[redacted]

Declass Review by NGA.

18 December 1963
P63-171-1

STAT

[redacted]
Washington, D. C.

STAT

Subject: [redacted] Proposal P63-171

Gentlemen:

In response to your request made during the recent visit by
[redacted] STAT
is pleased to present a revised proposal for the Vertical Reference
Unit and Photo Recorder.

Type of Contract: Cost plus fixed fee
Validity period: 90 days

F. O. B. Final Inspection and Acceptance Point: [redacted] STAT
Delivery: Prototype System 9-12 months STAT
each additional system - bi-monthly thereafter

Item	Quantity	Description	
1	1	Design Fabricate Prototype Vertical Reference Unit & Photo Recorder	[redacted]
2	2	Additional Units Item 1	
3	4	Additional Units Item 1	
4	9	Additional Units Item 1	
5	-	Qualification Test to MIL-E-5272	
6	1	Altitude Variation Syster	
7	2	Additional Units Item 6	
8	4	Additional Units Item 6	
9	9	Additional Units Item 6	

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[redacted]

- continued -

[redacted]

18 December 1963
P63-171

If further information is desired please do not hesitate to contact the undersigned.

Very truly yours,

RAZ:ja

Approved For Release 2005/07/13 : CIA-RDP78B04770A002900040009-9

TECHNICAL PROPOSAL
FOR A
RECORDING VERTICAL
REFERENCE SYSTEM

P-63-171

AMENDMENT I

PREPARED BY:

STAT

Approved For Release 2005/07/13 : CIA-RDP78B04770A002900040009-9

TABLE OF CONTENTS

List of Illustrations

I. INTRODUCTION

The recording vertical reference system, as proposed herein, is intended for use in a high performance airborne vehicle equipped with a complement of photographic cameras.

With the cameras fixed to the aircraft it will be necessary, in order to properly interpret and reduce the photographic data, to have an accurate recording of aircraft attitude at the time of exposure.

The proposed system is comprised of an improved vertical reference unit and a data recording system as an integral part thereof. The configuration of the vertical reference unit is such that the effects of disturbing torques about all three reference axis is minimized thereby allowing a choice of more reliable shaft position transducers for data recording.

The complete system concept is also based upon the minimization of weight and with the utilization of proven components throughout, thereby insuring high reliability in performance.

Also included is a proposal for an Altitude Variation System, the output of which is a digitized form of the change in altitude of the vehicle.

Approved For Release 2005/07/13 : CIA-RDP78B04770A002900040009-9

II. GENERAL SYSTEM CONSIDERATIONS

A) Vertical Reference Unit

The requirement for a recording vertical reference unit presents slightly different design criteria than that associated with conventional camera stabilization systems. Its function in a high performance reconnaissance aircraft is to provide accurate and smoothed attitude data in order to permit corrections to photographs taken from fixed cameras. The problem of short term steadiness for the duration of exposure now becomes one of long term steadiness or smooth tracking of aircraft motions.

This performance requirement is best met by a platform having inherent gyroscopic stability rather than only the inertial stability usually supplied by the camera, since the inertial stability of such a reference unit is small compared to a camera mount. Such a platform will provide the long term stability and will also be capable of driving suitable angular position transducers which can be read out by the remote data recording system.

In addition since the vehicle is highly maneuverable provision should be made for large angular freedom so that the vertical reference is not disturbed thus requiring extra time for erection after turns.

B) Data Recording System

The function of the data recording system is to monitor and record the vehicle's attitude in roll, pitch, azimuth, absolute time, and altitude - all at the instant of the exposure command to the main reconnaissance camera. The acquired data is subsequently ground processed for visual and/or computer readout for photo reduction and interpretation.

Mission requirements for the acquisition of a large number of photographs dictates that, in order to minimize weight, data is to be recorded only on command, in lieu of continuous recording, and that the system be completely automatic thereby emphasizing highest degree of reliability.

The choice of the proposed data recording system is based upon the following considerations:

1) Shaft position encoders-A 13 digit absolute type, gray code (cyclic binary) encoder is chosen from the many types available. Although incremental encoders yield less weight and are available in 'pancake' configuration they require peripheral equipment, such as up-down counters, for direction sensing (thereby increasing system weight), and in the event of intermittent power failure they will not be capable of maintaining the shaft

position 'count'. In contrast to the incremental type the absolute type of encoder requires no additional logic circuitry and is capable of keeping the count, since the logic is directly applied on the encoder disc.

A Gray code is chosen for two reasons. It requires the least number of digits (as in natural binary) for data recording, resulting in less weight and higher reliability and, in contrast to natural binary, there is no ambiguity of the count since only one digit changes at any one time. The form of the final data reduction information will, of course, depend upon the data handling system. Translation equipment, to convert from the Gray code to any other form may be required but, if desired, other codes such as BCD, Excess three BCD, etc., can be substituted for the Gray coded encoder at no additional cost.

Finally, a 13 digit per turn encoder is chosen yielding a resolution of approximately 2.6 arc minutes of shaft position. Although higher resolution encoders are readily available it is felt that their greater size, weight, and cost would not justify their use since the stated resolution is compatable with the platform verticality.

Approved For Release 2005/07/13 : CIA-RDP78B04770A002900040009-9

2) Data Recording - In consideration of the vehicle mission requirements it is concluded that frame photography of a lamp display panel is the most advantageous. The state of each lamp depicting the shaft positions, absolute time and altitude if desired, is photographed on command by a high rate single frame camera. Film is used only when interrogation is performed and, in addition, all the data is presented together (in parallel).

Much thought was given to the possible use of a magnetic tape recorder. This method would require a high tape capacity since, throughout the flight duration, tape will be taken-up even when the system is not interrogated. It was thought possible that start-stop commands could be incorporated in the tape drive but, on the basis of high interrogation rates, the required tape drive response was not practical when reliability was considered. Furthermore, each data would require serial presentation to the five track tape recorder, requiring five separate shift registers between each transducer and the recorder, resulting in more weight and a decrease in reliability.

Another consideration in magnetic tape recording is the unreliability in data notation due to tape 'drop-out'. Although great advances have been made to minimize this effect, by use of a more costly, quality controlled, instrumentation tape the state of the art is such that it still exists creating the possibility of losing some data.

The proposed panel lamps, having an initially long life, will be operated at a derated value and pre-biased at a low level, thereby extending their life many-fold. The proposed camera is chosen for its high reliability and accurate pin registration, with a mechanism having been much proved in service.

C) Altitude Variation System

If an altitude variation system is to be of value it must retain its accuracy and exhibit high reliability when exposed to temperature variations as well as a vibration environment, and a design approach such as employed for conventional altimeters, whether displacement or force balance, will not be adequate for high resolution altitude variation sensors.

To meet these requirements friction levels must be minimized and every effort must be expended to assure low hysteresis. In addition, the effects of thermal gradient must be minimized and the sensitive elements must be arranged so that the modulus variation with temperature either cancels or produces a negligible effect. Since the geometric configuration of such systems is utilized as an analog to compute a ratio, relative shifts of the elements due to temperature or vibration must be eliminated or minimized.

Operation in acceleration and vibration environments requires a mass balance of the sensitive elements usually meaning added weight which contributes nothing to the measurement mechanization.

In some transducers efforts to reduce the friction level have resulted in so called floating elements which shift position during acceleration and vibratory loading, upsetting the geometry and introducing errors.

The proposed Altitude Variation System consists of two units: the Absolute Pressure Transducer, schematically shown in Figure 6, and the Altitude Servo, shown in Figure 7, the description of which will be later explained.

Noting the problemmatic areas, stated above, in various altitude sensing systems the design selected [redacted] STAT either eliminates or minimizes these problem areas through the following features:

1) Use of cross spring flexure pivots minimizes friction. The only remaining source of friction is due to slight movement of balls in ball cage.

2) Materials used in all elements have equal coefficients of expansion--no shifts due to temperature.

3) Use of flexure pivots provides for invariant geometry. No shift due to acceleration or vibration loading.

4) Bellows and flexure pivots have a low spring rate and inductive pickoff is a bridge type with resolution in the micro inch range. This eleminates the need for spring rate compensation with permanent magnets and the attendant change in sensitivity with temperature due to thermal geometric variation and thermal magnetic modulus variation.

5) Transducer uses cable type isolators for vibration and shock loads and provide more effective vibration isolation than conventional shock mounts.

6) Force balance principal and high sensitivity pick-off permit motions only in the order of micro inches thus making hysteresis effects negligible.

7) Symmetrical design configuration permits mass balance without addition of counterweights thus eliminating shifts during acceleration or vibration.

8) Inductive pick-off is electrically balanced and mechanically symmetrical which makes its null and performance unaffected by temperature.

Approved For Release 2005/07/13 : CIA-RDP78B04770A002900040009-9

9) Use of proportional servo system instead of contact servo eliminates the need for a radio noise filter.

10) Torques generated by the input pressure are separated by two elements and balanced against each other instead of acting on the same element and resolved. This permits closer geometric control and eliminates another source of errors.

Approved For Release 2005/07/13 : CIA-RDP78B04770A002900040009-9

III. DETAIL DESCRIPTION

A) Vertical Reference Unit

The proposed vertical reference unit is depicted in schematic form in figure 1. It contains three gyro wheels labeled A, P and R for azimuth, pitch and roll. The pitch gimbal contains two single degree of freedom gyros, the pitch gyro providing stability about the pitch axis and the roll gyro providing stability about the roll axis. If there were no frictional restraints or other disturbing torques such as cable restraints, slip ring friction or unbalances about either the pitch or roll axis then the pitch gimbal would remain fixed relative to inertial space. However, such disturbing torques do exist for a variety of reasons. A disturbing torque about the roll axis will cause the roll gyro to precess about its sensitive axis, which is perpendicular to the roll axis, without platform motion about the roll axis. If we detect this precessional motion relative to the pitch gimbal and through a servo apply a torque to the roll gimbal so as to precess the gyro back to its original position then the energy dissipated in the system through the original precession has been restored and the disturbing torque whatever its origin is eliminated. Applying the same logic to the pitch and azimuth gyros it becomes apparent that the effect of disturbing torques on platform performance can be made negligible and it is obvious that the only source of friction which affects performance is the bearings on the sensitive axes.

Approved For Release 2005/07/13 : CIA-RDP78B04770A002900040009-9

In the proposed design we intend to utilize the present ARG-5 gyro wheels with an angular momentum of 6.82×10^6 gm-cm^2/sec, which is more than adequate, for all three gyros. The deviation from perpendicularity with the pitch gimbal of the roll and pitch gyro spin axes will be detected by a constant reluctance rotary differential transformer. The error signal from this detector is amplified and drives the roll and pitch torquers. The azimuth gyro spin axis parallelism with the plane of the pitch gimbal is also detected by a constant reluctance rotary differential transformer whose error signal is amplified and used to power the azimuth servo motor.

The erection system consists of the same pendulum assembly used on the ARG-5 gyro, a two channel erection amplifier and gyro torquers. The erection amplifier is the integrating type with provision for erection cut-out during turns or maneuvers. The rotary unbalanced pendulum assembly senses the vertical through inductive pick-offs the output of which is utilized as an erection signal and erects the gyro through a torquer on the sensitive axis.

The azimuth gyro will precess about its sensitive axis if a disturbing torque exists about the azimuth axis and thus cause the azimuth servo to compensate by applying a torque about the azimuth axis. A torquer is provided on the azimuth gyro

Approved For Release 2005/07/13 : CIA-RDP78B04770A002900040009-9

sensitive axis which enables it to be precessed to any desired position. A synchro can be provided on the azimuth axis which through the torquer will permit slaving to a compass system or a navigation system.

B) Data Recording System

1 - With reference to Figure 2, 'Block-Diagram, Data Recording System', the roll, pitch and azimuth encoders are mechanically driven by their respective reference platform shafts and having the capability of indicating ±80°, ±40°, and continuous 0-360° excursions, respectively. The altitude encoder is mechanically driven by the altimeter and having a capacity of 81,920 feet. All four encoders are an absolute Gray code type with a resolution of 13 digits per turn. This results in non-ambiguous code signals with shaft position resolutions of 2.6 arc minutes for the three attitude encoders and 10 feet for the altitude encoder. Since the code is absolute (the coded pattern on the encoder disc) intermittent power failure will not lose the shaft position count.

The time reference unit is driven by a crystal oven oscillator the stability of which can be furnished in any range up to 1 part in 10^9 per week. As an example of stability of 1 part in 10^8 per week will result in an oscillator drift of approximately 1 millisecond in a 24 hour period, for an oscillator of 1 megacycle per second basic frequency. The output of the unit is also in Gray code giving the count in universal time. The counter is started by a signal from a receiver tuned to a universal time transmitting station, such as WWV.

Outputs from all transducers are then given sufficient amplification to drive the lamps mounted on the display panel. Upon interrogation the framing camera photographs the state of each lamp on 35mm film.

The output from each of the four amplifiers is a dc level for a binary 1 and zero output for a binary zero. As the vehicle attitude changes so does the bit representation, in parallel, on the lamp display panel. Similarly, output from the time referance unit changes the state of the time channel lamp bank.

It is proposed that at the instant of shutter actuation of the primary reconnaissance camera an interrogation pulse be provided to the framing camera. Since the data lamps are always energized the framing camera photographs all of the bit information on signal. An output from the time reference unit is also provided to all of the recon cameras for subsequent time correlation between recon photographs and attitude information. It is envisaged that this time signal activate lamps, located in the data box of each recon camera, through a suitable shift register.

As the individual camera shutter is energized a switch closure, or pulse, is applied to the shift register to dump the individual running time count on to the lamps. Suitable data optics will then image the time data lamps on to the focal plane.

2 - With reference to Figure 3, 'Lamp Display Panel', all data information is represented by a matrix 20 bits long by 5 bits wide. Number 1 bits depict the most significant digit, number 20 the least significant digit for time, and number 13 the least significant for the other data. Since roll and pitch must be direction sensing (±80°, ±40°, respectively) number 1 digit is used for sign. When this lamp is on the vehicle attitude is in the positive side of reference zero, and when it is off negative side of zero is represented. The remaining lamps of these two data depict an increasing count from either side of zero.

Since azimuth requires continuous rotation the full 13 bit lamps are lit when azimith 359° 57'.4 is reached. Crossing over zero azimuth resets all the lamps to zero (all lamps de-energized). Increasing azimuth energizes the lamps starting with bit 13.

Altitude is also represented by 13 bits, corresponding to a total of 81,920 feet. Each 10 foot change in altitude changes the state of each bit starting with bit 13 at sea level. Altitudes higher than 81,920 feet will show as the altitude difference between the actual altitude and 81,920 feet.

The capacity of the time reference unit is $24^{h}\,00^{m}\,00^{s}.0$. With a resolution of 100 milliseconds this total time is represented by 20 bits. Exceeding 24 hours reset the lamps and the time count again recycles. Although a resolution of 100 milliseconds is herein proposed resolutions up to 1 millisecond can be provided with the addition of 7 more binary stages. This, of course, would require more weight and space.

The proposed lamps are rated at 6V, 150 ma but will be used at 80% of their rated voltage and pre-biased. Published data have shown that this type of service results, for all practical purposes, an infinite life.

3 - Figure Number 4 shows the proposed configuration of the data photographic system. The camera is a Flight Research Model 207, pulse-operated, and incorporating a 1000 foot 35 mm film magazine, sufficient for 5000 exposures. Its mechanism has been proven in service, exceeding a life of 41,000,000 cycles at a pulse rate of 6 pulses per second. It has fixed pin registration, ensuring an image orientation with respect to the film sprocket holes and focal plane markers to ±0.0005 inches. This feature renders a less sophisticated film reader for data reduction. The camera can operate at a

shutter pulse rate of 12 per second.

The lens is a standard 35 mm focal length, operating at an object distance of 5 1/2 inches and a minification of 3. It need not be a sophisticated design since its function is only to transfer a contrast ratio rather than resolution, field flatness, etc. Its speed will probably be between an F/2.0 and F/3.5, depending lamp brightness, film speed and minimum duration between the recon cameras exposures.

4 - The final film format is shown in Figure 5. Two frames are shown for data of roll, pitch, azimuth, altitude and time. The four indices may be used for automatic frame alignment in the film reader, but, it is likely, they may not be required since the accurate camera pin registration may be sufficient for orientation of the frame relative to the sprocket holes. The film reader may automatically read the film 'on the fly' or on a frame-by-frame basis.

C) Altitude Variation Sytstem

1 - General Description

With reference to Figure 6, the Absolute Pressure Transducer consists of two symmetrical pivoted plates, nested in a manner such that their pivot axes, which are perpendicular intersect at a common point. The inner plate contains four bellows all of equal effective area so disposed such that a pure couple is produced about the inner plate pivot axis proportional to atmospheric pressure P_a. The outer plate contains two reference springs of equal spring rates and configured in such a manner as to provide a reference couple about the outer plate pivot axis. These torques are opposite in sense and thus oppose each other through a set of ball pivots which are positioned along a line in the plane of the pivot axes parallel to the outer plate pivot axis. This provides one variable lever arm, as represented by the ball pivot position (x) and one constant lever arm, as represented by the ball pivot track distance (c). Thus the position of the ball pivots is dependent upon atmospheric pressure supplied to the P_a bellows and, as will be shown later, is a linear indication of the atmospheric pressure.

If the unit is originally set up so that at torque balance the plates are parallel then plate motion will denote unbalance This plate motion is detected by the inductive pick-off, the output of which after amplification causes the servo motor to rebalance the system through associated gearing. The rack synchronizing gear translates the racks, carrying the ball pivots, in opposite sense and to such a position as to

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If the unit is originally set up so that at torque balance the plates are parallel then plate motion will denote unbalance This plate motion is detected by the inductive pick-off, the output of which after amplification causes the servo motor to rebalance the system through associated gearing. The rack synchronizing gear translates the racks, carrying the ball pivots, in opposite sense and to such a position as to balance the plates and null the induction pick-off. The rack position (x) is therefore a direct measure of the atmospheric pressure (P_a) as is the potentiometer driven by the rack. The potentiometer serves as one leg of a balanced bridge, as shown in the altitude servo schematic of Figure 7.

The following is a treatment showing the linear relationship between the inlet atmospheric pressure and the transducer output:

The inner plate torque is $2 \cdot P_a A \cdot b$ and the outer plate torque is $2k\delta \cdot a$ where

'P_a'	=	inlet atmospheric pressure
k	=	spring rate of reference springs
δ	=	reference spring preload
A	=	effective area of bellows
a	=	Moment arm of reference springs
b	=	Moment arm of 'P_a' and Vacuum bellows

then the force at the ball pivots due to the inner plate torque is

$$F_i = \frac{(2\,P_a) \cdot A \cdot b}{X} \qquad (1)$$

and the force at the ball pivots due to the outer plate torque is

$$F_o = \frac{2k\delta \cdot a}{c} \qquad (2)$$

at balance $F_i = F_o$ or (3)

arm can all be made equal. Obviously neither the bellows area nor the lever arms can be manufactured identically, however, there is another bellows variable which while in some transducers is detrimental, in this design is useful. That is, the property that the center of the effective area is not coincident with the mechanical centerline. Thus, since the effective areas differ slightly and the eccentricity of the center of pressure also varies, by rotating the bellows it is possible to arrive at a combination where for the inner pivoted plate the product of areas and lever arms are identical. After these orientations are found and the bellows are rotationally locked, then by adjusting the ball pivots lever arm the design value of the conversion constant can be easily achieved. This adjustment is accomplished by shims between the ball pivot holder and the ball pivot slide.

The first step of the above calibration is accomplished with special test equipment on the plate and bellows assembly as a sub-assembly operation. The second step is accomplished during final assembly and test.

Calibration shifts or instability can only occur due to geometric changes since the output of the device is independent of bellows area and spring rate provided no additional forces are generated by ambient temperature variations. Temperature effects are eliminated by making the support structure of a material which has the same thermal coefficient of expansion as the bellows, reference springs, and the plates. Therefore, since no mechanical compression or extension of the bellows and springs will occur, no thermal torques will be generated, and it is not necessary to match spring rates.

Fundamentally, the transducer operates in the near-balanced condition at all times, resulting in infinitesmal plate excursions. Variable torques due to bellows and springs mechanical hysteresis are considerably minimized thereby resulting in a highly repeatable and accurate system.

Since the geometry is invariant due to the plates and the use of flexure pivots; and the temperature dependent physical properties have no effect on the output, the transducer will exhibit excellent stability throughout the temperature and vibration environment.

In addition, there are no elements of the transducer which will deteriorate during service and alter the calibration. Repeated stress on the bellows, springs, and flexure pivots could conceivably alter spring rates slightly but these have no effect on the output and only a third order effect on the sensitivity. However, these stresses are low and it is estimated that no significant effect will occur short of 20,000 hours of operation.

The design features and calibration techniques, as stated above, are such that the accuracy and resolution of the altitude variation system, given in the specifications of Section V, can confidentally be met.

Approved For Release 2005/07/13 : CIA-RDP78B04770A002900040009-9

IV FURTHER CONSIDERATIONS

1 - Incandescent lamps are proposed primarily for their relatively high brightness output and low energizing voltage. Their peak intensity response is such that approximately 20 pulses per second cannot be exceeded else bit changes will not be discerned. The roll, pitch, azimuth, and altitude encoders have a resolution of 8, 192 counts (13 bits) per revolution. The lamps will therefor limit the slew rates of the three reference axes to 7/8 degree per second, and for altitude 200 feet per second. Time has a resolution of 100 milliseconds per count, a value to which the lamps can respond.

Higher slew rates can be accomplished by the use of neon lamps, such as type NE-51, except that they require more than 100 volts for energization and have a low brightness level. If, indeed, higher slew rates are required experiments will have to be conducted to determine feasibility as regards cycling rates, shutter speeds, brightness, film and lens speeds.

2 - With reference to Figures 3 and 5, time data requires 7 more bits than the other data for a total of 20 bits. The 20 bits are a result of a total count of 24 hours of 100 milliseconds resolution. To fit all 20 bits in the format shown the use of the proposed 'double frame' camera is required. A mission requiring 5000 exposures results in the need for a 1000 foot film magazine for the data camera. As stated in the specifications of Section V the camera weighs 27 pounds, 12 1/2 pounds for the

camera and 14 1/2 pounds for the 1000 foot magazine and film, and with a size as shown in Figure 4.

If instead of time the correlation between the recon photos and the attitude data was in terms of frame number a total of 5000 frames would require the same number of bits as the other data, i.e., 13 bits. The format matrix will then be 13 bits by 5 rows. By eliminating the seven bits the smaller format size can be fit into a 'single frame' camera utilizing a film magazine of only 400 foot capacity for the 5000 exposures, in lieu of 1000 feet. This results in a weight reduction of 7 pounds and in a space saving, as shown in Figure 4. Further, a time reference unit weighing 3 pounds will not be required, but in its stead a 13 bit flip-flop circuitry weighing no more than 8 ounces. This, of course, also eliminates the weight for 7 lamps and associated amplifiers and 7 bits for each of the reconnaissance cameras data system.

If, indeed, the 1000 foot magazine camera is retained, a reduction of 6 pounds can be accomplished by substituting magnesium for the aluminum housing. The camera vendor states this can be accomplished, at no additional cost, if a minimum order of 10 units is placed.

V SPECIFICATIONS

A) Three Gyro reference Platform Airborne Verticality: 12 minutes of arc maximum.

Angular Freedom:

Pitch ±40°

Roll ±80°

Angular Rate: 7/8 deg/sec. with incandescent lamp panel. Higher rates may be possible by use of neon lamps.

Size: 18" long 10" wide 12" high

Weight: 25 lbs. max.

B) Data Recording System

Resolution:

Roll, Pitch, Azimuth	2.6 minutes of arc
Altitude Variation	0.1% or 10 feet whichever is greater
Time Reference Unit	100 milliseconds (1 millisecond can be furnished). Setable to Universal Time

Accuracy:

Roll, Pitch, Azimuth	2.6 minutes of arc
Altitude Variation	0.2% or 25 feet whichevr is greater
Time Reference Unit	±1 millisecond per day

Cycling Rate:

Framing Camera	12 pulses per second maximum

Size:

Camera - Panel Sub Assembly: see Figure 4

Size (continued):

Amplifier and associated circuitry package: 5x6x19

Time Reference Unit: 4x5x10

Absolute Pressure Transducer: 6x7 5/8x4 1/2 high

Altitude Servo: 4x6x4 1/2 high

Weight:

Camera-Panel Sub assembly: 28 lbs. with 1000 foot magazine, 21 lbs. with 400 foot magazine, Both can be reduced by 6 lbs. and 3 lbs, respectively, in quantity order of 10

Amplifier and Associated Circuitry package: 12 lbs.

Time Reference Unit: 3 lbs.

Encoders: 3 1/2 lbs. This includes 14 ounces for altitude encoder

Absolute Pressure Transducer: 4 1/2 lbs.

Altitude Servo: 2 1/2 lbs. This includes 14 ounces for altitude encoder

Power Requirements

Encoders: 6.3V dc ±5%, 1.5 amps. maximum

Amplifiers and Associated Circuitry: ±5V dc ±2%, 100 ma. average

Lamp Drivers: -6V dc ±5%, 6 amps average

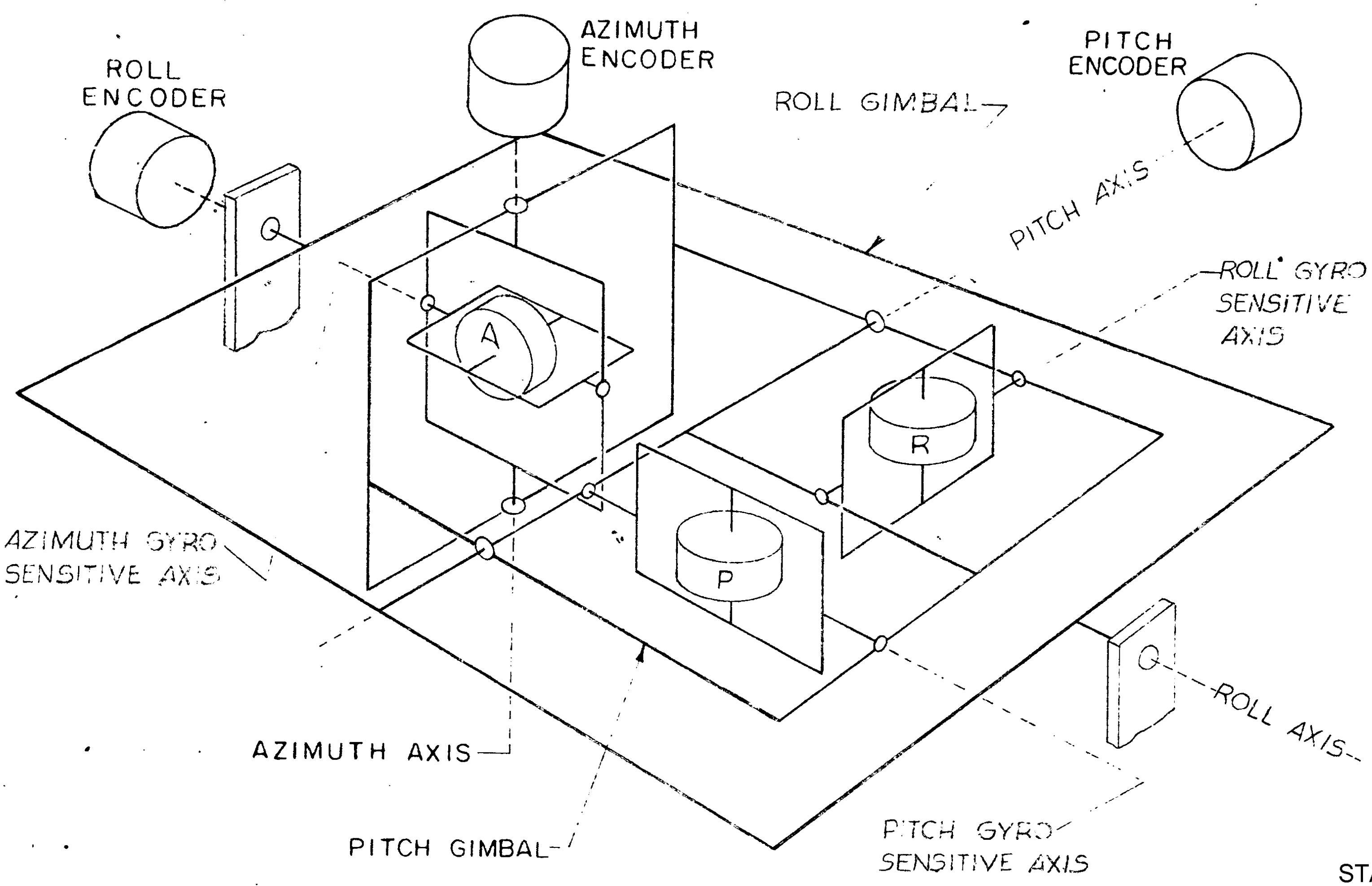

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FIGURE #1

SCHEMATIC VERTICAL REFERENCE UNIT

P-63-171

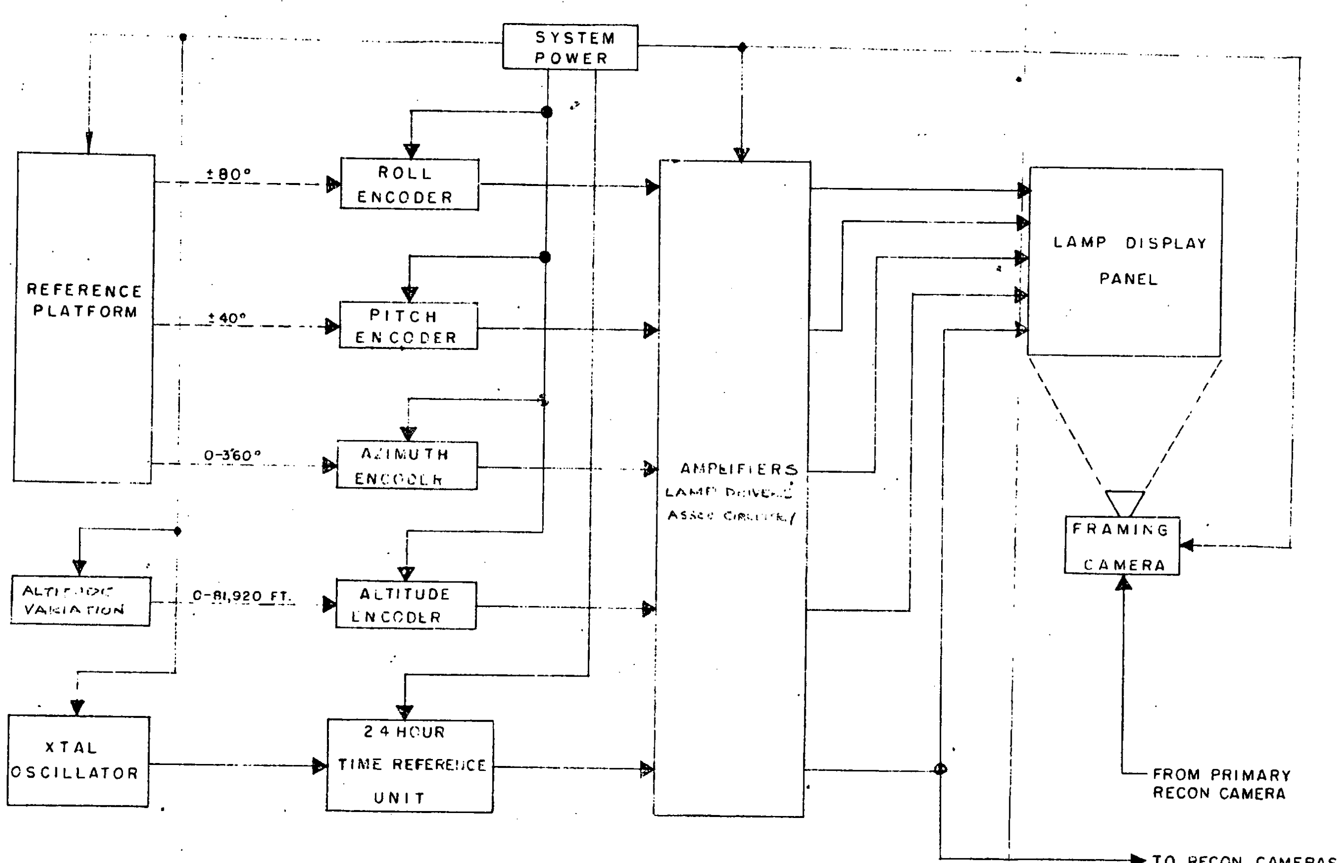

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FIGURE #2

BLOCK DIAGRAM-

DATA RECORDING SYSTEM

P-63-171

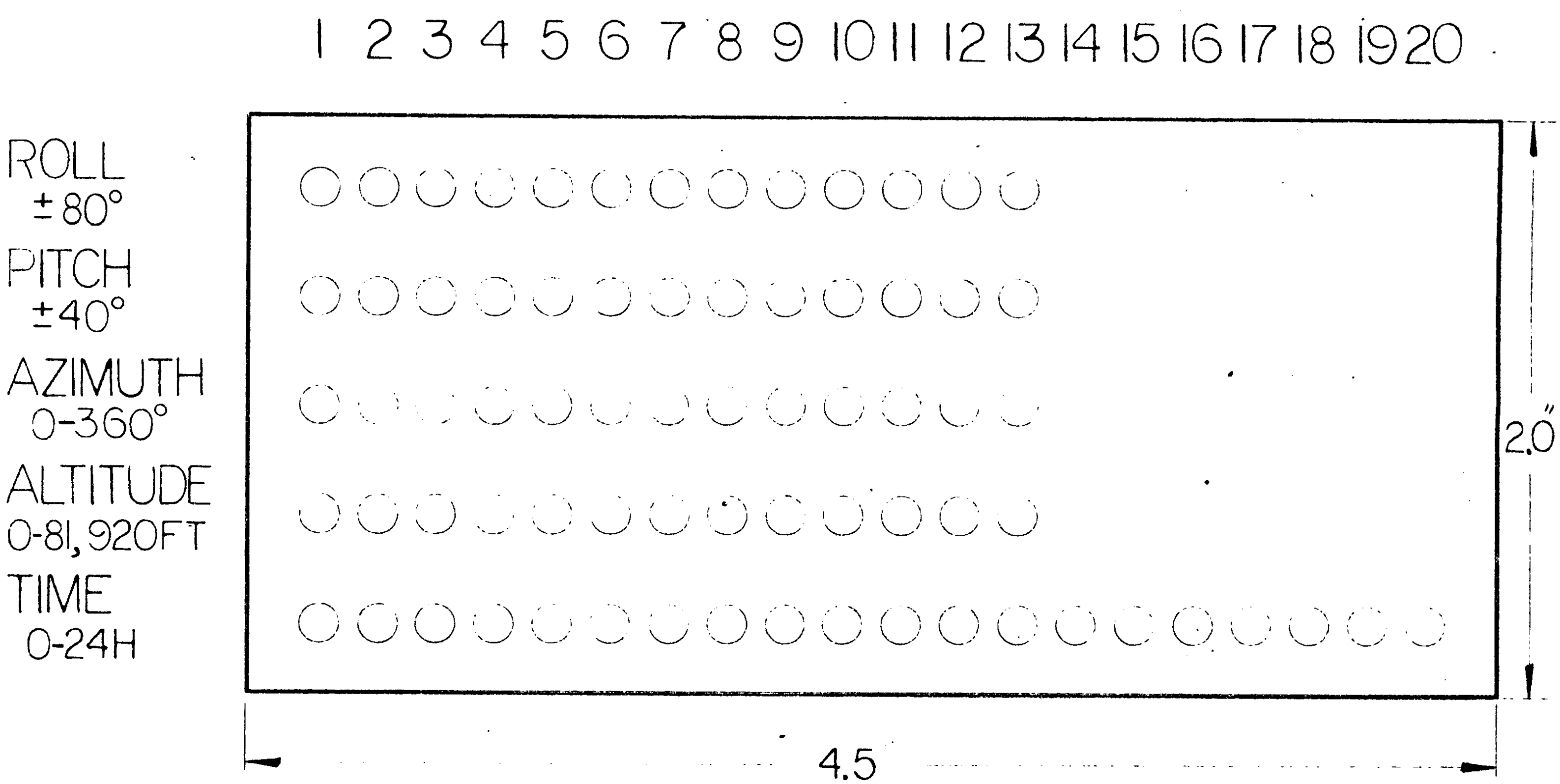

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FIGURE # 3

LAMP DISPLAY PANEL

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Approved For Release 2005/07/13 : CIA-RDP78B04770A002900040009-9

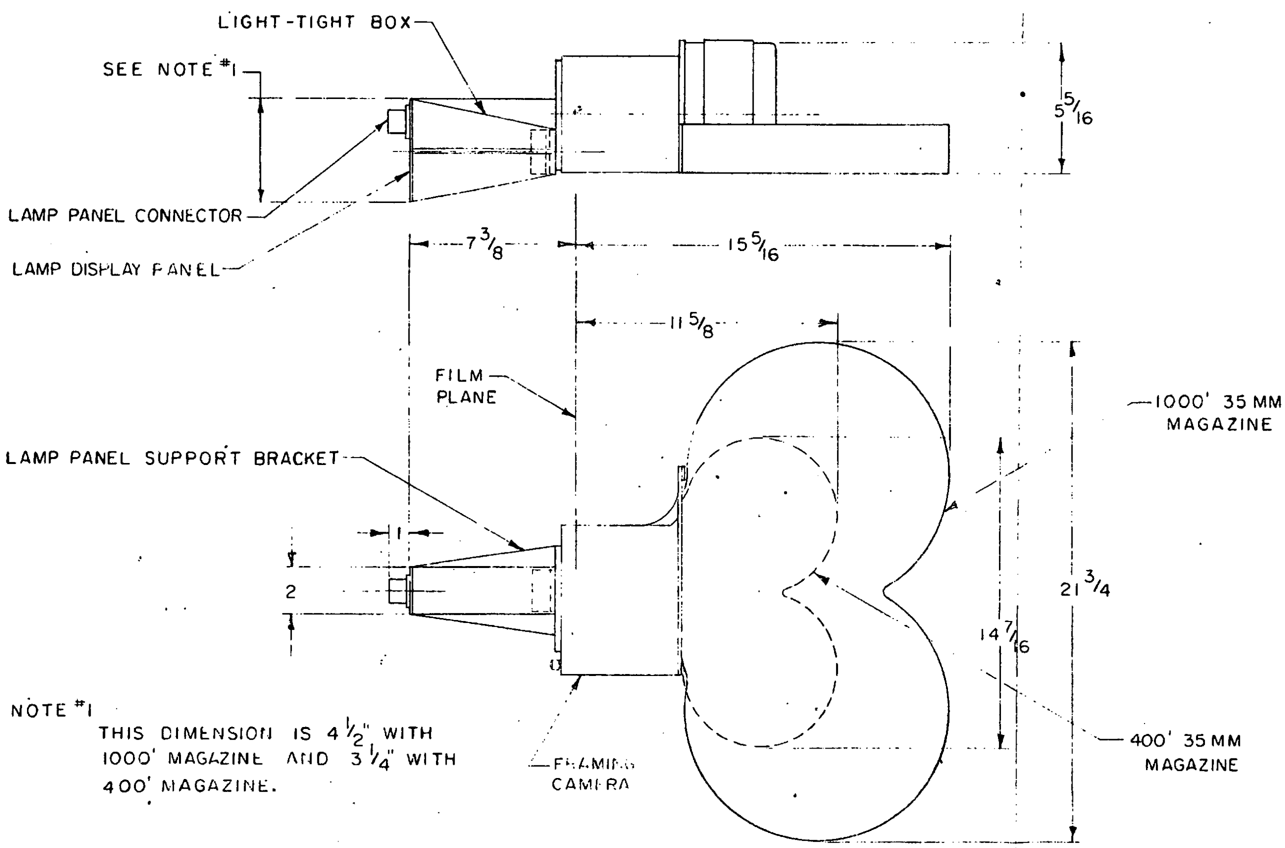

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FIGURE #4

CAMERA-PANEL-CONFIGURATION

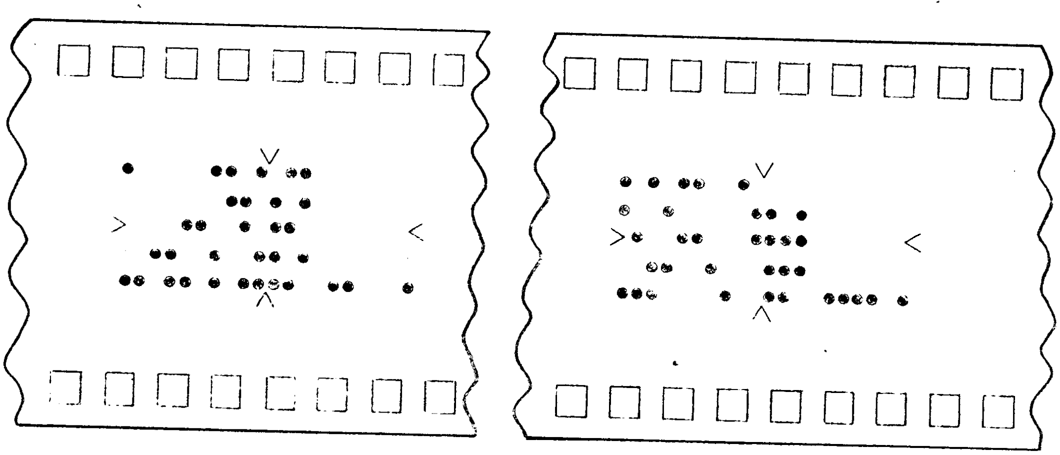

FIGURE # 5

35mm FILM FORMAT

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P63-171

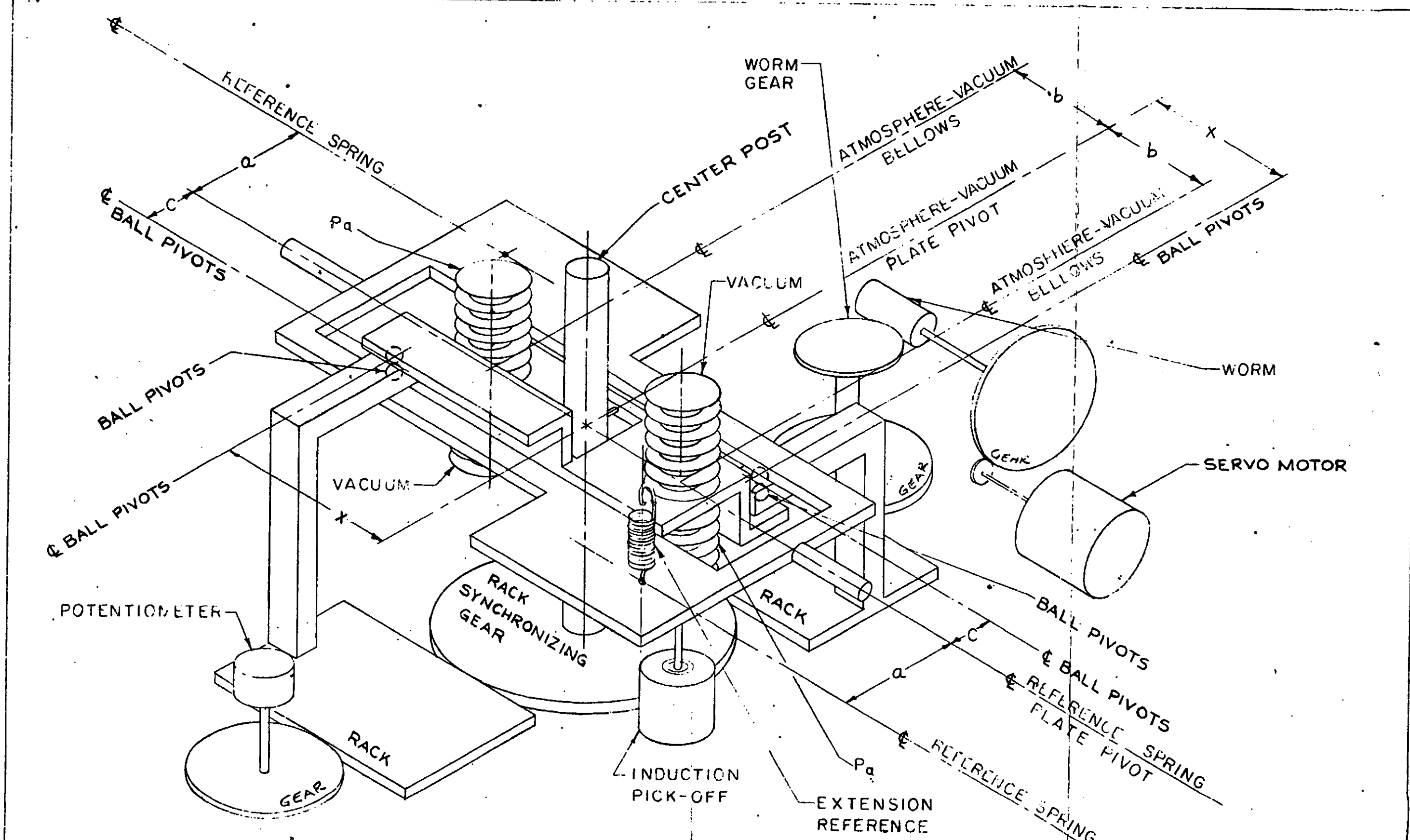

FIGURE #6

MECHANICAL SCHEMATIC-ABSOLUTE PRESSURE TRANSDUCER

P63-171

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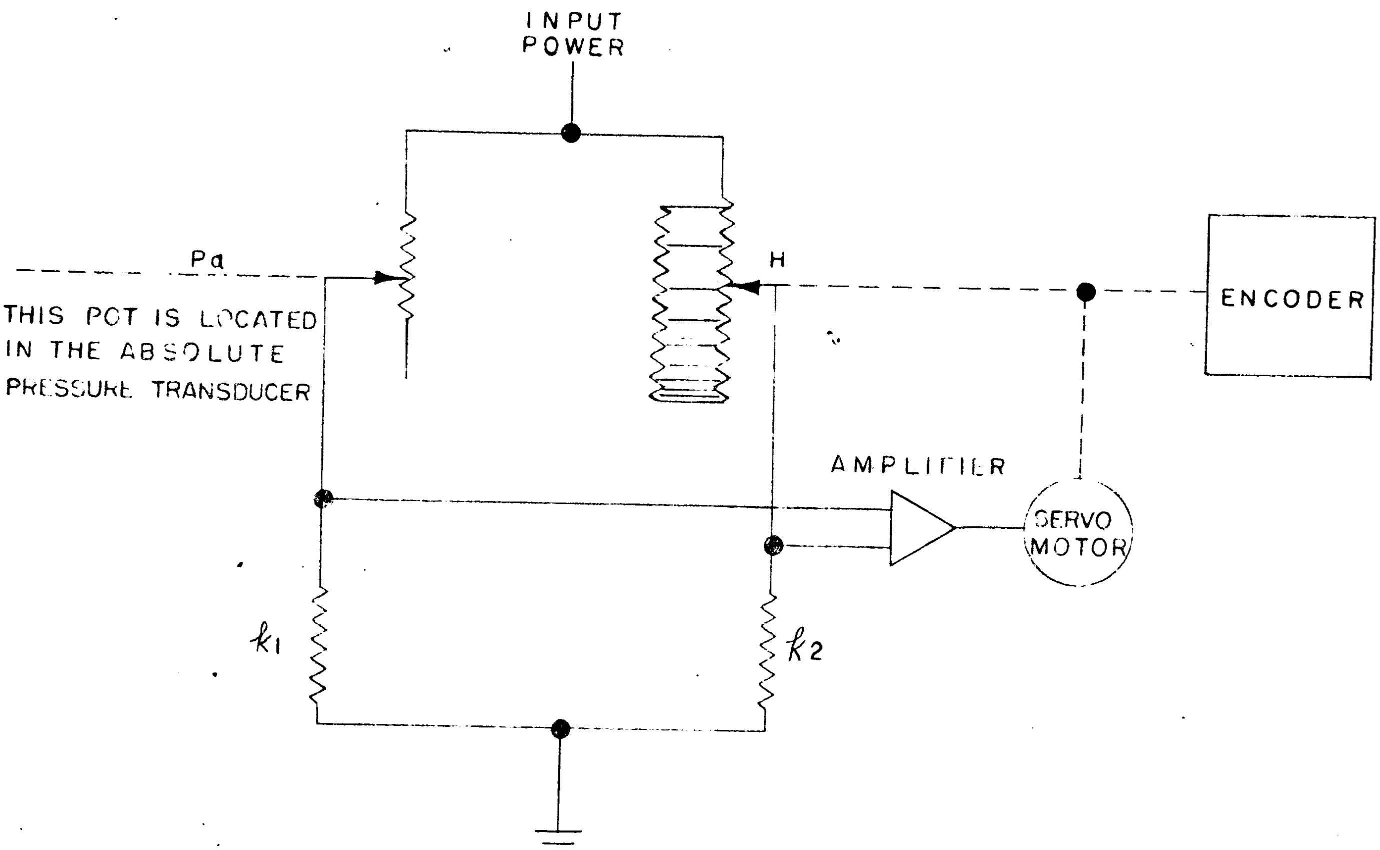

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FIGURE #7

SCHEMATIC ALTITUDE SERVO

P-63-171

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The NPIC Proposal #40/64 by the [redacted] as proposal P63-171-2 was given to this organization for information purposes only. No contractual action is anticipated by P&DS. In the event the proposal is accepted by [redacted] coordination action will be taken by this office to handle any data produced as a result of the proposed system.

PROPOSAL FOR A RECORDING VERTICAL REFERENCE SYSTEM

P-63-171

AMENDMENT II

STAT

FEBRUARY 27, 1964

TABLE OF CONTENTS

List of Illustrations

I. INTRODUCTION

The recording vertical reference system, as proposed herein, is intended for use in a high performance airborne vehicle equipped with a complement of photographic cameras.

With the cameras fixed to the aircraft it will be necessary, in order to properly interpret and reduce the photographic data, to have an accurate recording of aircraft attitude at the time of exposure.

The proposed system is comprised of an improved vertical gyro with synchro pickoffs, a servo repeater, and a data recording system. The servo repeater drives shaft position encoders for recording aircraft pitch and roll.

The complete system concept is also based upon the minimization of weight and with the utilization of proven components throughout, thereby insuring high reliability in performance.

II. GENERAL SYSTEM CONSIDERATIONS

A) Vertical Reference Unit

The requirements for a recording vertical reference system STAT presents slightly different design criteria than associated with [redacted] camera stabilization systems. The [redacted] ARG-5 vertical reference STAT unit utilizes a capacitive pickoff with a limited range and the camera platform containing the gyro is driven to null the error signal. This is an ideal system for stabilizing a camera or other device which can be mounted with its C. G. at the intersection at the roll and pitch axis. This system concept also requires minimum gimbal axis friction and usually about 10° of freedom.

In order to overcome the limitations of this system when used for a recording vertical reference system it is proposed to utilize the ARG-6 gyro which is the ARG-5 unit modified for synchro pick-offs. A servo repeater can now be used to drive pitch and roll encoders.

B) Data Recording System

The function of the data recording system is to monitor and record the vehicle's attitude in roll and pitch, as well as frame number and altitude - all at the instant of the exposure command to the main reconnaissance camera. The acquired data is subsequently ground processed for visual and/or computer readout for photo reduction and interpretation.

Mission requirements for the acquisition of a large number of photographs dictates that, in order to minimize weight, data is to be recorded only on command, in lieu of continuous recording, and that the system be completely automatic thereby emphasizing highest degree of reliability.

The choice of the proposed data recording system is based upon the following considerations:

1) Shaft position encoders-A13 digit absolute type, gray code (cyclic binary) encoder is chosen from the many types available. Although incremental encoders yield less weight and are available in 'pancake' configuration they require peripheral equipment, such as up-down counters, for direction sensing (thereby increasing system weight), and in the event of intermittent power failure they will not be capable of maintaining the shaft position 'count'. In contrast to the incremental type the absolute type of encoder required no additional logic circuitry and is capable of keeping the count, since the logic is directly applied on the encoder disc.

A Gray code is chosen for two reasons. It requires the least number of digits (as in natural binary) for data recording, resulting in less weight and higher reliability and, in contrast to natural binary, there is no ambiguity of the count since only one digit changes at any one time. The form of the final data reduction information will, of course, depend upon the data handling system. Translation equipment, to convert from the Gray code to any other form may be required but, if desired, other codes such as BCD, Excess three BCD, etc., can be substituted for the Gray coded encoder at no additional cost.

Finally, a 13 digit per turn encoder is chosen yeilding a resolution of approximately 2.6 arc minutes of shaft position. Although higher resolution encoders are readily available it is felt that their greater size, weight, and cost would not justify their use since the stated resolution is compatible with the platform verticality.

2) Data Recording - In consideration of the vehicle mission requirements it is concluded that frame photography of a lamp display panel is the most advantageous. The state of each lamp depicting the shaft positions, frame number and altitude if desired is photographed on command by a high rate single frame camera. Film is used only when interrogation is performed and, in addition, all the data is presented together (in parallel).

Much thought was given to the possible use of a magnetic tape recorder. This method would require a high tape capacity since, throughout the flight duration, tape will be taken up even when the system is not interrogated. It was thought possible that start-stop commands could be incorporated in the tape drive but, on the basis of high interrogation rates, the required tape drive response was not practical when reliability was considered. Furthermore, each data would require serial presentation to the five track tape recorder, requiring five separate shift registers between each transducer and the recorder, resulting in more weight and a decrease in reliability.

Another consideration in magnetic tape recording is the unreliability in data notation due to tape 'drop-out'. Although great advances have been made to minimize this effect, by use of a more costly, quality controlled, instrumentation tape the state of the art is such that it still exists creating the possibility of losing some data.

The proposed panel lamps, having an initially long life, will be operated at a derated value and pre-biased at a low level, thereby extending their life many-fold. The proposed camera is chosen for its high reliability and accurate pin registration, with a mechanism having been much proved in service.

III. DETAIL DESCRIPTION

A) Vertical Reference Unit

The proposed unit is essentially a very accurate vertical gyro (ARG-6) with pitch and roll servo repeaters. Assuming for the moment negligible error in the repeaters, accuracy of the measurement is dependent upon the degree to which the gyro can be erected and maintained in a vertical. An awareness of these factors and the degree to which they degrade performance must be realized in order to properly appreciate the choice of the system proposed.

Verticality:

A gyroscope is merely a spinning wheel and it alone does not indicate vertical. A pendulum is therefore provided to establish the vertical direction. Any difference between the gyro position and the pendulum is amplified and applied to torque the gyro into alignment with the pendulum.

Because the gyro tends to stay pointed in a fixed direction in space, as the earth turns in space, the gyro must be continually torqued to stay aligned with the pendulum. To produce this torque a displacement error occurs between gyro and pendulum. The magnitude of the error is dependent upon the erection loop gain employed and is referred to as "Earth's Rate Effect."

Similarly, if the gyro is carried about the surface of the earth by a moving vehicle it again must be torqued to follow the curvature of the earth. In an aircraft traveling at 600 mi. /hr. the gyro must be torqued at a rate of 9° /hr. to stay aligned with the vertical. This is called "Profile Effect".

In addition to these two effects of earth's rate and profile, which make it necessary to keep torqueing the gyro towards vertical, the gyro itself may, due to inherent restraints, drift away from a fixed position. This drift too must therefore be overcome by a counter-torque produced by the erection system.

Summarizing then, due to the gyroscopic effects of earth's rate, profile, and drift a counter-torque must be produced by an error signal in the erection loop to prevent the vertical gyro from straying away from the vertical. In order to minimize these errors, a high erection loop gain would seem desirable. Unfortunately, another error affect limits the amount of gain that can be applied in this loop.

This other class of errors, namely, pendulum errors, can best be reduced not by a high but a low erection loop gain. Pendulum errors arise in a moving system due to vibrations and accelerations which cause the pendulum reference to jog and swing away from vertical. With low erection gain when the pendulum is momentarily disturbed from its correct position, the gyro in following moves away slowly.

Before it has had enough time to build up an equivalent error, the pendulum will have returned to zero and the gyro moves back. The effect is that rapid deviations of the pendulum are not followed by the gyro, although the gyro does take up the long term average position of the pendulum. Indeed, it is this very feature of filtering the extraneous motions of the pendulous reference that makes the vertical gyro a desirable vertical reference unit.

It would therefore be advantageous to design an erection loop with high gain to reduce the verticality errors due to gyroscopic effects and low gain to minimize errors due to pendulum disturbances. This can be accomplished by the use of an integrating amplifier in the erection loop which will provide an output proportional to the error plus the integral of the error. The advantage of this type system is to reduce the degree of compromise between the two conflicting requirements of high and low gain. Gyroscopic errors are long term or low frequency effects while pendulum perturbations are short term or higher frequency effects. An integrating erection system has just these characteristics, high gain at low frequencies and low gain at high frequencies. The result, therefore, is to greatly reduce gyro stand-off errors while providing increased pendulum filtering. By virtue of the integrating erection system gyroscopic errors such as earth's rate, profile and drift can be kept below three minutes of arc while still providing a high degree of filtering to pendulum perturbations.

As a further aid towards system accuracy, to prevent additional verticality error due to aircraft turns, a rate switch will be provided. Whenever the aircraft goes into a prolonged bank during a turn the "Rate of Turn" switch will open the erection loop to prevent the vertical gyro from lining up with the false position of the pendulum caused by the centripetal force of the turn.

The vertical reference system with an integrating erection system as described above, has already been successfully employed by [redacted] in similar airborne systems.

Servo Repeaters:

The roll and pitch signals generated by the vertical gyro are transmitted from their respective gimbals by pancake type synchro transmitters whose inherent accuracy is better than 6 minutes of arc.

The servo repeaters must accurately follow this data at rates up to 10 milliradians per second. To keep the servo tracking error below one minute of arc the servo loops will have at least a 5 cycle bandwidth.

The roll and pitch servo repeaters consist of two phase servo motors, a synchro control transformer and a servo amplifier. The amplifier drives the control transformer so as to reduce the error voltage between the synchro transmitter and the synchro control transformer to zero, thus the motor shaft position is proportional to pitch angle or roll angle. The servo motors simultaneously position 2^{13} digital encoders which are interrogated on command by the data recording system.

B) Data Recording System

1 - With reference to Figure 2, 'Block-Diagram, Data Recording System', the roll and pitch encoders are mechanically driven by their respective servo repeaters having the capability of indicating ± 80° roll and ± 40°, pitch. Both encoders are an absolute Gray code type with a resolution of 13 digits per turn. This results in non-ambiguous code signals with shaft position resolutions of 2.6 arc minutes. Since the code is absolute (the coded pattern on the encoder disc) intermittent power failure will not lose the shaft position count.

Outputs from all transducers are then given sufficient amplification to drive the lamps mounted on the display panel. Upon interrogation the framing camera photographs the state of each lamp on 35 mm film.

The output from each of the four amplifiers is a dc level for a binary 1 and zero output for a binary zero. As the vehicle attitude changes so does the bit representation, in parallel, on the lamp display panel.

It is proposed that at the instant of shutter actuation of the primary reconnaissance camera an interrogation pulse be provided to the framing camera. Since the data lamps are always energized the framing camera photographs all of the bit information on signal.

The proposed lamps are rated at 6V, 150 ma but will be used at 80% of their rated voltage and pre-biased. Published data have shown that this type of service results, for all practical purposes, an infinite life.

2 - Figure Number 3 shows the proposed configuration of the data photographic system. The camera is a Flight Research Model 207, pulse-operated, and incorporating a 400 foot 35 mm film magazine, sufficient for 5000 exposures. Its mechanism has been proven in service, exceeding a life of 41,000,000 cycles at a pulse rate of 6 pulses per second. It has fixed pin registration, ensuring an image orientation with respect to the film sprocket holes and focal plane markers to ±0.0005 inches. This feature renders a less sophisticated film reader for data reduction. The camera can operate at a shutter pulse rate of 12 per second.

The lens is a standard 35 mm focal length, operating at an object distance of 5 1/2 inches and a minification of 3. It need not be a sophisticated design since its function is only to transfer a contrast ratio rather than resolution, field flatness, etc. Its speed will probably be between an F/2.0 and F/3.5, depending lamp brightness, film speed and minimum duration between the recon cameras exposures.

IV. SPECIFICATIONS

A) Vertical Reference Unit Verticality: 15 minutes of arc dynamic.

Angular Freedom:

Pitch ±40°

Roll ±80°

Angular Rate: 7/8 deg./sec. with incandescent lamp panel. Higher rates may be possible by use of neon lamps.

Size: 12" long 10" wide 10" high

Weight: 25 lbs. max.

B) Data Recording System

Resolution:

Roll, Pitch	2.6 minutes of arc

Accuracy:

Roll, Pitch	2.6 minutes of arc

Cycling Rate:

Framing Camera	12 pulses per second maximum

Size:

Camera - Panel Sub Assembly: See Figure 3

Amplifier and associated circuitry package: 5x6x19"

Weight:

Camera-Panel Sub Assembly: 21 lbs.

Amplifier and Associated Circuitry package: 12 lbs.

Encoders: 2 1/2 lbs.

Power Requirements:

Encoders:	6.3V dc ±5%, 1.5 amps. maximum
Amplifiers and Associated Circuitry	± 5V dc ±2%, 100 ma. average
Lamp Drivers:	-6V dc ±5%, 6 amps average

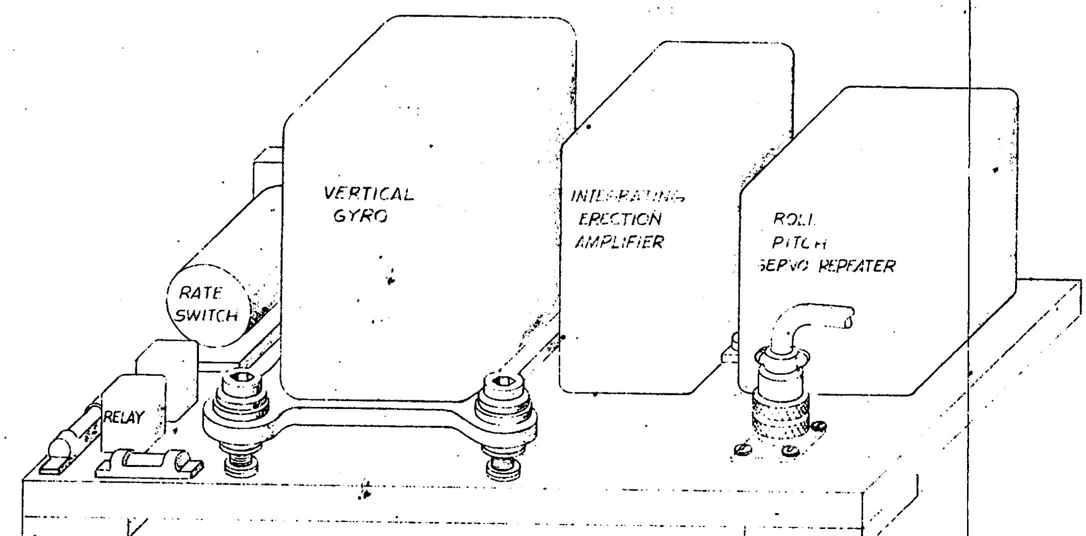

FIGURE #1
VERTICAL REFERENCE UNIT

STAT

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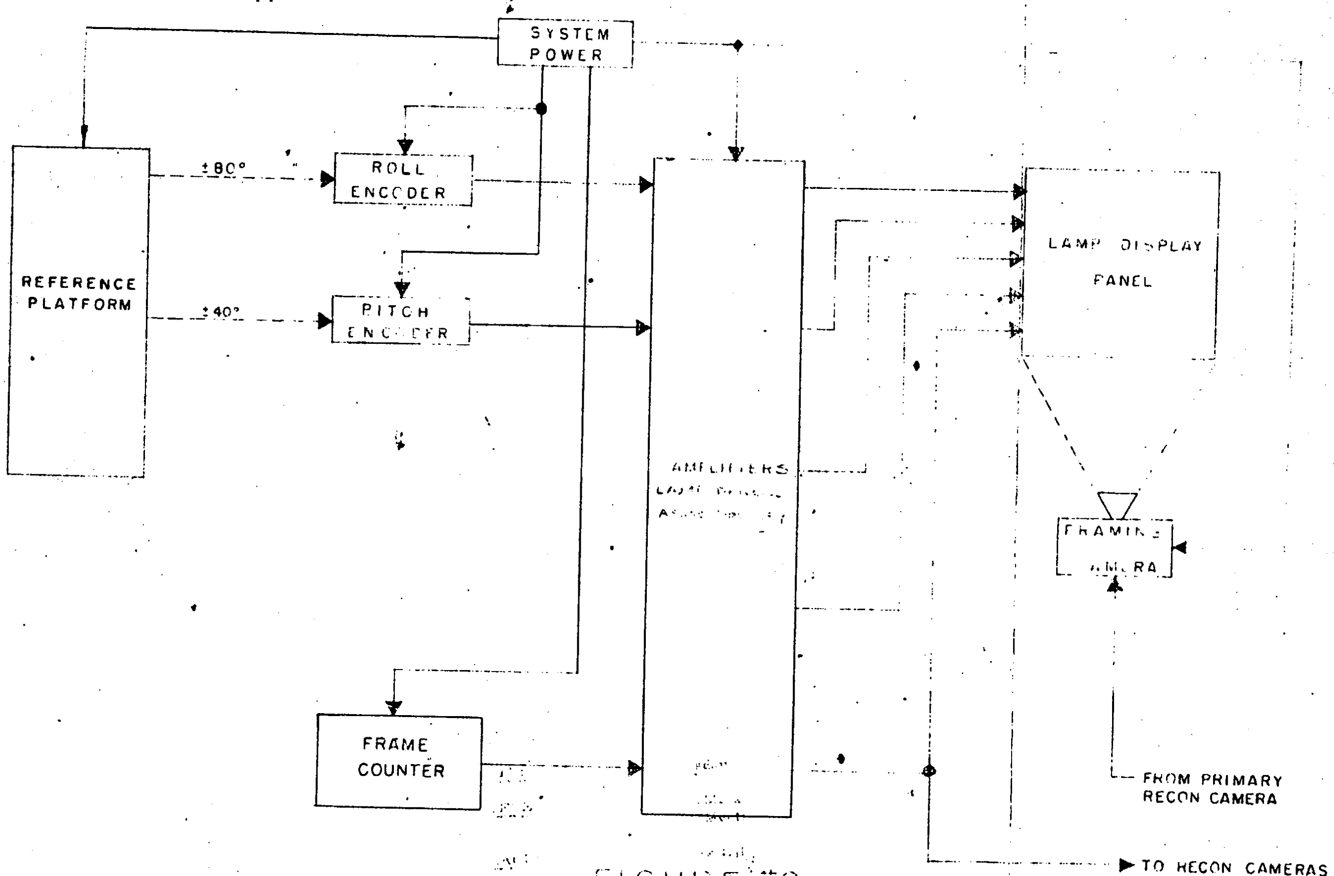

FIGURE #2
BLOCK DIAGRAM-
DATA RECORDING SYSTEM

STAT

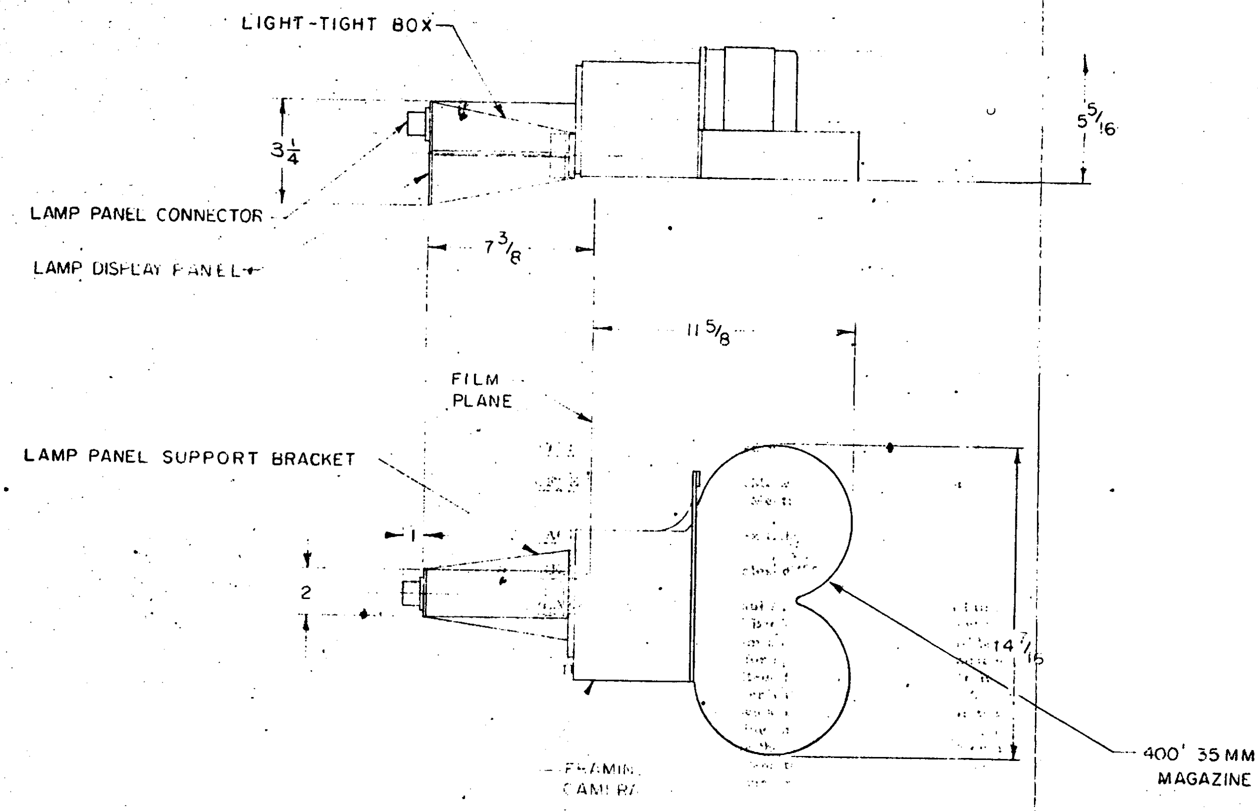

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FIGURE #3
CAMERA PANEL-CONFIGURATION

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