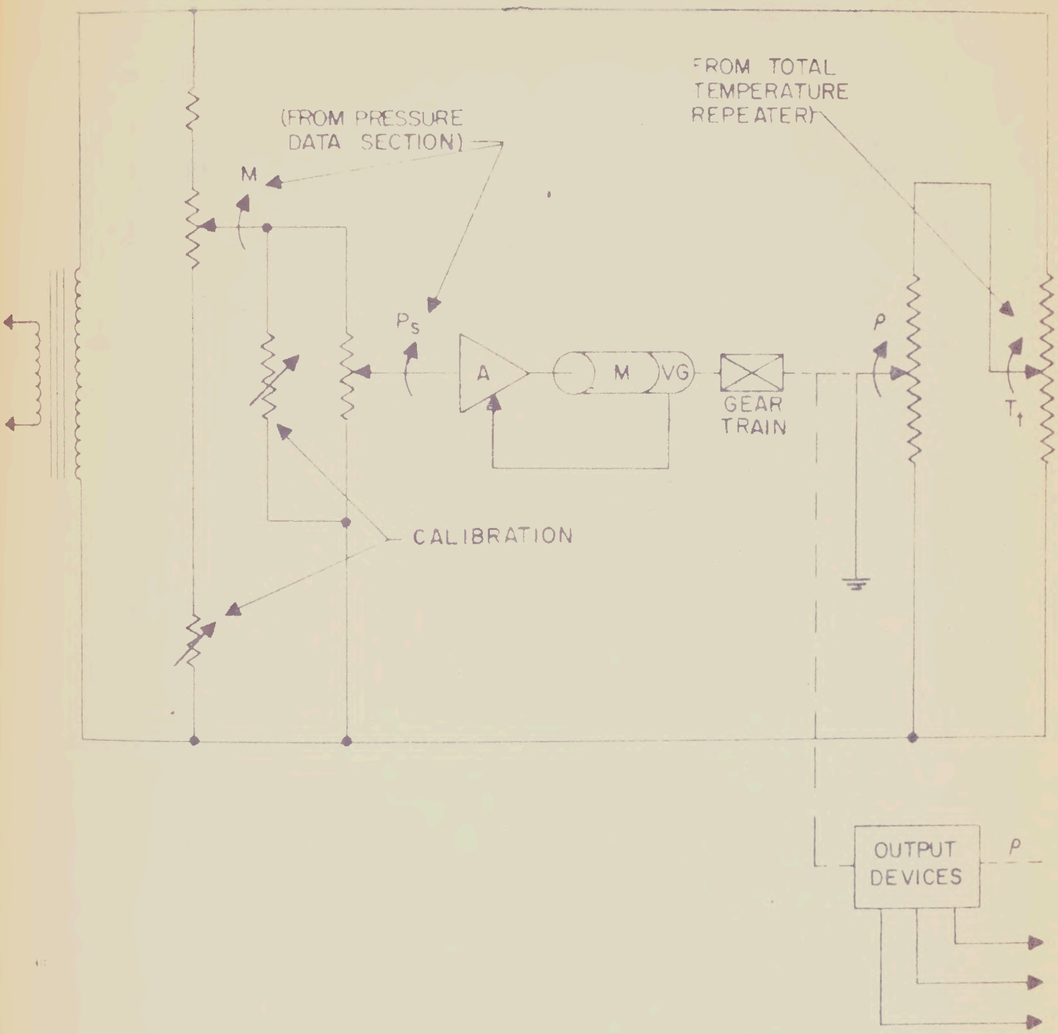
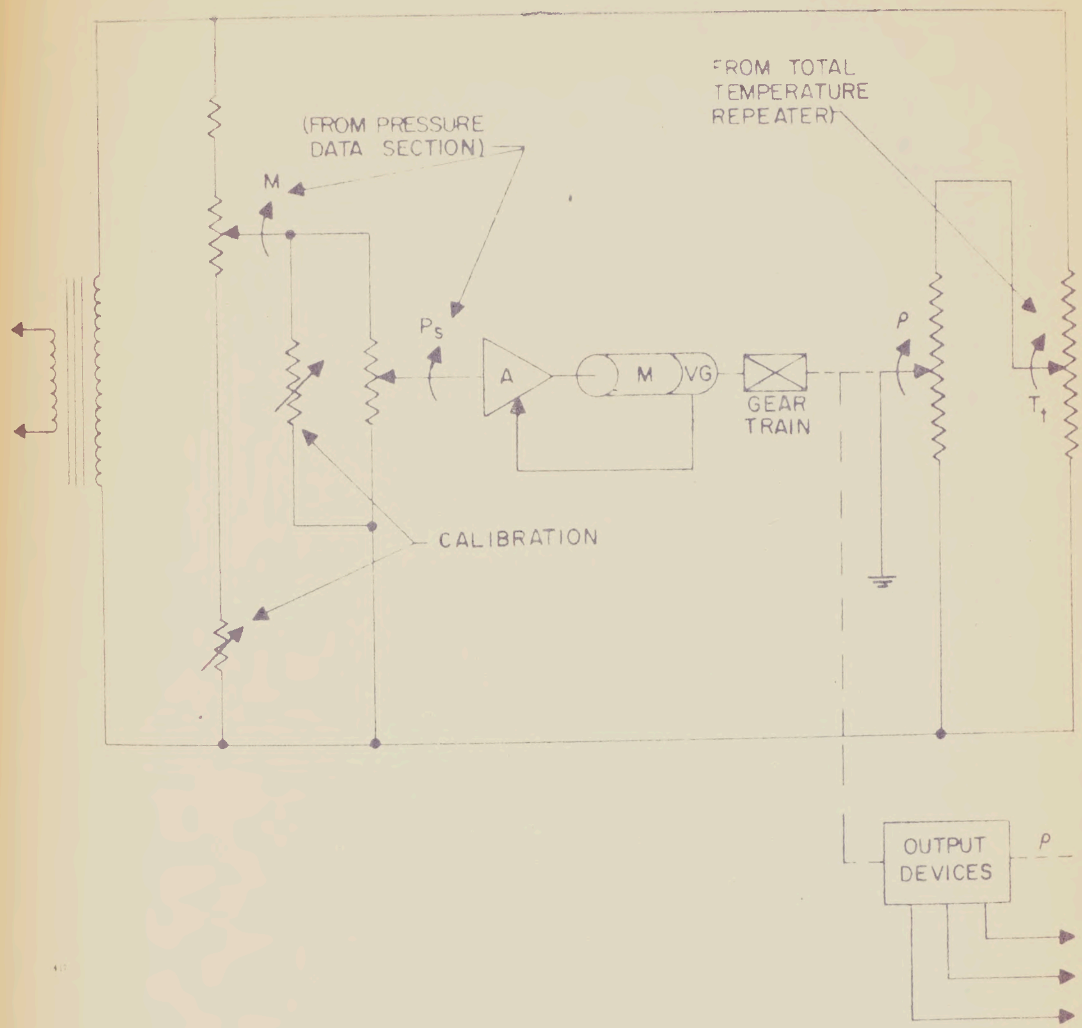


PRESSURE TRANSDUCER
Figure 3



Static Air Density Computer Schematic Diagram
Figure 4



Static Air Density Computer Schematic Diagram
Figure 4

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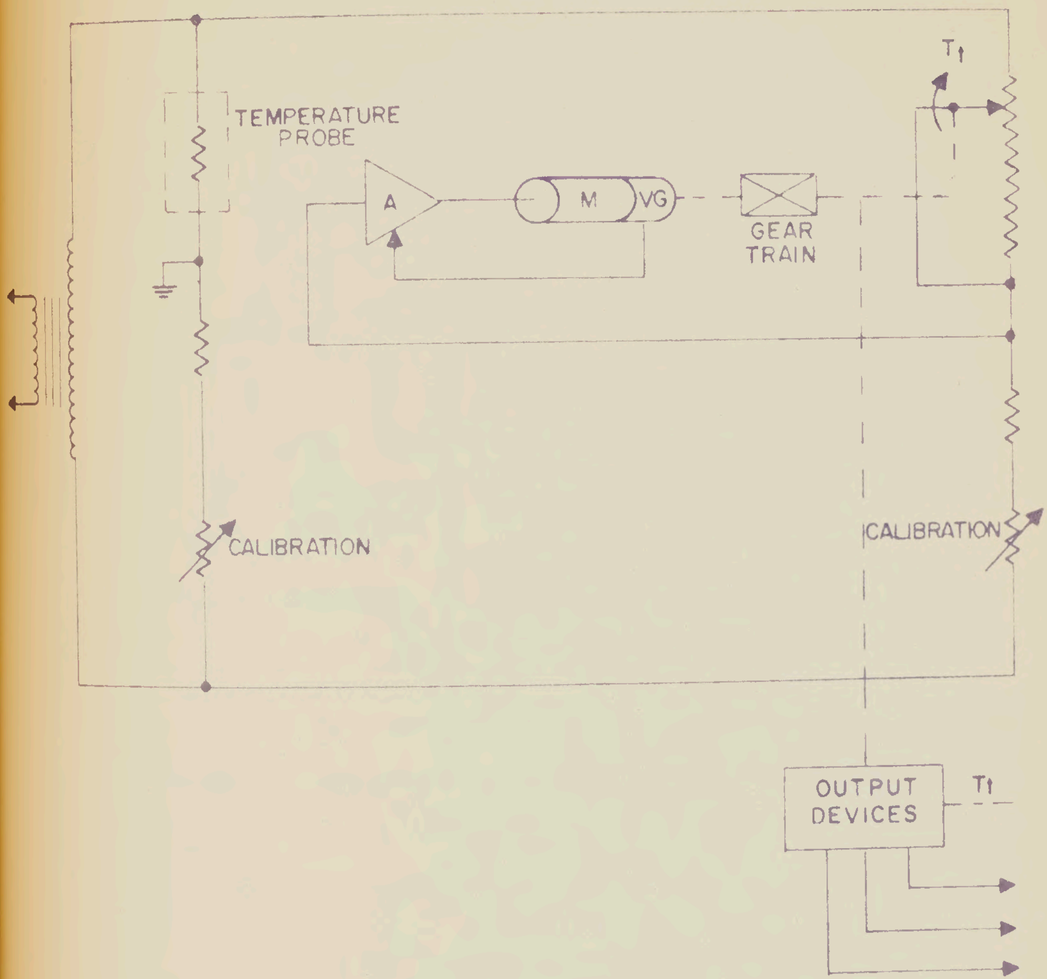

Total Temperature Computer Schematic Diagram
Figure 5

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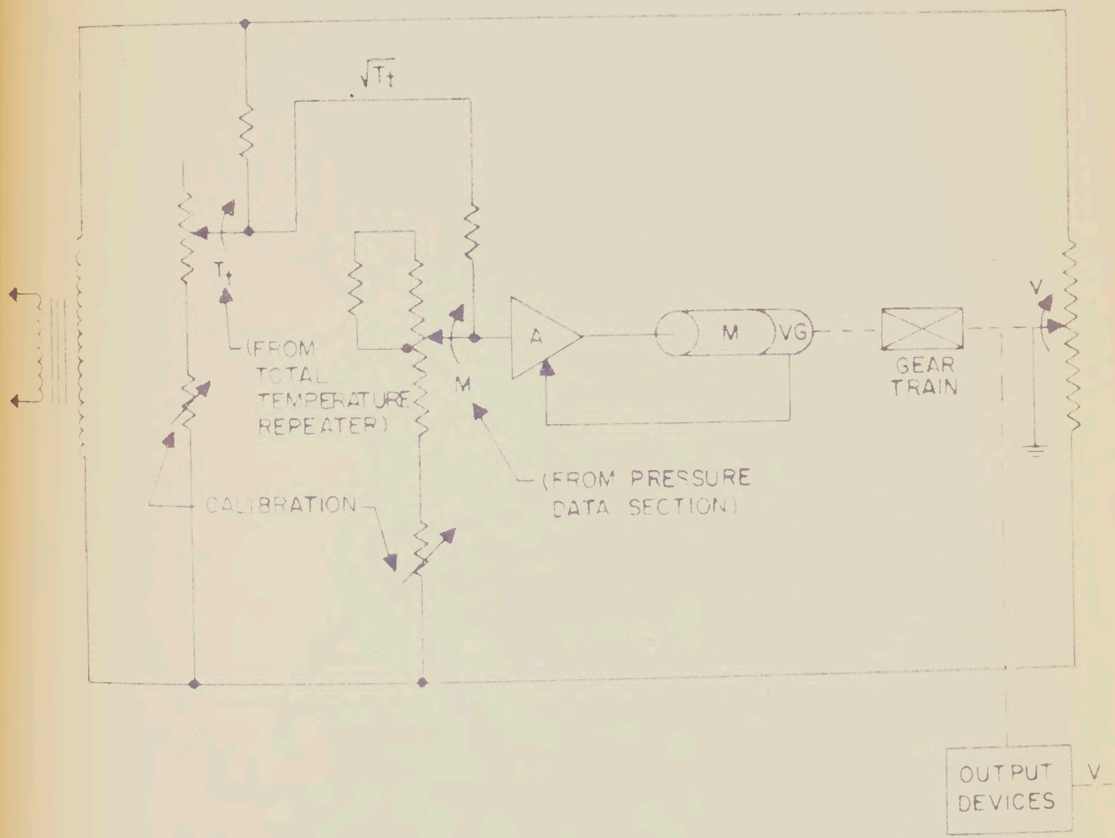

True Airspeed Computer Schematic Diagram
Figure 6

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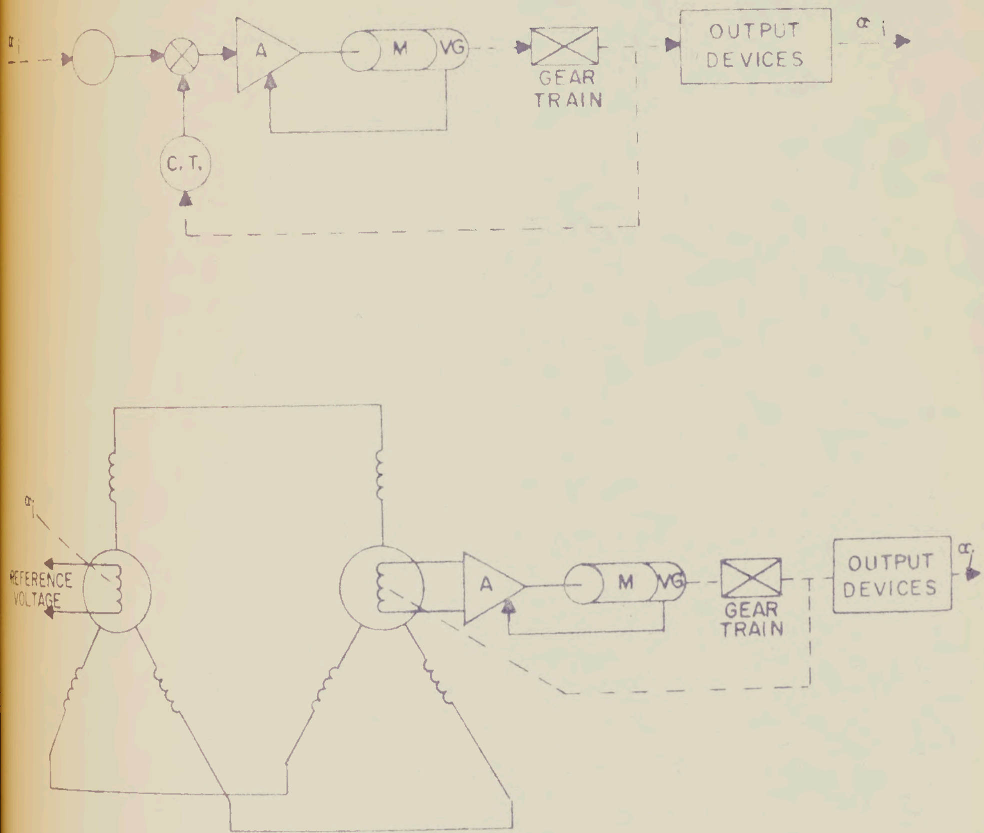

Angle-of-Attack Repeater Schematic Diagram

Figure 7

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