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MECHANIZATION OF AIR DATA COMPUTERS

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Approaches

Air data computers historically evolved to their present integrated state from two areas of emphasis. One approach developed from airspeed and altitude instruments used to provide the pilot with visual indications of the ambient air conditions about him. These panel instruments were usually simple mechanical devices in which an indicator needle was driven by an aneroid system. Many ingenious schemes were utilized to compensate temperature, increase sensitivity, linearize and similarly enhance the accuracy, reliability, and other properties of the devices. These instruments are characterized by the following features: (1) the pressure cells must expand a considerable distance as a function of cell effective area, pressure, system spring rate, and friction; (2) the mechanism is delicate and watchlike because the pressure cell must provide all the power to move the indicator with a minimum loss of sensitivity throughout the range; (3) it has a light weight-to-volume ratio; (4) they produce range indications and are calibrated for scale accuracy; and (5) tapping or vibration is necessary to overcome friction.

The second approach was the outcome of pressure transducers designed to provide the automatic pilot with knowledge of changes in air pressures for the purpose of flight control to a specific altitude or air speed. Since the eyes and muscles of the pilot are not a part of this control system, the transducers had to have power to drive signal generators such as potentiometers, synchros, or inductive devices to indicate to the surface actuator what it must do to control the aircraft. This system also required careful control of the error between sensor and actuator since the eye-hand coordination of the human pilot was lacking. This is a natural and logical application of servomechanism practice, so the fundamentals of this science dictated the pattern of these mechanisms. The transducers used in autopilot pressure-sensing applications are usually of the force rebalance type which have certain basic characteristics:

1. The pressure cells move only slightly, creating a force to unbalance the static equilibrium of the sense system.

2. Because minute movements of the sense system are all that is required to produce an electrical signal, the system may be rate (or reed) suspended and the signal may be used to control a motor and gear train providing the rebalance force which is sufficiently rugged and powerful to drive many output signal devices.

3. Though these pressure transducers were originally used to provide auto-pilots with highly sensitive displacement and rate signals for constant Mach and altitude control, they can also be calibrated to give accurate full range outputs.

4. These units are high-density, complex devices.

5. The transducers require no tapping or vibration to develop very high sensitivities because the reed suspension has essentially no friction.

Air data computers have been designed and built on the basis of each of these approaches. Considered from the standpoint of providing air data for panel instruments, scheduling functions and computing either basis might serve equally well. However, the simplicity of the original direct-driven, visual instrument is lost in that approach as the numerous outputs and computing functions require more power to drive them than is available from the transducer. A chaser or position servo loop is employed to provide this power, which makes the device as complex as the force rebalance transducer without the advantages of force rebalance. When automatic flight control requirements are added to the design considerations for a complete central air data computer, then pressure sensitivities must approach 0.0005 psi, reversal loss or dead spot of 0.002 psi and rate thresholds of 5 psi per minute at sea level. The appreciation of these requirements came from 13 years of designing, building and flight testing Mach, altitude and pressure controllers of many configurations and concurrently producing over 16, 000 production units which are providing automatic flight control systems on large numbers of aircraft of various types with pressure data control and scheduling.

The sensitivity and response of an air data computer supplying an automatic flight control system is derived by evaluation of flight path deviations acceptable to the pilot. If the autopilot cannot do better than the pilot, he has little respect for it. It is beyond the scope of this paper to derive the requirements for an air data computer, but it is sufficient to state that the mechanism must be capable of meeting all the intended uses of pressure data in an aircraft or it does not fulfill the intent of the air data computer concept.

It has been established that the air data mechanism must have extreme sensitivity, low reversal loss, high repeatability and accuracy, and sufficient power to drive several output and computing functions. Other desirable features are reliability, simplicity, flexibility of output functions, and lowest weight and size commensurate with other requirements.

A block diagram of a typical air data system is shown in Figure 1.

Transducer Design

The transducer design pattern and means of deriving signal outputs from pressure inputs have a decided effect on the mechanization. First from P_T and P_{si} pressure inputs there is a choice of transducing them as P_T and P_{si} absolute, q_{ci} as $P_T - P_{si}$ or R or f(M) as $\frac{P_T - P_{si}}{P_{si}}$.

Using a ratio (R) transducer and a P_{si} transducer to produce the inputs to the computer requires that two entirely different instruments be designed, tooled, produced, and stocked as it is necessary to have both the R function and P_{si} separately for computing purposes. Since P_{si} is a term of the R transducer function and also the term of the P_{si} transducer function, the static error correction must be applied to both inputs to convert the P_{si} to P_s or true static pressure. This is also true when considering q_c as a transducer function. Another consideration in the case of the ratio transducer is the added complexity of construction and calibration which should be eliminated if simpler means were available.

From this reasoning, the best course is to transduce P_T and P_{si} as absolute pressures and compute the other pressure-data functions. Mechanizing for transducing single absolute pressures may be most simply constructed by use of a single pressure element. This element is evacuated internally, and the sense pressure is external or in the mechanism case. This, however, is a difficult situation if the volume of air handled by the static or pitot lines is kept low to avoid the effect of pressure lags on the dynamic response of the whole computer.

The pressure transducers used in the pressure data section of the Honeywell air data computer are the most advanced version of a long line of force re-balance pressure-sensing flight controllers pioneered and produced in large quantities in Honeywell factories. The general pattern of these transducers follows that of the highly sensitivie PG7030 and PG10 altitude controls which are standard equipment in several present first-line military planes.

A schematic diagram of the transducer is shown in Figure 2. One sense bellows and one evacuated reference bellows are mounted in fixed opposition to each other. The outer headers are mounted to the transducer structure while the bellows connecting link between the opposed headers is tape connected to an "X" reed-suspended beam. The beam serves as a direct motion multiplier to the signal pickoff. This can be a capacitor or inductive pickoff, as required by the type of amplifier used in the servo loop of the rebalance system.

To compensate for angular acceleration sensitivity of such a freely suspended beam, a second inertia beam with the same polar moment of inertia similarly reed-suspended, is coupled in phase opposition to the sense beam. This complete system is also carefully statically balanced to reduce position error to a minimum.

The configuration of moving parts in the sensing mechanism must be carefully designed to ensure static and inertial balance. Forces applied to the beam are pressure and rebalance under all conditions of acceleration. The torsion bar reference or rebalance spring and tubular beam mount are coaxial, thus providing constant distribution of mass throughout the operating pressure range.

The effects of temperature on the transducer have been minimized by selection of materials with respect to thermal coefficients and relative dimensional proportions of the suspended parts and structures. Further compensation for transient thermal conditions is provided by bi-metal bias links acting on the beam.

The bellows are multiple-cell diaphragms held to a close tolerance on effective area so area compensation is not necessary. Further, the design of these bellows reduces change in effective area with pressure level, a factor in nonlinearity of transducers. The two-bellows absolute-pressure sensing system used in these transducers reduces the volume of air sample required to about 0.22 cubic inch for either P_{si} or P_T. These small volumes have a negligible effect on the pressure lag of the pitot-static system.

Since each of these transducers (P_{si} and P_T) is of the force-rebalance type, the bellows and sense beam move only enough to create an error output signal from the pickoff. The rebalance force to return the transducer to null comes to the rebalance torsion bar spring through a log cam and adjustable cam corrector. The adjustable cam described elsewhere in this paper serves to calibrate out repeatable nonlinearities in the transducers to less than 0.1 per cent of full scale.

The P_{si} and P_T transducers are identical in design, except the torsion spring is changed to accommodate the higher pressure levels. The ranges of the two units are scaled to make the log cams identical.

Computing Means

The use of a logarithmic cam in the transducer rebalance input causes the rebalance motors and gear trains to perform as the log of the pressure inputs. Since one of the intended output functions is the ratio of the two pressures and there is no ratio transducer, the simple way is to compute this ratio. By driving the log P_s and log P_T gear trains into an instrument differential, the ratio function is the resulting rotation of the spider shaft output of that differential by subtraction of the logarithms giving log R. (See Figure 3).

Two other conditions can be worked to advantage in this mechanization. Gear differentials have an input-to-output error which is characteristic to one revolution. Additional revolutions to accommodate the data range serve to divide the effect of this error by the numerical value of those revolutions. When this is carried out, they become negligible at about 25 or more revolutions.

When the differential is placed at a relative high revolution point in the gear train, the second advantage can be acquired by arranging the gear ratio at the log R shaft to drive the Mach hold output with the required sensitivity of 0.0005 Mach in a modulation range of ±0.05 Mach.

Here a basic design premise must be expressed. For satisfactory flight control response and sensitivity, it is imperative that the outputs used for that purpose be driven directly by the pressure transducer servo loop, preferably a force rebalance loop rather than by a repeater loop with its inherent lag, larger deadspot, and poorer sensitivity. The Mach or ratio hold output is directly driven by the P_T and P_s loops which fulfills this premise. This is not done without attention to the individual response characteristics of the two loops, however. For conditions where maximum accelerations of the aircraft can be achieved, the computed output R tends to favor a cancellation of the individual loop lags; but when lesser accelerations are the rule, adding of the loop lags is accepted. In areas like this, an analog computer simulation of the control loops was used to study the dynamic consequences of the pattern of instrumentation.

This portion of the air data computer called the pressure data section now consists of two force-rebalance absolute pressure transducers developing shaft rotations of log P_{si} and log P_T which drive a gear differential producing a shaft rotation which is a function of Mach, hereafter called log R_1.

This point is one of the most disturbing areas of air data computer design. The information from which all this data is derived can be in error. Fortunately, this error is determinable although it may have three factors: One factor is a function of Mach; a second factor often found is angle of attack, or α; and a third factor is angle of yaw, or β. The offender among the sensors providing pressure samples to the computer is the P_{si} or indicated static pressure sensor as noted by the subscript "i" in the term. In this area, signals from another portion of the air data computer not discussed yet must be used in the internal computations.

As noted in Figure 1, five sensors can provide inputs to the air data computer. Only P_T and P_{si} have been discussed. Indicated temperature of the ambient air (T_i) and the angles of the aircraft to the relative wind in two axes (α and β) may also be required information. As this portion of the computer will be discussed later, it is sufficient to state here that an electrical signal may be provided from these computer sections to the pressure data section and vice versa. This might question the use of electrical signals instead of mechanical shaft rotations, but for reasons of design flexibility and simplicity, electrical transmission is more appropriate.

The prime factor in static error correction is the function of M or log R_i. In most applications the static pressure sensor and damper system have been worked out sufficiently well so β variations are negligible and even α corrections may not be necessary. In any case, the solution of an equation with two independent variables is provided; one is a function of Mach and the other angle of attack with the possibility of some additional scheduled modification.

Early in the development of the air data computer concept, the idea of making the static pressure correction directly in the static line was favored because it permitted use of all existing panel instruments where pressure data was transduced. Several ill-fated attempts were made, but the dynamic requirements of such a system when considered for automatic flight and fire control problems were not attainable. This approach was dropped and several other techniques were utilized, all concerned with making the correction in the computer and providing corrected signal outputs for all purposes.

The mechanization of the two-variable equation can be handled by a three dimension cam. This is a rather cumbersome inflexible piece of machinery requiring shaft inputs of the Mach function to rotate the cam and a lead screw to position the cam follower as a function of angle of attack with the rise and fall of the follower rotating a signal output as a function of static error correction. Variations of this, of course, are possible. The output signal must then be fed into the P_{si} servo loop by some means to cause the correction to be made in all the outputs of that loop.

Because the function of the three dimension cam is difficult to determine until the final configuration of the airplane is flown, it was decided to use a more easily modified means of computing the static error. This took the form of a potentiometer bridge network, incorporating an angle of attack characterization with one side driven by a log R_i shaft from the log R_i differential. The other side is driven by the static error corrector servo loop which also drives into a gear differential in the P_s servo loop gear train. The static error servo loop runs to cancel out the static error in the P_s loop by a rotation input from the differential between the P_{si} transducer and the P_s rebalance motor. The motor of the P_s loop, therefore, is never required to balance out static pressure error so it runs as log P_s. This, of course, is somewhat oversimplified as there is some error in this correction process and the dynamic consequences require very careful investigation by analog computer analysis.

The log P_T and log P_s motor gear trains are coupled to a third gear differential, the output of which is log R. The subscript i is left out indicating that this is a correct or true output. These three gear differentials with related gearing are the center of the computing function of the pressure data section. All other inputs and outputs are as arms of an octopus about this center mechanism. Each of these arms is a separate demountable module attached to the center structure of the pressure data mechanism. These modules, in turn, are broken down into sub-modules in some cases. The modules arranged around the differential center are:

Log P_T Motor-Gear
Log P_s Motor-Gear
Static Error Motor-Gear
Log R Output
Log P_s Output
Static Error Corrector
P_T Transducer
P_s Transducer

Each of the modules represents a dead end-gear train with each output having a very accurate relationship to some other output or standard. To overcome the consequences of backlash, the gear trains without torque inputs are provided with spring bias to keep them loaded in one direction back to the differentials. This is much simpler than double trains, split gears, etc,. and functions very well with no appreciable difference in rate in either direction.

The potentiometer stacks are one form of sub-module. A typical stack has an adapter base containing a bias spring and stop plate, mounted on a tubular shaft of appreciable diameter. All potentiometers on the stack are driven by and centered by this shaft as each potentiometer case contains a ball bearing to locate it. No other locating means is used and the clamp between cases is designed to concentrate the force axially. Wiper arms are clamped to the tubular shaft in each potentiometer case as stacked. A hair spring pickoff is used instead of a slip ring to reduce noise possibilities. The bobbins are impregnated hard coat aluminum, precision wound and potted in the cases concentric with the bearing bores. Terminals and leadwires are likewise potted in. Expansion coefficients of materials here are carefully matched. The top unit of the stack, fully accessible, is the adjustable cam.

The adjustable cam (See Figure 4) is driven by a coaxial input shaft coming up through the tubular potentiometer shaft. The lower end of this shaft carries the gear which meshes with the gear train. The other end inside the adjustable cam case carries an arm with an elbow and follower roller arm with gear sector. The sector engages a pinion on the end of the tubular potentiometer shaft. This mechanism serves primarily as a driver coupling between the coaxial shafts when no movement is allowed at the elbow pivot, as in the case when the follower roller follows a path concentric with the coaxial shafts. The path this roller can follow is a flexible band with the contour controlled by a number of screws set radially into the adjustable cam case. Since this path may be altered from concentric, the follower arm is caused to ride in and out relative to the coaxial shafts as they rotate and through the sector to pinion engagement add or subtract from their relative rotation. This mechanism is always loaded by the bias spring to eliminate backlash. All repeatable nonlinearities may be calibrated out of the output signals with this device. They are used only on those outputs where accuracy or characterization requirements make it necessary and on the transducers to correct for the log cam errors.

The corrector cam is capable of such characterizations as log P_s and h or feet altitude and serves both the computer and corrector function on that output. In the case of log R to Mach characterization and the anti-log function of log P_s to. P_s, as are often requied for certain outputs, a pair of tape cams of the correct contour to practical machine tolerances is made and produce the basic characterization as required for each function. The output potentiometer stacks, in turn, driven by this fixed cam mechanism have adjustable cams to calibrate out the mechanical tolerance errors of the fixed tape cams.

Another function of pressure data which must be provided is q_c or $P_T - P_s$. This function is usually used for scheduling many automatic flight control operations. A single signal of q_c is provided inasmuch as the many scheduling functions are more readily managed in their area of use. The air data computer with the mechanization described here uses a synchro generator geared to the P_T transducer force balance input to produce a signal proportional to P_T. This is fed into a differential synchro generator on the P_s output shaft. The resultant output of the differential is proportional to q_c and is supplied to automatic flight control for use in the airspeed compensator servo loop where a synchro control transformer serves as the error signal generator.

The computing means utilized in the pressure data section of the air data computer is essentially mechanical by gear differentials and cams. The true airspeed, density, temperature, and angle of attack (β, if required) functions are all electrical computers, using motor-driven electrical bridge networks to do the computeing. (See Figure 5). These outputs have less stringent requirements in terms of sensitivity and response. They can use electrical signals computed in the pressure data section to combine with the electric signals transduced in their respective sensors to best advantage in an electrical computation. The motors in these computing repeaters have sufficient power to drive not only the bridge network potentiometers but all required outputs for that function.

The temperature computer is a motor gear train driving a stack of potentiometers one of which is a part of an electrical bridge with the potentiometer in the temperature probe or sensor. The error output of this bridge network, when unbalanced, is fed into a transistor magnetic amplifier, and then to the motor. This motor gear train then runs as T_i or indicated temperature. The velocity generator integral with the motor furnishes an error rate damping signal which is summed with the error signal at the input to the amplifier. One potentiometer in the stack is rigged to produce the square root of temperature by typical techniques. The voltage output of this network is supplied to the true airspeed computer. Here a similar servo loop drives a potentiometer stack with one potentiometer as one side of a bridge network. On the other side is the product of the square root of temperature voltage and a function of Mach voltage from the pressure data section to balance the bridge. This servo runs as true air speed and drives all outputs of that function.

Density, angle of attack, and yaw are handled in the same manner. As each of these functions is separately powered and packaged, it adds considerably to the flexibility of the whole air data computer as any one of these plug-in functions may be replaced by one of a different characterization or omitted altogether without disturbing the balance of the computer.

Preservation of Accuracy, Sensitivity and Response

The principle motive behind most of the reasoning to this point in developing the design philosophy has been preservation of prime input quality. To meet the stringent requirements of sensitivity and response for acceptable automatic flight control, no deteriorations of transducer parameters such as takes place in series repeating is allowed in the system design. This is not entirely possible, as in the case of static error correction where one function must be computed in order to determine a second function but the order of dynamic performance losses must be limited for acceptable automatic flight control.

The most critical outputs for aircraft flight control are the altitude and air speed or Mach hold functions. These are composed of a displacement error signal and a rate of error signal which are summed and characterized in the automatic flight control calibrator and sent directly to the pitch axis servo loop. The displacement error output is geared directly to the prime transducer servo loop through a magnetic clutch and spring recentering mechanism. The rate signals are generated by the velocity generators of the prime transducer servo motors. No repeater loops are used for these functions.

In planning an air data computer, the power requirements to drive the numerous outputs as well as all the computing functions can have a major effect on the mechanization. An attempt should be made to balance the outputs across the necessary motors. Further, no mechanical computing load should be applied to the motors if it can be done equally well electrically.

The gear trains should be as friction-free as possible by use of ball bearings and liberal tooth clearance and polished finish on the gears. A free-running gear train is essential to smooth rate signals and low threshold. Optimizing the ratios near the motors for best torque-to-inertia qualities will help preserve transducer response.

The motor-amplifier design or selection requires considerable care to be sure it is capable of meeting the frequency response and power requirements. The signal-to-noise ratio of the integral velocity generator in combination with the load speed curve of the motor should be of the highest order of the art. The amplifier and transducer pickoff must be matched to operate efficiently together and with the motor-velocity generator.

In the force rebalance servos in the pressure data section, the logarithmic cams cause the loops to have a nonlinear gain. A consequence of this is a nonlinear requirement for error rate damping to stabilize the dynamic character of the loop without overdamping or limiting the response in any part of the range. The damping ratio is scheduled as a function of the range to optimize this. It is also possible to schedule the amplifier gain to counteract the loss of mechanical gain because of the log cams. These scheduling potentiometers are driven by the gear trains of the loop in which they schedule the gain.

Wear is one cause of deterioration of performance. Liberal dimension of the gears, shafts, bearings, potentiometer windings, and all wearing surfaces relative to load helps to slow this wear. Rough finish on running surfaces soon wear smooth with a resulting change in response characteristics, hang up of spring actuated mechanisms, noise in potentiometers and other undesirable effects. Polishing or superfinishing all wearing surfaces is required in these highly sensitive devices to ensure lasting performance to specification.

Flexibility of Functions

Modular construction is the chief contribution to a flexible design. All sub-modules which are mechanically driven have no extra couplings but are gear coupled by meshing them directly into the gear trains. Each potentiometer stack or synchro is a sub-module and may be easily detached from the gear plates, since they are all externally mounted.

The modules with all sub-modules mounted on them are also each separately detachable from the balance of the device. These modules in the pressure data section are all gear coupled to adjacent modules. All of these gear modules are mounted on one common backbone frame casting. The transducers and the related gearing are mounted as modules on opposite sides of one end of this backbone member. The three gear differentials are integral with and in the center of the backbone frame casting. The transducers and the related gearing are mounted as modules on opposite sides of one end of this backbone member. The three gear differentials are integral with and in the center of the backbone. The three motor gear modules and static error corrector module are mounted on either side of the differentials. The log R or Mach module and the log P_s or altitude module are mounted on opposite sides of the end of the backbone at the opposite end from the transducers. The latter two modules contain all the external output signal devices for pressure data and may be arranged in numerous combinations without any modification of the rest of the modules. This flexibility is afforded without impairing quality of the outputs by use of repeater servos. Further, reliability, complexity, and economy are improved as fewer parts of simpler construction are required. This may or may not effect the weight depending on how the design is carried out. Since the concept is basically simpler, it is lighter; however, the margin of weight saved under that required by the specification could be used to produce a more rugged serviceable unit.

The other computer sections of the air data computer such as density and true air speed are each independent modules electrically coupled to the rest of the system. These can be altered in internal arrangement of outputs or omitted entirely for different applications without effecting each other or the pressure data section.

Packaging

The philosophy of packaging this air data computer is flexibility of number and types of outputs in a single unit package. It is possible to extend this flexibility to permit inclusion of an arrangement where a remote converter or repeater unit was the intended useage of the computer outputs with exception of those for automatic flight control.

The pressure data section with all associated outputs is a complete independently housed system. When mounted on a chassis containing the necessary amplifiers, power supply and connectors , it is a complete flight control pressure data device performing all the functions of the former altitude, Mach, and q_c units. This pressure data section remains completely wired to its four connectors, even with the covers removed. Two connectors are arranged to be accessible on front of the chassis for external connection. The other two connectors are located for internal connections inside the chassis. When a complete air data computer is the requirement, a larger chassis is used and the individually-housed true air speed, density, temperature, and attitude modules are plugged in. All amplifiers are mounted on racks within the chassis along with other sealed components, such as transformers. The units are all interconnected by a wiring harness inside the chassis in the single chassis layouts. This packaging arrangement makes it possible to break up the whole computer into relatively small packages of pressure data, power chassis, true air speed, density, temperature, etc., when difficult space problems exist. However, each of these units would have to have a separate mounting rack, so there would be no economy in weight or cost as in a single-chassis layout.

Summary

Following this design philosophy has resulted in an air data computer with the following desirable characteristics:

A single pattern transducer for both pressures

Very low sense pressure displacement

Flight control outputs directly driven by prime transducer servo loops

Most efficient use of computer media commensurate with requirements

Outboard modular mounting of all output devices

Sufficient size and ruggedness for extreme life and reliability

Logical grouping of functions in packages for utmost flexibility of application

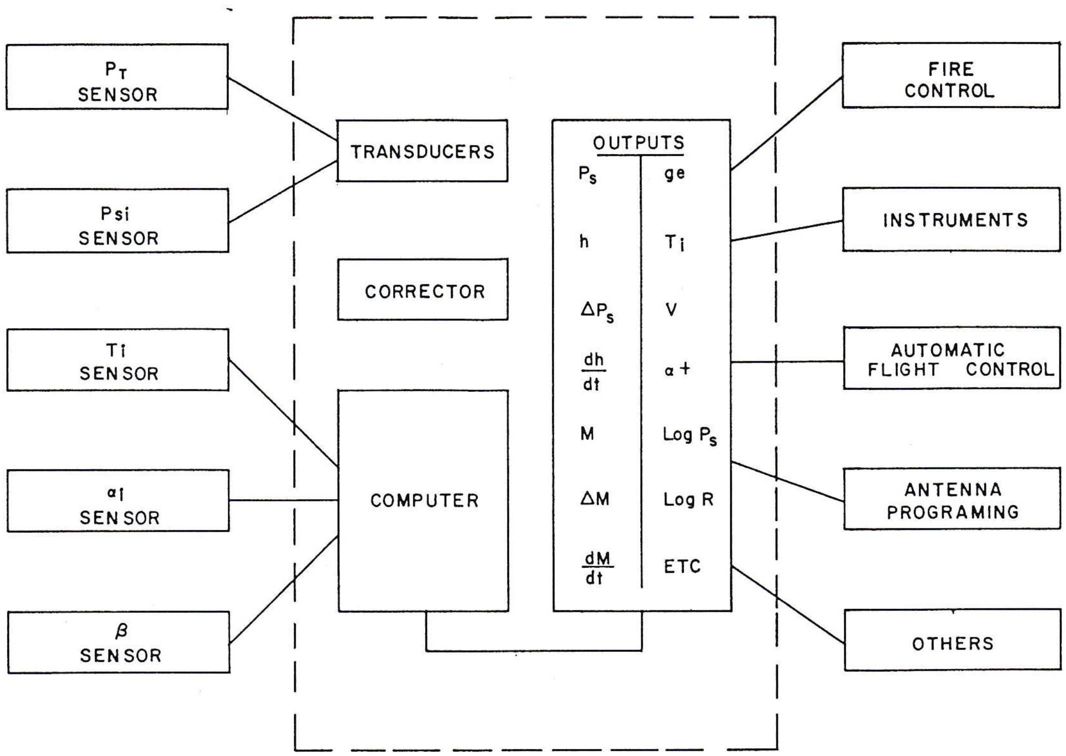


Figure 1. Block Diagram - Basic Air Data System

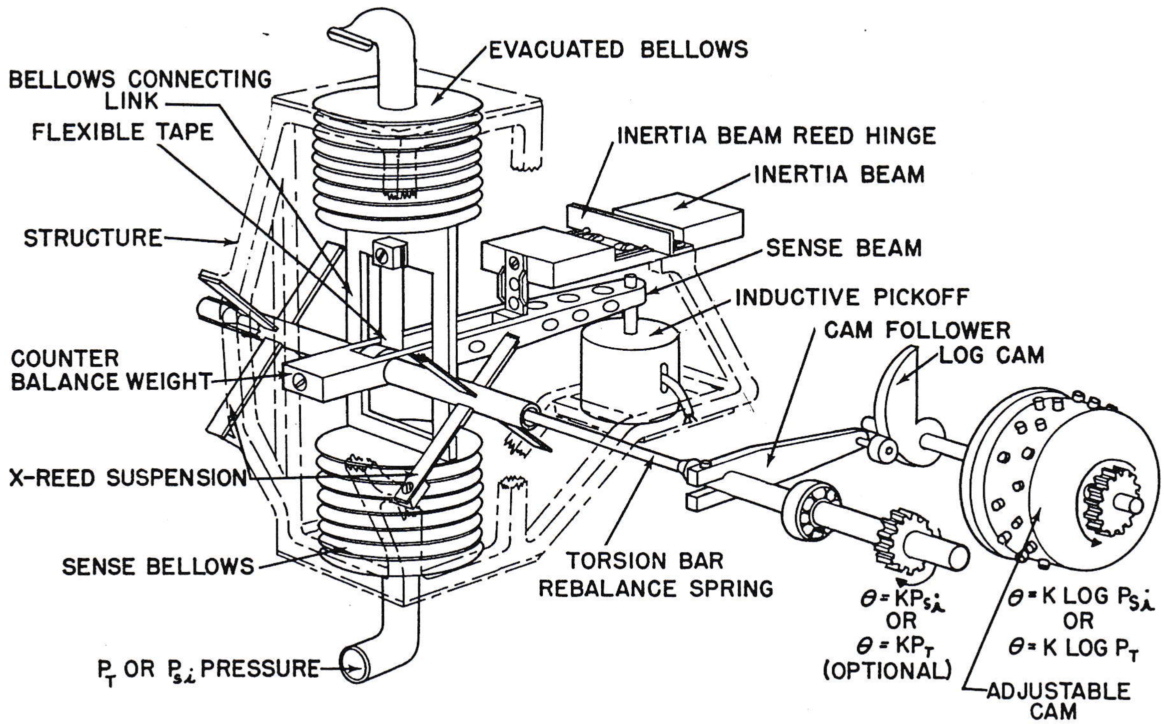


Figure 2. Transducer Schematic

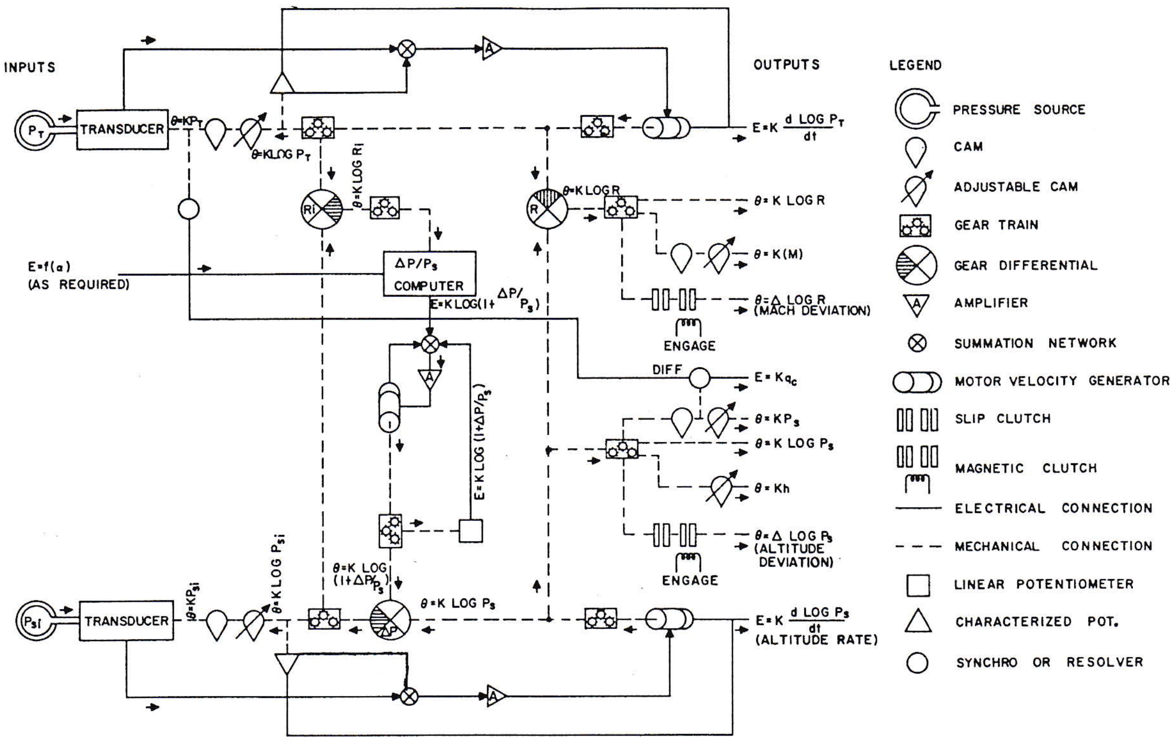


Figure 3. Detailed Schematic Diagram of Mechanical Computer Section (Pressure Data Section)

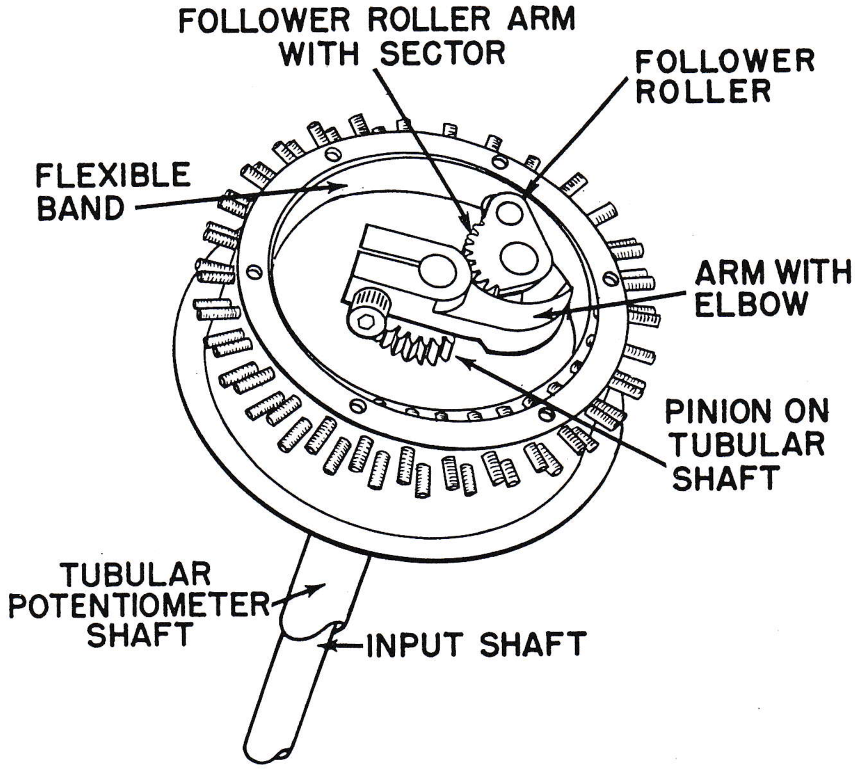


Figure 4. Adjustable Cam

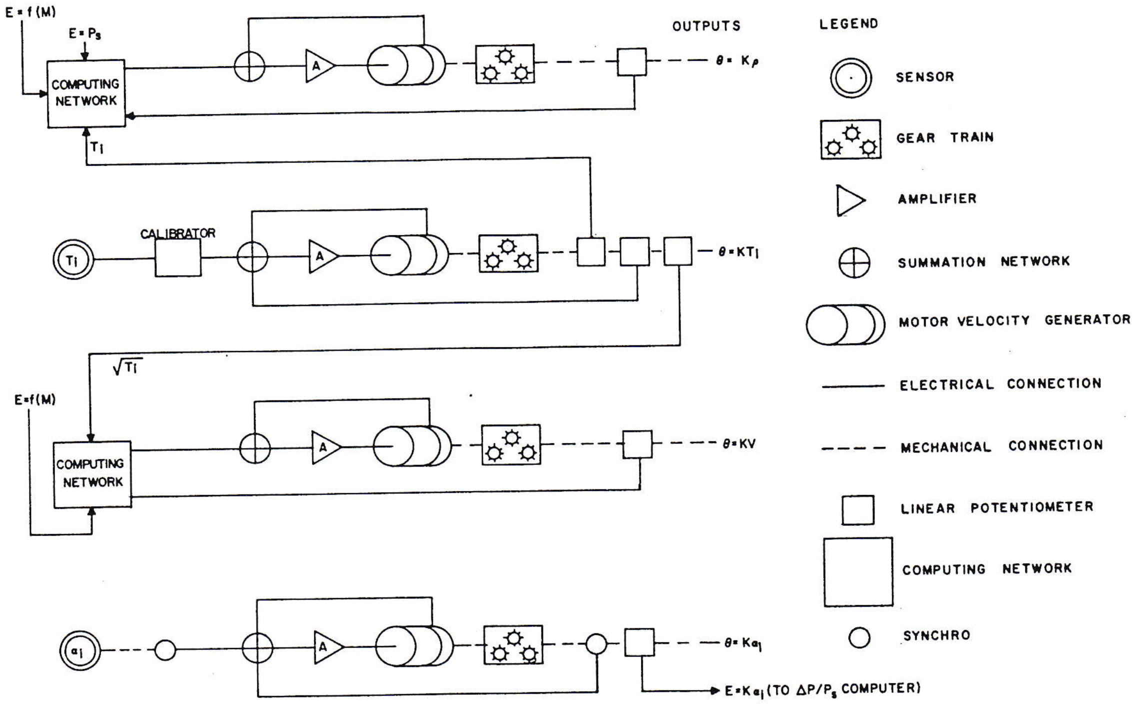
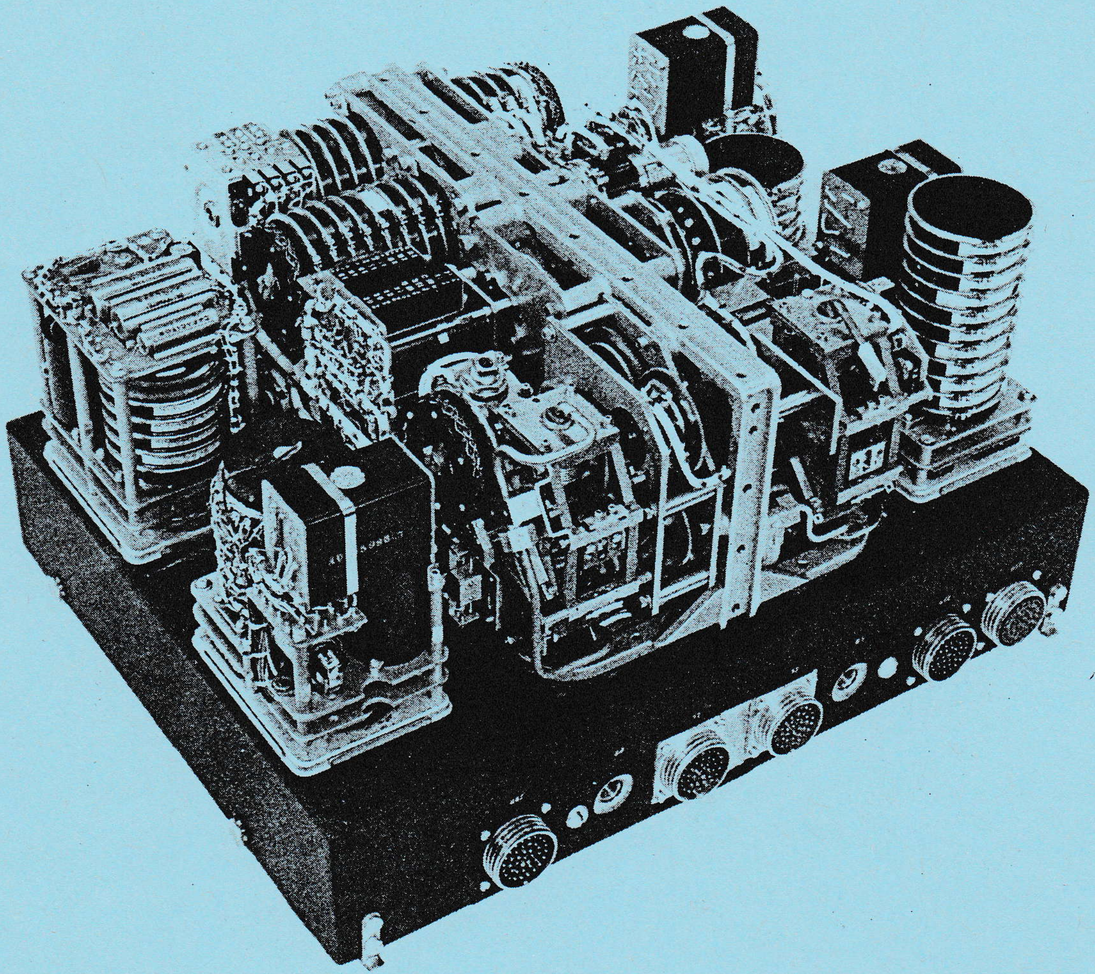
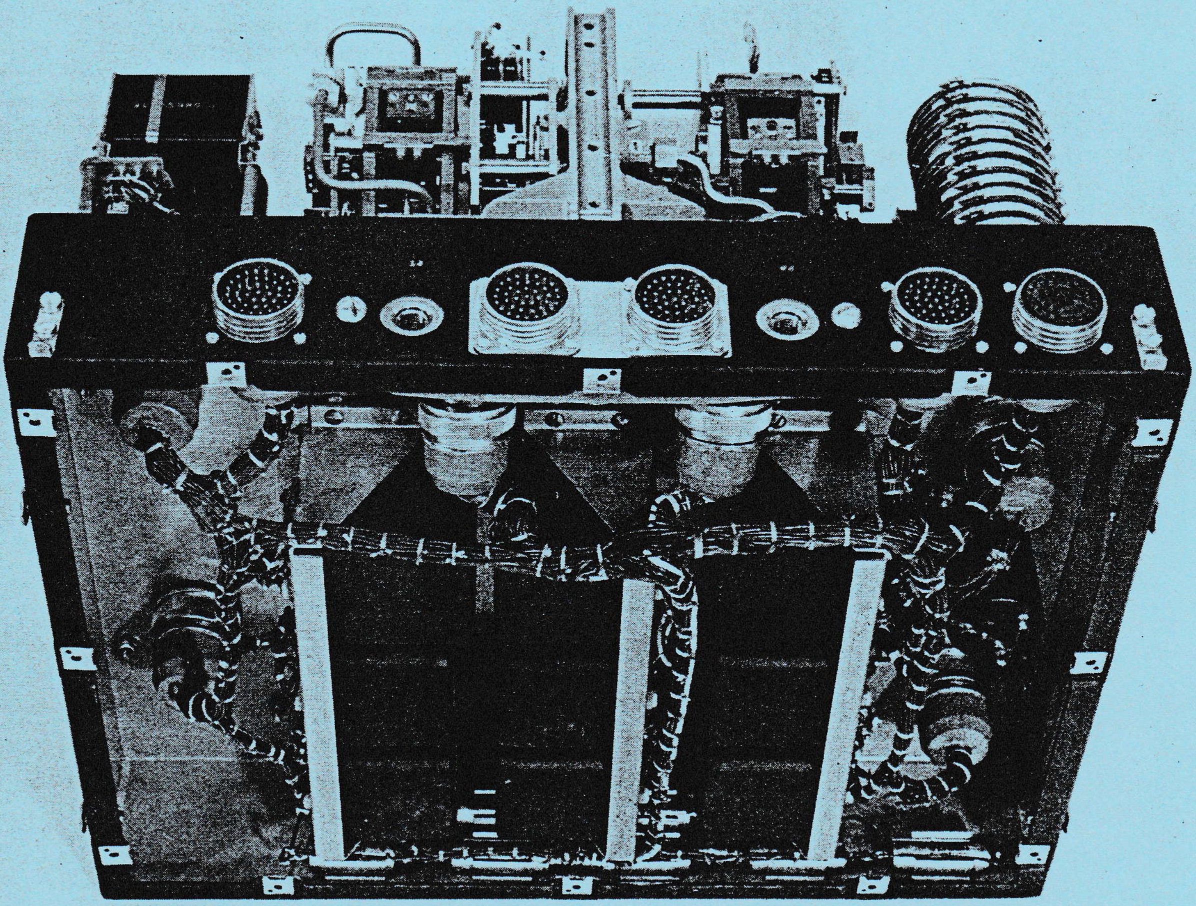


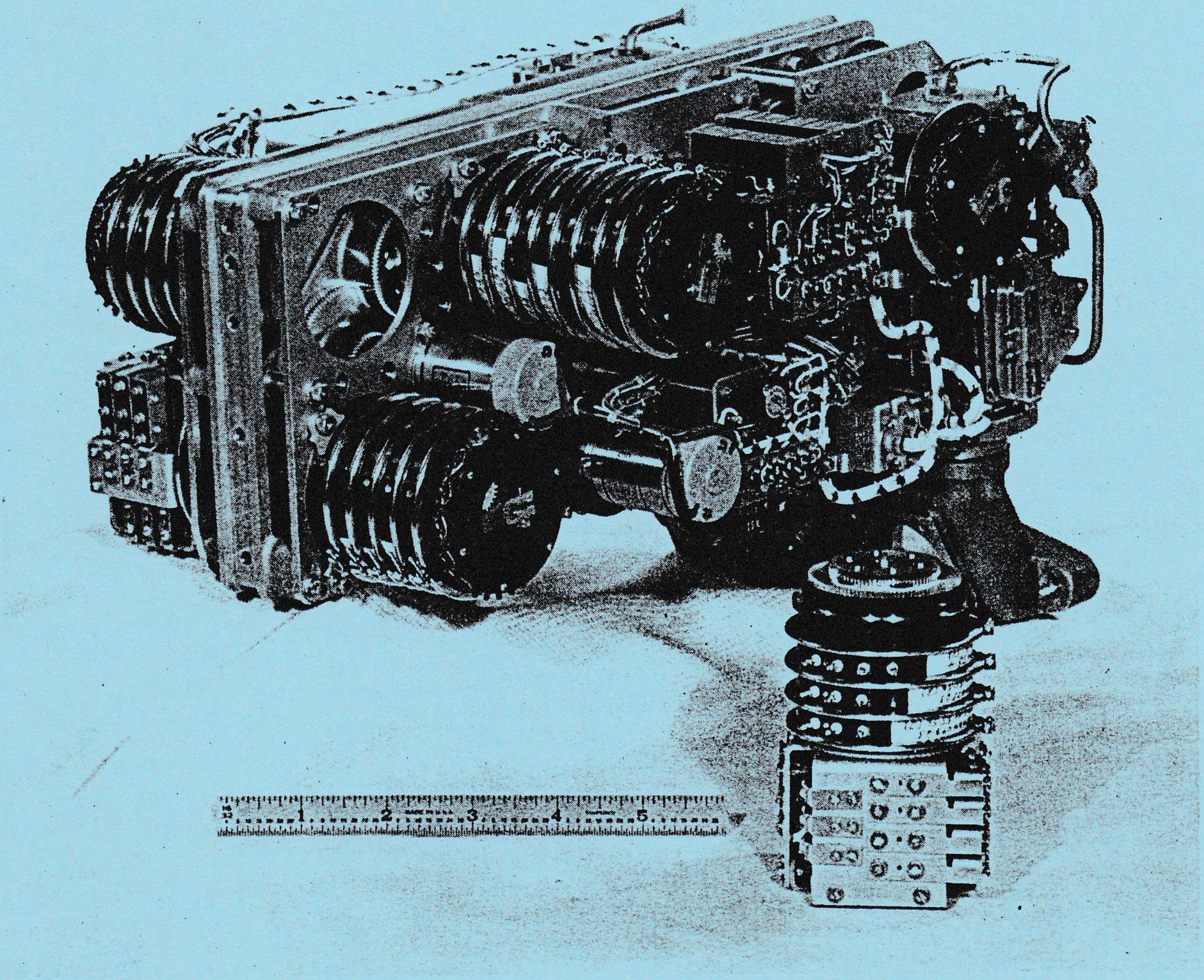
Figure 5. Detail Schematic Diagram of Electrical Computer Modules



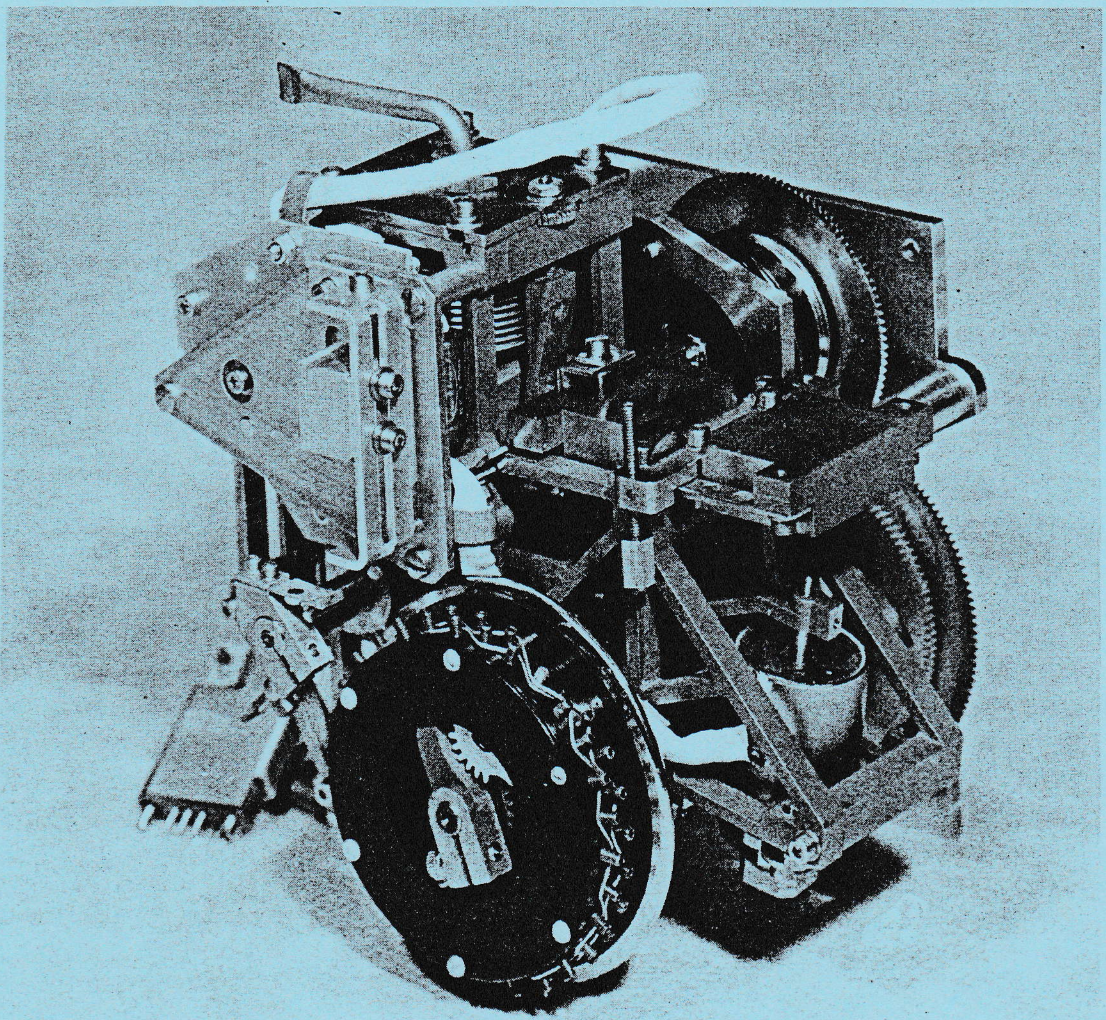
1. Top View of Complete Computer



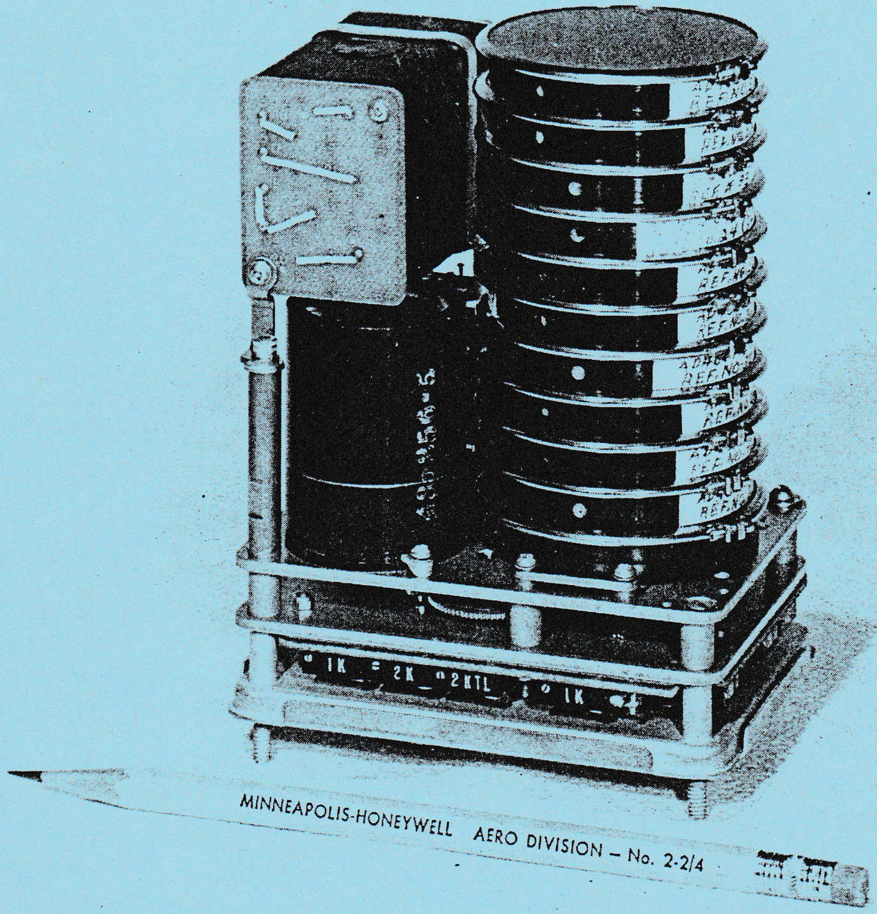
2. Bottom View of Complete Computer



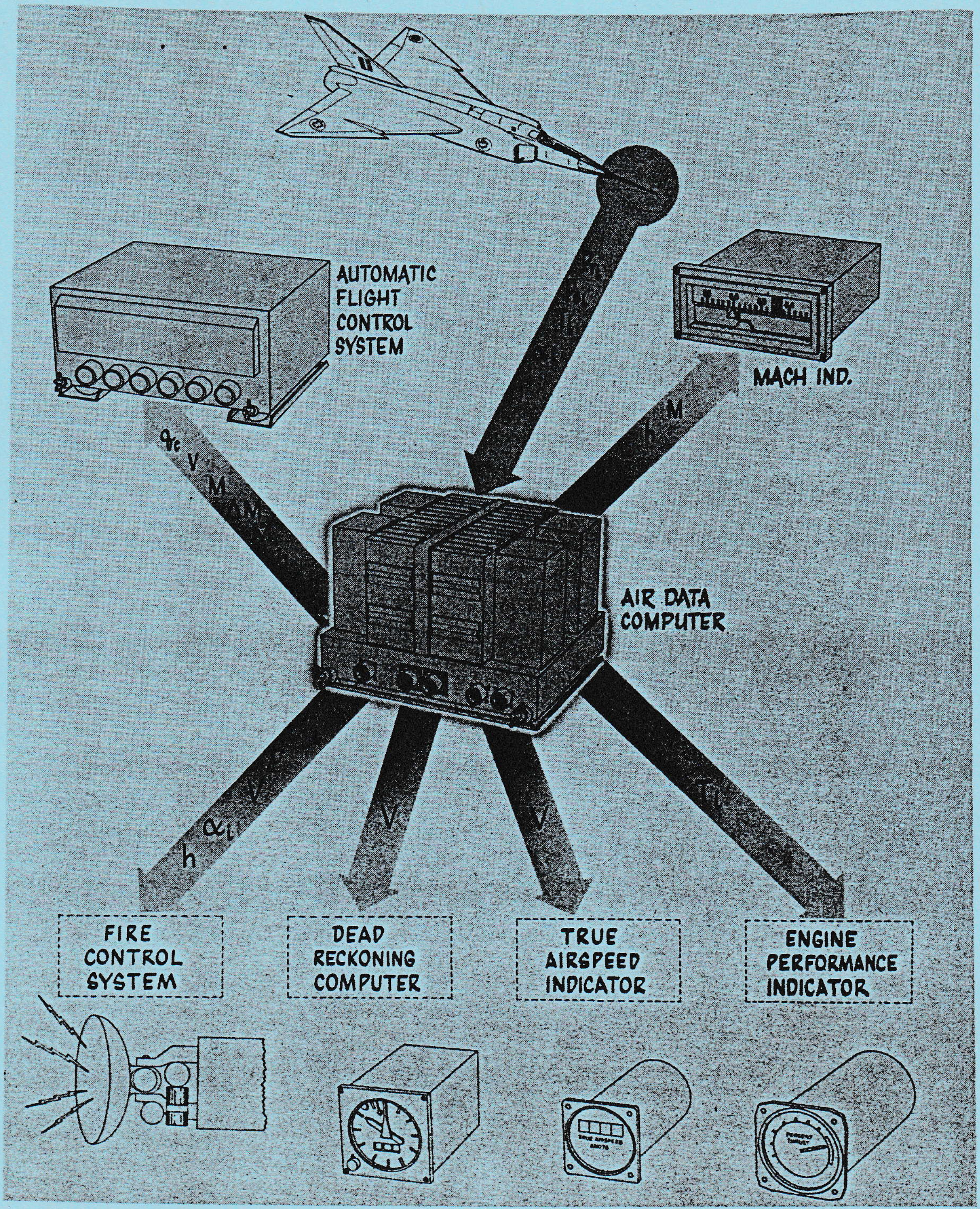
3. Pressure Data Subassembly, including Transducers and Computers



4. Transducer and Input Assembly



5. True Airspeed Computer



6. Schematic showing Computer and Tie-Ins

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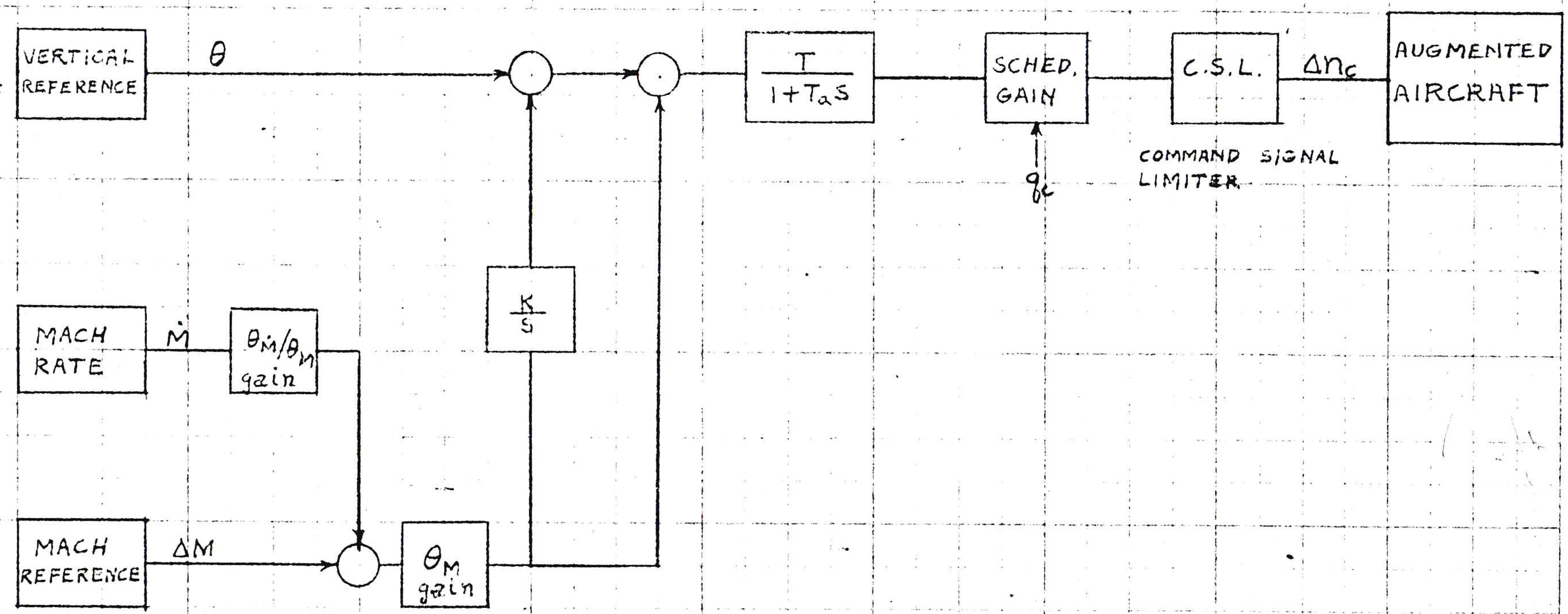
MACH HOLD BLOCK DIAGRAM



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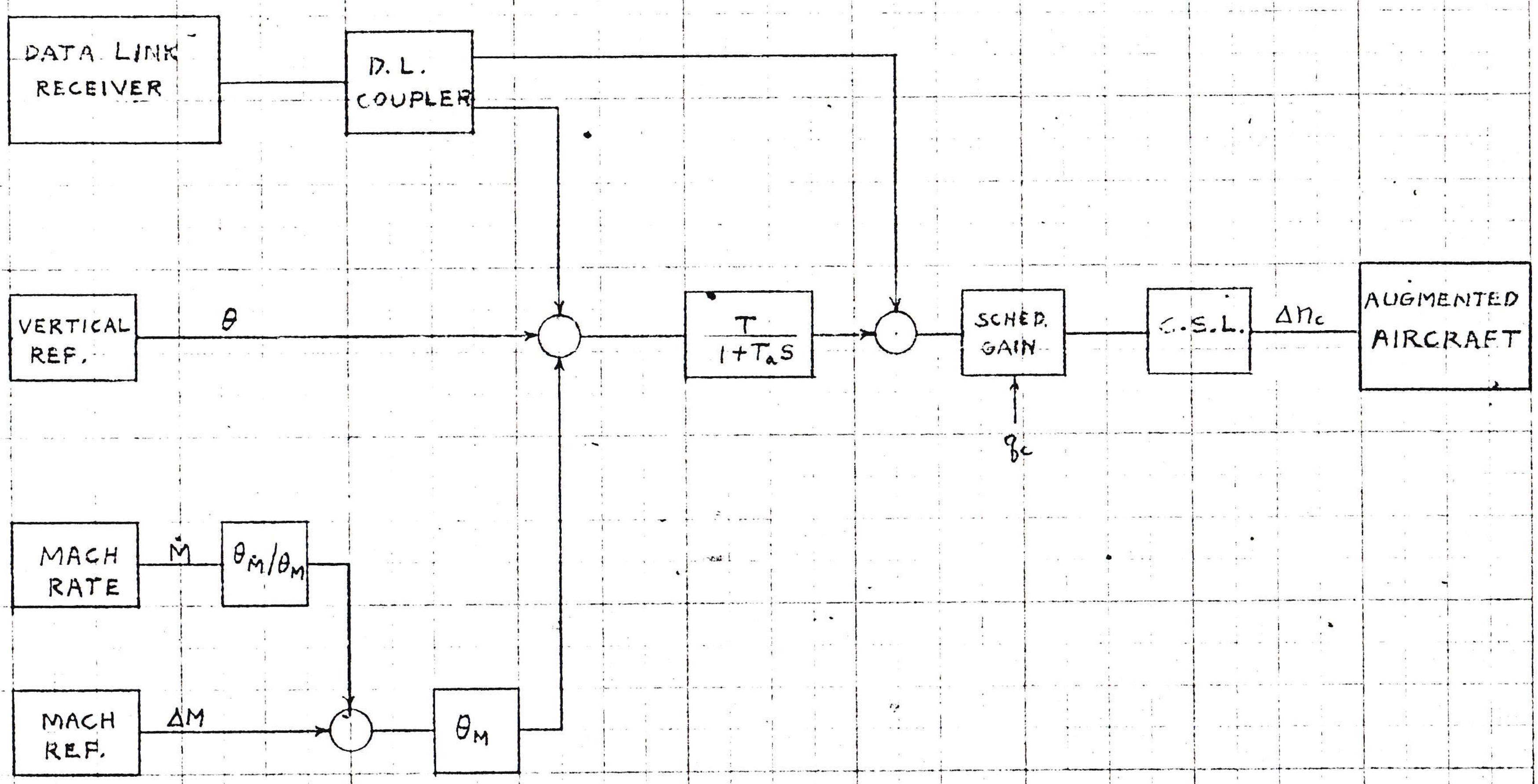
A.S.C.A. BLOCK DIAGRAM



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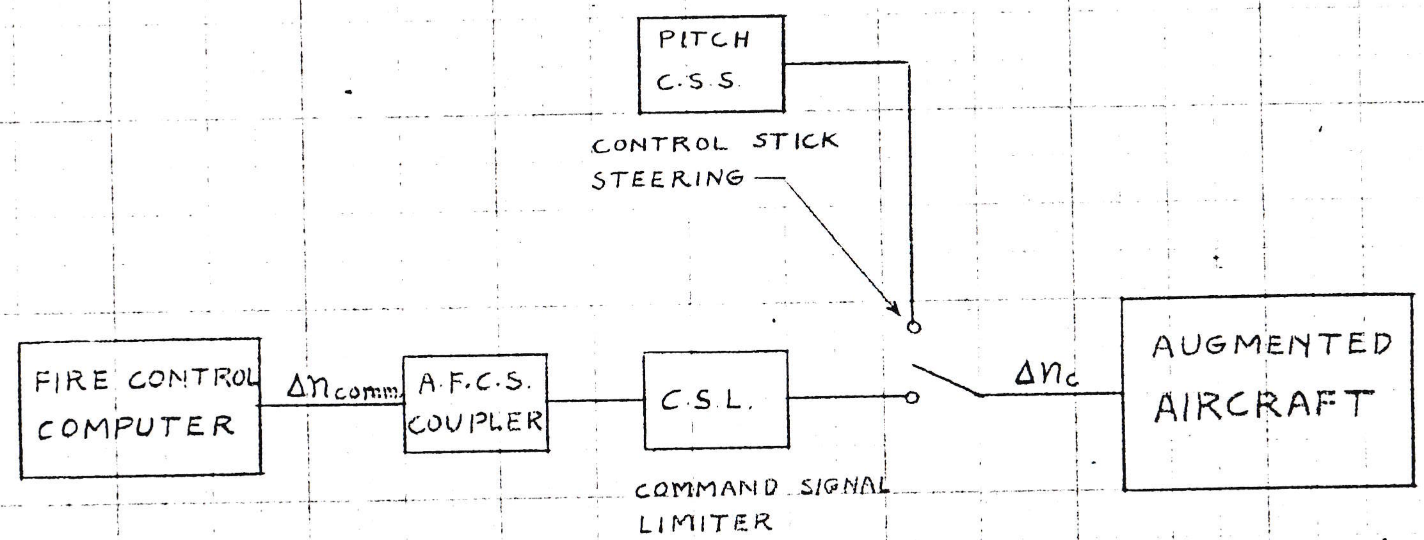
LONGITUDINAL A.F.C.S BLOCK DIAGRAM



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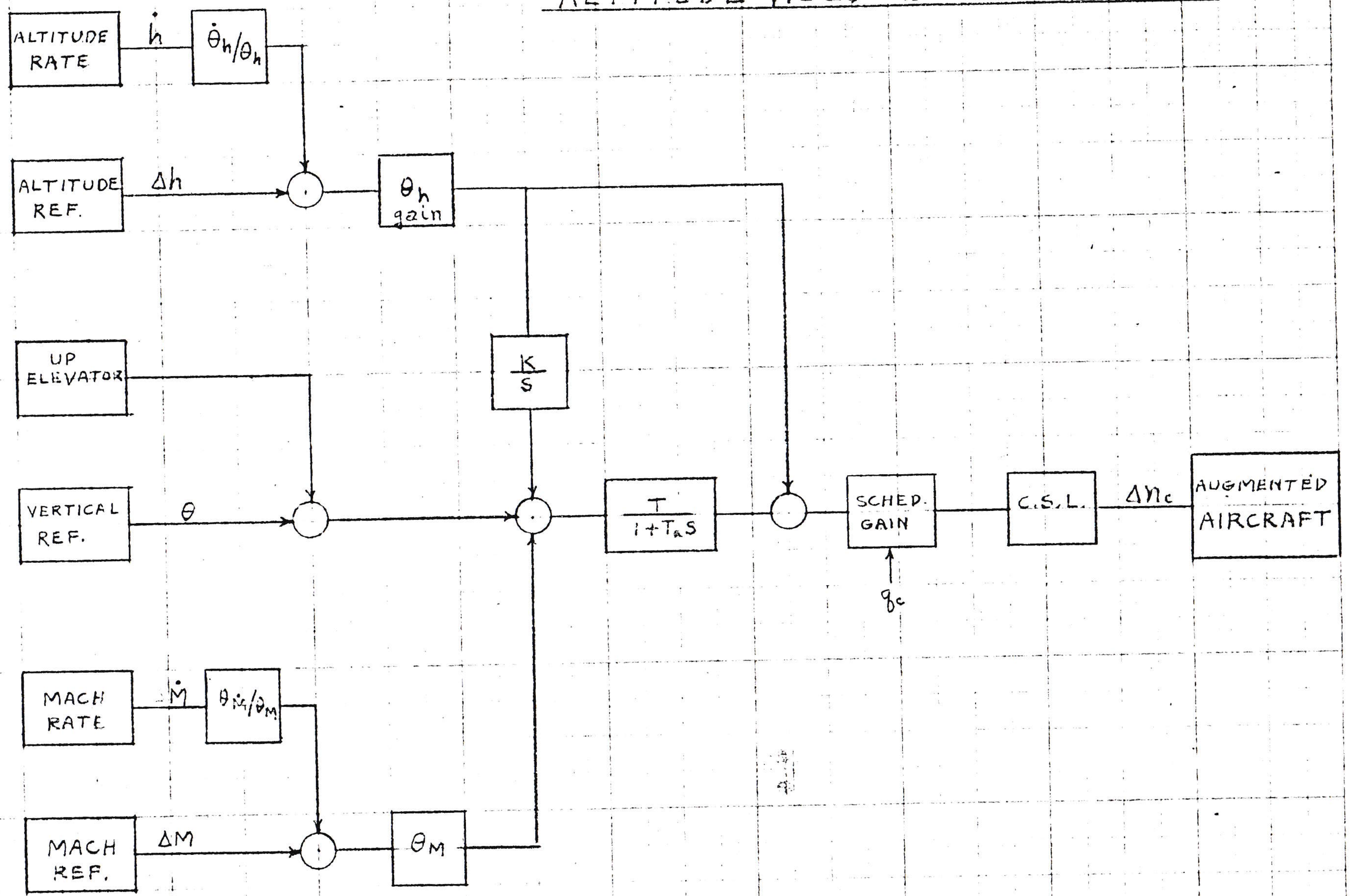
ALTITUDE HOLD BLOCK DIAGRAM



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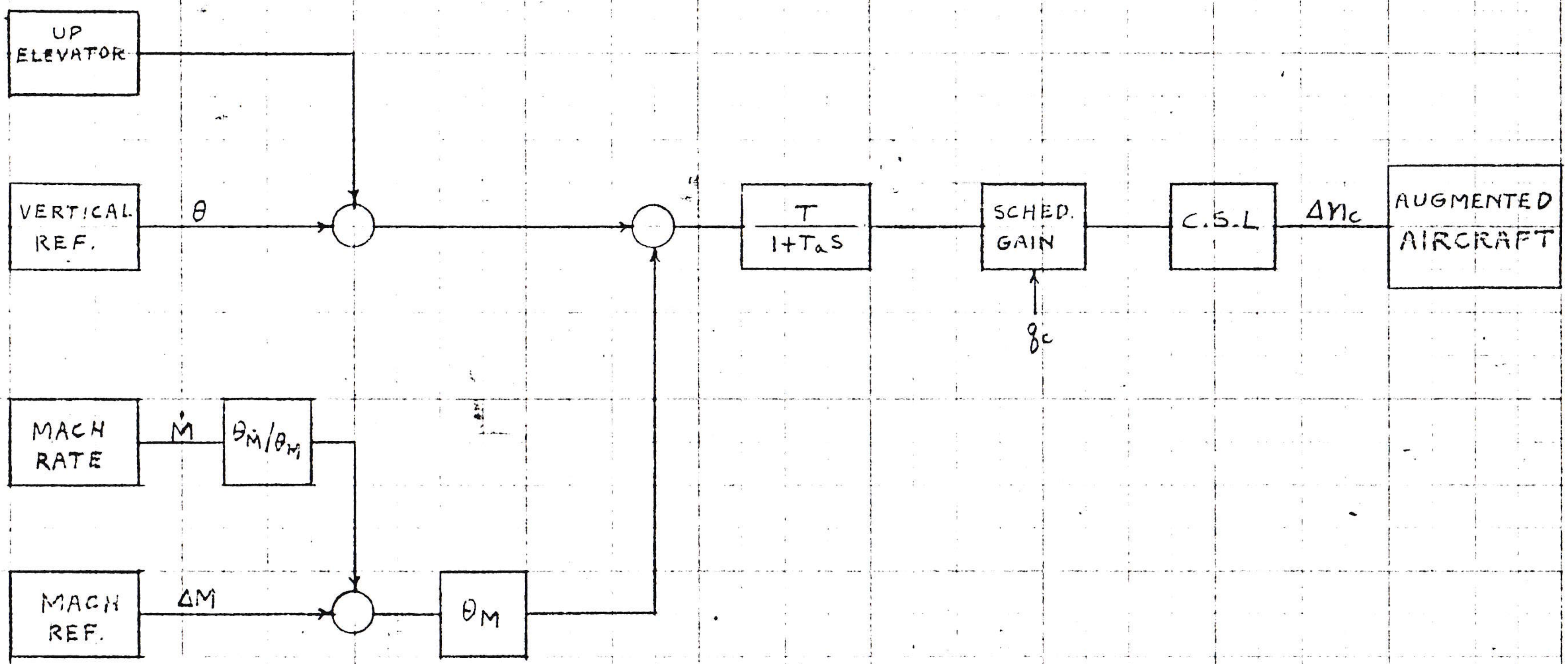
9/6/57

ATTITUDE HOLD BLOCK DIAGRAM



AIRCRAFT
A. L. W.

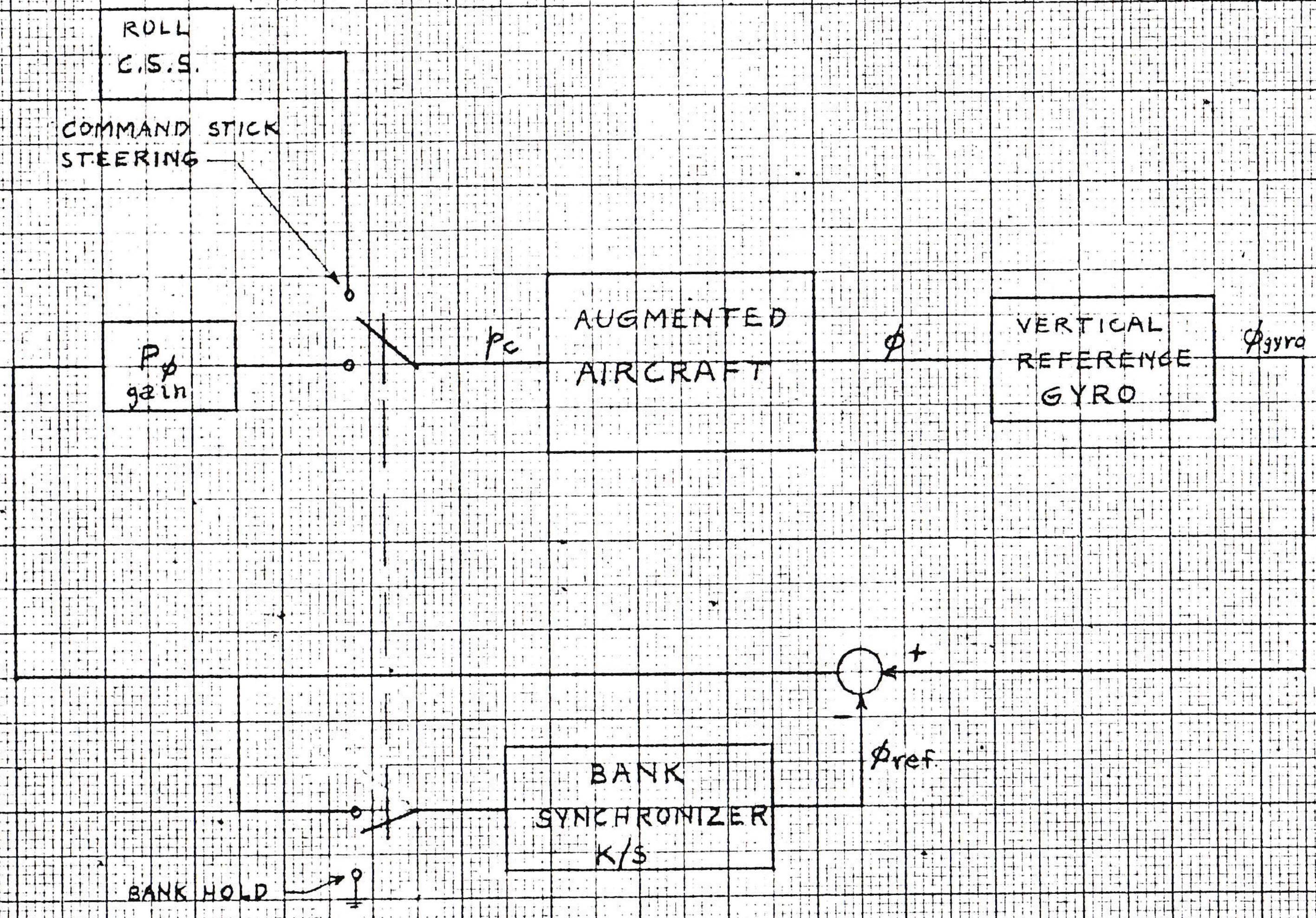
COMPONENT

SHEET NO. ______ REPORT NO. ______
DATE ______ PREP. BY ______

H. S. D.
9/6/57

BANK HOLD BLOCK DIAGRAM

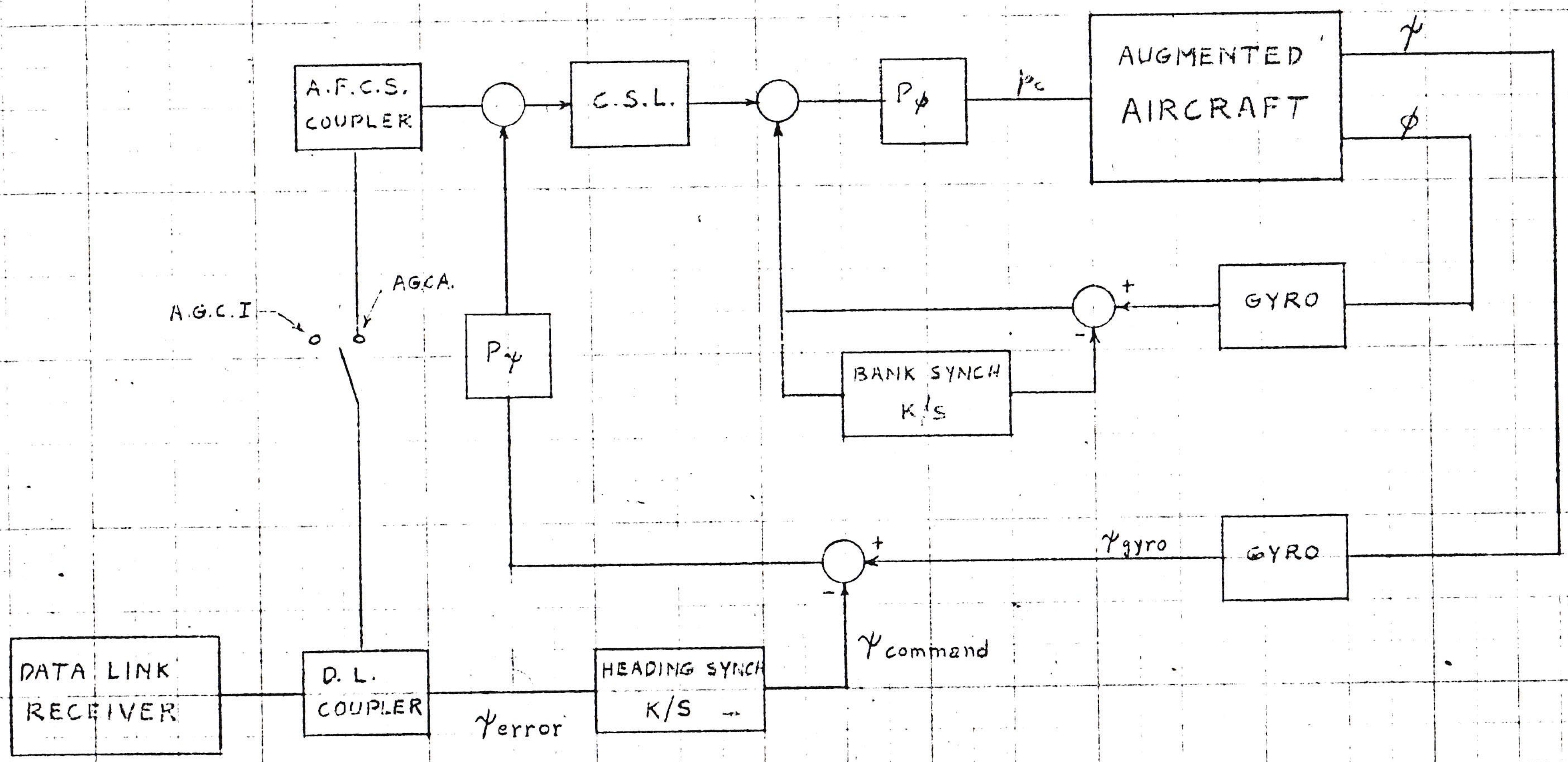
$|\phi| < 76°$



H.S.D
9/6/57

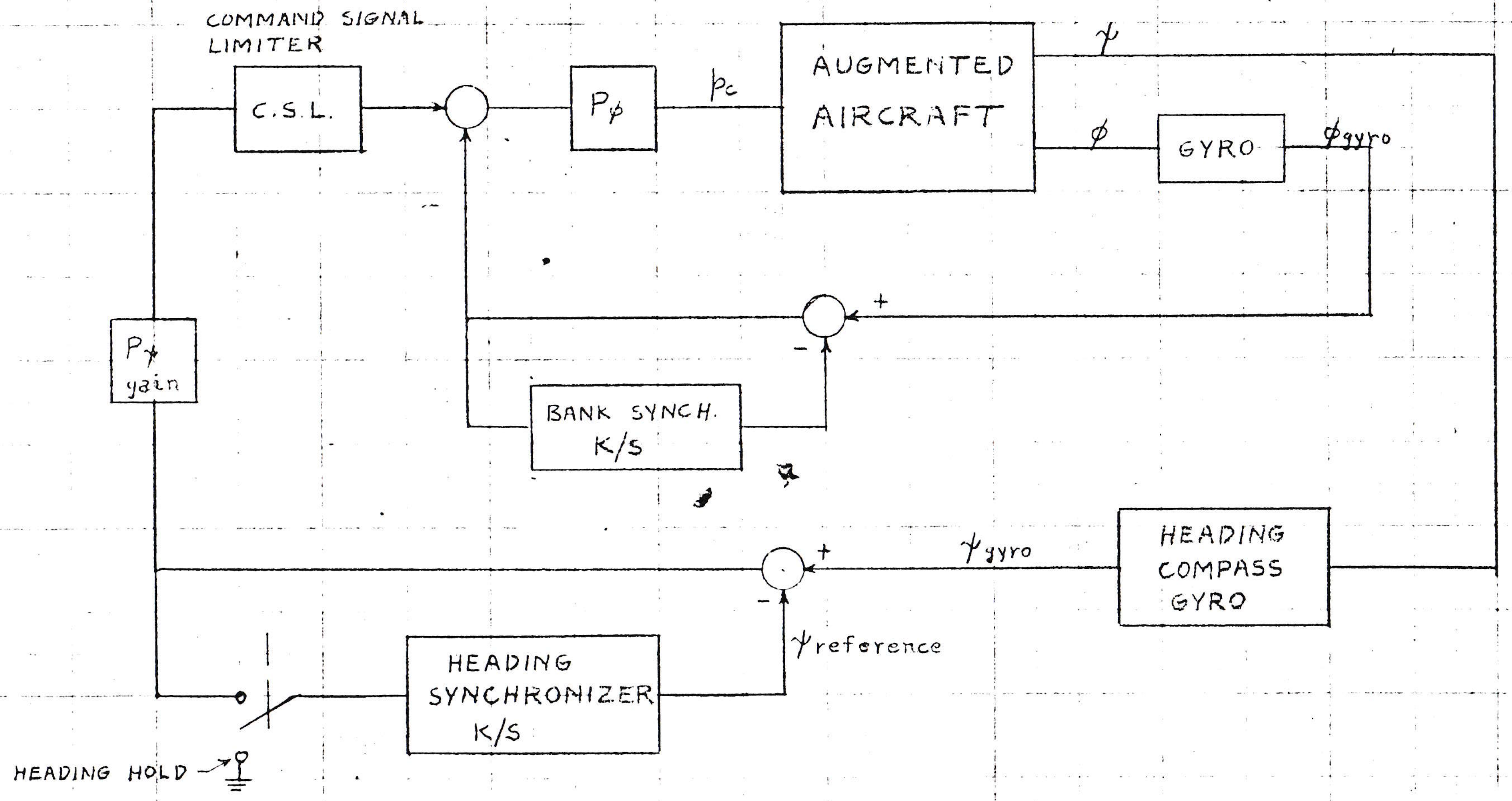
A.G.C.A. & A.G.C.I BLOCK DIAGRAM

AUTOMATIC GROUND CONTROL



H.S.D
9/6/57

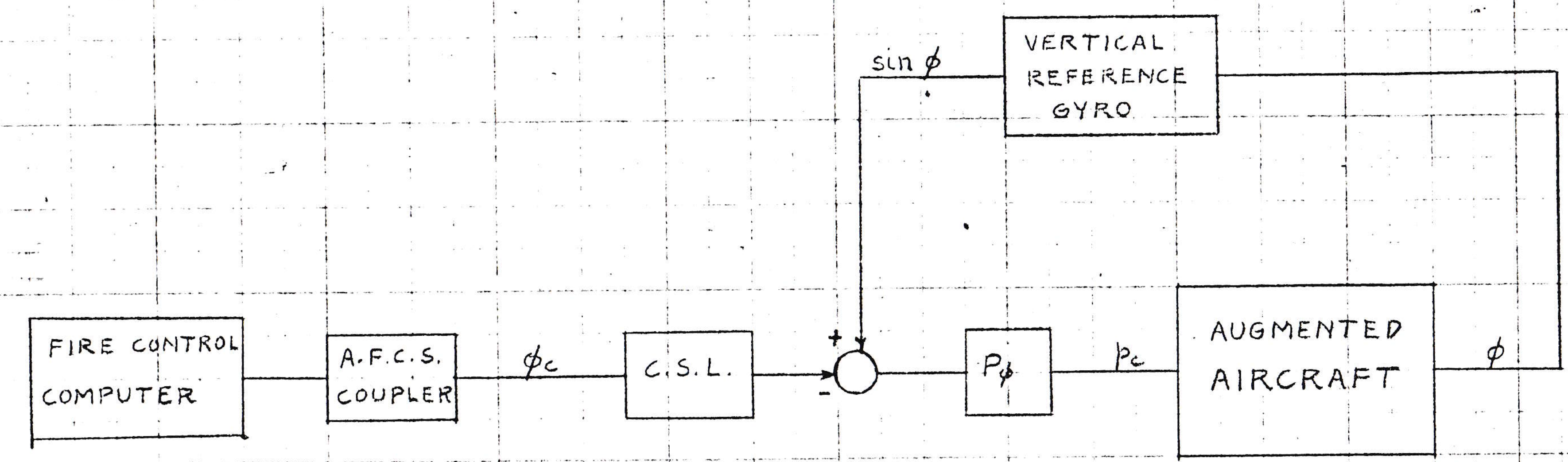
HEADING HOLD BLOCK DIAGRAM



H.S.D.
9/6/57

LATERAL A.F.C.S. BLOCK DIAGRAM

AUTOMATIC FIRE CONTROL SYSTEM



AFCS Amplifier Calibrator

L. Jones (5)

Signal to be Recorded	Dynamic Range: Voltage (volts)	Dynamic Range: Frequency (cps)	Isolation Required	Minimum Recorder Input Impedance (ohms)	Signal may be recorded: From	Signal may be recorded: To
AFCS Pitch Command to Damper	5	400	yes	50K	FTB2-7	FTB2-6
AFCS Roll Command to Damper						
(a) gear-up	1	400	no	50K	FTB3-1	Grd.
(b) gear-down	2	400	no	50K	FTB3-3	Grd.
Mach Displacement	10	400	yes	50K	FTB1-5	FTB1-6
Altitude Displacement	18	400	yes	50K	FTB1-1	FTB1-2
Mach Rate	8	400	no	50K	FTB4-3	Grd.
Altitude Rate	8	400	no	50K	FTB1-3	Grd.
Lagged pitch attitude output.	12	400	yes	50K	FTB2-9	FTB2-8
Heading Deviation	10	400	yes	150K	FTB3-4	FTB3-5
Up Elevator	1	400	yes	50K	FTB4-10	FTB4-5
1-cos E	1	400	no	50K	FTB2-6	grd.
Command Signal Limiter Input	12	400	no	C.F.	FTB2-5	Grd.
Command Signal Limiter						
(a) positive level	10	400	no	C.F.	FTB4-7	Grd.
(b) negative level	2	400	no	C.F.	FTB1-4	Grd.
[illegible] Angle Limit	0-28	dc	no	50K	FTB4-2	Grd.
[illegible] Angle Limiter Output	7	400	yes	150K	FTB2-10	FTB4-5
Stick Force Switch	0-28	dc	no	50K	FTB4-9	Grd.
Pitch Step	7	400	yes	50K	FTB2-5	FTB4-10
Dynamic Pressure, q'_c (from DG33)	0-28	dc	no	50K	FTB4-8	Grd.
Pitch Deviation	7	400	yes	50K	FTB1-7	FTB1-8
Roll Deviation	2	400	no	C.F.	FTB2-10	Grd.
Pitch Rate	4	400	no	50K	8028TB2-1	Grd.
Roll Rate	4	400	yes	50K	8028TB4-2	8028TB4-1
Yaw Rate	4	400	no	50K	8028TB3-7	Grd.
Lateral Accelerometer (normal damper)	5	400	yes	50K	8028TB3-4	8028TB3-3
Normal Accelerometer	5	400	yes	50K	8028TB2-2	8028TB2-3
Control Stick Steering Force. (a) Pitch	5	400	yes	50K	8028TB2-4	8028TB2-5
(b) Roll	6	400	yes	50K	8028TB4-4	8028TB4-3
Aileron Position	6	400	yes	50K	8028TB3-6	8028TB3-5
Roll Parallel Servo Feedback.	9	400	yes	50K	8028TB5-7	8028TB5-8
Roll Differential Servo Feedback, (a) right	2	400	yes	50K	8028TB5-6	8028TB5-4
(b) left	2	400	yes	50K	8028TB5-3	8028TB5-4
Pitch Differential Servo Feedback, (a) right	2	400	yes	50K	8028TB6-4	8028TB6-2
(b) left	2	400	yes	50K	8028TB6-1	8028TB6-2
[illegible] Parallel Servo Feedback.	9	400	yes	50K	8028TB6-5	8028TB6-6
Yaw Differential Servo Feedback (normal Damper)	3	400	yes	50K	8028TB5-1	8028TB5-2
AFCS Engage	0-28	dc	no	50K	R-2TB23-3	Grd.

January 21, 1958

L. Jones (5)

WIRE FUNCTION TABLE

(Refer to SK66004, Cabling required for recording MH-64 Damper signals during MH-65 flight testing).

CONNECTOR 8001P1

Pin	Function
$\bar{d}$	Pitch Rate
$\bar{s}$	Roll Rate
$\bar{f}$	Roll Rate
$\bar{n}$	Roll CSS Force
$\bar{p}$	Roll CSS Force
F	Lateral Accelerometer (Normal Damper)
G	Aileron Position
H	Aileron Position
J	Yaw Rate
P	Pitch CSS Force
R	Pitch CSS Force
S	Normal Accelerometer
T	Normal Accelerometer

CONNECTOR 8001P3

B	Roll Parallel Servo Feedback

CONNECTOR 8001P5

B	Roll Differential Servo Feedback, Right

CONNECTOR 8001P6

Z	Pitch Rate

CONNECTOR 8001P7

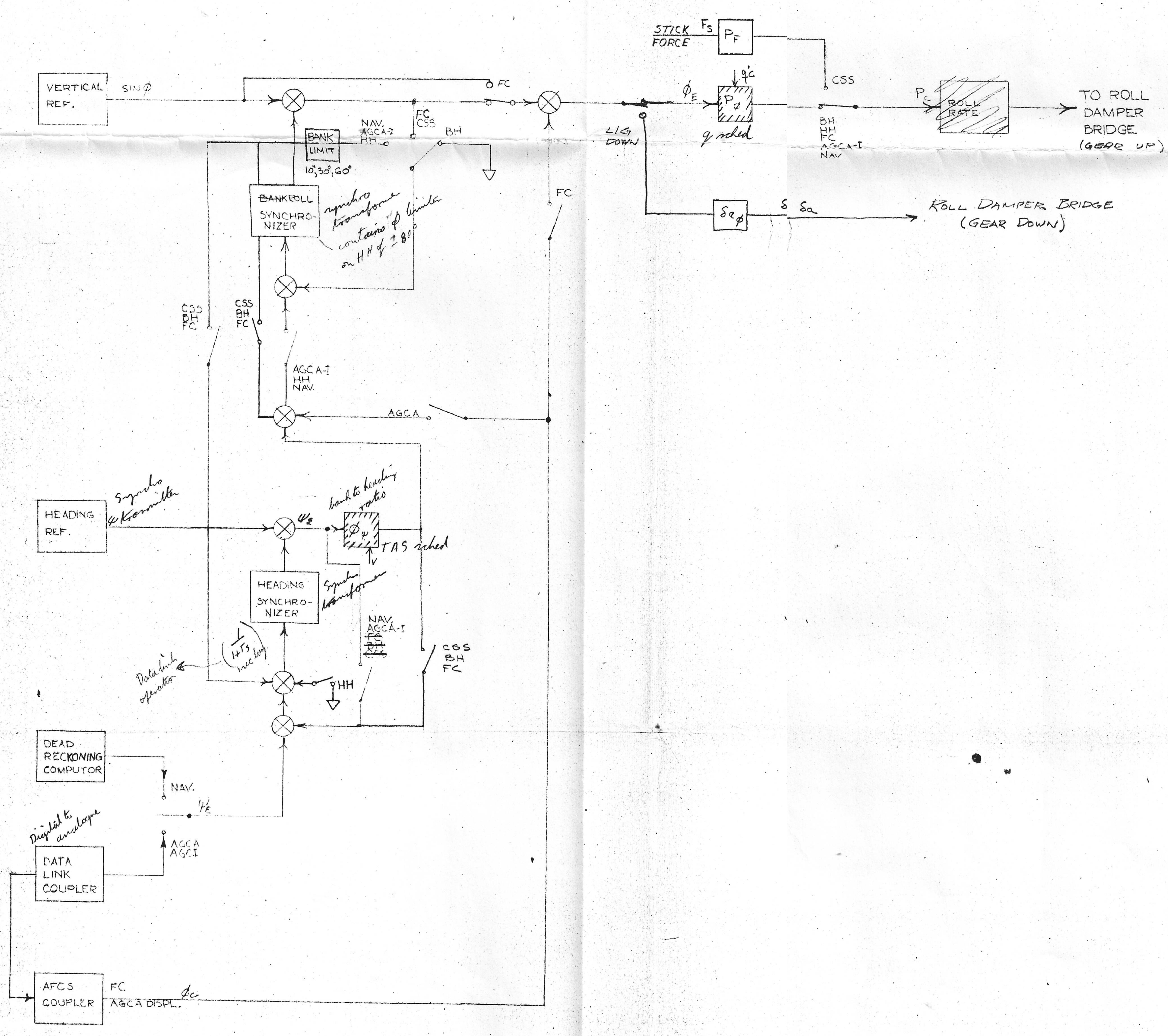
B	Pitch Differential Servo Feedback, left
R	Pitch Parallel Servo Feedback
$\bar{m}$	Yaw Differential Servo Feedback (Normal Damper)

WIRE FUNCTION TABLE (CONT.)

CONNECTOR 8001P11 *

Pin	Function
A	Roll Differential Servo Feedback, left
B	Roll Differential Servo Feedback, right
C	Roll Parallel Servo Feedback
D	Pitch Differential Servo Feedback,left
E	Pitch Differential Servo Feedback, right
F	Pitch Parallel Servo Feedback
G	Yaw Differential Servo Feedback (Normal Damper)
H	Lateral Accelerometer (Normal Damper)

*This connector will be added to the MH-64 Damper Amp-Cal during MH-65 Flight Test and will be specified later.



ϕ limits by voltage divider after Bank synchronizer.

AGCI	60°
AGCA	30°
on glide	10°

bank angle ϕ

BH = BANK HOLD $7\frac{1}{2}°$ & $76°$ $\phi < 7.5 \rightarrow HH$
HH = HEADING HOLD $\phi < 7.5$
CSS = CONTROL STICK STEERING
FC = FIRE CONTROL
AGCA = AUTOMATIC GROUND CONTROLLED APPROACH
AGCI = " " " INTERCEPT
NAV = NAVIGATION

LABELLING ON SWITCHES INDICATES MODES IN WHICH THE SWITCHES ARE CLOSED

▨ SCHED GAINS.

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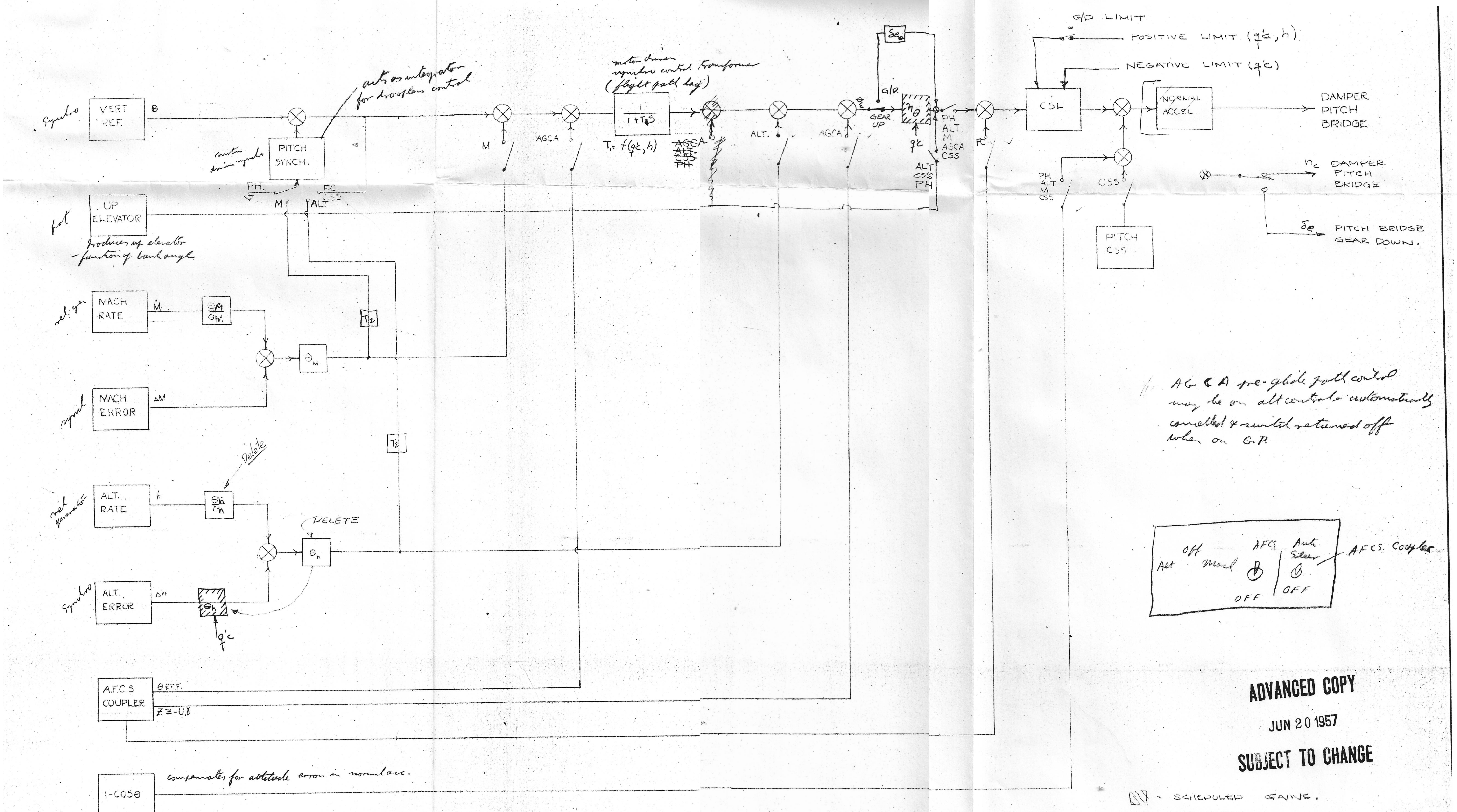
JUN 20 1957

SUBJECT TO CHANGE



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SUBJECT TO CHANGE

▨ = SCHEDULED GAINS.

F.C. = FIRE CONTROL
P.H. = PITCH HOLD ±60°
C.S.S. = CONTROL STICK STEERING
ALT. = ALTITUDE HOLD
M = MACH HOLD
AGCA = AUTOMATIC GROUND CONTROL APPROACH (GLIDE SLOPE)

LABELLING ON SWITCHES INDICATES MODES IN WHICH THE SWITCHES ARE CLOSED