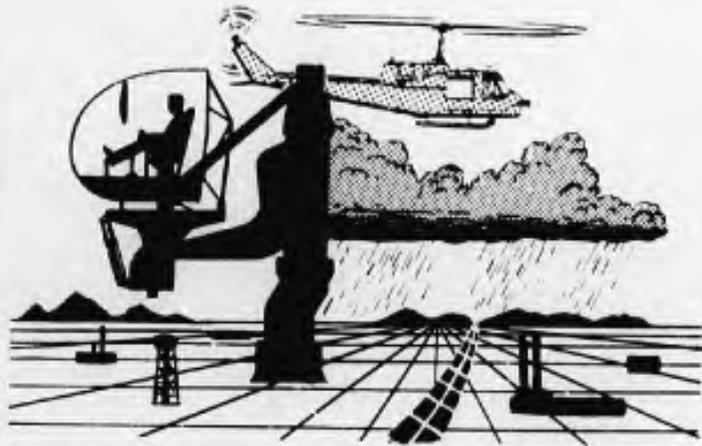


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JOINT ARMY-NAVY AIRCRAFT INSTRUMENTATION RESEARCH

TECHNICAL REPORT  
NO. D228-420-009



## FLIGHT EVALUATION OF THE CONTACT ANALOG PICTORIAL DISPLAY SYSTEM

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JANAIR

JOINT ARMY NAVY AIRCRAFT INSTRUMENTATION RESEARCH

FLIGHT EVALUATION OF THE CONTACT  
ANALOG PICTORIAL DISPLAY SYSTEM

Technical Report No. D228-420-009

February 1966

By:

J. G. Curtin  
Human Factors Engineer

J. H. Emery, JANAIR Human  
Factors Project Engineer

C. B. Elam, Director Human  
Factors Research

D. J. Dougherty, Chief  
Human Factors

APPROVED:

H. W. Mitchell  
Chief Electronics Engineer

Office of Naval Research  
Contracts Nonr 4429(00) and Nonr 1670(00)



This report presents work which was performed under the Joint Army Navy Aircraft Instrumentation Research (JANAIR) Project, a research and development program directed by the United States Navy, Office of Naval Research. Special guidance is provided to the program for the Army Materiel Command, the Office of Naval Research and the Bureau of Naval Weapons through an organization known as the JANAIR Committee. The Committee is currently composed of the following representatives:

U. S. Navy, Office of Naval Research  
CDR D. D. Kilpatrick

U. S. Navy, Bureau of Naval Weapons  
CDR W. A. Engdahl

U. S. Army, Materiel Command  
Mr. Len Evenson

The goals of JANAIR are:

a. The Joint Army Navy Aircraft Instrumentation Research (JANAIR) project is a research project, the objective of which is to improve the state of the art of piloted aircraft instrumentation.

b. The JANAIR Project is to be responsive to specific problems assigned, and shall provide guidance for aircraft instrumentation research and development programs.

c. The JANAIR Project will conduct feasibility studies and develop concepts in support of service requirements.

d. These efforts shall result in reports and the knowledge to form the basis for development of improved instrumentation systems, components and subsystems.



ABSTRACT

The work reported in this document represents a series of flight test evaluations of a vertical flight display or contact analog. It was conducted by Bell Helicopter Company under the sponsorship of the Joint Army Navy Aircraft Instrumentation Research (JANAIR) Program. Three experimental flight tests were conducted in the JANAIR flight test vehicle which was a UH-1 helicopter known as Research Helicopter Number 2 (RH-2). The first study evaluated the vertical display containing the basic grid plane plus a ground position indicator. The hover flight mode was the test maneuver. Four types of control stabilization were tested with the display with varying degrees of control sensitivity. The second study examined the basic grid plane with and without a director symbol in the form of a flight pathway. Speed indices were presented on the pathway in the form of tarstrips and speed markers. During cross-country flight maneuvering, a ground position indicator defined final touch-down position. Only one flight stabilization mode was tested. The flights were comprehensive in their coverage of the spectrum of basic flight maneuvers. The final investigation was designed to determine the usefulness of augmenting the display components (horizon line and basic grid plane) with a TV presentation superimposed upon the vertical flight display. Several flight modes were investigated.

The experimental results are reported and discussed for each of these studies.

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## I. INTRODUCTION

The slow evolution of display development and testing was brought into a final first phase for the JANAIR rotary wing program when the display was air tested. This report details these first air tests. The many years of engineering build-up of sensors, equipments, displays and scoring apparatus found culmination in the Research Helicopter Number Two (RH-2). This program of flight testing paralleled, but lagged, the simulator program in which the same displays were evaluated. The simulator program was thereby permitted to act as a feasibility test. With it a determination could be made of safe procedures and maneuvers to perform with the new display system in flight.

The RH-2 flight tests represented the first series of applied evaluation in which selected experimental variables were examined during the performance of mission segments. These were basic or common to all missions. The test maneuvers were representative of the capabilities of the vehicle and the ability of the operator, and were not a radical departure from instrument flight test maneuvers. It should be emphasized that these tests were by no means exhaustive, but provided a basic test program designed to yield a feasibility index as to the validity of design combinations, as furnished in this research vehicle, to meet the criterion of full "black bubble" capabilities.

This series of studies verified the conclusions obtained during the simulator evaluations in an operational environment. Generally this conclusion revealed the contact analog to be a quite feasible concept under full instrument flight conditions. The simulation study of Sgro and Dougherty (1963) was conducted as a prelude to the flight test experiment in the JANAIR flight test vehicle, Research Helicopter Number 2 (RH-2). This experiment evaluated several display configurations during surface operations. As a result of this investigation, the vertical display configuration which was chosen for presentation for the hover study was the grid plane, horizon line, sky texture, and ground position indicator. The rationale for investigating the hover maneuver initially arises from the philosophy that this maneuver is one of the most demanding tasks for the operator to perform. Standard instrumentation has proven adequate for airborne cruise maneuvers and to an extent, for terminal area work. Therefore, to demonstrate the additional capability afforded by the pictorial displays of the JANAIR system under zero-zero conditions, a task was selected which normally could not be accomplished utilizing standard instrumentation. This task was the hover maneuver under simulated IFR conditions. The obvious follow-up studies entailed increasing the scope of the program to include other anticipated operational applications, specifically the cross-country flight regime (Emery & Dougherty, 1964a, 1964b).



The simulator pilot performance tests were designed to examine only the displays for the RH-2. The flight vehicle provided the complete operational environment. The operator load was increased by the addition of system duties, and the stress level was increased. The subject (S) pilots lost the psychological advantage of knowing the experimental vehicle was "tied to the ground".

Throughout the entire flight test program, zero ceiling and zero flight visibility conditions were simulated paralleling the simulation of zero-zero conditions in the laboratory experiments.

It is suggested that criterion missions of a more sophisticated nature might be examined in subsequent testing to indicate the universal aspects of this design philosophy. It is anticipated that full compliance with information requirements for specific missions could be accomplished by building on the display system designed for ANIP/JANAIR and tested on basic maneuvers.



## II. THE RH-2 SYSTEM DESCRIPTION

### A. General

The system was developed with the objective of providing a flexible research vehicle in which to investigate the problems of instrument flight. More specifically, the system was designed with the intent of proving the feasibility of safe zero visibility flight in helicopters from takeoff to landing. Figure 1 is a photograph of the RH-2 flight vehicle.

The historical development of the RH-2 JANAIR system is traced in Figure 2 . As can be seen in this figure, work on the complete system was begun in 1957. Engineering flight tests of the complete system were made in 1963.

A data flow chart which includes the complete system and a more simplified block diagram of RH-2 system are contained in Figures 3 and 4 , respectively.

The primary instruments in the RH-2 system were the vertical and horizontal displays. The vertical display not only provided an analog picture of the real world, as seen through a forward looking window, but, at the pilot's option, an earth stabilized pathway and ground position identifier. On the horizontal display an aerial map or photograph of the terrain was shown along with other pertinent navigation information such as heading, course, ground track, etc. Grouped around these two primary displays were a number of auxiliary displays and controls showing other pertinent information and allowing the pilot to communicate with the system computers. Figure 5 shows the installation of the various components on the instrument panel of RH-2 aircraft. This pertains to a left panel area only and the arrangement of instruments available to the observer pilot in the right panel area remained standard.



Figure 1. Research Helicopter No. 2 (Bell UH-1 Iroquois Helicopter with JANAIR Flight System)

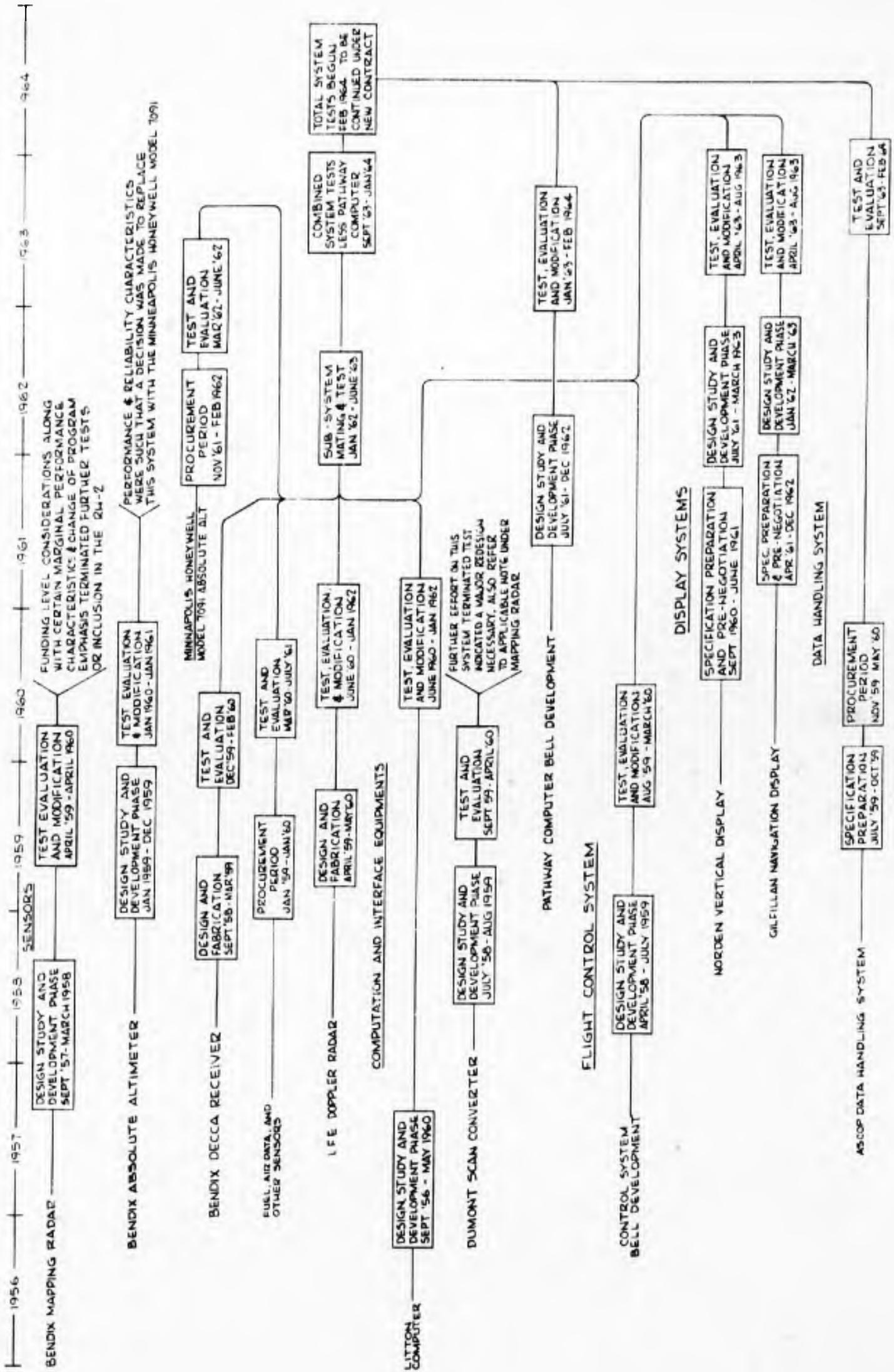


Figure 2. RH-2 Development History



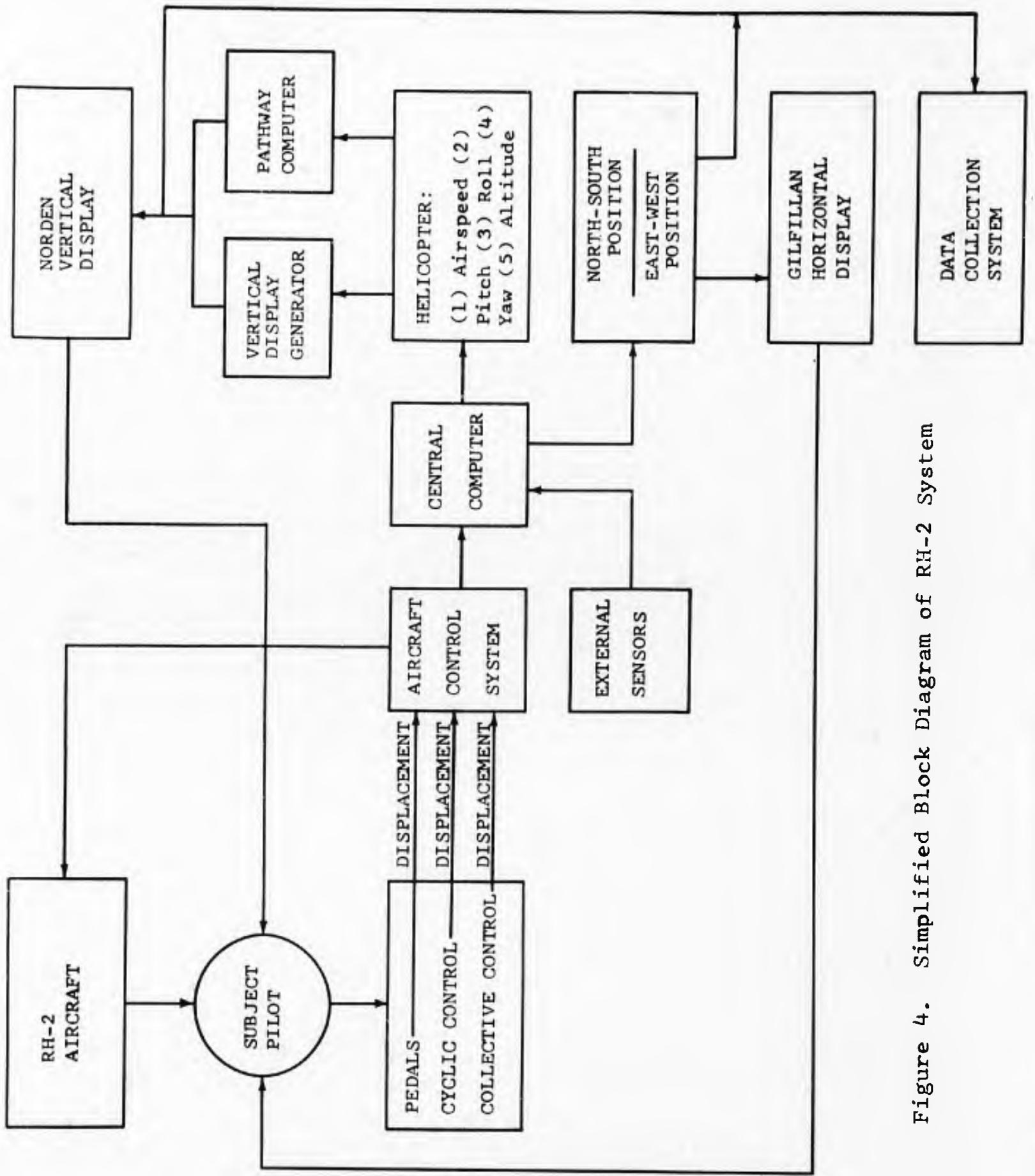


Figure 4. Simplified Block Diagram of RH-2 System

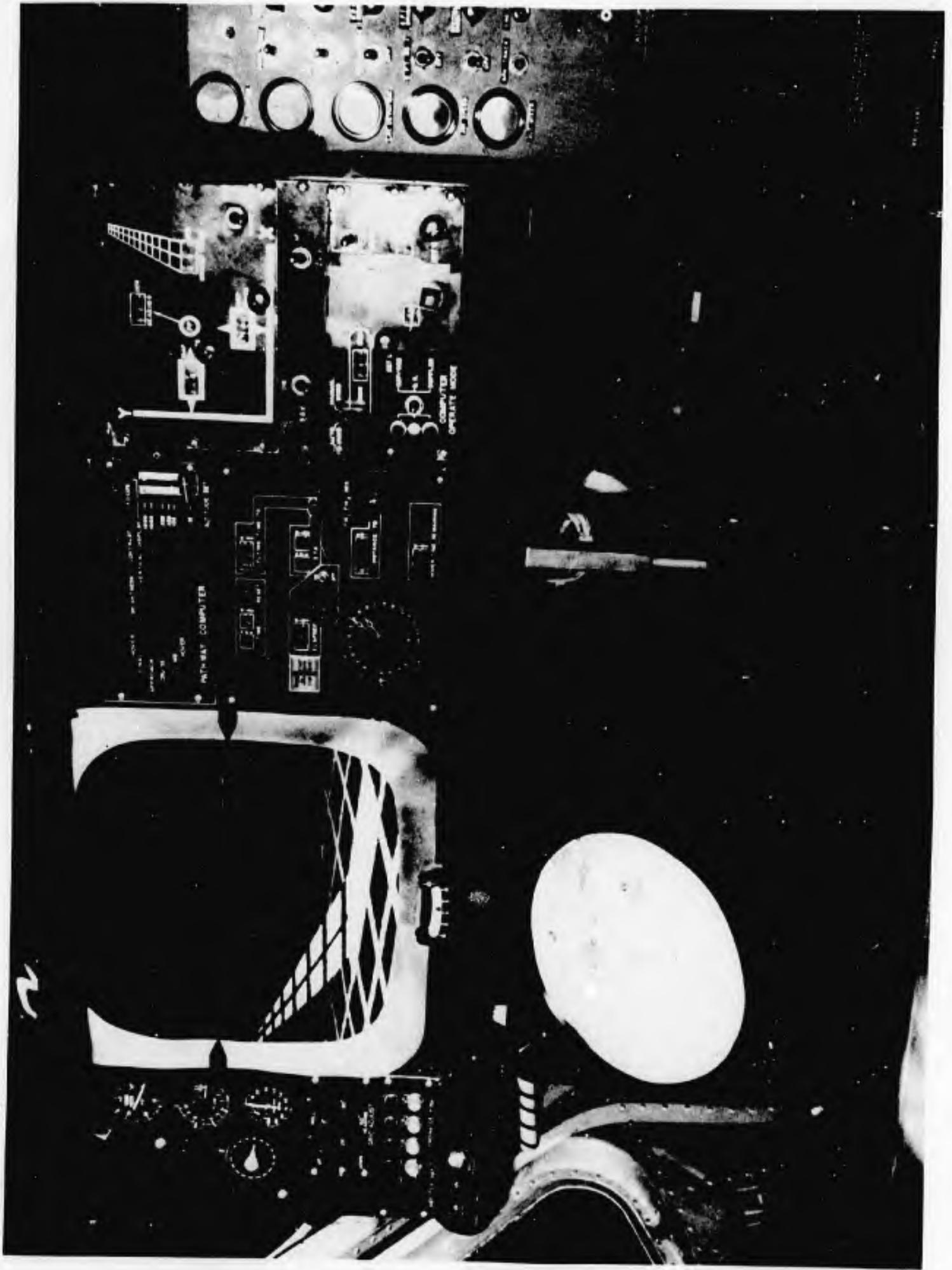


Figure 5. Cockpit Design



## B. Horizontal Display

A block diagram of the Horizontal Display System is shown in Figure 6 . In addition to the horizontal display itself, it included a navigation computer, various sensors and auxiliary displays. Basic navigation problems were solved by the navigation computer, a digital machine built by Litton Industries. It was programmed to solve problems associated with a three-legged cross country flight. The input data that were required is shown in Figure 6 , and the characteristics of the various sensed and handset inputs are summarized in Tables I and II. It may be noted that all input data is in the form of shaft encoders (or diode matrices) except for ground velocity which is in the form of pulse trains.

The primary computer mode of operation was "Decca/Doppler" in which accurate position information was obtained from a Decca navigation chain. It gave position in hyperbolic coordinates. Actually, the Decca receiver gave position within a Decca lane. Should the Decca signal be lost the computer reverted to Doppler which insured proper lane identification when the Decca signal becomes good. The second mode was "Doppler" in which the computer navigated solely on the basis of resolved Doppler ground speed data. Doppler accuracy was better than 99% of distance traveled. The computer could also be operated in the "Dead Reckoning" mode in which true airspeed (T.A.S.) was computed from indicated airspeed, outside air temperature, and pressure altitude. At cruising speeds, T.A.S. could be computed within one knot accuracy. However, position accuracy in this mode was determined primarily by the accuracy of the wind velocity and direction data.

The computer output characteristics are summarized in Table III. The computer computed and up-dated all quantities once every 1.2 seconds. The various output quantities were in the form of error signals which drove instrument type servos. Servo outputs were encoded by means of digital shaft encoders, with the servo loops being closed and errors computed within the computer. Thus, all computer outputs were converted to shaft positions which drove counters, indicators, map slides, etc. as required in the different displays.

Present position was computed to within 4.75 feet over an area of 200 miles square, exclusive of sensor errors. However, the present position output was capable of being scaled to cover any area within the coverage of the computer from 6.25 miles to 200 miles square. In all cases, the output was resolved into 4000 bits, giving a resolution of from 9.5 feet to 340 feet depending on scale.

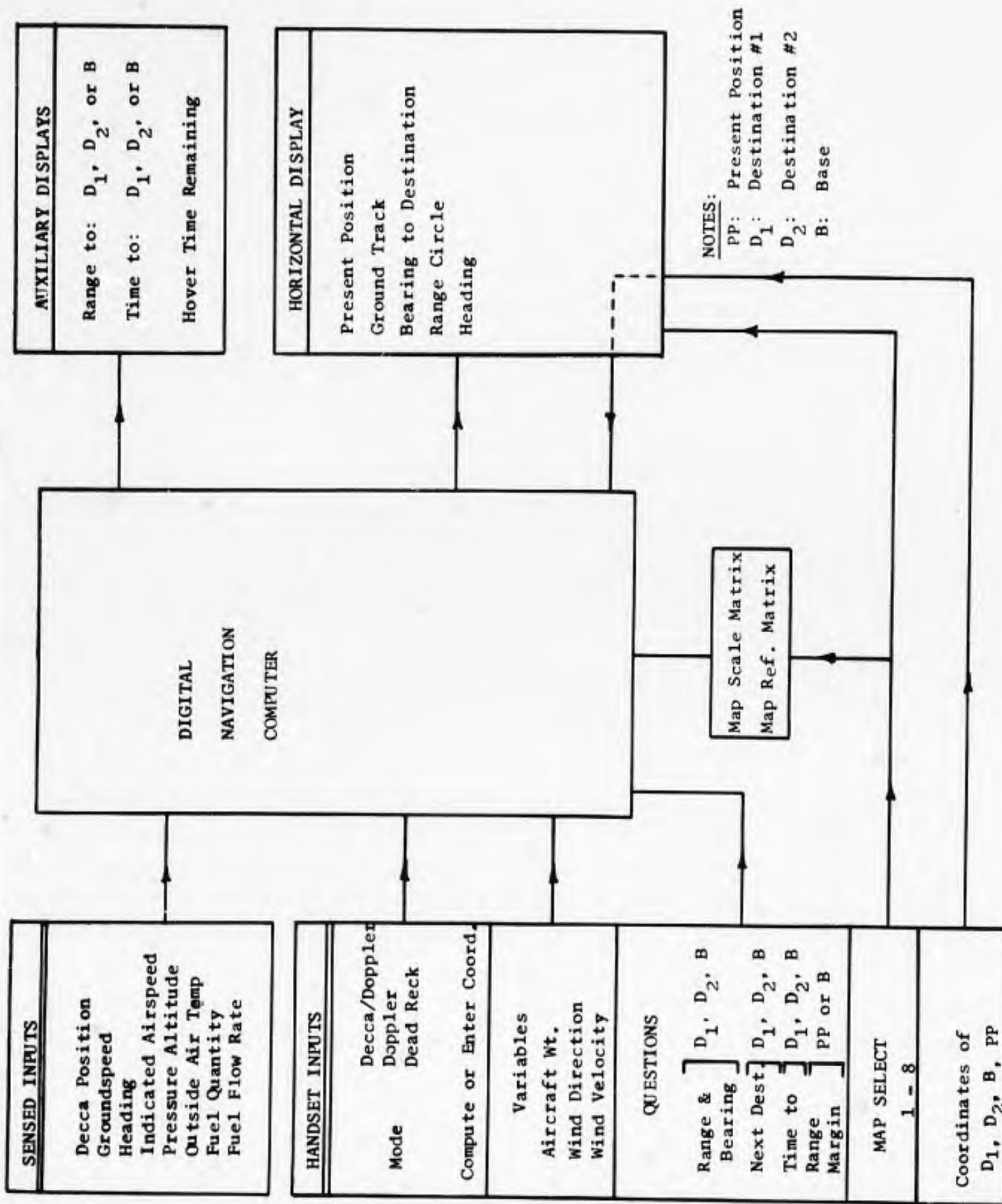


Figure 6. RH-2 Horizontal Display System



TABLE I  
RH-2 NAVIGATION COMPUTER SENSED INPUTS

SENSOR	QUANTITY	RANGE	FORM	SCALE FACTOR
Bendix RE/A-33 Decca Receiver	Aircraft position in a Decca Lane (hyperbolic coordinates)	100 mi. (approx.)	Shaft Encoder 8 bit	1 lane/256 bits approx. 8 ft/bit
Laboratory For Electronics APN/119-2	Aircraft N-S & E-W Ground Velocity	-50 to 200 Knots	Pulse Train	1.78 in/pulse
Sperry J-2 Compass	Heading	360°	Shaft Encoder 9 bit	0.7°/bit
G.M. Giannini 543-T-12 I.A.S. Sensor	Indicated Airspeed	25K-175K	Shaft Encoder 8 bit	0.6K/bit
G.M. Giannini 547 T-12 Pressure Altitude	Pressure Altitude	0-15000 ft.	Shaft Encoder 8 bit	60 ft/bit
Bendix 9156 Fuel Flow Sensor	Fuel Flow Rate	100#/hr - 600#/hr	Shaft Encoder 7 bit	3.9#/hr/bit
Simmonds Aero-cessories Fuel Quantity Sensor	Fuel Quantity	0 - 1125#	Shaft Encoder 7 bit	17.5 #/bit
MS 28034-1 Temperature Probe	Outside Air Temperature	-83.2°F to 146.3°F	Shaft Encoder 8 bit	0.9°/bit

NOTE: The resolution of each sensor is one bit as indicated by the scale factor.



TABLE II  
RH-2 NAVIGATION COMPUTER HANDSET INPUTS

INPUT QUANTITY	RANGE	SCALE FACTOR	FORM	DISPLAY OR CONTROL
Coordinates of present position	Within an area 200 miles square	*	Shaft Encoder	Horizontal Display
Coordinates of Dest. #1				
Coordinates of Dest. #2				
Coordinates of Base				
Map Scale	360 degrees	0.7°/bit	Shaft Encoder	Switch
Coordinates of Map Reference	0-60 knots	1 knot/bit	Shaft Encoder	Computer Control panel
Wind Direction (before takeoff)				
Wind Velocity (before takeoff)	4000-7000 Pounds	12#/bit	Shaft Encoder	Computer control panel
Aircraft Weight				

NOTE:

\* Coordinates of present position, destinations, and base are entered through the horizontal display. Accuracy and resolution of entered data is dependent on the map scale used for entering data.



TABLE III  
RH-2 NAVIGATION COMPUTER OUTPUTS

QUANTITY	RANGE	RESOLUTION	DISPLAYED ON
Aircraft Position	(1)	(1)	Horizontal Display (2)
Bearing to Destination	360°	0.7°	Horizontal Display
Ground Track	360°	0.7°	Horizontal Display
Range Margin (about base or present position)	250nm.	0.5 nm	Horizontal Display
Distance to Destination	250 nm.	0.08 nm	Time Panel
Time to Destination	6 hours	1 minute	Time Panel
Hover Time Remaining	3 hours	1 minute	Time Panel
Distance N-S to Destination	6.25 nm	9.5 ft.	Not displayed - used in other computations
Distance E-W to Destination	6.25 nm	9.5 ft.	Not displayed - used in other computations

NOTES:

- (1) Range and resolution of present position output is a function of map scale. Range varies between 6.25 nm to 200 nm with corresponding resolution of 9.5 ft. and 304 ft.
- (2) Aircraft heading is also displayed on the horizontal display. Heading is obtained direct from the compass.



The horizontal display which was designed and built by the Gilfillan Corporation was a direct view display employing a back projection system. It indicated present position on a moving map or aerial photograph. The projected image was seven inches in diameter. The aircraft symbol remained fixed in the center of the display with heading always up. Heading, ground track and bearing to destination were indicated by moving indices about the periphery of the map.

A simplified optical schematic of the display is shown in Figure 7. The map slide, which was approximately 1.4 inches square, was moved in X and Y by the map carriage servos. A fixed "heading compass ring reticle" and a moving "bearing to destination reticle" were inserted in the optical path. The image was then rotated by a single dove prism, following which a fixed reticle containing aircraft symbol, heading index, and a moving reticle of ground track were added. The entire image was projected onto a semi-specular screen backed with a fresnel lens. The fresnel lens gave an even distribution of light over the face of the display and the semi-specular screen, built by Eastman Kodak Company, concentrated the available light into an approximate 20° viewing angle. It eliminated almost all reflections and provided an image visible in bright sunlight.

As noted previously, the minimum map scale available within the computer (9.5 ft/bit) gave an area of 6.25 miles on a side. After completion of the computer design it was determined that a smaller area map was highly desirable. This was achieved by shifting the scan matrix to the map carriage shaft encoders over by 5 bits. This was equivalent to changing the 13 bit encoder to an 8 bit encoder. This yielded an additional external scale reduction of 32 and made possible a minimum area coverage of approximately 1170 ft. on a side. Actually, by appropriate display and computer scaling, almost any map scale could be provided. However, minimum resolution was 9.5 ft, regardless of scale.

The map carriage had provisions for 8 map slides. The S pilot could select any map he desired through a map select switch. The map select switch also applied voltage to a "map scale" and "map reference" diode matrix for the particular map selected. If the aircraft was within the area displayed, it was shown in its proper position. The time required to switch from one map to another was about 3 seconds.

The map slides for areas 12 miles square and above were standard aeronautical charts reduced to proper scale. Aerial photographs were used for the smaller area maps.

As noted in Table II, the horizontal display was also used to advise the computer of the coordinates of present position or destinations. This was accomplished by switching from "compute" to "enter coordinates" on the Navigation Panel. The appropriate

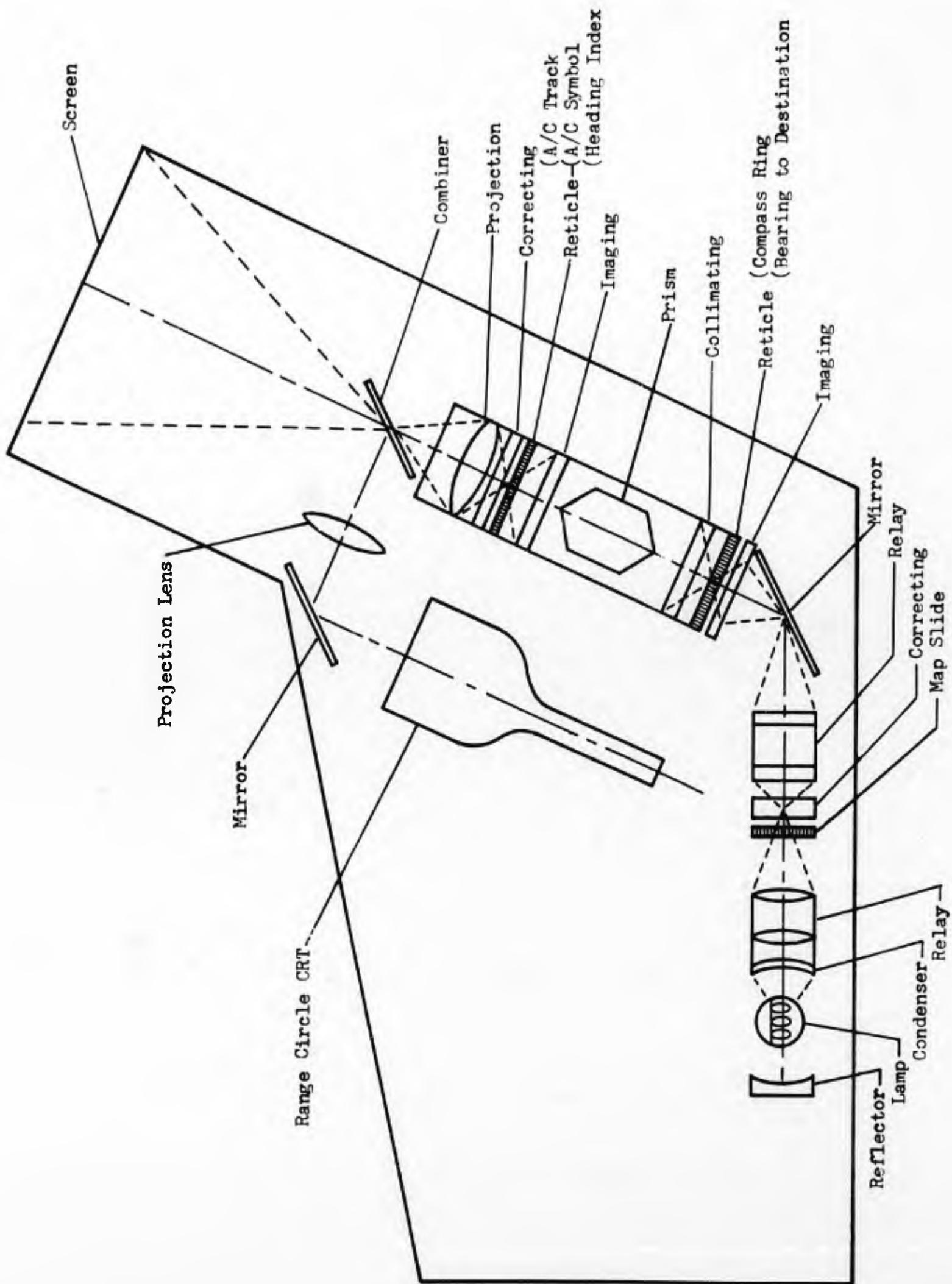


Figure 7. Horizontal Display Optical System



map was then selected and the map was slewed to the desired position. Pushing the proper selector on the control panel, i.e. "present position," "fix 1," "fix 2", or "dest", caused the computer to "read" the map carriage position. This position was then stored in the computer and used in further computations. The pilot could enter new destinations at any time he desired.

### C. The Vertical Display

The Vertical Display Generator was designed and built by the Norden Division of United Aircraft Corporation. The system utilized standard T.V. techniques to synthetically generate on a T.V. monitor a picture of the real world as it appeared through a forward looking window in the aircraft. It was a 500 line system utilizing interlaced scan at 30 frames per second. The generator was basically an electronic analog computer which accepted inputs from various sensors and transformed the position of the various display elements in earth coordinates into screen coordinates. These computed quantities were converted to video signals and properly synchronized with the vertical and horizontal deflection currents of the T.V. monitor. The system was capable of generating the following elements:

- A ground plane
- A flight pathway with tarstrips and speed command marker
- A Ground Position Identifier located at the end of the pathway
- A Ground Position Identifier positioned independently on the ground plane
- Sky texture (clouds)
- Director Symbols in the form of a cross and square

All display elements could be individually blanked. The ground texture GPI and pathway had six-degrees of freedom. The cloud texture moved only in response to pitch, roll, and yaw inputs, and was used primarily for orientation information during extreme attitudes when the horizon line or ground texture became obscured.

Table IV defines the input signal requirements for the display generator. Although the ground plane inputs could be provided from standard sensors, the pathway and GPI required computed navigation type inputs, since they were positioned relative to a fixed point on the earth. It was imperative that the flight path and/or GPI be synchronized with the horizontal display, which was driven by the navigation computer as previously discussed. Unfortunately, the navigation computer did not have the additional capacity nor data rate required for the pathway computations. Consequently it was necessary to design and build a separate analog computer to position the pathway.

The computer integrated resolved doppler ground velocity to determine aircraft position relative to the pathway and GPI. However, because of errors in doppler, even though small and inte-



TABLE IV

## INPUT DATA FOR RH-2 VERTICAL DISPLAY GENERATOR

DISPLAY ELEMENT	INPUT SIGNAL	RANGE	FORM
Ground Plane	Pitch	360°	Synchro
	Roll	360°	Synchro
	Yaw	360°	Synchro
Sky Texture (clouds)	N-S Ground Velocity	-40 to 200 K Longitudinal	Pulse Train
	E-W Ground Velocity Altitude	±40K Lateral 0-6000'	Pulse Train 3 Potentiometers
GPI #1	None (Texture remains parallel to ground plane)		
Pathway	N-S Distance to Destination	0-96000'	3 Potentiometers
	E-W Distance to Destination	0-96000'	3 Potentiometers
	Path Bearing	360°	Transolver
	Path Slope	0 - 90°	Transolver
	Distance to end of path Lateral deviation from Path Vertical deviation from Path	0 - 128,000' 0 - 6000' 0 - 300'	3 Potentiometers 2 Potentiometers 1 Potentiometer
Path Tarstrips	Velocity along Path	50 Knots	A.C. Analog Voltage
Path Speedmarker	Speed Error	± 40 Knots	A.C. Analog Voltage
GPI #2	None (tied to end of path)		
Director Symbols, cross and square			D. C. Voltage



gration errors, it could not be expected that the output of the pathway computer would be sufficiently accurate to present landing and precise navigation information unless special precautions were taken. This problem was solved by using position information from the navigation computer to correct the pathway computer output at a slow rate. The technique was comparable to that used in a magnetically slaved directional gyro. The pathway computer was thus interlocked with the navigation computer such that the end of the pathway (or GPI) was located at the "next destination" set in the computer. Steady state errors between the vertical display and horizontal display were reduced to approximately the resolution of the computer output, i.e., 9.5 feet.

The computer provided cruise, takeoff, and landing modes of operation. In all modes the basic position computations were identical but altitude, speed command and pathway slope varied as a function of maneuver. Tar-strip speed, speed error, and attitude error signals were computed by conventional analog techniques. A block diagram of the entire vertical display system is shown in Figure 8 .

It is beyond the scope of this report to give a more detailed description of the RH-2 system. Rather, the intent has been to provide insight into some of the basic ideas and engineering concepts that went into its development. Figure 9 shows the two displays as observed by the Subject pilot during airborne operations. Figure 10 illustrates the vertical display rear projection.

#### D. The RH-2 Data Acquisition System

The Airborne Acquisition System is shown in Figure 11 . It had provision for recording seven channels simultaneously. Only two were used during any one flight, one being used to record voice information, the second used for data.

Technical information relevant to the recorder is as follows:

- 30 data channels, two of which were utilized for sync signals
- Sampling rate - 30/sec.
- Signals which were recorded - low frequency to D.C.
- Minimum tape speed - 15 inches/sec.
- Voltage level 0-5 volts
- Recording tracks and heads - seven only two of which are simultaneously in use.
- Power (1) 27.5 volts D. C. + 10%, -20% at 3.5 amps  
(2) 115 volts A.C.  $\pm$  10% at 400 cps  $\pm$  20 cps and 6.1 amps

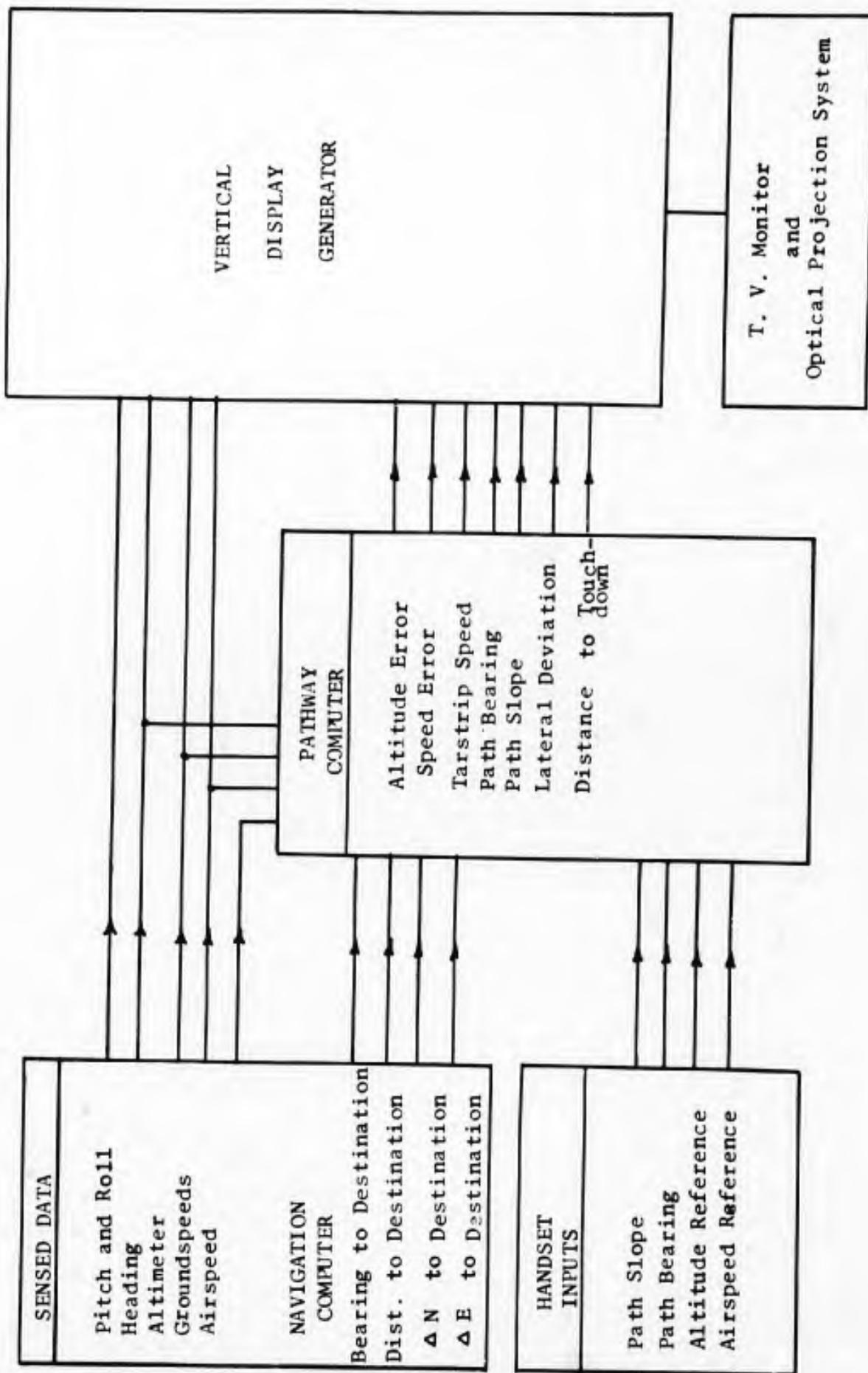


Figure 8. Vertical Display System

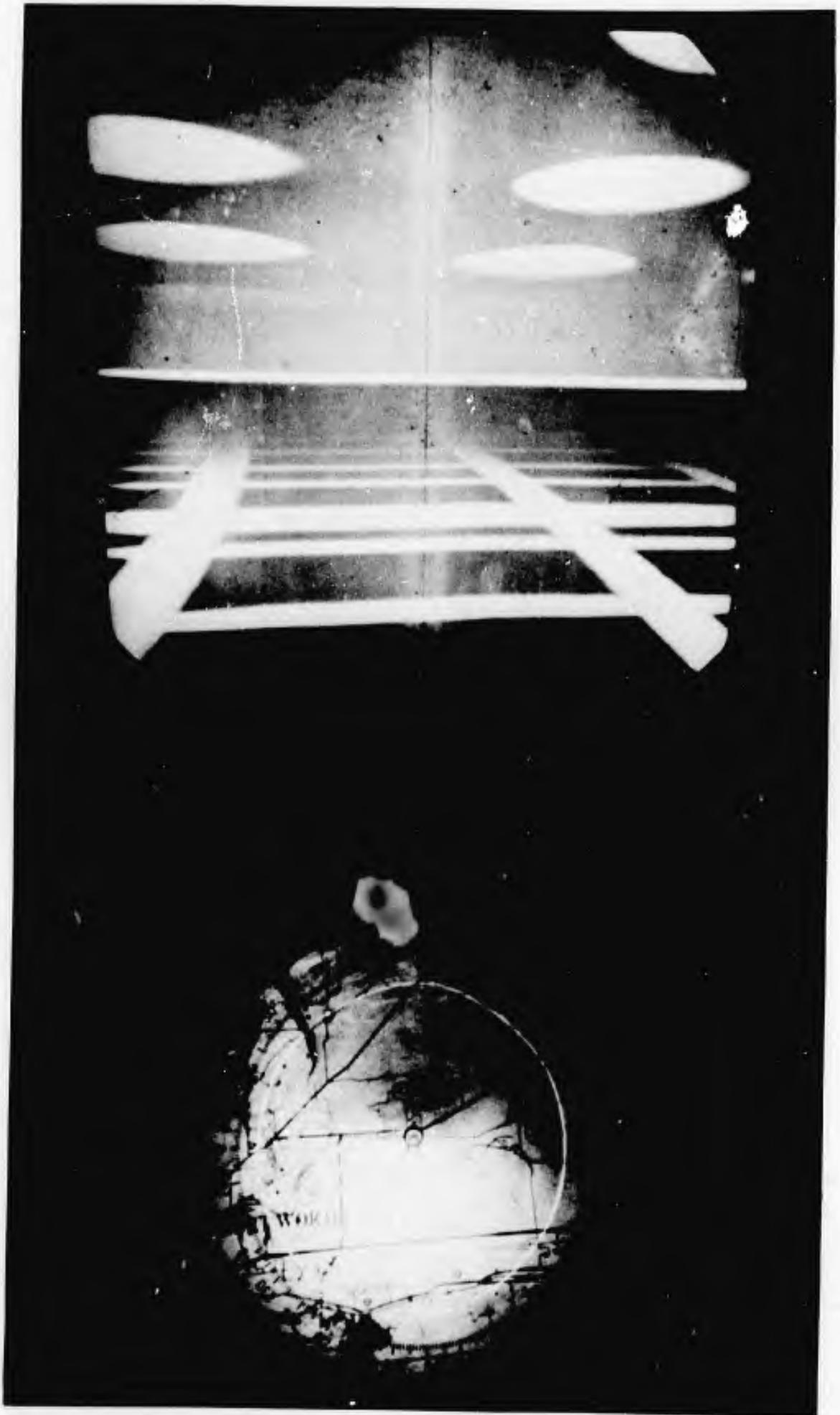


Figure 9. Photograph of Displays of Vertical and Horizontal Displays as Viewed by the Pilot

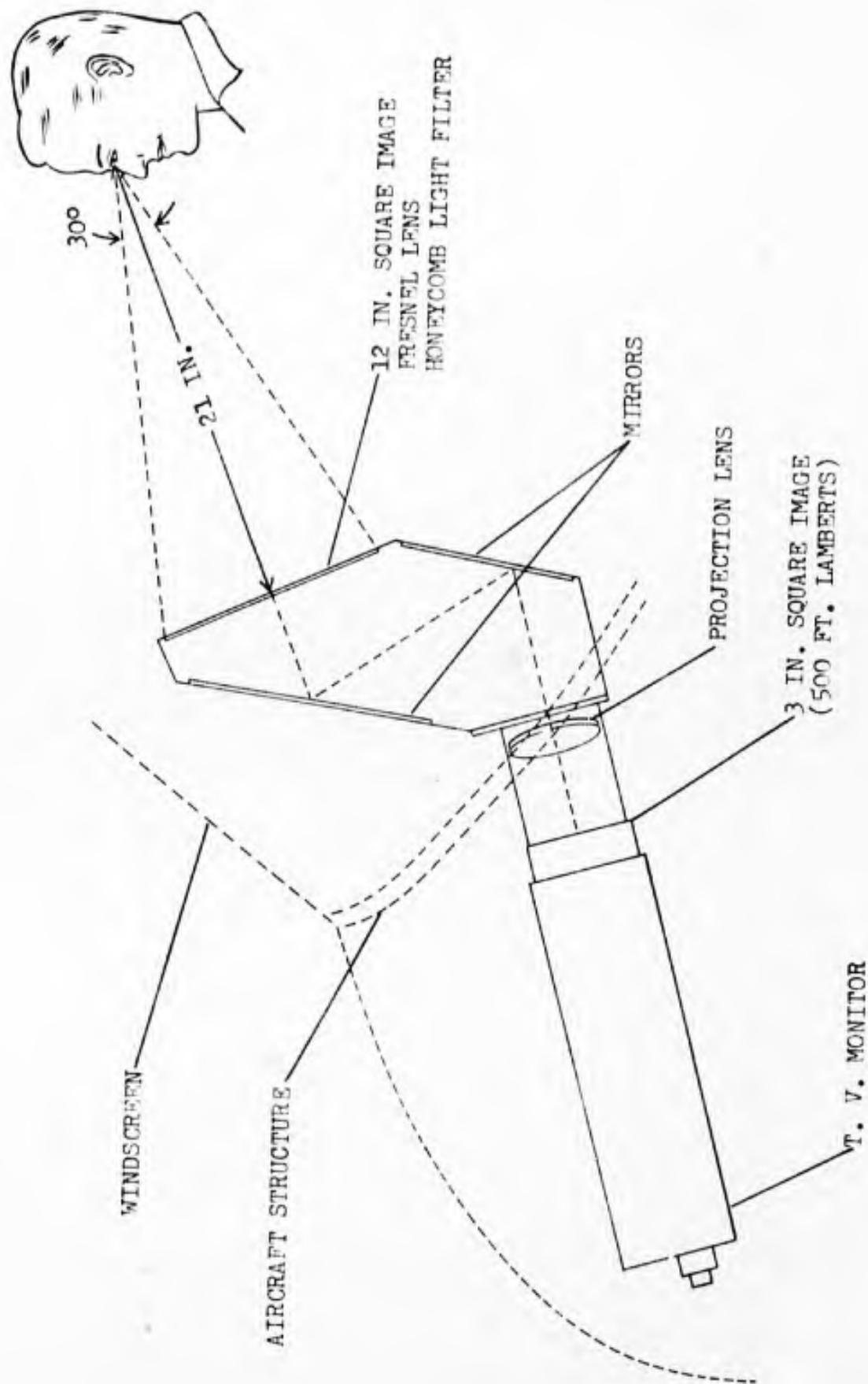


Figure 10. RH-2 Vertical Display Back Projection System

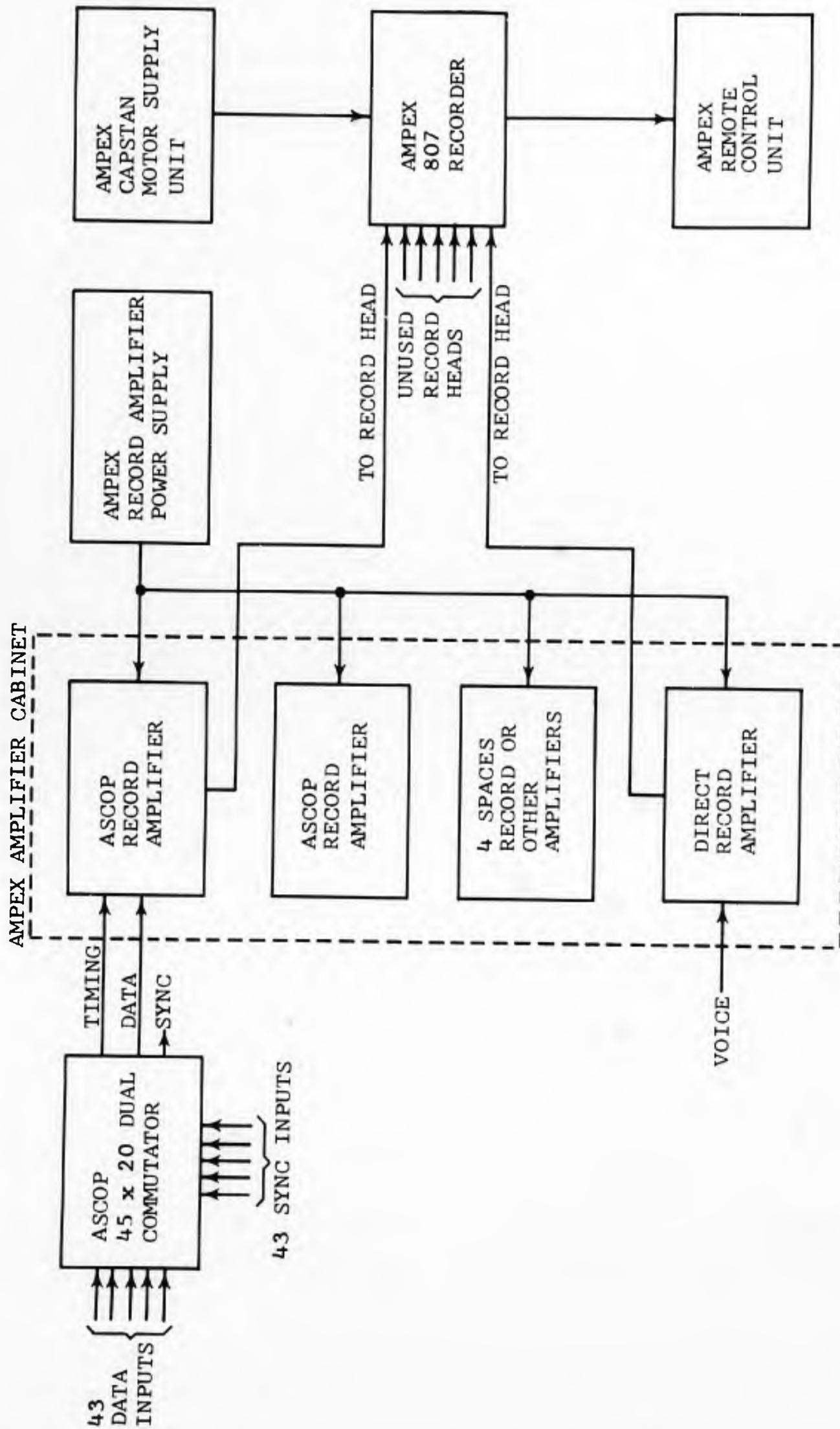


Figure 11. Airborne Data Acquisition



The remote control unit was located to the rear of the center pedestal so as to be readily accessible to the E. It contained the following:

- Power on-off switch for system electronics
- Start tape transport switch
- Master timer 28 volt control signal to record the beginning of data
- Master timer off control signal terminating data taking
- Stop tape transport switch either manual or automatic

#### E. RH-2 Controls and Stabilization System

The control system was designed about a cyclic stick, a collective stick, and rudder pedals, with the cyclic stick configured as a side arm controller. The stabilization system had modes generally associated with current SAS systems, namely:

- A "normal" mode in which aerodynamic control position was directly related to controller motion.
- A "damper" mode which provided short term stabilization only.
- An "attitude" mode which provided steady state control of pitch, roll and heading, with rate of change of the controlled variable proportional to applied force.

A "fly by wire" system was chosen, i.e., no mechanical link between the controllers and the actuators. Since a check pilot was aboard at all times, no safety problems were introduced by this type of system.

Consideration was given to performing the stabilizing computations in the centralized digital computer, designed and built by Litton Industries. However, simulation of the digital computer indicated that performance might be marginal. Problems of signal conversion, generation of complex networks (notch filters, for example), etc. also were considered. In the end it was decided that the stabilizing and control computations would be accomplished by conventional analog techniques and packaged as a separate analog module in the computer rack.

From this point on, the project became a typical hardware program involving system synthesis and hardware design.

The system was analyzed by the use of the root-locus technique. From the linearized differential equations of motion, transfer functions were developed. The decoupled pitch axis transfer functions at hover were:



$$(1) \quad \frac{a}{b} = \frac{50S}{(S + 0.60)(S - 0.09 \pm j 0.33)(S + 11)} \quad (1)$$

$$(2) \quad \frac{v}{b} = \frac{370 (S \pm j 2.10)}{(S + 0.60)(S - 0.09 \pm j 0.33)(S + 11)} \quad (2)$$

where:

a = pitch angle in radians  
 b = fore and aft swashplate angle in radians  
 v = velocity in ft/sec

The procedure for stabilizing velocity was to first stabilize pitch attitude by use of pitch attitude and pitch attitude rate feedback. Velocity functions were then fed back around the stabilized pitch loop.

The pitch feedback function may be expressed as follows:

$$B_a = K_a + K_{\dot{a}} S = K_{\dot{a}} S + \frac{K_a}{K_{\dot{a}}} \quad (3)$$

where:

$K_a$  = degrees swashplate per degree attitude  
 $K_{\dot{a}}$  = degrees swashplate per degrees per second attitude

In addition to this function, a low pass first order filter was added to attenuate the two-per-rev rotor induced noise of approximately 10 cps. This term was inserted in the forward loop and lumped with the power servo. The power servo loop had a bandpass of approximately 60 radians per second and was considered only as a gain term. The servo-filter combination then became:

$$G_s = \frac{W_s K_s}{S + W_s} \quad (4)$$

where  $W_s = 10$  radians per second.

In order to preclude excessive switching of gains when switching modes, it was desirable that the gains selected for this "inner" loop be used for the attitude mode. The design criteria for the attitude mode was a  $W_n$  of approximately 1.5 radians with a damping of 0.7. These criteria determined the value of the feedback zero (position to rate ratio) as being between 1.0 and 1.5 with a rate gain in the vicinity of 0.4.

The low frequency approximation of the closed loop attitude transfer function was:

$$\frac{a}{i} = \frac{35S}{(S + 1.5 \pm j 1.5)(S + 4.5)} \quad (5)$$



where:  $i$  = input to servo.

With equation (5) as a starting place, we obtain velocity as a function of attitude from Equations (1) and (2).

$$\frac{v}{a} = \frac{7.5 (S \pm j 2.1)}{S} \quad (6)$$

The basic outer loop closure was the integral of velocity since it is desirable to have zero velocity error at hover. To achieve a reasonably fast velocity response, it then became necessary to add velocity and acceleration feedback. The total feedback function was then:

$$\begin{aligned} B_v &= \frac{K}{S} \int v + K_v + K_{\ddot{v}} S \\ &= \frac{K_{\ddot{v}}}{S} S^2 + \frac{K_v}{K_{\ddot{v}}} + \frac{K}{K_{\ddot{v}}} v \end{aligned} \quad (7)$$

where:  $K \int v$  = radians per foot  
 $K_v$  = radians per foot per second  
 $K_{\ddot{v}}$  = radians per foot per second<sup>2</sup>

In general, the object was to move the feedback zeros as far to the left as possible, the limiting point being the point where they lost control of the poles near the origin. The gain limit was established by the position of the conjugate complex poles which moved to the zeros on the imaginary axis, giving an under-damped system for the higher gains. The feedback gains selected for the hover condition were:

$$\begin{aligned} K \int v &= 0.0036 \\ K_v &= 0.012 \\ K_{\ddot{v}} &= 0.01 \end{aligned}$$

The above analysis was repeated for cruising speeds. At 100 knots airspeed at sea level the transfer functions were:

$$\frac{a}{b} = \frac{41 (S + 0.012)(S + 0.75)}{(S + 9.6)(S + 0.11 \pm j 0.19)(S + 0.57 \pm j 1.25)} \quad (8)$$

$$\frac{v}{b} = \frac{880 (S + 0.48)(S + 0.002 \pm j 1.62)}{(S + 9.6)(S + 0.11 \pm j 0.19)(S + 0.57 \pm j 1.25)} \quad (9)$$

It is noted that an extra degree of freedom was added, due to coupling of vertical velocity. This gives two oscillatory modes. However, both modes have positive damping at this speed. No stability problems exist, and the closed loop root structure became quite similar to the hovering condition. However, the hover



requirement for a fast velocity response was undesirable at cruising air speeds. Therefore, all velocity function gains were programmed inversely with airspeed. This produced a relatively "soft" system insofar as gust response was concerned. From the pilot's standpoint, the system tended to revert to an attitude control, transient wise. Steady-state wise, however, the change in airspeed per unit stick displacement remained the same.

Analysis of the roll axis is almost identical to the pitch axis. The major difference was that the system time constants were lower due to lower inertia. At hover, for example, the oscillatory mode had a period of approximately 10 seconds compared to 20 seconds for pitch.

Mechanization of the system was relatively straightforward. A simplified block diagram of the pitch axis is shown in Figure 12. Airspeed was fed through a velocity mixer which functioned as a simple follow-up servo above 30 knots airspeed. Output of the mixer was summed against stick position to produce a velocity error signal which was fed to the pitch command integrator. Output of the integrator drove the power servo through a summing amplifier. Airspeed acceleration was derived from the tachometer on the velocity mixer. This acceleration signal was also integrated through the command integrator to give the velocity feedback term. Although this was a rather roundabout way to obtain velocity, it simplified switching and synchronization. Attitude from a vertical gyro was summed through the command integrator control transformer. The rate signal from a rate gyro was fed directly into the summing amplifier.

During the transition phase from airspeed to ground speed control (between 60K and 30K), all velocity gains were programmed inversely with airspeed. Also during this phase, a different signal of ground speed minus airspeed was fed into the velocity mixer. The gain of this signal was varied linearly from zero to one during this transition. Thus at airspeeds below 30 knots the net effective input to the velocity mixer consisted of ground speed only. Also at the 30 knot point, the time constant of the mixer was increased by increasing the tachometer loop gain. Simultaneously a ground acceleration signal was fed into the mixer. The mixer then functioned as a low pass filter for the ground speed signal (derived from a doppler radar) and as a high frequency integrator for the acceleration signal. The accelerometer signal was also submitted for derived airspeed acceleration.

It is noticed that stick position was also fed directly to the power servo. There were two reasons for this. First, during the normal (no feedback) mode this signal was required to position the actuator. It simplified the switching and synchronization problem if it was retained for the succeeding modes.

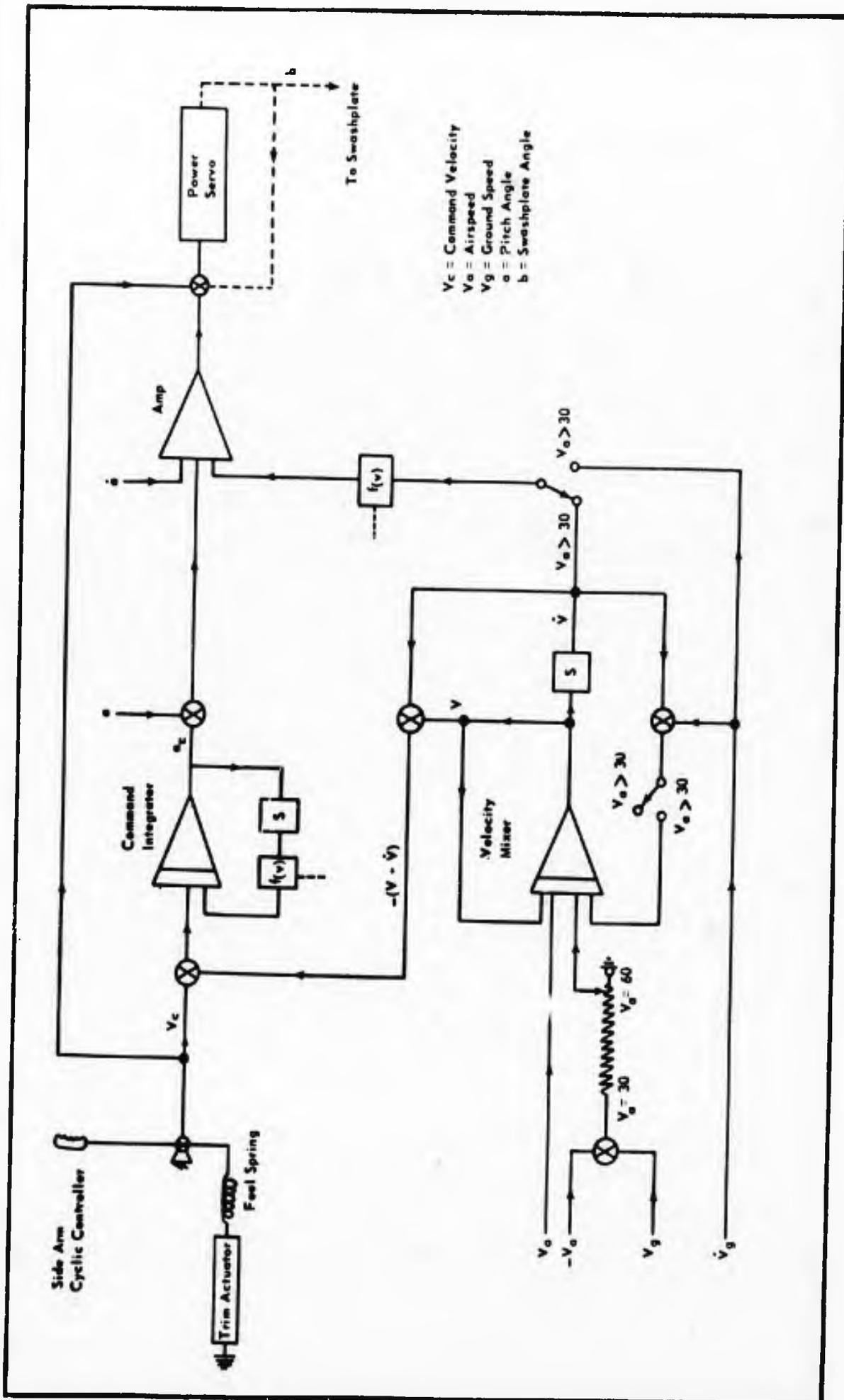


Figure 12. Block Diagram of Pitch Axis Stabilization.



Second, and perhaps more important, it furnished a lead term. Without it, maneuver entry tended to be somewhat sluggish.

The stick was referenced to ground (structure) through a trim jack and a feel spring, providing a linear force versus deflection curve. For any steady state position the pilot could trim out his stick force by positioning the trim jack.

Time histories to a step input, obtained from analog computer runs are shown in Figures 13 and 14 for zero and 100 knots respectively.

The lateral axis was almost identical with the pitch axis with the exception that at cruising speeds, lateral cyclic became a rate of roll control instead of a velocity controller. This was accomplished by commanding the roll command integrator from a stick force signal. As in the pitch axis, the feed forward signal was retained.

The yaw axis was handled analytically as a separate independent degree of freedom. It reduced to a simple second order system and presented no stability problems. To prevent large standoff heading errors due to power changes, the integral of heading error was required as a feedback term. Heading and heading rate feedback were also required.

A block diagram of the yaw axis is shown in Figure 15. As in the cyclic controller, pedal forces were referenced to ground through a trim jack and a feel spring. Pedal force, measured by the compression of the feel spring, commanded a rate of heading change through the command integrator. Pedal position was also applied directly to the power servo. The heading integral term was obtained by commanding the trim jack from the heading error. During maneuvers this supplied a force feedback term to the pedals, making the steady state turn rate a function of force only. This was, in effect, a combination series-parallel system since the high frequency position and rate terms were applied as series signals through the summing amplifier.

At cruising speeds, coordinated turns were made as a function of bank angle. In the past, some difficulties had been experienced in making coordinated turns by the use of accelerometers because of noise and roll to yaw coupling. It was decided to try an "open loop" type coordination based on bank angle and velocity. For a level coordinated turn, the following equation must be satisfied:

$$\dot{\psi} = \frac{g}{v} \tan \gamma \frac{g}{v} \quad (10)$$

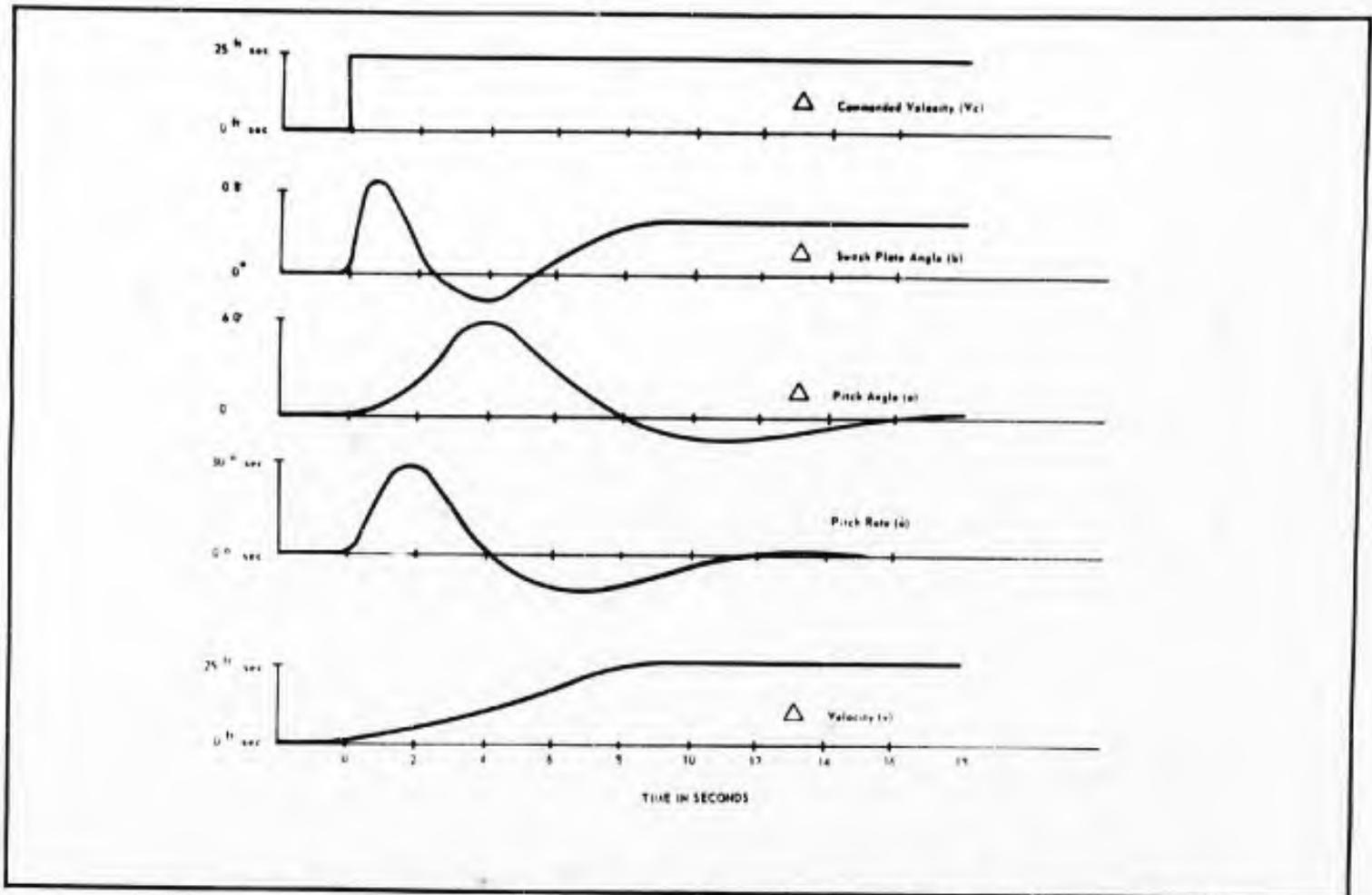


Figure 13. Pitch Axis Transient Response at Hover.

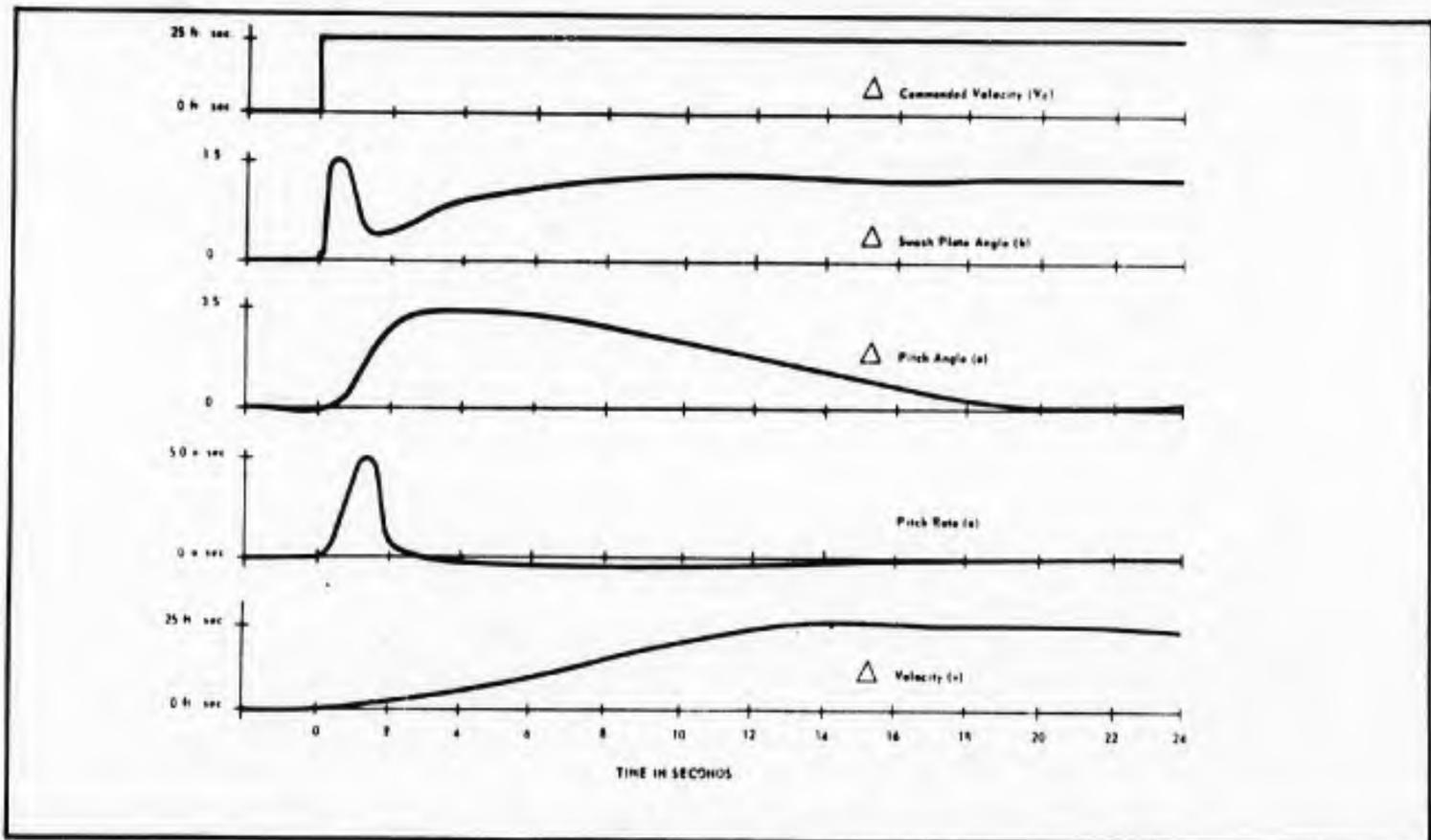


Figure 14. Pitch Axis Transient Response at 100 Knots.

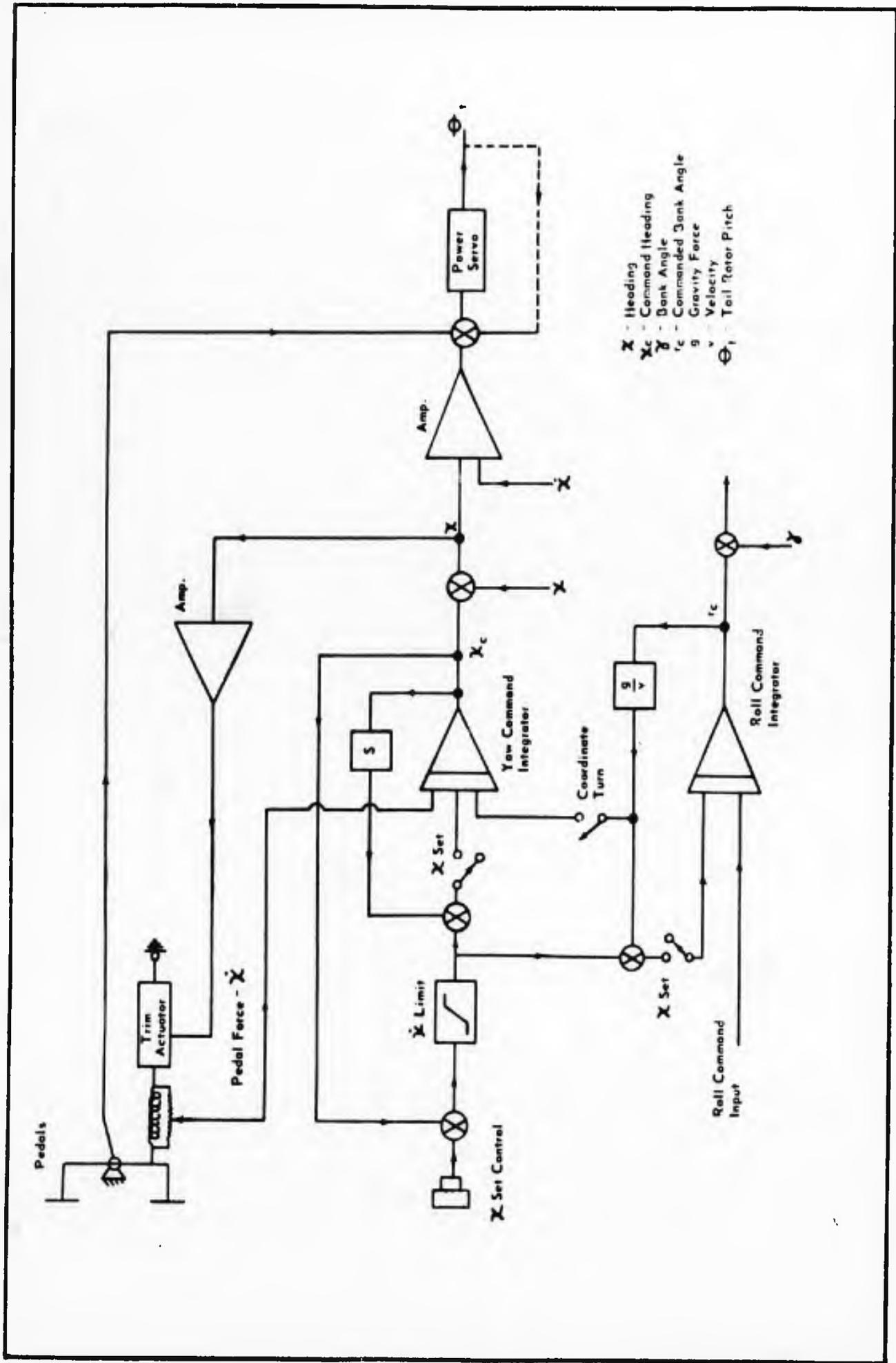


Figure 15. Block Diagram of Yaw Axis Stabilization.



where:

$\dot{\psi}$  = turn rate  
g = gravity force  
v = velocity  
r = bank angle

This equation was mechanized by driving the yaw command integrator from commanded bank angle (taken from the roll command integrator) programmed inversely with airspeed.

During the cross-country flights it was felt that a heading set feature was desirable, which would allow the pilot to command a new heading by merely setting a knob. This feature was used in conjunction with a navigation display. This was accomplished by converting the yaw command integrator to a follow-up servo. A heading set signal (from a control transmitter) was summed against commanded heading (a control transformer). The resulting error signal was limited and fed into the servo amplifier. Transientwise, the heading servo functioned as a velocity servo, with the maximum rate determined by the value of the limited input signal. The helicopter was obliged to follow along at this turn rate. Steady-state wise, however, the commanded heading and actual heading, was equal to the heading set. Coordination during this maneuver was accomplished by commanding a bank angle as a function of turn rate and airspeed. As shown in Figure 15, this was done by inserting the airspeed function pot in the feedback loop of the roll command integrator. Thus, Equation (10) is turned inside out and mechanized in the following form:

$$\gamma = \frac{\dot{\psi} v}{g} \quad (11)$$

The collective or altitude axis was basically a repeat performance of the yaw axis. Rate of change of altitude was a function of force. At cruising speeds a barometric altitude reference was used. For the hover condition (below 30 knots airspeed and below 200 feet absolute altitude) an absolute altitude reference was used. In order to achieve a smooth transition a step switching function is used, based on altitude and speed as noted above.

In general, conventional type hardware was used in the system. All signal transducers were of the inductive type, synchros and linear transformers, except for the force transducers which were linear potentiometers. The circuitry was transistorized and packaged on plug in circuit cards 3-1/2 by 4-1/2 inches. Valve amplifiers and motor amplifiers utilized printed circuit construction. Other circuits were assembled with standard component board construction. All signal switching was accomplished directly on the cards.

The power actuators were designed and manufactured by Hydraulic Research and Manufacturing Company and replaced the standard hydraulic power servos in the UH-1. They featured two modes of



operation, manual and electrical. In the manual mode they functioned exactly like the standard system with the valve spool being positioned by the standard mechanical controls. In the electrical mode, the manual input was locked out, and the valve spool was positioned by a conventional electrical flapper valve. A mechanical feed back spring was connected between the output piston and the flapper. Thus for a given input current to the valve torque motor, the actuator moved until the force exerted by the torque motor was overcome by the force exerted by the feedback spring. The net result was a positioning actuator with output position proportional to input current. A nominal force on the manual input linkage overrode the lock-out pistons, and the unit reverted to the manual mode. In the RH-2, the copilot flew the helicopter through a standard set of controls and could assume control when he so desired. The test pilot flew through the "fly by wire" controls, utilizing the electrical mode of the actuators.

All of the basic sensors except ground speed and absolute altitude were standard "off the shelf" items with the exception that in some cases the output transducers were modified to fit a particular requirement. The majority of the sensors also provided data for the display and navigation systems.



Figure 16. Side Arm Controller.

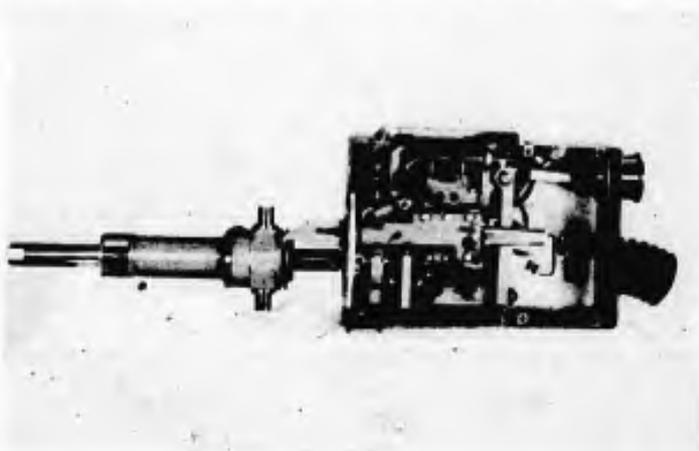


Figure 17. Side Arm Controller Power Servo.

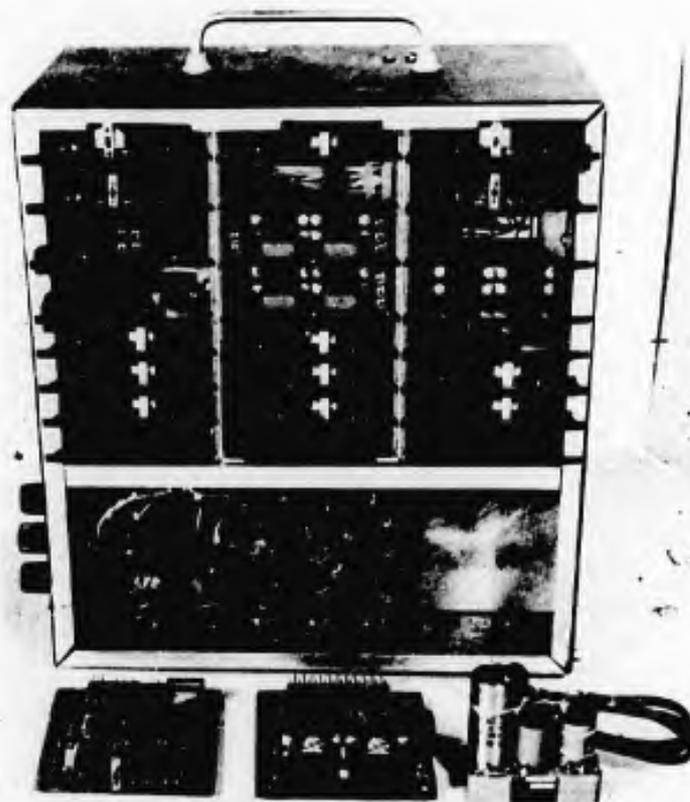


Figure 18. Side Arm Controller Electronics Package.



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Photographs of the side arm controller, the power servo, and the electronics package are shown in Figures 16 through 18.

In conclusion, it should be pointed out again that the system was used as a research tool to investigate control functions in conjunction with display functions. The design began with generally accepted control concepts but provided the flexibility and the data sources to mechanize a wide variety of controller configurations and system dynamics.



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### III. SUBJECTS

Six Bell Helicopter Company employees served as subjects in these two experiments. All were qualified licensed helicopter pilots with flight experience ranging from 500 to 1400 hours. Only two of the six were rated to fly instruments. They had all participated in numerous simulator studies, but only one of the S had in excess of 150 hours of UH-1 experience. Two of the S participated in both studies. It was initially planned to utilize the same four Ss for both studies, but two were unable to participate in the second experiment due to other work commitments. They were replaced prior to the familiarization phase of Experiment II.



#### IV. EXPERIMENT I - HOVER STUDIES

##### A. Introduction

As a part of the studies representing a comprehensive flight evaluation of the JANAIR pictorial displays, some of the most critical are those at hover, air taxi and ground contact. Conventional instrumentation does not permit performance of such maneuvers. They were the first examined in this series of studies.

The selection of the vertical display configurations was based upon the findings in the simulator studies for comparable flight modes. The display consisted of the basic grid, incorporating the ground position indicator (GPI). Details of this presentation are presented in another section of this report.

Performance was tested under four conditions of control stabilization. These included:

1. "Fly-By-Wire" or "Normal" Mode - A mode in which aerodynamic control position was directly related to controller motion.
2. "Damper" Mode - This mode provided short term stabilization only.
3. "Attitude" Mode - This mode provided steady-state control of pitch, roll and heading with rate of change of the controlled variable proportional to applied force.
4. "Attitude" Mode with Altitude Hold (Simulated) - This was the same as (3) above with the addition of an altitude hold capability, simulated by the safety pilot.

The task required the Subjects (Ss) to maintain altitude, heading and position. Command altitude was established so that at the initiation of the trial the helicopter was at a hover height of fifteen feet above the ground. Command heading was the cardinal heading which yielded a direct or quartering headwind; and the initial X-Y position, which also was command, was 125 feet aft of the GPI. This was the situation which the safety pilot established for the initiation of each S testing trial. Error scores were collected about the command values of the aforementioned parameters, altitude, heading and X-Y position, throughout each testing trial.

##### B. Tasks and Procedures

Hovering is one of the most demanding tasks of the helicopter pilot. It requires accurate error-nulling about all parameters. One of the most difficult to display is the translations in all 360°. Information requirements had established a maximum rate of approximately 1/2 knot. To display this data in all lateral as



well as fore-aft vectors provided a critical test of both sensors and display interpretability.

The flight test studies evaluated S performance in the hover mode under the four conditions of control system stability previously described. Henceforth, these shall be referred to as the normal mode as CM1 (Control Mode 1), the damper mode as CM2, the attitude mode as CM3, and the attitude mode with simulated altitude hold as CM4.

The task required the S to perform the hover maneuver at a command altitude. (This altitude was always within ground effect.) The task also required maintaining a command hover position and heading. This task was to be accomplished for a two minute duration in each of the four control modes. The S was informed of the control mode prior to each trial. The observer pilot set the initial conditions by lifting off to approximately 15 feet altitude and a cardinal heading. The GPI appeared on the vertical display just below the haze layer beneath the horizon line, thus approximately 125 feet forward of the aircraft. An illustration of the task is contained in Figure 19. After having set up these initial assigned conditions and having assured that the S was prepared to assume control, the observer pilot engaged the secondary system with a toggle button located on the cyclic control. At this point, the observer pilot informed the S, "You have the controls." The trial terminated either upon completion of 120 seconds of flight or upon takeover by the observer pilot due to some marginal flight condition.

Four Ss were tested in four experimental sessions, each consisting of four trials in each of the four control modes for a total of 16 trials per session. The duration of each trial when completed was 120 seconds. The first two sessions were composed of eight VFR and eight simulated IFR trials presented in counterbalanced order. The final two sessions each consisted of 16 IFR trials, four in each control mode and presented twice with two repetitions each in a counterbalanced design. The continuance of the contact flights during the third and fourth sessions was not considered necessary for two primary reasons: (1) all Ss had reached asymptotic level of performance in all control modes under VFR conditions by the end of the second session, (2) it was felt that the time could be better utilized for IFR flights, i.e., twice as many IFR trials could be accomplished in the final two sessions if the VFR trials were suspended.



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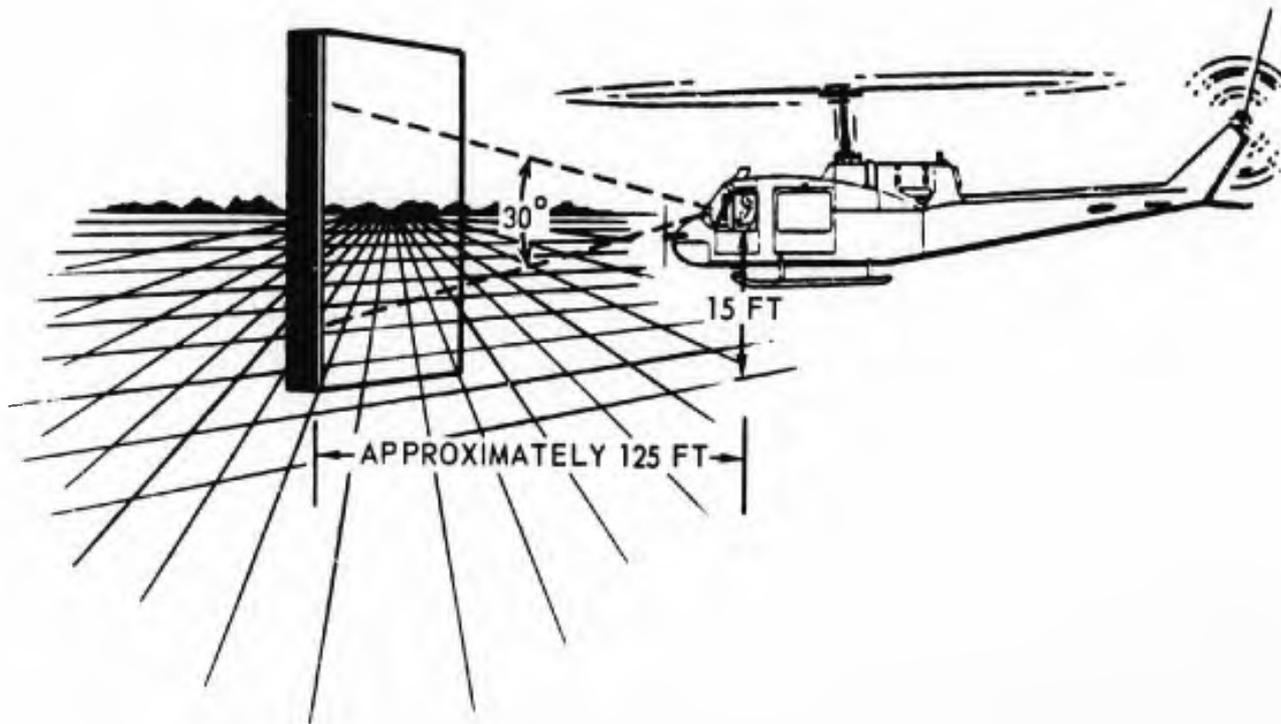


Figure 19. Sketch of Hover Position Indicating the Area Represented on the Vertical Display

In all sessions each trial was separated from the previous trial by a 60-90 second interval. There was a five minute rest break between trials eight and nine after one-half of the trials had been completed. During these intertrial intervals, the observer pilot would set up the command values for the subsequent trial, and the experimenter (E) would change the control mode and inform the S in which mode he would be operating.

#### Training Procedures

Preceding S checkout in the hover mode in preparation for Experiment I, a short familiarization period was conducted at altitude in order to acquaint each S with handling characteristics and unique features of the RH-2 aircraft. The S was exposed to only two of the control modes in this checkout, the normal mode (fly-by-wire) and the damper mode. These modes were chosen for two reasons: (1) in order to obtain maximum control input by the S



and (2) the fact that the normal mode is considered the basic mode and most responsive due to increased sensitivity.

The S assumed control of the aircraft initially from the safety pilot in the normal mode at approximately 1000 feet ( $\pm 50$  feet) and performed maneuvers at his discretion which assisted him in establishing a "feel" for the system's dynamics. Thereafter, the predetermined maneuvers described below were specified by the safety pilot and S performance was recorded. This scoring procedure was accomplished by the "kneepad" method (Figure 20) in which each deviation from Criterion was written down by the E, noting the magnitude and direction of the performance error. This type of evaluation was somewhat subjective, in that the safety pilot and E determined the criterion for performance, but objective in that this criterion was the basis for evaluation.

In the first task the S was asked to maintain an assigned altitude throughout various maneuvers, specifically turns and acceleration-deceleration maneuvers. The criterion in this case was  $\pm 100$  feet and each deviation was scored by the E. In the second task the S was required to maintain airspeed in climbing and descending turns, the criterion being  $\pm 10$  knots. As stated previously, the goal of this period was primarily familiarization rather than proficiency, although it was not totally discounted as evidence by the fact performance criterion had been established. Upon completion of the tasks, the control system was placed in the damper mode and the S proceeded to the area in which Experiment 1 pretest trials were conducted, and executed an approach to landing. This completed the altitude familiarization period. Total time for this period was approximately 30 to 45 minutes. The instructions read to Ss are found in Appendix A.

The next segment consisted of pretest trials for Experiment 1. The purpose was to insure that each S had complete control of the aircraft in the hover mode in order to avoid bias of performance in testing as a function of the Ss inability to handle the dynamics of the vehicle. The trials were all in one minute contact flights. The method of scoring remained the same as previously described in recording performance at altitude, by the "kneepad" method (Figure 20). The magnitude, direction and repetition of performance errors, as determined by deviation from criterion, was written down by the E. The criterion in this case was to hold altitude within  $\pm 5$  feet of the assigned altitude, to hold heading within  $\pm 5^\circ$  of the assigned heading, and to remain within a 15-foot radius of the point of origin as determined at the initiation of the trial. The primary source of information was the external environment, but the vertical display remained on throughout all trials, the display configuration being the grid plane plus GPI. The S was afforded the opportunity to monitor this display at his convenience in order to relate it to "real world" information. The first trial was performed by the observer pilot for the purpose of demonstration.



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DATE

WIND

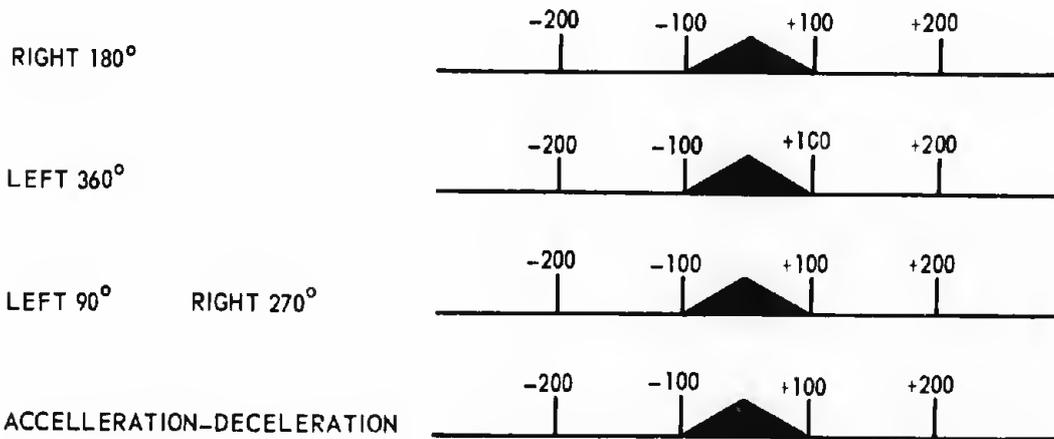
SUBJECT NUMBER

OBSERVER PILOT

TURNS

(A)

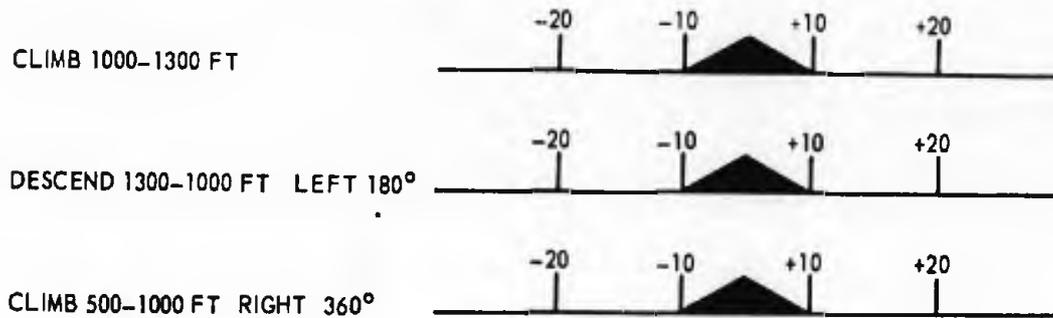
ALTITUDE



MANEUVER

(B)

AIRSPEED



PARAMETER

(C)

HOVER

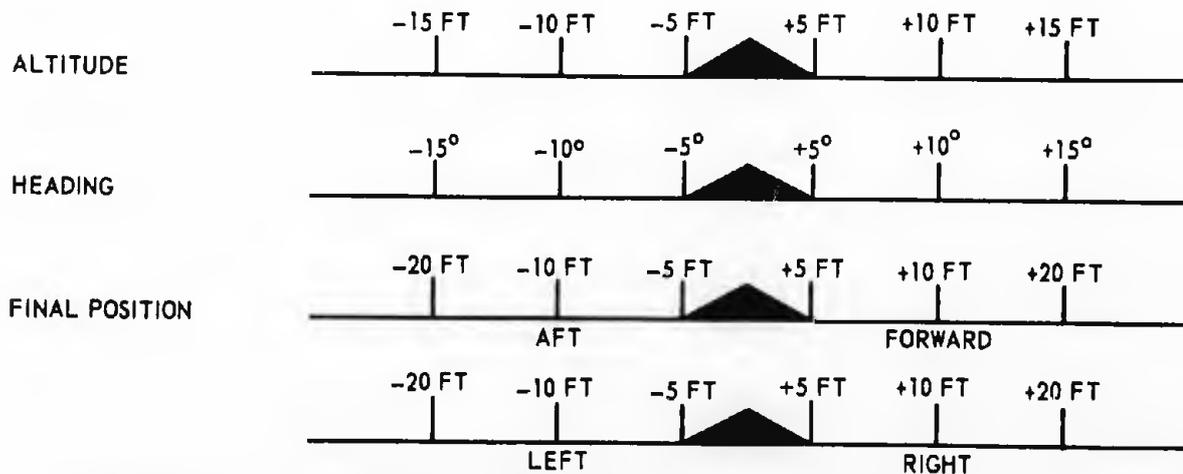


Figure 20. Sample Form for Data Collection by the Kneepad Method.



This permitted the S to divide his attention. In subsequent trials in which S performance was scored, it was suggested that the ratio of external to internal monitoring should be approximately 4 to 1, i.e., internal or display monitoring be held to a minimum, and this was indicated in the instructions to Ss. The prerequisite for S entrance into the testing phase was two successful trials in succession. All trials were performed in the normal control mode, and total time required for this particular phase varied from 15 to 30 minutes. Thus, the total time for the session, encompassing both checkout at altitude and checkout in the hover mode, ranged from a minimum of 45 minutes to a maximum of 1 hour, 15 minutes. Instructions to Ss preceding the first pretest trial are found in Appendix A.

### Test Procedures

After all Ss had met the inflight criteria which had been established and had demonstrated proficiency hovering the flight test vehicle, they proceeded into the four testing sessions of Experiment 1. This experiment evaluated S performance in the hover mode. The task required the Ss to maintain the position experienced at the initiation of the trial over a point designated on the horizontal display, on an assigned heading (a cardinal heading determined to compensate for a direct or quartering headwind) at an assigned altitude (approximately 15 feet) under four unique control modes. These control modes applied only to the secondary set of controls, that is, when the S had direct control of the aircraft upon engagement of the secondary system. With the secondary system disengaged, the primary control system reverted to normal operation without augmentation.

The flight conditions were encountered by Ss in this experiment. The task was accomplished: (1) under contact flight conditions, i.e., with the S monitoring the "real world" environment, and (2) under simulated instrument conditions with the S under the hood, monitoring the vertical display for attitude information. The display configuration presented in this experiment was the grid plane plus ground position indicator.

Each of the four Ss were tested in four experimental sessions. In the first two sessions, eight trials were conducted under each flight condition, contact and simulated IFR for a total of 16 trials per session. Sessions 3 and 4 were composed of 16 IFR trials.

Prior to commencement of the first trial of Session 1, instructions were read to S. These are contained in Appendix A. The aircraft then was picked up to a hover by the observer pilot, and when a stable hover condition had been established fulfilling the assigned conditions, the S was given control of the aircraft. The E then informed the S that the trial was beginning, activated the recording system, and depressed the timer switch. Upon trial completion, that is, after either two minutes duration or takeover



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by the observer pilot due to some marginal flight situation, the recording system was turned off, and the trial terminated. The observer pilot retained control of the aircraft until the initiation of the next trial, allowing the S a brief intertrial break. The E during this time informed him of the next condition to be presented.



C. Experimental Design

The design used in the first two sessions of this experiment was a 4 x 2 incomplete partially balanced Graeco-Latin square with two replications. One variable was the control mode in which the S operated. The four control modes discussed previously were: the normal mode of fly-by-wire (control mode 1), the damper mode (control mode 2), the attitude mode (control mode 3), and the attitude mode with the altitude hold on (control mode 4). Alpha characters, designating order of presentation of these control modes, are contained in Table V below. The second variable was the flight condition, the VFR or contact flight mode (condition a), and the simulated IFR flight mode, utilizing the contact analog with the display configuration of grid plane plus ground position indicator and the horizontal display (condition b). This design yielded eight fixed experimental conditions, with two replications for each subject in the first two sessions.

In sessions 3 and 4, the only parameter varied was the control mode. Thus, each S encountered each control mode four times per session in a partially counterbalanced design. The experimental design utilized for these sessions is contained in Table VI.

TABLE V

Order of Control Mode Presentation  
As Designated by the Alpha Character

Alpha Designation for Control Mode Order of Presentation				
Sessions 1 and 2				
	A	B	C	D
Control Mode Presentation Sequence	1	2	3	4
	2	3	4	1
	3	4	1	2
	4	1	2	3



TABLE VI

Experimental Design for Experiment 1

The order of presentation for the control mode variables are designated as A, B, C, and D. The orders of presentation are constructed by a randomized procedure and are presented in Table VI.

First Session

Serial Order

Subjects	1st	2nd	3rd	4th
1	Ca	Cb	Db	Da
2	Bb	Ba	Ca	Cb
3	Aa	Ab	Bb	Ba
4	Db	Da	Aa	Ab

(a-VFR condition, b-IFR condition)

Second Session

Serial Order

Subjects	1st	2nd	3rd	4th
1	Ab	Aa	Ba	Bb
2	Da	Db	Ab	Aa
3	Cb	Ca	Da	Db
4	Ba	Bb	Cb	Ca



TABLE VI (Cont'd)

Sessions Three and Four

Subjects	1st	2nd	3rd	4th
1	C	D	A	B
2	B	C	D	A
3	A	B	C	D
4	D	A	B	C

Sessions Three and Four

	A	B	C	D
	11	22	33	44
Control Mode Sequence	22	33	44	11
	33	44	11	22
	44	11	22	33



#### D. Measures of Performance

The selection of performance measures is a critical section of each study. The validity of the results and ability to apply results to operational procedures is dependent upon measures which reflect real or valid performance. Although the RH-2 contained a sophisticated data collection recorder, certain limitations are often imposed on performance measure selection by the equipment.

It was desired that both continuous measures and maximum deviations scores be obtained about each attitude control (pitch, roll and yaw) and each position deviation in three dimensional space from the originating hover position (altitude, X and Y).

A continuous error was integrated in terms of absolute deviations in terms of heading, altitude and position hold. Since the circuits could saturate, an area 100 feet square was selected as criteria. Manual scores were recorded for time outside of this square.

The lateral position error was examined in terms of two values, the total number of maximum left lateral deviations and maximum right lateral deviations. These scores reflected the total number of times the S violated the boundaries which had been established, that is, in excess of 100 feet laterally in either direction. Longitudinal position errors were recorded in a similar manner, i.e., the total number of times the forward boundary and the rear boundary were surpassed. The individual directions (fore, aft, right, left) were examined separately to determine if any performance bias was indicated. The combined analysis served to illustrate differential effects in the various control modes.

An additional score which was recorded throughout this experiment was the trial duration. This was the total time the S remained in control of the flight vehicle during the trial, either 120 seconds or until a takeover was required by the observer pilot. This score to some extent reflects the ability of the S to remain within the specified boundaries. Although some takeovers did occur within these boundaries due to minimum altitude or aft translation most takeovers were beyond these limits and were prompted by proximity to obstacles, such as trees, wires, fences, etc.

#### Integrated Absolute Error Scores

Deviations from an assigned standard for three flight parameters (heading, altitude, and position) were integrated for the duration of the trial. The absolute error about this standard was recorded on magnetic tape and was converted from analog to digital form and printed out in the computer facilities. The raw inte-



grated error was then divided by the total time of the trial (120 seconds or less). This provided a measurement of the average deviation, the formula being  $1/t \int_0^t /e/dt$ . This error per second measure was designated as the average deviation for each S, the final output being transformed into engineering units (degrees, feet, seconds) as appropriate.

In comparing the "kneepad" data with the data from the magnetic tape, it was discovered that there was a very definite conflict for the position error scores, in both the lateral and the longitudinal directions. System "drift" and inadequate sensors probably contributed a great deal to this error, but there was no bias indicated in these scores. Therefore, a correction factor could not be applied to the data due to the inconsistency of the error, the recorded (mag tape) position information was not utilized. However, the heading and altitude data were verified by the observed data and were used.

#### Maximum Deviation Error Scores

The total number of boundary penetration (maximum deviations) and the direction of each deviation was obtained from the "kneepad" data for position scores. These scores were recorded by the experimenter (E) through use of the externally positioned flags at 25 feet intervals, covering a range of 200 feet laterally ( $\pm 100$  feet) and 200 feet longitudinally ( $\pm 100$  feet).

#### E. Method of Analysis

All Ss performed under every control mode in both the VFR and simulated IFR flight regimes. In all cases, the operator task consisted of three main effects, an assigned heading, an assigned altitude, and an assigned position which was the point of trial origination.

The error data for heading and altitude were analyzed by parametric analysis of variance to determine whether any significant difference existed between the VFR and IFR trials and among the four control modes under the assigned conditions. Non-parametric analysis was also used in the same manner on the position data through use of Pearson's chi-square statistic.

#### F. Results

Initially, a series of trials was conducted on both visual hover control and hooded hover control. During these trials the experimental pilots had an opportunity to become familiar with both the vehicle's Automatic Stabilization Equipment and the display system. The purpose of these trials was to prepare Ss for a series of simulated IFR hover trials which would test the contact analog as a sole visual reference for hover control. Data were collected on visual hover control during these trials in order



to provide an index of comparison with subsequent hooded trials. Three performance measures were recorded during the visual trials. Two of the measures were heading control and altitude control. The experimenter was prepared to score maximum position deviations during these trials; however, no excursion was noted to have occurred beyond a fifteen foot radius about the initial hover position. Because of the level of proficiency exhibited by the subject pilots during these initial visual trials no further visual trials were conducted during the subsequent testing sessions except for practice preceding the hooded testing trials.

Hooded Hover Trials

Sixteen practice hooded trials were conducted by each of four Ss. These were conducted over two sessions during which time no test data were recorded. However, Ss were given knowledge of results of their performance at the end of each practice trial. During the third and fourth sessions for each of the four Ss, a total of 32 testing trials were conducted. All of these were hooded hover trials. Eight trials were conducted on each of the four control modes of aircraft stabilization during these two sessions of testing.

Four measures of performance were recorded on the hover testing trials, including altitude control, heading control, position control and trial duration. Three of these measures, altitude control, heading control, and trial duration, were broken down into three main effects and statistically analyzed. Results of the analyses of variance for these measures are found in Tables VII, VIII and IX.

TABLE VII

Summary of Analysis of Variance for Altitude Control

Source	df	SS	MS	F	P
Control Mode	3	10,965,294	3,655,098	11.338	.01
Trials	7	884,722	126,389	-	
Subjects	3	26,081,906	8,693,969	26.408	.01
CM X T	21	5,596,649	266,507	-	
CM X S	9	8,768,926	974,325	3.022	.01
T X S	21	5,047,922	240,377	-	
CM X T X S	63	20,309,210	322,368		
Total	127	57,345,419			



TABLE VIII

## Summary of Analysis of Variance for Heading Control

Source	df	SS	MS	F	P
Control Mode	3	38,530,734	12,843,577	13.347	.01
Trials	7	13,040,390	1,862,912	1.936	NS
Subjects	3	8,785,583	2,928,527	3.043	.05
CM X T	21	11,077,932	527,520	-	
CM X S	9	23,950,473	2,661,163	2.77	.01
T X S	21	16,928,865	806,136	-	
CM X T X S	63	60,623,468	962,277		
Total	127	172,937,445			

TABLE IX

## Summary of Analysis of Variance for Trial Duration

Source	df	SS	MS	F	P
Control Mode	3	23,171	7,724	6.512	.01
Trials	7	15,005	2,144	1.809	NS
Subjects	3	38,889	12,962	10.899	.01
CM X T	21	16,558	788	-	
(CM X S	9	17,599	1,955	1.648	NS
(					
* (T X S	21	21,798	1,038	-	
(					
(CM X T X S	63	70,923	1,126		
Total	127	203,934			
* Combined Error	93	110,320	1,186		



Analyses of control mode scores under the measures for altitude control, heading control and trial duration were each significantly different at the .01 level of confidence. The mean scores for these three measures are listed in Table X .

TABLE X

## Control Mode of Aircraft Stabilization

Performance Measure	CM1	CM2	CM3	CM4
Mean Altitude Error*	1157	993	984	388
Mean Heading Error*	1618	1407	586	303
Mean Trial Duration (sec.)	68	64	77	99

\*Measurement of error is in arbitrary units

It is seen that the order of magnitude of altitude error was twice as great in CM1, CM2 and CM3, without the aid of an altitude hold capability, as in CM4, which required no altitude control adjustments from Ss. It is also seen that the order of magnitude of heading error was over twice as much in CM1 and CM2 as in CM3 and CM4. In CM1 (normal mode) and CM2 (damper mode) no heading stabilization was provided. In both CM3 and CM4, a heading hold capability in the automatic stabilization equipment was in operation.

Trial duration was revealed by the analysis of variance to be significantly affected by Control Modes at the .01 level of confidence. The mean time in seconds under each of the four modes, listed in Table X , show that as aircraft attitude stabilization was introduced into the system that mean hover time increased.

Maximum hover time that could occur on any trial was 120 seconds. At that time the trial was terminated by the experimenter. Trials with time durations of less than 120 seconds were terminated on the basis of insufficient attitude, altitude or position control. The Ss hover duration for the trial was scored with respect to the length of time he had exercised unaided control of the aircraft. Should the observer pilot assume control of the aircraft for any reason the trial was terminated and the time recorded. The mean trial duration computed over all trials for each of four Ss was significantly different at the .01 level of confidence. The mean hover durations per subject for all trials were 93 seconds, 84 seconds, 84 seconds and 47 seconds. From these mean values, it is seen that the mean trial durations for three



of the four Ss ranged between 93 and 84 seconds while the fourth S's mean hover time over all trials was considerably less, with a mean of 47 seconds, indicating that the level of proficiency of the fourth S in performing the task was not of equal quality with the three other members of the group.

None of the three performance measures was differentially affected by repetitions when tested in the analyses of variance. It is thus assumed that neither learning nor fatigue was significantly responsible for any variations which occurred in the data and that further practice would not have increased the level of proficiency of the group of Ss tested.

A comparison was made of Ss' final hooded trials with their visual trials to validate differences in the data which were assumed to be attributable to the effects of the experimental conditions. The difference in quality of performance between the two situations was readily apparent in some parameters and needed no statistical analysis for assessment. Two have already been mentioned. One was trial duration. In none of the visual hover trials did the observer pilot find it advisable to assume control of the aircraft before completion of the 120 second trial duration. A qualitative difference was also illustrated in hover position. As previously mentioned, visual hover deviations were restricted to a very small radius about the initial hover position. These were estimated by the experimenter on board the aircraft to never have exceeded fifteen feet in any direction. Records of the position deviations occurring during the 128 hooded trials revealed that in 107 trials Ss exceeded the boundaries of a 200 by 200 foot hover area. Of the 21 trials having no records of boundary penetration, 13 were terminated short of the 120 second period for successful trial completion. Thus, on only eight unattenuated trials was position control maintained within the scoring area. The frequency and direction of boundary penetrations are illustrated in Figure 21.

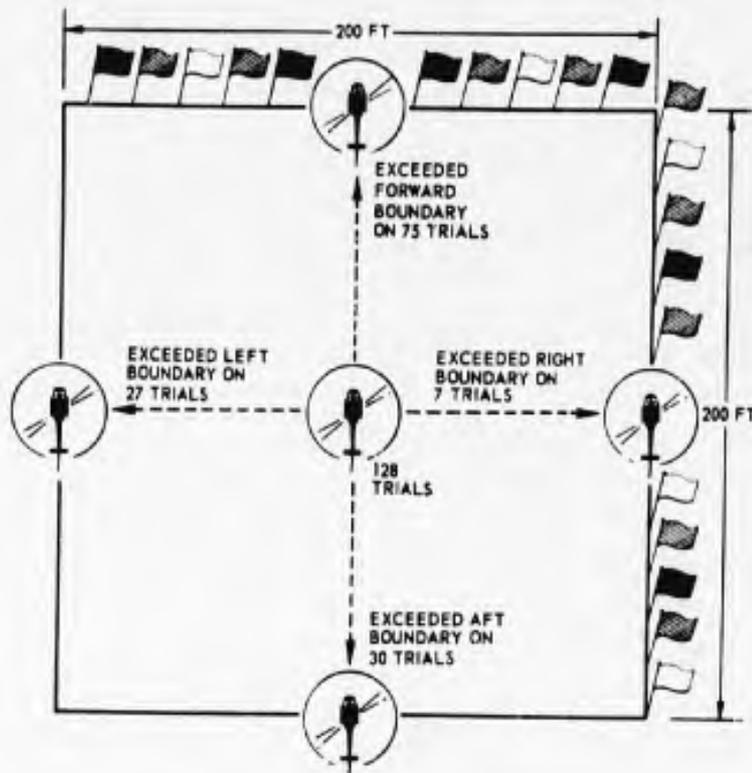


Figure 21. Frequency and Direction of Boundary Penetrations During Hooded Hover Trials

It is shown that on 75 trials there were forward penetrations, on 30 trials aft penetrations, on 7 trials right penetrations and on 27 trials left penetrations. Tabulations of the direction of penetration per trial show that on 6 trials there were boundary penetrations in three directions, on 17 trials in two directions and on 82 trials in any one direction. A Chi square analysis of the frequency distribution of penetrations in the four directions yielded a value of 85.97. With 3 degrees of freedom, a value of 11.341 exceeds the .01 level of confidence of chance distribution. Thus, an obtained value of 85.97 was sufficiently great to reject the chance factor in the direction of position deviations and to accept direction of deviations as a true bias in the overall position performance.

#### Comparison of Hooded and Visual Flight References

In Tables XI and XII are found analyses of variance for altitude control and heading control under hooded and visual flight references. The significance of overall differences between visual flight reference data and hooded flight reference data are seen to exceed the .01 level of confidence indicating statistically real differences in both altitude control and heading control between the two hover visual references. The analysis also reveal that control mode differences overall exceeded the .01 level of confidence and the interaction of visual reference and control mode was also significant at the same level of confidence for both altitude control and heading control.

**TABLE XI**
**Summary of Analysis of Variance for Heading Control**

Source	df	SS	MS	F	P
Flight Reference	1	22,270,303	22,270,303	34.970	.01
Control Mode	3	11,961,393	3,987,131	6.104	.01
Trials	3	1,669,110	556,370	-	
Subjects	3	4,411,777	1,470,592	2.251	NS
FR X CM	3	9,819,163	3,273,054	5.011	.01
FR X T	3	2,291,597	763,866	1.170	NS
FR X S	3	6,230,070	2,076,690	3.179	.05
CM X T	9	2,366,062	262,896	-	
CM X S	9	9,117,604	1,013,067	1.551	NS
T X S	9	5,425,893	602,877	-	
Pooled Error	81	52,906,184	653,163		
TOTAL	128	188,469,156			

**TABLE XII**
**Summary of Analysis of Variance for Altitude Control**

Source	df	SS	MS	F	P
Flight Reference	1	17,615,080	17,615,080	83.358	.01
Control Mode	3	2,871,156	957,052	4.529	.01
Trials	3	208,356	69,452	-	
Subjects	3	5,086,008	1,695,336	8.023	.01
FR X CM	3	2,661,606	887,202	4.198	.01
FR X T	3	24,896	8,299	-	
FR X S	3	5,577,709	1,859,302	8.796	.01
CM X T	9	2,008,203	223,133	1.056	NS
CM X S	9	1,644,852	182,761	-	
T X S	9	1,255,657	139,517	-	
Pooled Error	81	17,116,857	211,319		
TOTAL	128	56,070,380			



In Tables XIII and XIV are illustrated the nature of errors that occurred in the altitude control and heading control parameters. The values in each cell are the mean errors of all Ss and trials for that condition and are reported in arbitrary units.

TABLE XIII  
Mean Heading Error Under Two Flight References  
And Four Control Modes

Flight Reference	Control Mode				Mean Error
	CM1	CM2	CM3	CM4	
Visual	181	226	159	127	173
Hooded	1708	1422	640	260	1008
Mean Error	944	823	400	194	590

TABLE XIV  
Mean Altitude Error Under Two Flight References  
And Four Control Modes

Flight Reference	Control Mode				Mean Error
	CM1	CM2	CM3	CM4	
Visual	153	116	122	124	129
Hooded	1143	969	996	375	871
Mean Error	647	542	559	250	500

It is seen that a disproportionate amount of the altitude and heading error occurred in the normal and damper control modes under the hooded flight reference. It can also be seen that the control mode with maximum stabilization (CM4), with three channels automatically stabilized (attitude, heading and altitude), produced the least number of errors in hooded flight. However, greater errors were accrued in CM4 under the hooded reference than any of the four Control Modes under the visual reference. There was a general consistency in the magnitude of errors which occurred under the visual flight reference.

In summary, these results illustrate that under the normal visual reference, Ss exhibited proficiency in aircraft hover control and that aircraft automatic stabilization did not significantly affect their hover capability. On the other hand, during hooded flights using the contact analog display as the visual reference,



the data reveal that severe decrements in hover control occurred and that the decrements were inversely proportional to the amount of automatic stabilization provided. As less stabilization was provided, hooded hover control decreased. The most difficulty in hover control occurred when there was no automatic stabilization provided.

Analyses of the performance data indicate a significant bias in hover position error under the hooded flights in terms of the frequency of direction of position errors. The analyses show that a significantly greater number of penetrations occurred in the forward longitudinal axis and in the left lateral axis.

#### G. Discussion

Results of the hover experiment show that performance using the contact analog as the visual reference although in large portion safe, did not approach that of normal visual hover control. Control augmentation with automatic stabilization equipment in the hooded flights resulted in increased trial duration and performance in the parameter stabilized, however, had no facilitating affect on position control. Without exception, all pilots experienced difficulty in this area. Empirically, the difficulty was one of unawareness in real world translations. On many occasions, the pilots' verbal description of what the aircraft was doing at the moment, according to the display information, did not coincide with the actual aircraft movements and position changes. There were occasions of position changes in the aircraft where the pilot made no attempt to return to the original position. Often times there was no report from the pilot that indicated his awareness of a change, thus no corrective action was initiated.

The results of these flights suggest the possibility of deficiencies in two areas. One area would be the perceptual threshold limits for detection of translational changes. There were two sources of data that suggest a limitation in this area. One, no verbal accounts of translation detections were reported in the zero to three knot region; and, two, pilots did not attempt to correct for translations down in the region as though they were unaware of their occurrences. By these standards, i.e., at a five feet per second threshold limit rate, considerable position changes could have occurred surreptitiously throughout the duration of a hooded hover trial.

The other possible fault to account for such results is directed toward the display system dynamics. The frequency of direction of position excursions suggest a probable system inaccuracy here. There is no reason to suspect that a bias constancy for position preferences innately existed in Ss, in their tendencies to deviate in one direction more often than in the others. However, the position data did, in fact, reveal a significant bias in



both the longitudinal and lateral axes, forward and to the left of the original hover position. Such data would infer a bias shifting in the displayed information, requiring Ss to correct the aircraft in that direction to maintain the desirable hover position or a misinterpretation of the display.

The anomalous discrepancies between the flight test results and previous simulator results further suggests a system's source error. Previous simulator results (which evaluated what may be regarded as pure pilot performance) revealed no particular problems in this area using the contact analog display (see Sgro and Dougherty, 1963). In the actual flight tests both pilot and system performances were under evaluation. Thus, the results that are reported reflect total system error. In this sense, no fruition of true differentiation between the pilot and the system was attempted in these results.

Further investigation should be conducted in this area of contact analog use. Greater system accuracy should be explored at both the sensor and computer sources. The angular perceptual qualities of grid enclosed information at the lower limits of operation needs further identification and could best be achieved through further simulator studies. This would include studies in limited fields of view and rate and altitude enhancements for hover and touchdown maneuvers.

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## V. EXPERIMENT II - CROSS COUNTRY STUDIES

The display configuration presented during Experiment II introduced the flight pathway in addition to those components included in the Phase I configuration. The final flight for each S was conducted without the pathway. The sole source of position information, in the absence of the flight pathway, was the horizontal display, and the vertical display yielded the primary source of attitude information. Only one mode of stabilization was presented during Experiment II, this being the damper mode. Experiment I suggested that no significant differences existed between Control Modes 1 and 2, which were the only two modes which were being considered for presentation. This choice was based upon the mean trial duration score which was the only performance measure available at the time of selection. The constants imposed by time available to complete the study also had some bearing on the choice of a single control stabilization mode.

The task required the Ss to accomplish a cross country flight consisting of three legs, identifying checkpoints en route, executing precision turns, and maintaining a command altitude and airspeed while adhering to a command ground track, established either by the flight pathway or extrapolated from the information presented on the navigation display in its absence. The course flown was predetermined, as were the checkpoints which terminated each course leg. There was an alternative to fly the course so as to yield a northerly or southerly takeoff and approach as dictated by the existing wind conditions. The checkpoints remained constant, but the course legs were reciprocal values for the two patterns. Each S was exposed to each course at least once.

### A. Task and Procedures

The second experiment entailed a more complex task than Experiment I, a simulated IFR triangular cross-country flight. It encompassed the cruise mode of flight, terminal area work and precision turn maneuvers at specified locations. In this experiment, the S was required to perform this task under two display configurations, the basic grid plane with and without the flight pathway. The configuration with pathway also included the ground position indicator (GPI) identifying the initial position and the final position, the pathway cutoff being 50 feet absolute altitude. The task given the Ss was to program for the flight, i.e., insert the necessary information to the computer for pathway orientation, present position coordinates, and checkpoint coordinates. The S then was given control of the aircraft during the takeoff by the observer pilot, completing the climbout to 1000 feet on pathway (if present), and transitioned to a cruise mode of flight. The S overflew the first checkpoint, performed a procedure turn, and proceeded on leg 2 of the flight. This same procedure was repeated for leg 2 and the overflight of checkpoint



2. The S then continued inbound to destination executing an 8° approach to the projected point of touchdown, and the observer pilot assumed control of the aircraft at some point on final approach. This point of takeover by the observer pilot (OP) ranged from approximately 1100 feet absolute altitude to 1 foot absolute altitude, and was normally the decision of the E. However, the OP could take over at any time throughout the flight if he felt some unsafe situation was imminent. There were no attempts to perform touchdowns for the S had not received practice at this maneuver, so in the interests of flight safety and equipment preservation, termination at hover was considered more practical. The projected point of touchdown was the primary consideration in the decision of the E to terminate the trial.

The Ss were provided with some additional standard instrumentation to complement the display presentations. These were utilized primarily when operating without the flight pathway, that is, for off-pathway maneuvers or when the entire flight was conducted in the absence of the pathway. These instruments included an airspeed indicator, an absolute altimeter, a modified turn and bank indicator and a vertical speed indicator. Command altitude and course were dictated by the pathway, and command airspeed was 65K as indicated by the speed markers located on the right edge of pathway. In the absence of the pathway, the Ss were instructed to maintain 65K airspeed, 1000 feet altitude, and a command bearing for each leg. Figure 22 illustrates the two courses that were flown during this study with each checkpoint identified at the termination of a course leg. The selection of the course to be flown was based upon wind direction, i.e., the flight was planned so that takeoff and approach would always yield a direct and/or quartering headwind. The trial terminated upon takeover by the observer pilot; thereupon the E would deactivate the recording system.

Five Ss were tested in four experimental sessions, each session consisting of one cross-country flight with the pathway. Four Ss were tested in a fifth experimental session, a flight without the pathway. Due to illness and personal work load, the fifth S was unable to complete his final session. Each session or trial was divided into ten segments in order to simplify the data handling and to isolate the various flight maneuvers for comparison. Regardless of the course flown (north or south), the corresponding numeric segments identified the same maneuvers, for example, segment 2, takeoff, segment 6, cruise, and segment 9, approach.

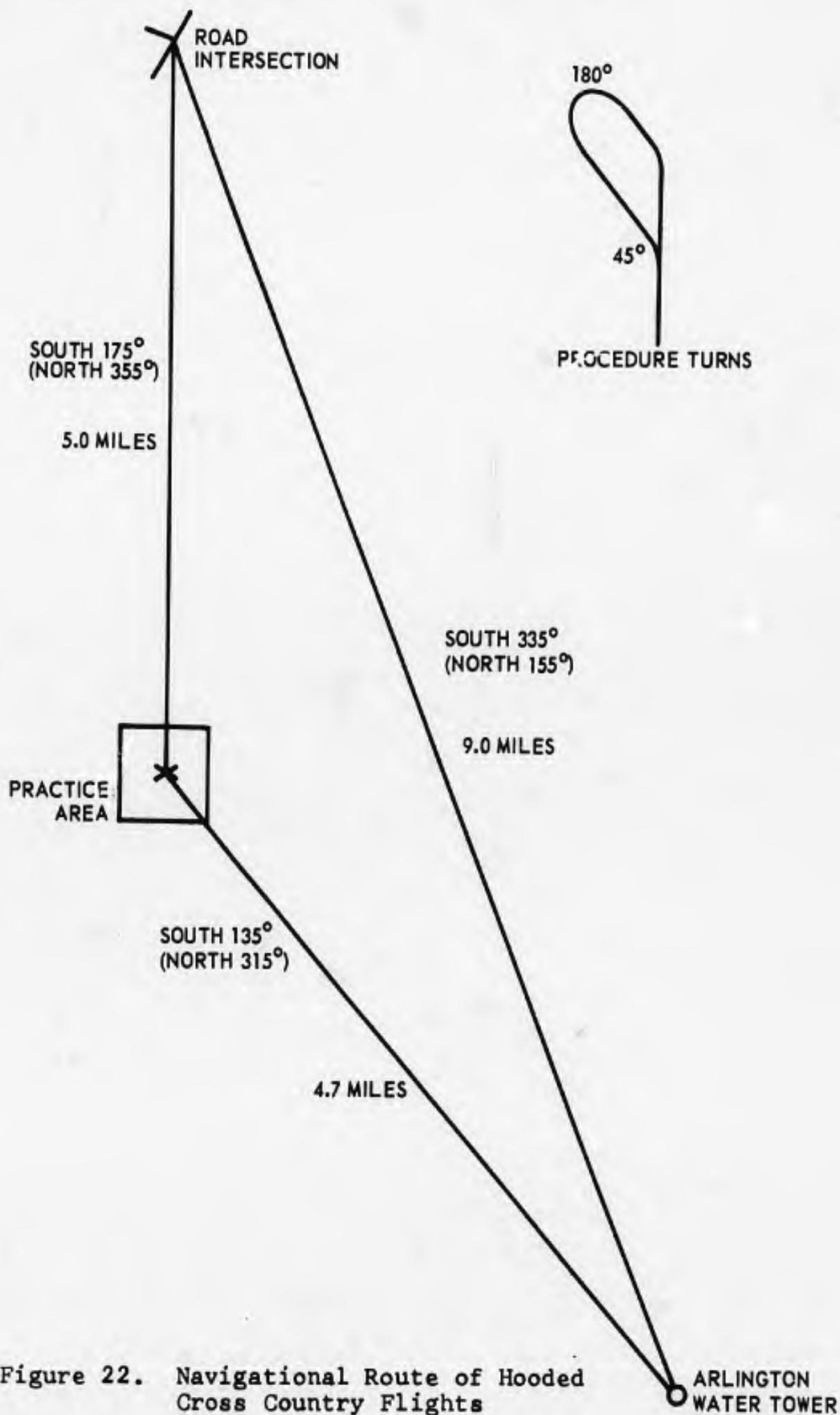


Figure 22. Navigational Route of Hooded Cross Country Flights



This study was conducted in three phases, two preparatory and one testing. The procedure checkout was conducted first. This was accomplished in the RH-2 aircraft with the revised procedures checklist. The procedure modifications and the revised flight plan were emphasized during this phase. This required one S session of approximately 60 minutes. The instructions to Ss preceding this session may be found in Appendix B together with the revised procedures checklist.

Due to the extended time period that had intervened between flight test studies (Experiment 1), brief familiarization flights were considered necessary to acquaint the Ss with the required task and to reestablish the "feel" for the system's dynamics. All flights during this phase were performed in the "damper" flight mode. An illustration of the route flown is shown in Figure 23.

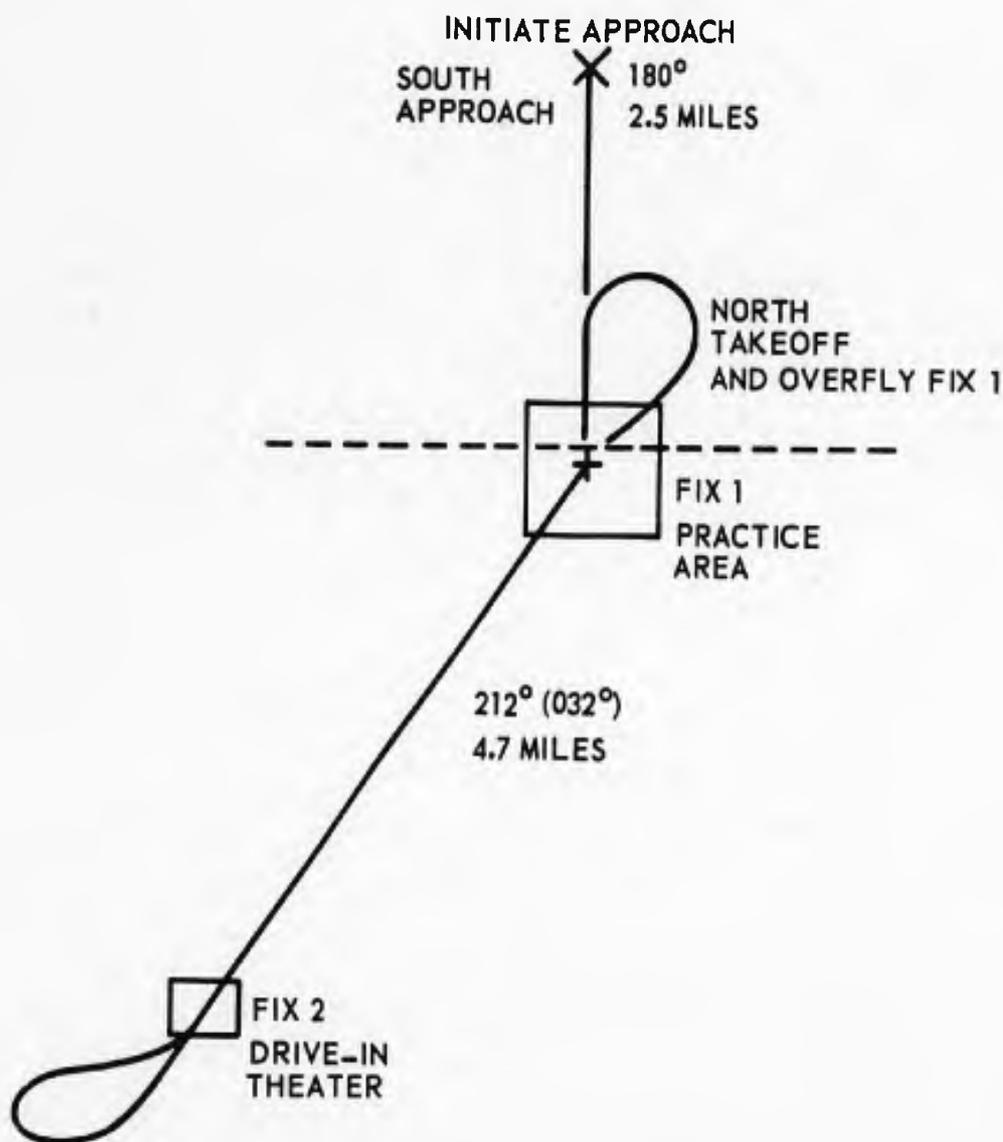


Figure 23. Navigational Route for Familiarization Flights



Two flights per S were conducted for this purpose; both were simulated IFR flights. The same course was flown for both of these flights, a single leg (Figure 23) to a specified checkpoint, a procedural turnaround, and return to the point of origination on a reciprocal heading. These initial flights for all Ss were judged acceptable for their entrance into the testing phase by the E and observer pilot. The performance criteria were quite general and somewhat qualitative, that is, the subjective evaluations by the E and OP were based upon the ability of the Ss to control attitude, altitude and airspeed adequately throughout the flights.

Prior to embarking upon these flights, a brief period was spent in the VFR flight regime, enroute from the Bell Helicopter Hurst plant where Ss boarded the A/C to fly to an open field approximately 1 mile southeast of the plant. All S testing and familiarization trials originated at this site which is referred to as the "practice" area. Throughout the first flight, the E would assist the S at any time he experienced any difficulty with the procedure. The technique which was used to determine this was a verbal commentary by the S throughout the flight. The S was requested in the instructions to verbalize inflight performance of the required procedures. The failure to do so would indicate he had encountered problems and assistance would be given as deemed appropriate by the E. Very little verbal assistance was given to any S in the course of the second flight. The instructions read to Ss prior to the first flight, which are contained in Appendix C, outlined the task to be accomplished and the procedure to be followed during the refamiliarization flights. These were read prior to the first flight and were not repeated for the second flight which was accomplished in the same session.

The final or testing phase followed immediately upon completion of the familiarization flights and required the Ss to fly a triangular cross country flight. All flights were simulated IFR (hooded) and were accomplished in the damper control mode. The total distance of the flight, including procedural turns, was approximately 21 miles. Command altitude and command bearing was defined by the pathway, and command airspeed was given by the speed markers located on the right edge of the pathway, 65K in cruise and a function of distance from the referent in takeoff and approach. This configuration was presented in the first four S testing trials. The instructions read to each S prior to the first testing flight are contained in Appendix D. The S programmed for the flight on the ground in the "practice" area. The real world position being occupied by the A/C was inserted into the computer by the S as "present position" and as "Fix 1" by slewing the aircraft position index (bug) to the correct position on the navigation display and pressing the correct button to enter. This was the procedure used for entering all positions. When the north course was flown, the first checkpoint inserted into the computer was a road intersection in the town of Colleyville, Texas, approxi-



mately 5 miles north of the "practice" area. The path bearing to this fix from the "practice" area was  $355^{\circ}$ . Checkpoint 2 was a water tower located on the northern perimeter of the town of Arlington, Texas, approximately 9 miles from the road intersection at Colleyville and on a bearing of  $335^{\circ}$  from it. The final position was located in the practice area, approximately 4.7 miles from the water tower and on a bearing of  $315^{\circ}$  from it. Theoretically, Fix 1 identified the same real world position for origination and termination of the flight and was used as the referent for takeoff and approach glideslope. When the south course was flown, the Arlington water tower became checkpoint 1 and the Colleyville road intersection, checkpoint 2. The command bearing for the three course legs were the reciprocal value of those noted above. Once the checkpoints had been inserted and the other relevant procedures accomplished, such as pathway altitude selected, path mode chosen, etc., the S informed the E that he had completed the programming and was prepared for the flight. At this point, the trial verbal identification was given by the E for recording purposes, and the observer pilot executed the pick-up to a hover. The observer pilot then performed the takeoff, using the flight path instruments which were provided for him to maintain his lateral and vertical position on the pathway. At approximately 50' - 150' absolute altitude, the controls were turned over to the S in the damper mode and the recorder was activated for S trial initiation. The flight then proceeded around the triangular course until the OP assumed control of the aircraft. The flight was divided into ten segments for recording purposes and to maintain consistency of the comparable flight modes regardless of the course flown. Two segments were for position information, initial and final position in the practice area. One segment was devoted to the climbout and one to the approach leg. Two segments were required for the turn maneuvers subsequent to the overflight of the checkpoints and four segments were devoted to the cruise mode. During the climbout and approach maneuvers, the S task was to maintain glideslope position, that is, angle, altitude, vertical speed, lateral position and airspeed as indicated by the speed markers of the pathway. While executing the turns, the S task was to maintain altitude and airspeed while accomplishing the required turns off of the pathway. In the cruise mode between the fixes, the task was to maintain altitude, heading and position on pathway in addition to identifying the overflight of the checkpoints verbally as indicated on the navigation display. The entire flight was conducted under simulated IFR (hooded) conditions.

Five Ss were tested in four experimental sessions and four Ss were tested in one additional session. Each experimental session was composed of one testing trial, that is, one cross-country flight. Each flight was divided into ten segments as previously discussed; the first four trials were conducted with the flight pathway while the final trial for four of these Ss was without the pathway. The fifth S was unable to complete his final testing trial due to illness and an increased work load. The minimum



time between sessions was approximately 30 minutes, and the maximum separation was ten days. The maximum number of S testing sessions for any 24 hour period was two. A number of experimental testing trials required rerun due to equipment malfunctions while airborne (data collection system, sensors, etc.). Throughout the testing trials, the Ss gave verbal commentaries as time permitted. This gave the E knowledge of the procedures being accomplished by the S and gave the observer pilot information regarding the execution of maneuvers. Instructions were read to the S prior to the first testing session covering their task, and again prior to session 5, when the display configuration did not include the flight pathway. Both sets of instructions are contained in Appendix D .

### B. Experimental Design

The nature of this study did not permit adherence to a stringent experimental design, however, the experimental controls were rigidly enforced. All flights for all Ss were conducted over the same course and included the same checkpoints; only the direction of the flight was altered. Instructions were read to the Ss prior to trials 1 and 5; the first four trials were conducted with the flight pathway and the final flight without the pathway. The Ss all received adequate training, reviewed the revised check list and demonstrated flight proficiency prior to the testing trials. All of the Ss had participated in the mock-up study and also in many of the simulator studies. All were familiar with the vertical and horizontal displays and associated controls in the flight test vehicle. The flights without the pathway were presented as time allowed, that is, only one flight (per S) was conducted in the absence of the flight pathway due to the time allocated for this phase of the flight test program. Upon pick up of the S at the Bell Hurst plant, the S handled the controls en route from the heliport to the practice area. This was only done prior to the first testing session if two sessions were held within the same 24 hour period. The comments of the observer pilot and experimenter were held to a minimum. Only safety of flight items, air traffic detection and trial segment identification were commented upon throughout the testing flights. Thus, even though no experimental design was developed, the experimental procedures and controls were standardized for all testing flights.

### C. Measures of Performance

This study examined the completed flight, climbout through approach, whereas Experiment I had investigated only the hover maneuver. Therefore, the measures obtained during hover were not sufficient for this study.

In attempting to demonstrate how each flight was accomplished, there were continuous XY-position plots recorded throughout each S testing flight. In addition, there were altitude plots for the



takeoff and approach maneuvers, and altitude and airspeed plots throughout the procedural turns. All of these plots served to qualitatively describe each flight. It was necessary to segment the XY-plots in the same manner as the other data, that is, a total of ten segments, none of which exceeded 5.5 minutes, and approximately 5 seconds between segments during which there were no usable data collected. As previously mentioned, this procedure was followed due to constraints imposed by the computer data handling capabilities, that is, handling blocks of data not to exceed six minutes of continuous recording. These plots were recorded for each S testing flight. Also, quantitative data were collected pertinent to the various modes of flight - climbout, approach, cruise, turns. These included groundspeed, vertical velocity, lateral deviation, vertical deviation and airspeed error. Track error and heading turn rate information was gathered but proved to be erratic and of no value. The plots of the Ss testing flights are contained in Appendix E. Of particular interest throughout the first four testing trials were the response measures describing the Ss ability to remain on the pathway, specifically lateral and vertical deviation scores. In the fifth session, perhaps the best comparative data were provided by the position plots when the flight pathway was not available to the Ss. The checkpoints which are indicated on the plots are the real world coordinates of the fixes, the Arlington water tower and the Colleyville road intersection. The initial position is marked on all of the XY-plots; the final position is marked on the majority of these plots, but is excluded on several flights where the concern for fuel remaining precluded the completion and recording of a final flight segment. The dotted lines appearing on the XY-plots are those phases of the flight where position information was extrapolated from other data. This was necessary because of a flaw on the potentiometer which yielded erroneous X-coordinate data.

Those plots which are discontinuous, as exhibited by an extensive break between segments, are indicative of takeover by the observer pilot due to the proximity of other aircraft. During this period, the OP had complete control of the system and the data collection system was deactivated. When this potential safety hazard was removed, the controls were returned to the S and the recording system was reactivated. The flight continued from this point, that is, there was no attempt to return to the point of takeover and fill this data gap.

#### D. Method of Analysis

All Ss were tested in four experimental sessions under one experimental condition, the vertical display with pathway. Four Ss were tested in an additional session, the experimental condition being the vertical display without pathway. Data was treated graphically and through non-parametric analyses. The position plots, altitude plots and airspeed profiles serve as qualitative descriptions of the flights. There is no analysis of these illustrations which are contained in the Appendix.



E. Results

From takeoff through touchdown Ss were placed under a hooded visibility mode of operation. They assumed control of the aircraft immediately after lift off at which time data collection simultaneously commenced. Data recording continued throughout the entire flight until the final approach was terminated. Results of the flights are presented in three separate segments -- (1) the climb to altitude, (2) the cross country cruise, and (3) the approach to hover.

Climb to Altitude

The Ss flight performance was scored between the time S assumed control of the aircraft at climbout and the moment of his indicated initiation into the cruise mode. Scores were obtained of the lateral track control and the vertical altitude control referenced to the flight pathway. Records were also made of the airspeed deviations from the command speedmarkers. Although these results were too spurious for systematic presentation, observer evaluations of Ss airspeed control during the climbout mode indicated that no particular problems in handling the aircraft's speed control were observed during this flight mode.

The lateral track control results are presented in two forms -- (1) the momentary absolute climb lateral error and (2) the maximum lateral track excursion from command bearing. Scores for the five Ss and their five flights are found in Tables XV and XVI.

TABLE XV

Momentary Absolute Error of Climbout Lateral Track Control  
for Five Ss and Five Flights  
(Units of Measurement are in Feet)

	Flight					
	1	2	3	4	5*	Mean 1-4
S <sub>1</sub>	375	195	243	411	3253	306
S <sub>2</sub>	157	286	177	133	**	188
S <sub>3</sub>	627	361	97	207	384	323
S <sub>4</sub>	83	316	1306	151	339	464
S <sub>5</sub>	219	651	**	516	174	462
Mean	292	362	456	284	1038	349

\* This flight was conducted without the flight pathway.

\*\* No data available.



TABLE XVI

Maximum Deviation for Climbout Lateral Control  
for Five Subjects and Five Flights  
(Units of Measurements are in Feet)

	Flight					Mean <sub>1-4</sub>
	1	2	3	4	5*	
S <sub>1</sub>	1330	882	1198	1828	6102	1310
S <sub>2</sub>	493	1073	1232	420	**	805
S <sub>3</sub>	1331	936	1089	848	1237	1051
S <sub>4</sub>	306	1352	2717	1093	900	1367
S <sub>5</sub>	1224	1490	**	981	429	1232
$\bar{X}$	937	1147	1559	1034	2167	1169

\* This flight was conducted without the flight pathway.

\*\* No data available.

It can be seen in Tables XV and XVI that the track errors of the Ss five flights were generally unaffected by the presence of the pathway for track information during the climbout mode. The two types of track errors presented were not independent measures. Presented together, however, is indication of both how well on the average track could be maintained and the degree of magnitude of excursions the Ss experienced on their various flights. The scores show that only one subject (S<sub>1</sub>) experienced a severe decrement in his climbout track performance. This occurred on the flight without the flight pathway (Flight 5). His maximum displacement score (6102 feet) and momentary absolute track error (3253 feet) depart from his usual scores on other flights with the pathway and with the remaining four Ss scores on flights with and without the flight pathway.

Vertical climbout control for the five Ss flights is found in Table XVII. The values found in the table are the mean momentary vertical climbout deviations cumulated on each flight.



TABLE XVII

Mean Momentary Climbout Vertical Deviations for  
Five Ss and Five Flights  
(Units of Measurement are in Feet)

	Flight					Mean 1-4
	1	2	3	4	5*	
S <sub>1</sub>	-165	+ 5	-87	+118	- 19	-32
S <sub>2</sub>	- 1	+ 89	+59	+167	**	+79
S <sub>3</sub>	+183	+254	+83	+ 80	+126	+150
S <sub>4</sub>	+ 93	+147	-111	+120	- 44	+62
S <sub>5</sub>	+ 71	+136	+97	+106	+190	+103
Mean	+ 36	+126	+ 8	+118	+ 63	+72

\* This flight was conducted without the flight pathway.

\*\* No data available.

The overall average momentary error in the vertical position from the command for those flights with the pathway was 72 feet. When compared with the flights without the pathway (Flight 5) it can be seen that for the climbout mode the pathway was of no apparent effect on the Ss scores in judging climb angle. Their performance was as good, and even a little better, when the pathway was not available. It may be noted also that, on the average, the tendency was to climb above the pathway for most Ss and hold their climb position with the pathway under them. In this manner the pathway was more readily seen on the display. Without the pathway this relative difference was not as great.

Cross Country Cruise

The cruise portion of the flight encompassed three legs of a triangular course. These legs were 4.7, 5.0 and 9 miles making the total flight more than 20 miles including the distance required to perform the procedural turns at the course leg inter-sections. Records of the Ss performances were cumulated throughout the cruise legs and during the procedural turns. Some cruise data is presented quantitatively while other cruise data is presented graphically. A distinction is made between these scores that were considered to be primarily pilot errors and those scores that were not only pilot performance errors but included total system error. Included in the results describing the pilots'



cruise performances are the momentary integrated lateral track error, maximum lateral track deviations, momentary absolute vertical error from the pathway and the momentary absolute airspeed error.

The results of the Ss lateral track error and maximum deviations were recorded as deviations from the flight pathway and are presented in Tables XVIII and XIX.

TABLE XVIII

Momentary Absolute Error of Cruise Lateral Track Control  
for Five Ss and Five Flights  
(Units of Measurement are in Feet)

	Flight					
	1	2	3	4	5*	Mean 1-4
S <sub>1</sub>	428	2586	1614	472	1363	1275
S <sub>2</sub>	887	2608	404	594	**	1123
S <sub>3</sub>	440	400	182	205	616	307
S <sub>4</sub>	716	406	1094	750	1251	742
S <sub>5</sub>	830	986	**	979	3683	905
Mean	660	1397	824	600	1728	870

\* This flight was conducted without the flight pathway.

\*\* No data available.



TABLE XIX

Maximum Deviation for Cruise Lateral Control  
for Five Subjects and Five Flights  
(Units of Measurements are in feet)

	Flight					Mean <sub>1-4</sub>
	1	2	3	4	5*	
S <sub>1</sub>	1205	4000	1893	1444	2431	2136
S <sub>2</sub>	2064	3676	835	1509	**	2021
S <sub>3</sub>	1258	890	796	832	1209	944
S <sub>4</sub>	2247	900	2278	1465	1715	1723
S <sub>5</sub>	1422	1393	**	2749	4696	1754
Mean	1639	2172	1451	1600	2513	1716

\* This flight was conducted without the flight pathway.

\*\* No data available.

It can be seen that on the average, with the flight pathway displayed, that Ss track control was maintained within  $\pm 870$  feet. When the flight pathway was not present lateral track error increased to an average of  $\pm 1728$  feet, more than twice the error with the pathway available. The range of track deviations, found in Table XIX, show that the average maximum track displacement which occurred with the pathway displayed was  $\pm 1526$  feet. Without the flight pathway the average maximum displacement from command track was increased to  $\pm 2513$  feet.

Airspeed control during the cruise flight was measured with respect to deviations from a programmed command. These results are presented in Table XX .



TABLE XX

Momentary Absolute Error for Cruise Airspeed Control  
for Five Subjects and Five Flights  
(Units of Measurements are in Knots Deviation from Command)

	Flight					Mean 1-4
	1	2	3	4	5*	
S <sub>1</sub>	11	9	6	5	8	8
S <sub>2</sub>	12	17	9	11	**	12
S <sub>3</sub>	18	13	18	5	5	14
S <sub>4</sub>	8	7	11	12	8	10
S <sub>5</sub>	6	6	6	5	8	6
Mean	11	10	10	7	10	10

\* This flight was conducted without the flight pathway.

\*\* No data available.

From these results it can be seen that the presence of the flight pathway with tarstrips and programmed speed markers was of little, if any, aid in control of the cruise airspeed. Overall airspeed error averages with and without these aids were  $\pm 9.5$  and  $\pm 10.0$  knots, respectively.

Altitude control during the cruise course legs was determined by recording the vertical deviations from the flight pathway. These deviations are presented in Table XXI .



TABLE XXI

Momentary Absolute Error for Cruise Altitude Control  
for Five Subjects and Five Flights  
(Units of Measurement are in Feet Deviation from Flight Pathway)

	Flight					Mean 1-4
	1	2	3	4	5*	
S <sub>1</sub>	109	121	99	89	106	105
S <sub>2</sub>	89	100	148	151	**	122
S <sub>3</sub>	115	142	44	59	92	90
S <sub>4</sub>	98	139	131	163	135	133
S <sub>5</sub>	144	84	105	108	254	110
Mean	111	117	105	114	147	112

\* This flight was conducted without the flight pathway.  
\*\* No data available.

On the average the pilots flew within  $\pm 112$  feet from the pathway. Without the pathway the average momentary deviations from 1000 feet command altitude were within  $\pm 147$  feet. During the flights without the pathway, Ss used the basic grid plane and a remote altimeter for altitude references.

Real world position data obtained from these flights reflect both pilot performance and system performance. No systematic solution is offered to differentiate between the pilots' and the system's inaccuracies except through extrapolations of the observed performances exhibited by the Ss in flying the displayed information in relation to the recorded real world inaccuracies. For instance, an inspection of the horizontal and vertical displays at the termination of several flights revealed that the pilots' terminal position on the display was accurate; however, the terminal touchdown position of the aircraft in reference to the takeoff point was sometimes displaced several hundred feet. Some of these terminal area inaccuracies are illustrated in Figure 23 .

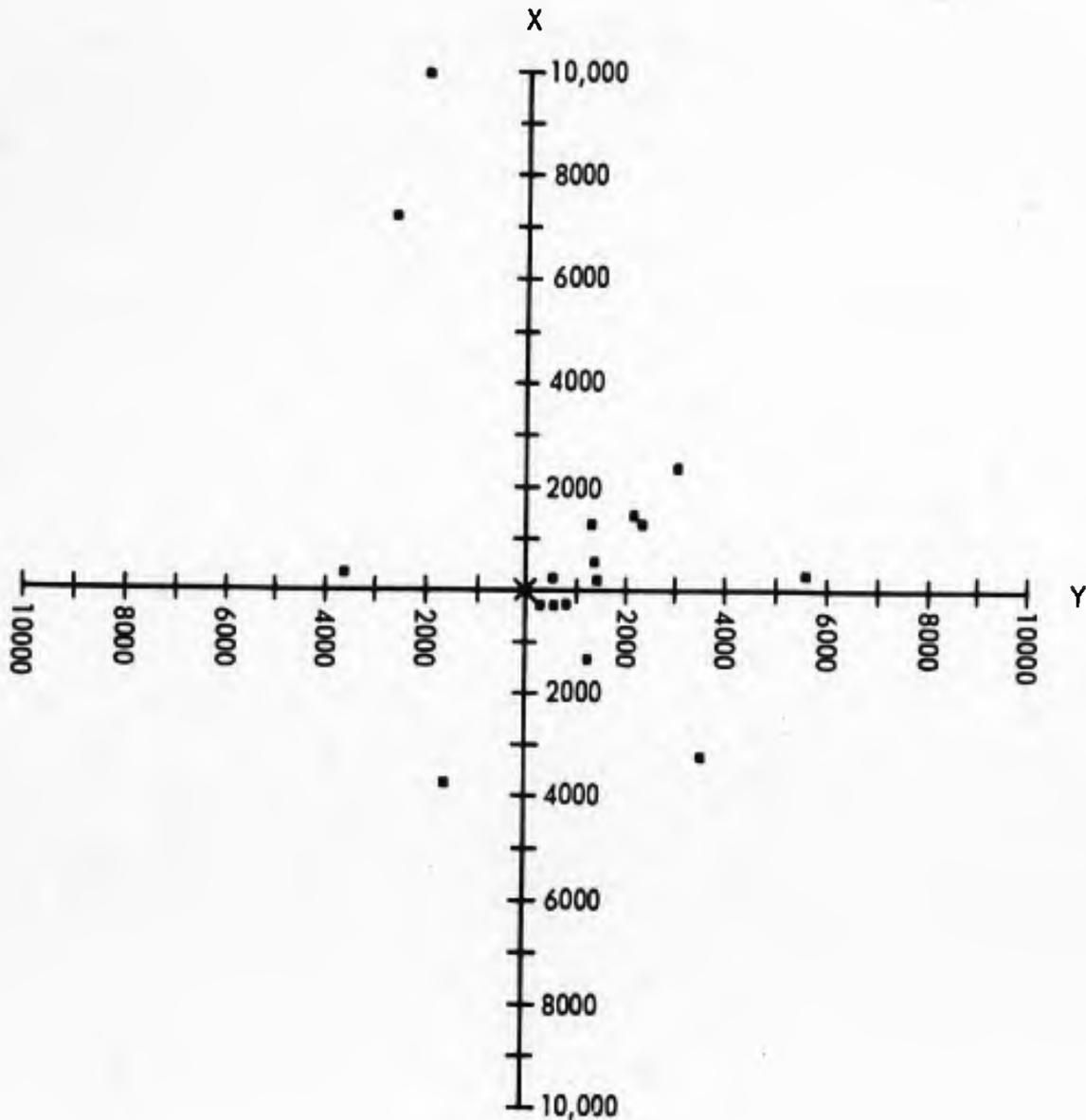


Figure 24. Illustration of Final Touchdown Position Errors For 17 RH-2 Hooded Cross Country Flights

It can be seen in this figure that, while the greatest number of inaccuracies were recorded in the upper right hand quadrant, overall dispersions were sufficiently large in all quadrants to preclude differentiations in the data which would account for any constant bias in the system's inaccuracy.

A graphical X-Y plot of each of the 24 flights was recorded. These plots are contained in Appendix E . No quantitative summaries of navigational accuracies were tabulated since discrepancies in the course traces and geographical checkpoint position



reflect both the pilot and system inaccuracies. Thus, any quantification of errors which might be interpreted to pilot performance would indeed be deceptive. The virtue of the plots lies in the portrayal of Ss use of the display system for navigational orientation. From these plots it is readily apparent that on practically all the flights conducted there was no variation in the execution of the navigational procedures, that is, each check-point was overflown and identified. There was no geographical disorientation reported by any of the subject pilots and all course deviations that occurred were corrected without the assistance of the observer pilot.

Another portion of the cruise mode graphically recorded were the procedural turns and course interceptions. Profiles of airspeed control and altitude plots were recorded during these exercises. These profiles and plots are contained in Appendix E. The graphical profiles of the procedure turns may be used to describe this portion of the flight better than quantitative summaries. In general, the turns were executed in the planned fashion and could be considered as coordinated. No excessive airspeed deviations were recorded and altitude control could be considered as optimum.

Approach to Hover

The approach to hover position of the flight was a straight in extension of the final course leg. Momentary glideslope error, momentary approach track deviation, and final altitude at termination of the approach were recorded. The approach glideslope and track errors were recorded from the time that the "distance to go" meter read 2.5 miles to the termination of the approach. The approach glideslope errors are presented in Table XXII.

TABLE XXII  
Mean Momentary Error of Approach Glideslope Control  
for Five Subjects and Five Flights  
(Units of Measurements are in Feet)

	Flight					
	1	2	3	4	5*	Mean 1-4
S <sub>1</sub>	+ 41	-235	+ 80	-130	- 27	- 61
S <sub>2</sub>	**	+104	+156	+126	**	+105
S <sub>3</sub>	+ 31	- 32	+ 13	+ 18	-129	+ 8
S <sub>4</sub>	+ 59	+166	- 5	+ 84	-232	+ 76
S <sub>5</sub>	+ 6	+108	+130	- 52	+224	+ 48
Mean	+ 34	+ 22	+ 75	+ 9	- 41	+ 35

\* This flight was conducted without the flight pathway.

\*\* No data available.



The values listed in the table are momentary vertical deviations from the flight pathway throughout the scoring portion of the approach. When summed and averaged for all Ss over all flights the mean slope error was +39 feet. Without the flight pathway the mean momentary error was -41 feet.

The approach track error was recorded throughout the glideslope until the approach was terminated. The scores contained in Table XXIII are the momentary absolute deviations from the command glide path.

TABLE XXIII

Momentary Absolute Error of Approach Lateral Track Control  
for Five Ss and Five Flights  
(Units of Measurements are in Feet)

	Flight					
	1	2	3	4	5*	Mean 1-4
S <sub>1</sub>	581	276	2820	76	517	938
S <sub>2</sub>	**	52	266	104	**	285
S <sub>3</sub>	263	334	142	100	752	210
S <sub>4</sub>	1806	588	206	252	1312	713
S <sub>5</sub>	218	945	**	167	4346	547
Mean	717	439	859	140	1732	539

\* This flight was conducted without the flight pathway.

\*\* No data available.

These results contained in Table XXIII indicate that Ss errors were less on the final flight with the pathway (Flight 4) than on the three initial flights, but when the pathway was removed on the fifth flight, the data on four of the five Ss show that a severe degradation in glide path track control resulted.



## F. Discussion

It must be emphasized that the results of flight tests reported here reflect the total system's performance, including pilot error, computer error and recording error. Thus, a cautious interpretation must accompany the assignment of errors to particular sources. When possible, however, attempts have been made to dichotomize the error sources, but it is candidly admitted that in some areas the dichotomies imposed upon the data may be pseudo-dichotomies.

There are, however, several conclusive results that became manifested through this series of cross-country flights using the contact analog display system. One is that the actual flight system can be flown in the absence of outside visibility and conventional instrumentation throughout a complex navigational problem. Insofar as the information displayed was proper and accurate, the group of pilots tested displayed thorough awareness of geographic orientation and deliberateness in executing the command maneuvers. These results may be offered as validation of the previous contact analog simulator evaluations and their results.

In those areas where apparent conflicts exist between the simulator results and flight test results regarding the precision of control exhibited by the pilots tested, it must be recognized that the laboratory evaluations reflect what may be considered as pure pilot performance data, whereas the flight tests included both the pilot performance in addition to the system performance.

It is known in many respects that at times the system performance was of marginal acceptance when flight data was being recorded. This is most markedly illustrated through the total number of flight hours conducted before engineering acceptance was approved and through the number of aborted flights that accompanied the actual flight tests. In the 1964 Annual JANAIR Progress Report it was reported that ninety flight hours had been utilized to that date for engineering evaluation of the system. Once human factors acceptance was approved a total of forty-one cross country flights were conducted. On seventeen of these flights system failure produced either insufficient or unacceptable human factors data. On the remaining twenty-four unattenuated flights acceptable system performance could only be graded on the basis of the system's apparent operation. To this extent the flight tests included both an evaluation of the pilots' performances and an evaluation of the systems' performances.

Attestation to the validity of the overall flight test results is submitted by the consistency of performance displayed in the unattenuated flights. In none of these cross-country flights did the pilots report any experiences of disorientation either in flight control or geographic unawareness. In every flight the command procedures were capable of being executed within optimal limits.



Reactions of the pilots to the flight system were obtained through a prepared questionnaire. This questionnaire and the respective responses are found in Appendix F. The comments and criticisms contained therein, in general, substantiate the records of the respective pilots' flights. Several idiosyncrasies of the flight system were reported by the pilots to be disturbing but not disrupting. No doubt their criticisms of such things as video blanking, pathway sensitivity, and the like, are reflected in the performance data. It is strongly suspected that more reliable sensor sources and an updated navigation and central computer would produce a significantly enhanced all visibility capability with the presently configured contact analog vertical and horizontal flight display systems.

It is certain that the flight test results reported here do not begin to exhaust the full potential of the concept or the system. On the contrary, they should be regarded as a major milestone in the development of a fully operational all visibility instrument system for all types of V/STOL aircraft. Further research and development in all areas of the program are urged. In parallel with the development of adequate hardware, full use of the system should be explored. This should include research in such areas as inflight flight planning, the incorporation of obstacle information as well as the display of other information now confined to standard instruments, and the superpositioning of real world data as would be received from low light level television, radar, infrared and lazer returns.



## VI. EXPERIMENT III -- TELEVISION STUDIES

The contact analog displays, as have been evolved thus far, are based upon the notion of sensing events (acceleration, changes in altitude, etc.) which are either hidden from the operator (due to fog, darkness or other conditions) or to which he is somewhat insensitive. Through electronic computation and display integration, events are displayed in a manner that is analogous to the direct visual content. To this extent, such systems as radar, infrared and low light level television clearly fall within the subject matter of the contact analog program since they operate by sensing events that are beyond the sensory competence of the operator and through electronic contrivance, recreate these conditions under circumstances that are favorable for interpretation by the human agent.

As such, the JANAIR activity impinges upon many current programs that have the limited goals of making specific examination of such systems as infrared and low light television. This conjunction of interest does not imply a reproduction of effort, however. The JANAIR program has a broader philosophy than any specific system evaluation. Its primary intent is to examine the theoretical aspects of the system combination rather than a concern for isolated systems. Thus the present problem is not whether low light level television has merit generally, but what value it has within the larger avionics frame of reference.

Nearly any event or condition can be sensed in a number of ways, some of which are adequate, operational descriptions of the event and some of which are not. The temperature of a cylinder may be adequately described by the voltage generated at a thermocouple. But this would be insufficient as an index of total engine condition. Similarly, radar can give much information concerning the position of some objects in space, but it is not a fully trustworthy guide if one wishes to fly in very close proximity to these objects. Television provides another possible source of such information. Some of its content is redundant to radar, but there is not a point for point identity. The introduction of new systems to the concept already contained within the contact analog ensemble will undoubtedly recapitulate much that is already available, but it will also introduce some that is unique. The redundant as well as the distinctive information may have use or again it may be without value. Some information while being precise may not relate to the operation of flying an aircraft. Other information, while redundant, may greatly increase the reliability of the total system. On the basis of good maps and on automatic navigation system, it may be evident that there is a mountain pass immediately in front of the aircraft. The pilot will act with greater assurance, however, if he can see the pass on a TV monitor. TV thus serves to validate the information generated by the computer. If the pilot has satisfied himself after flying a certain distance that a water



tower shown on a map can also be seen on TV, he is more likely to accept subsequent information provided by the navigation system than would otherwise be the case. There will be times when TV will not be sensitive enough to discern needed information, but if it is sensitive enough to provide a periodic check on the computer, the pilot will be more willing to accept the data given by the navigation system alone.

The present study relates only to the problem of how the contact analog vertical display and the TV picture could be combined and following combination, how pilots will react to it.

It seems evident that the most useful way of combining the TV image and the grid plane would be a point for point overlay on a single cathode ray tube. In this way, the operator could select either or both by the simple manipulation of a three position switch. Two features argue against so simple an arrangement, however. One involves the obvious advantage in varying the degree of magnification of the TV lens. For attitude control, cross-country navigation and initial detection of targets and checkpoints, a relatively wide angle lens ( $40^{\circ}$  to  $60^{\circ}$ ) is needed. For the assessment of more minute detail, especially target identification, a narrow angle lens (about  $7^{\circ}$ ) is to be preferred. A promiscuous interchange of viewing angle for the TV in the presence of a constant viewing angle for the contact analog should be approached with care.

The second problem arises from the desirability, indeed the necessity, of having the viewing direction of the TV camera under the operator's control. In an earlier study under the JANAIR contract (Elam, 1964) it was indicated that the task of attitude control was made easier if the camera position could be controlled in pitch. A superficial analysis will suffice to reveal that control in yaw, in addition to control in pitch, will be necessary for target following and identification. A perceptual anomaly is created if the TV picture is to move and the contact analog remains in constant reference to the airframe attitude. To have both move, on the other hand, could produce a yet more serious problem since orientation might quickly be lost.

The present study examined the above conditions along with a third arrangement in which the contact analog was automatically removed from the display whenever the references were in disagreement.

METHODA. Subjects

Six subjects were used in this study. In experience, they ranged from novices to test pilots. Two had limited rotary wing pilot training, two were approximately at the level of Army pilots and the remaining two were highly qualified test pilots. This variability was adapted in order to examine the use of the system through as wide a spectrum of training as possible. All of these subjects had been given previous work with contact analog displays either in the simulator or in flight testing or in both.

B. Apparatus

The arrangement of displays and controls described earlier also applies to this study. A closed loop TV system was added, however the output of this was video mixed with the contact analog format on the vertical display. The camera was mounted on the lower nose structure of the aircraft. It was fixed in yaw and roll, but was capable of being moved in pitch ( $+10^\circ$  to  $-20^\circ$ ) at the command of the subject pilot. This was accomplished by means of a thumb operated position control located on the cyclic stick. Detents were provided on this control to enable the subject pilot to select certain positions of the camera ( $+10^\circ$ ,  $0^\circ$ ,  $-10^\circ$  and  $-20^\circ$ ) with ease. Also provided on the cyclic was a toggle switch that provided two modes of control. In one mode, the camera assumed a position corresponding to the position of the thumb operated control just described. In the alternate mode, the camera automatically assumed the  $0^\circ$  position regardless of the selection of the thumb operated control. This was done so that the subject pilot could very quickly check back to a normal attitude reference whenever he wished. In previous experimentation involving a moving camera, the danger of disorientation when the camera was away from straight ahead position was made manifest. In the present arrangement, the pilot could very quickly and easily obtain the conventional attitude reference by engaging this switch without having to adjust the thumb operated position selector switch.

The TV camera was a Dage Model 333B Vidicon system. Two lenses were compared. One produced a  $30^\circ \times 30^\circ$  field of view which displayed a one to one relationship with VFR to the subject pilot when he was in the normal seated position. The other magnified the image considerably by producing a  $9^\circ \times 9^\circ$  field of view.

Three relationships of contact analog to TV displays were available. These conditions were selected by the experimenter in accordance with a preestablished order. They are listed below:



- a. The TV image was superimposed over the contact analog format. The latter always took its reference from the aircraft attitude with respect to the earth regardless of the depression or elevation of the TV camera. This produced a geometrical equivalence of the formats only when the TV camera was at the zero position. When the camera was depressed, the TV horizon was above the contact analog horizon. When it was elevated, the opposite relation held. Thus, a conflict of cues was present unless the camera was aligned with horizontal axis of the aircraft. This required the subject pilot to differentiate between simultaneously presented displays in accordance with their separate references. The arrangement was selected for evaluation to determine if the ambiguity thus produced could be perceptually resolved or whether it caused orientation difficulties.
- b. In the second arrangement, the TV and contact analog displays always took the same reference. This reference was the attitude of the camera with respect to the earth's surface. This occurred naturally for the TV display, but for the contact analog, it was first necessary to sense the aircraft attitude to the earth's surface and then modify this to coincide with the camera angle before displaying it. Thus, both horizons moved together regardless of camera position. This produced a non-ambiguous display but left the operator without a true indication of where the actual horizon lay except as he could derive it from knowing where the camera was pointed.
- c. The third arrangement was simply one in which the contact analog format was deleted from the vertical display whenever the TV camera was moved away from the zero position. In this situation, no display ambiguity resulted although the pilot was again left to infer the true position of the horizon whenever the camera was not looking along the horizontal axis of the aircraft.

All testing was done with the subject pilot's head under the hood. In addition to the vertical display, the following conventional instruments were to be seen by him:

- a. attitude indicator
- b. vertical velocity indicator
- c. ball and bank indicator
- d. absolute altimeter
- e. airspeed indicator

### C. Procedure

The basic task imposed on all subjects was to lift off the aircraft from an unprepared site (in the midst of a plowed corn field marked with a 12' x 12' sheet of white plastic), ascend to



cruising altitude and speed, make four 90° turns at pre-selected and identified checkpoints, reapproach the landing site and set the aircraft down again. Thus, the maneuvers of lift-off, take-off, cross-country navigation, approach, hovering and landing were included. No firm criteria as to angle of ascent, descent, etc. were implied in the instructions nor was the rate of turn, altitude and airspeed specified. Rather, they were instructed to conform to good flying practice and to the recognized rules of safety. Insofar as was practical, the direction of takeoff and approach was allowed to vary with the prevailing wind.

Prior to testing, the subjects were given practice in the use of the system and familiarization with the display. They were taken at least once around the orbit they were to follow and the checkpoints were identified for them. In addition, a number of landings and takeoffs were allowed over areas other than the landing site used for testing.

During testing, the subjects were systematically evaluated on the three display conditions described in the preceding section. This is to say that on some of the flights, the reference of the TV and contact analog differed while on others they were the same.

The number of flights differed somewhat between subjects. In general, testing was continued with each subject until it could be determined which conditions were most favorable for each maneuver for each individual subject concerned. The median number of flights exceeded a dozen for the three conditions of measurement.

#### D. Results and Discussion

Data were taken in a number of ways. In addition to the inflight recorder, photographs were obtained from the ground on the hovering, takeoff and landing maneuvers. On the basis of these photographs, the position and altitude of the aircraft could be determined as a function of time.

As it turned out, however, this type of data was not useful in differentiating between test conditions. The execution of most maneuvers was generally fair to good. Since these fell within the envelope of acceptable flight procedure and safety, the differences obtained by quantitative measure provided an insensitive and probably spurious indication of performance. For this reason, they are not included in the present report. In general, the data agree that takeoff, hovering and cross-country navigation can be easily accomplished using the TV contact analog ensemble, but that approaches are only fair and landings are often poor as compared to VFR conditions. These findings were more forcefully illustrated in the comments of the pilots than in records obtained.



The most useful data arising from this study appears to be the results of the questionnaire given to the subject pilots after their experience. An example of one of these forms is contained in the appendix of this report. Based upon these questions, as well as upon the observed and measured results, the following statements can be made. The order of the statements conforms somewhat to the degree of certainty that can be attached to them.

- a. The study showed that so far as precision of movement was concerned, the TV display contributed nothing that was not already possible using the contact analog. The TV did, however, contribute greatly as a check on the validity of the information being presented by the contact analog. Thus, if the basic information going to the contact analog is correct, there seems to be nothing to prevent the pilot from executing a precise and correct maneuver. His performance, however, will be no better than the information going to this display. The TV on the other hand has a more "intimate" contact with momentary reality. While it is not as good as the contact analog in showing drift, rate of closure, altitude, etc., the TV has an immediacy and validity that is not at present enjoyed by the other system.

One can conclude from these findings that for the present at least, both systems can be used to advantage in support of one another, the TV being used to validate or update the contact analog while the latter system is used for the precision of control required for the maneuvers of hovering, landing, etc.

- b. With the contact analog and TV working in concert, there is little value in having the TV camera position under variable control insofar as attitude control is concerned. It would, of course, continue to have value in checkpoint and target identification where a magnified image is obtained. This finding is in interesting contrast to the previous results (Elam, 1964) where it was found that without the contact analog, camera movement was useful for attitude control.
- c. It was found that the pilots did not approve of the simultaneous integration of TV and the contact analog. It was the general opinion that both images should appear on the same screen, but individually as selected by the pilot. The primary reason given for this opinion was the unseemly and unnecessary amount of "clutter" that resulted.



- d. For attitude control in landings, hovering, etc., the wide angle lens (30° x 30°) was much preferred. For checkpoint identification, however, the narrow angle lens was more useful. This appears to call for either a zoom lens or a lens turret on future systems.
- e. As an addition to the vertical display, the following instruments were considered to have value. These are listed in the order of their value for cruise and terminal area work:

<u>Cruise</u>	<u>Terminal Area</u>
(1) Ball and Bank Indicator	(1) Absolute Altimeter
(2) Airspeed Indicator	(2) Omni-directional Air speed Indicator
(3) Vertical Velocity	(3) Vertical Velocity
(4) Absolute Altimeter	(4) Ball and Bank Indicator
(5) Rate of Turn Indicator	(5) Dual Tachometer
(6) Compass	(6) Omni-directional Ground-speed Indicator
(7) Dual Tachometer	

- f. Between the conditions of having the contact analog take its reference from the aircraft position relative to the earth (condition #1 above) and taking its reference from the camera (condition #2), the former was preferred for terminal area control while the latter tended to be supported for cruise control. Since, however, the pilots are generally loath to alter the camera from the zero position in terminal work, condition #2 appears to be the better technique. Condition #3 is to be preferred to either of these approaches although, as mentioned in the third statement of this list, the pilots would choose no mixing at all, preferring to select between the TV and contact analog modes.

#### E. Summary and Conclusions

The vertical display was allowed to mix the contact analog format with a video input from a TV camera located on the lower nose structure of the aircraft. The visual angle of this picture was varied (9° square and 30° square) as was the position of the camera in pitch (+10° to -20°). Three conditions of reference were used: (a) when the camera moved, the contact analog format remained fixed; (b) the contact analog moved with the TV picture; and (c) the contact analog was deleted when the TV picture was moved from zero elevation.

The data obtained from the inflight recorder and from ground observation were without differentiating significance. From questionnaires and interviews of the pilots, however, it was established that: (1) The contact analog is best for control while the TV is useful for validating the contact analog by



checkpoint identification, etc. (2) Camera movement is of insignificant value for control when the contact analog is available. Such movement is to be desired only for checkpoint identification using a narrow angle lens. (3) Simultaneous mixing of the contact analog format with the TV return was not as preferred as selecting between these pictures. (4) Wide angle TV lenses are preferred for attitude control while narrow angle views are desired for checkpoint identification. (5) A number of conventional instruments are desired for this type of flying.

Generally these results did not confirm the expectations based upon previous research and analysis. It was thought that TV would be at least as good for precise control in terminal area work as the contact analog. It was not. TV does not lend itself well to judgments of distance, rates of closure, drift, etc.

It was also expected that the ability to move the TV camera would be useful for terminal area work. It was not. The presence of the contact analog appeared to make this facility superfluous.

It was believed that mixing the displays would produce a better display than if presented separately. It did not. The primary usefulness of the two systems occurred at different times. The combination only produced an undesirable clutter.

It seems clear, therefore, that TV and the contact analog system each have their uses and are basically not redundant to one another in terms of information content. They can support one another, but neither is an adequate substitute for the other.

APPENDIX A



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TRAINING INSTRUCTIONS TO SUBJECTS - HOVER EXPERIMENT

"The primary purpose of this session is to familiarize you with the handling characteristics of this aircraft prior to entrance into the pretest and testing phases of RH-2 Experiment I. You have already received the mockup checkout and have participated in many of the JANAIR simulator studies, so the overall system and procedures required will not be new to you; but the handling characteristics in the various control modes will require a short period of transition and this is the purpose of this session."

"The two control modes which will be presented are the normal mode (fly-by-wire) and the damper mode, with the majority of the maneuvers being accomplished in the former mode, in which control sensitivity is at a maximum. The tasks and procedures will be as follows. The safety pilot will perform the takeoff and climb to an altitude of approximately 1000 feet. At this point you will be given control of the aircraft in the normal mode. You will perform maneuvers at your discretion to establish a "feel" for the dynamics of the system. When you are satisfied that you can handle the aircraft well enough to accomplish specific tasks requiring maintenance of altitude and airspeed in various modes of flight with some degree of proficiency, inform me on the intercom. I will then describe the tasks to be accomplished, the parameters to be scored, and the procedures to be followed."

"Do you have any questions?"

Then preceding the proficiency tasks, these instructions were read.

"Your first task will be to maintain 1000 feet altitude as nearly as possible throughout turns and acceleration-deceleration maneuvers. The safety pilot will specify the rate and angle of turn to be accomplished and you will roll-out to straight and level flight after satisfying the given requirement. Your range of operation in the deceleration-acceleration maneuver will be 40-60 mph, i.e., a gradual continuous deceleration to 40 mph, a short pause, then a gradual continuous acceleration to 60 mph, with two repetitions of this procedure throughout this range. You will then be asked to maintain an airspeed of 60 mph throughout various climbing and descending turns, again as specified by the safety pilot. There has been a criterion of performance established for each task, and there will be a smooth transition from one task to another rather than a discrete presentation. All tasks will be assigned by the safety pilot and he will answer any questions you may have pertaining to a particular maneuver."



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"Do you have any questions?"

Upon completion of the assigned tasks when the desired proficiency has been demonstrated, the following was read:

"The system will now be placed in the damper mode and you will proceed to the practice area where Experiment 1 pretest will be run. Execute an approach and landing to the specified point in the area and complete the maneuver to touchdown."

"Do you have any questions?"



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PRETEST INSTRUCTIONS TO SUBJECTS - HOVER EXPERIMENT

"This will complete the pretest requirements for Experiment 1. Trials will be of one minute duration each, and will be performed in the normal control mode. The vertical display will be ON throughout each trial, but your primary concern will be with the external cues for attitude and position information. The first trial will be accomplished by the safety pilot, so that you may monitor both sources with equal attention. Thereafter your performance will be scored by recording any deviation from the criteria which has been established for the various parameters. Specifically these parameters are heading, the command being degrees (determined by wind direction), altitude, the assigned being approximately 15 feet, and aircraft position, the origin or zero position being determined at trial initiation. Thus your task will be to maintain these assigned conditions in the hover mode throughout the 60 second trial period. Inter-trial intervals will be approximately one minute, and two successful trials in succession will be the prerequisite for entrance into the testing phase. This will conclude the pretest period of Experiment 1. It should again be emphasized that your primary source of cues for attitude and position information will be from the external environment, and only secondary consideration should be given to the vertical display during the pretest trials. The take-off and touchdown, as well as control of the aircraft between trials, will be accomplished by the safety pilot, so your only concern will be performance in the hover mode. I will inform you when the trial is to begin, when it has concluded, and when you have successfully fulfilled the pretest requirements."

"Are there any questions?"



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INSTRUCTIONS TO SUBJECTS FOR TESTING TRIALS  
HOVER EXPERIMENT

"Your task will be to hover under two flight conditions, one being contact flight using the external or real world environment as your source of cues for attitude information, and the other being simulated instrument flight, using the vertical display for presentation of real world analogy and the NAV display for position information. The display configuration to be utilized is the grid plane plus GPI and will remain constant throughout this experiment. Each trial will be initiated at an altitude of approximately 15 feet and on a cardinal heading. Your task will be to hold these initially assigned conditions, once established, for a two minute period over a predetermined position designated on the horizontal display. Aircraft heading will yield a direct or quartering headwind at all times. You will not be asked to change heading in the course of any trial. If a wind direction shift of 90° or more is encountered during a trial or windspeed exceeds 25K throughout the trial, the maneuver will be aborted and the data disregarded. If this occurs frequently in any session, that is so as to affect several trials in succession, the session will be delayed temporarily or terminated."

"You will operate in four control modes: the normal mode or fly-by-wire, in which the control sensitivity will be at a maximum; the damper mode in which artificial damping in the system reduces sensitivity, and the attitude mode, which will enable you to fly "hands off" once the ship is trimmed. The three modes thus far presented pertain only to the side-arm cyclic controller and yaw pedals. The fourth mode will be the attitude mode with the altitude hold on. Although complete "hands off" flying is indicated in the latter two modes, you will have complete manual control of the collective pitch in one instance, and corrections for drift will be required in both cases. This will be accomplished by overriding the control trim in these modes, causing the system to revert to the damper mode. When pressure is released, that is, when stick force is zero, the system automatically switches back to the attitude mode. Thus, complete "hands off" flying, or hovering in this case, is not recommended, rather constant control pressures or continuous inputs are not required, thus pilot work load is greatly reduced."

"The procedure for each trial will be as follows. The safety pilot will pick up to a hover and stabilize the aircraft on the command heading and at the assigned altitude. It will be necessary for me to identify each trial prior to commencement, which will be done via the intercom, and at the same time I will inform you of the mode of



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operation and trial conditions. The safety pilot will then inquire, 'Are you ready?' When you say, 'Ready,' he will reply, 'You have it.' At this time the recording system will be activated and the trial will begin."

"After two minutes I will say 'End of trial,' the trial will be terminated and the safety pilot will assume control of the aircraft. If at any time during a trial, performance falls within a marginal area of safety, as determined by the safety pilot, he will take over the controls, say 'I have it.' and the trial will terminate. Should you touchdown at any time throughout a trial, if the condition is not unsafe, continue the maneuver, attempting to regain the assigned altitude as quickly as possible. Under no condition will the control mode be changed during the course of a trial intentionally by either the safety pilot or myself. If you detect any change, inform the safety pilot and he will take the appropriate action."

"Do you have any questions?"

Immediately preceding the first presentation of the vertical display configuration and under simulated IFR conditions, the following instructions were given:

"This is the basic grid plane plus ground position indicator. Your task will be to hover maintaining position, heading and altitude as experienced at the initiation of the trial. It is important to remember each square is 12 feet per side in the lower altitude scale, and the GPI appears as a white square 1-1/2 times the basic grid square. It will appear ahead of you approximately 100-125 feet at the beginning of each trial and the consistence with which you maintain your relative position, as established at commencement of the trial, will determine your task proficiency."

"Do you have any questions?"

Preceding the first contact flight, the following instructions were read:

"Your task of maintaining position, altitude and heading in the hover maneuver will be performed under contact or VFR flight conditions in the following trials. All control modes will be presented in this block and altitude, heading and position cues will be taken from external objects."

"Do you have any questions?"



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APPENDIX B



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### INSTRUCTIONS FOR PROCEDURE CHECKOUT

During the next few minutes there will be a brief orientation similar to the mockup checkout. The purpose of the orientation is to point out the changes which have been made to the original flight plan, together with the procedure changes which are reflected on the new checklist which you have received. This briefing will cover the flight plan and procedures for both north and south patterns. If you have any questions at any time during the briefings, stop me immediately and ask. I will then repeat that portion of the instructions.

Before we begin, are there any questions?



## RH-2 PROCEDURES

### Start-Up Procedure

1. Check "system master" switches on (Power) and doppler in standby position.
2. Set "pathway mode" switch to hover.
3. Select pathway altitude (1000 feet) with "path altitude" selector.
4. Set time and distance selectors to Fix 1.
5. Set "Navigation mode" selector to Doppler/Decca (Doppler) and check green light on.
6. Set "wind mode" switch to auto.
7. Set "computer input" switch to enter.
8. Select Map 4 (2 mile) with "map scale" selector.
9. Push "map engage" button. (Center of practice area)
10. Slew present position to aircraft symbol (bug) on the navigation display with the "slew" handle.
11. Press "present position" (PP) enter button until green light comes on.
12. Push "Fix 1" button until green light comes on.
13. Return "computer input" switch to compute and check for stability (drift indicates PP improperly entered).
14. Return to enter position.
15. Select Map 6 (12 mile) with the map scale selector and push "map engage" button.
16. Slew map to Fix 2 and push "Fix 2" button until green light comes on.
17. Slew map to destination and push Fix 3 button until green light comes on.
18. Return "computer input" switch to compute.
19. Adjust vertical display "pitch" and "roll" trim.
20. Set "path bearing" to coincide with map bearing to Fix 2.
21. Set "pathway mode" switch to climb.

### Pattern Procedures

1. Hover translate and climb on pathway.
2. When pathway levels, set "pathway mode" switch to cruise.
3. Set time and distance selectors to Fix 2.
4. Adjust "path bearing" to desired bearing to Fix 2 (if necessary).
5. Proceed to Fix 2.



Cross-Country and Landing Procedure

1. Approaching Fix 2, check distance readout for near zero miles.
2. Overfly Fix 2 and turn time and distance selectors to destination. Check bearing to destination on the navigation display.
3. Re-orient path bearing to desired bearing to destination.
4. Execute a  $45^{\circ}$  left turn, proceed outbound for 15 seconds, execute a  $180^{\circ}$  right turn, fly inbound and intercept the pathway. Perform a right turn onto the pathway and proceed to destination.
5. Approaching destination, check distance readout for near zero miles.
6. Overfly destination and turn time and distance selectors to Fix 1. Check bearing to Fix 1 on the navigation display.
7. Re-orient path bearing to desired bearing to Fix 1.
8. Execute a  $45^{\circ}$  left turn, proceed outbound for 15 seconds, execute a  $180^{\circ}$  right turn, fly inbound and intercept the pathway. Perform a right turn onto the pathway and proceed to Fix 1.
9. Check distance readout approaching 2.5 miles.
10. Place path mode selector in the approach mode.
11. Approximately 1.6 miles out intercept the approach glide-slope, descend as commanded by the pathway.



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APPENDIX C



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INSTRUCTIONS TO SUBJECTS  
FOR REFAMILIARIZATION FLIGHTS

The purpose of this flight is to acquaint you with the airborne procedures which will be required during the cross-country testing trials and to re-establish your "feel" for the system. We will begin with a brief VFR flight, performing maneuvers at your discretion, followed by VFR hovering maneuvers in the practice area (damper mode), also executing take-offs and touchdown. After approximately 30 to 40 minutes, we will land the aircraft and program for the cross-country flight, following the same general procedures that will be used in subsequent testing trials. Familiarization with airborne display features which you have not encountered to date, such as the indices on the navigation display and the speed markers on the vertical display pathway, will be of specific interest during this flight. Your performance will be recorded, solely for the purpose of program check-out, and you are requested to give a running commentary throughout the flight. Command altitude will be on pathway (approximately 900 feet) and command airspeed 65 knots in the cruise mode. Climb-out and approach glideslope angle is  $8^{\circ}$ . The heading to the Handley Drive-In (Fix 2) is approximately  $212^{\circ}$ , and the reciprocal heading ( $32^{\circ}$ ) will be used for return. Only one check point will be used. (If a north take-off is required, after command altitude is reached, the practice area will be overflown and Fix 1 to Fix 2 heading will be used.) If a north approach is required, a straight-in approach will be executed to the practice area on the same inbound heading from the Handley Drive-In. If the approach is to the south, the safety pilot will take over after you over-fly the practice area and set up your final approach, informing you when he has taken over and when you are to take over and perform the approach to touchdown. If an unsafe flight condition is encountered at any time, the observer pilot will assume control of the aircraft and inform you he has done so by saying, "I have it". The speed markers, located on the right edge of the path, are programmed for the command airspeed of 65 knots in cruise and for the appropriate airspeed in approach. The markers will tend to move away from you if you are below command airspeed and move toward you if your airspeed is too high. If you maintain 65 knots the markers should appear stable, moving in neither direction. The time and distance readouts will provide precise numeric information for check point identification, glideslope interception and position information when used in conjunction with the displays. To reiterate, you will be operating in the damper control mode. A verbal commentary is requested throughout the flight covering such aspects as switching modes, pathway deviations and interception, and check point I. D. This way I can cross-check your procedures in flight. Should you fail to comment on your actions, I will assume you have encountered difficulty and instruct you on the proper procedures.



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Your task is as follows: After programming for the flight, as specified by the procedures check list, you will be given the controls on climbout from the practice area when you are ready. You will appear to be on the pathway when the mode switch is turned to climb, so upon take-off, the A/C will be on an  $8^{\circ}$  angle of climb. Your reference point will be Fix 1, so you will be flying an outbound heading from Fix 1. You will continue to climb on the pathway until you reach command altitude, at which time the path will transition to a level "highway in the sky" (path mode selector to cruise) and 65 knots will be command air-speed. Select Fix 2 with the time and distance selectors, note the bearing to Fix 2 on the NAV display, and attempt to regain the pathway if you are not on it. Proceed to Fix 2 on the pathway. Note the distance readout approaching zero and identify verbally when overflying Fix 2. Select Fix 1 with the time and distance selectors and dial the appropriate bearing with the path-bearing knob (approximately the reciprocal  $32^{\circ}$ ). Execute a  $45^{\circ}$  turn to the right, fly outbound for 15 seconds, perform a  $180^{\circ}$  turn, fly inbound toward the pathway and intercept the pathway by performing a  $45^{\circ}$  turn to the left on the path. Proceed to Fix 1 on the pathway. If an approach to the north (on  $032^{\circ}$ ) is desired, approximately 2.0 miles from Fix 1, turn path mode selector to approach and descend as commanded by the path (1.6 - 1.4 miles out) and land. If a south approach is required, upon the overflight Fix 1, the observer pilot will take over and set up for the final approach. After he assumes control, you are requested to dial  $180^{\circ}$  with the path-bearing knob and turn the mode switch to "approach". He will inform you when to take over approximately 2.5 miles north of Fix 1. You will be inbound and will then perform the approach from this point. Your approach glideslope will be  $8^{\circ}$ . In both approach and take-off, the speed markers are programmed as a function of distance out, increasing from 0 knots to 65 knots from 0' to 1000' from the reference point (Fix 1).

This flight will be under simulated IFR conditions (hooded). Both displays, horizontal and vertical, will be operational during the flight. The two instruments to the right of the display, airspeed and the absolute altimeter, will be available for your use. There is also a modified ball bank indicator located below the vertical display for your use. This will assist you in performing coordinated turns.

Do you have any questions?

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APPENDIX D



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### INSTRUCTIONS TO SUBJECTS FOR TESTING FLIGHTS 1-4

You have received the revised flight procedures checkout and the familiarization flights. The following flights which you will perform are the testing trials for the cross-country phase of this study. All trials will be in the damper control mode under IFR conditions. You will fly the same course on each flight. The only alteration will be a change in the direction of takeoff and approach which will reverse the sequence of the leg destination (fixes) around the programmed triangular course. You will have a command altitude of approximately 950-1000 (on pathway) feet and a command airspeed of 65 knots in the cruise mode. Once again you are requested to give a verbal commentary throughout the flight as time permits.

Your task is as follows: you will program for the flight using the check list (if necessary) in the practice area, the point from which the flight will be initiated. The Arlington water tower and the Colleyville Road intersection, as previously pointed out, are to be used as leg destinations. The headings for the south course will be: (Demonstrate with placards) practice area to water tower, 135 degrees; water tower to intersection, 335 degrees; intersection to practice area, 175 degrees (if the north course is to be flown, the following will be used in lieu of the above - practice area to intersection, 355 degrees; intersection to the water tower, 155 degrees; and water tower to the practice area, 315 degrees). You will follow the same procedure as in the checkout flights, assuming control during climb out on the pathway, level off at command altitude and transition to 65 knots airspeed. Switch path mode to cruise and turn time and distance selectors to Fix 2. Regain the pathway if you have deviated from it. Monitor "distance to" approaching zero, identify over-flight of Fix 2. Turn time and distance selectors to Fix 3 (destination) and select the appropriate bearing with the path bearing knob. Perform the procedure turn, 45 degrees left, outbound for 15 seconds, 180 degree right turn, proceed inbound to intercept the path and execute a right turn onto the pathway. Proceed on pathway to destination. Check "distance to" readout approaching zero, identify over-flight of destination verbally. Turn time and distance selectors to Fix 1 and select the appropriate bearing to Fix 1 with the path-bearing knob. Execute a 45 degree left turn, outbound for 15 seconds, 180 degree right turn and continue inbound until the pathway is intercepted. Execute a right turn onto the pathway. Proceed to Fix 1 on the pathway. Approximately 2-2.5 miles from Fix 1, place the path mode selector in the approach position. About 1.6 miles from Fix 1, initiate the approach (8 degree angle) as directed by the pathway. Terminate the approach in order to come to a hover at 50-25 feet altitude.



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The airspeed indicator, absolute altimeter and the modified ballbank instrument will be available to you throughout the flights. The pathway speed markers are programmed for 65 knots in cruise, and in the approach and takeoff maneuvers, the markers are programmed to differentially transition from climb to cruise (0 knots to 65 knots) and cruise to approach (65 knots to 0 knots) as a function of distance out from the reference point. As previously stated, the speed markers will move away from you if airspeed is below command and toward you if airspeed is too high. Your performance will be recorded throughout the flight, and I will make some verbal inputs at various times for purposes of identification of the flight segments. The trial will be terminated at hover, at which time the safety pilot will assume command of the ship. If at any time during the flight an unsafe condition arises, the observer pilot will take over and inform you that he has done so. This portion of the flight will not be scored.

Do you have any questions?

#### INSTRUCTIONS PRIOR TO TEST FLIGHT 5

Your task will remain the same as in the previous four trials, the performance of the triangular cross-country flight with a running commentary as time permits. During this flight, however, the vertical display pathway will not be available, thus airspeed and altitude information will be obtained primarily from the A/S indicator and absolute altimeter. The command altitude will be 1000' and command airspeed 65 K. The procedure for checkpoint identification and subsequent turns remains the same as with the command bearing between checkpoints. Rather than intercepting the pathway upon completion of the procedural turns, attempt to overfly the same checkpoint which you have identified enroute to the subsequent check point. This will yield the appropriate command bearing between checkpoints and heading and position information may be obtained from the horizontal display. You will be set up on the correct heading for climbout by the observer pilot when he gives you control of the aircraft. All other digital information will be presented as in previous trials, that is, time to, distance to, wind direction, etc. I will inform you of the command bearing for each leg during the flight, and request that you set this value in with the path bearing selector. This is solely for the purpose of data collection and will not affect your flight in any way. This trial will be flown with a southwesterly (northerly) takeoff and command bearing is 135° (355°) for Leg 1. Proceed with your flight programming in the usual manner.

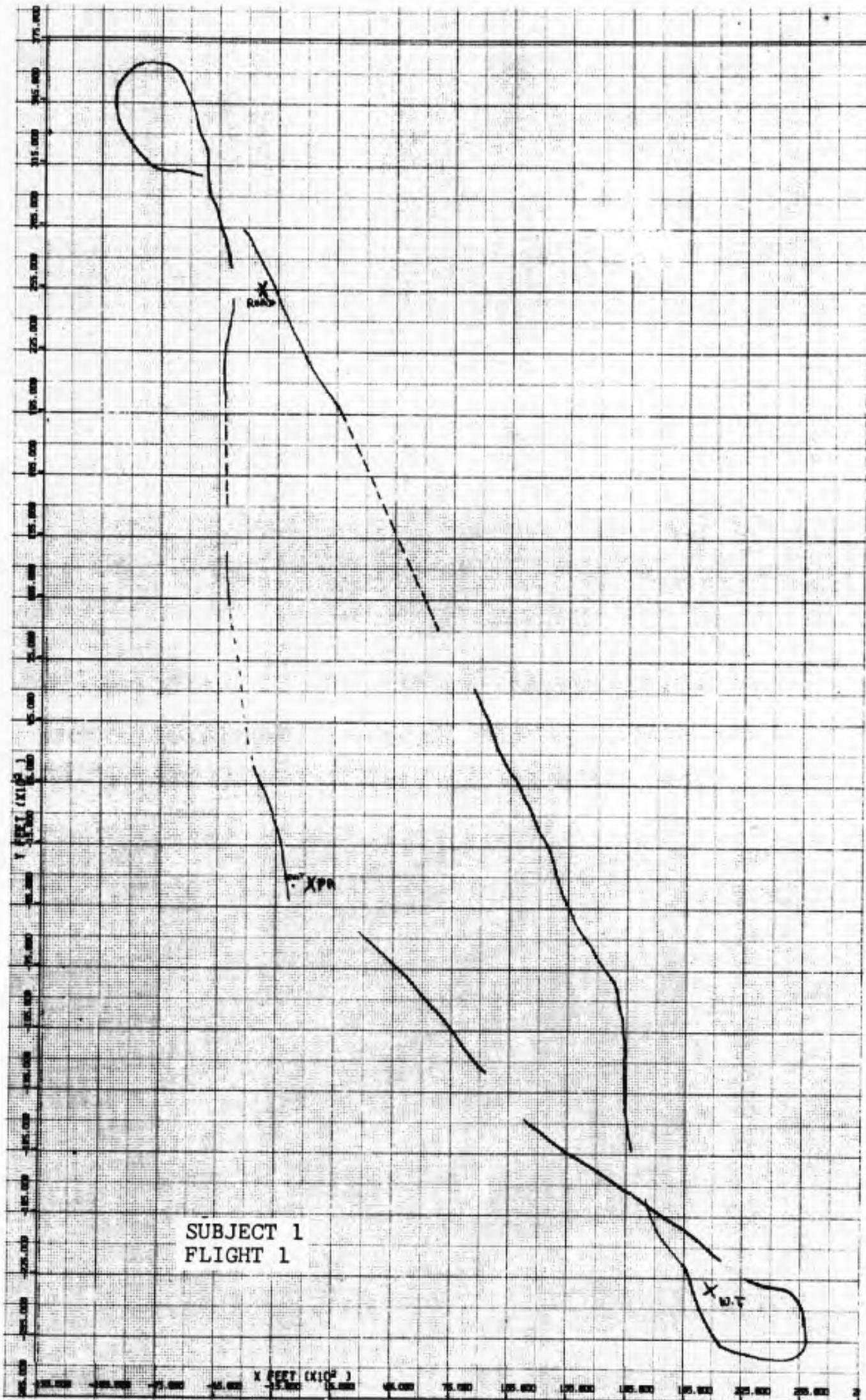
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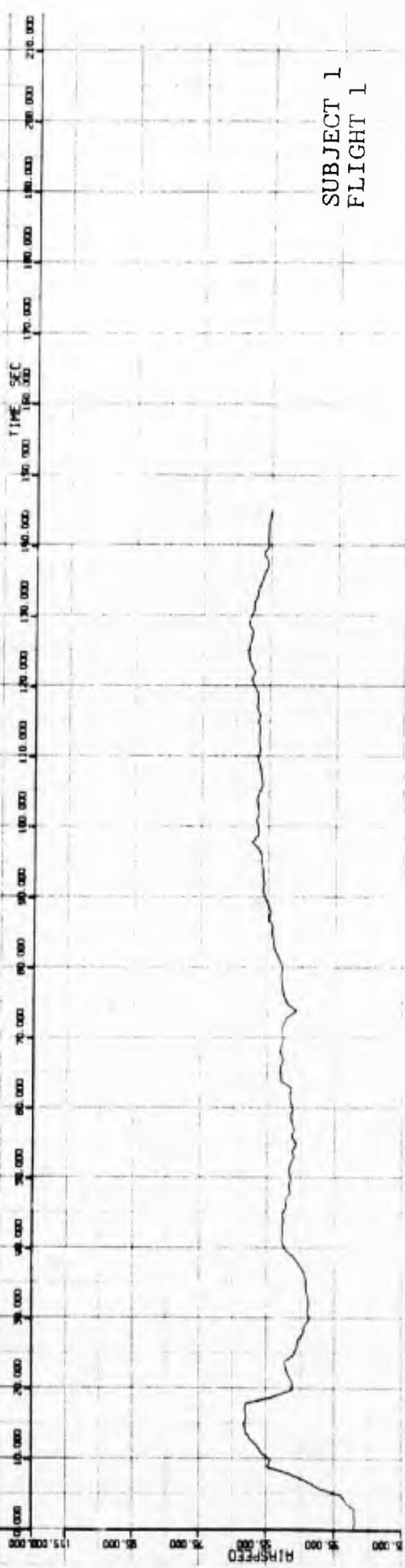
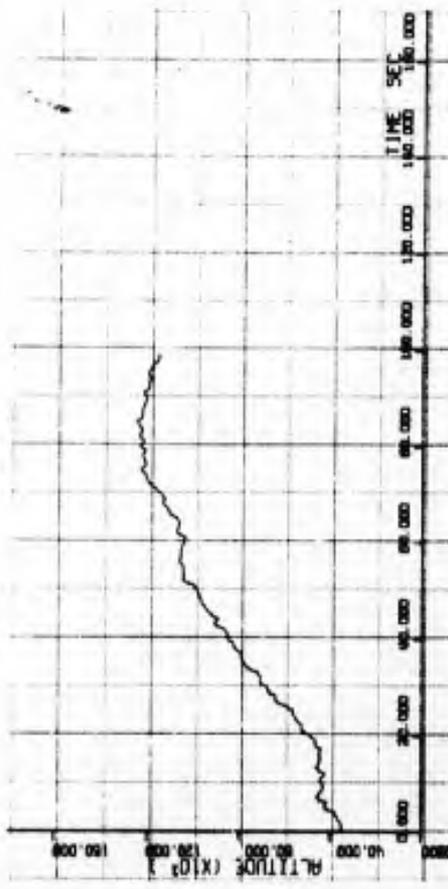
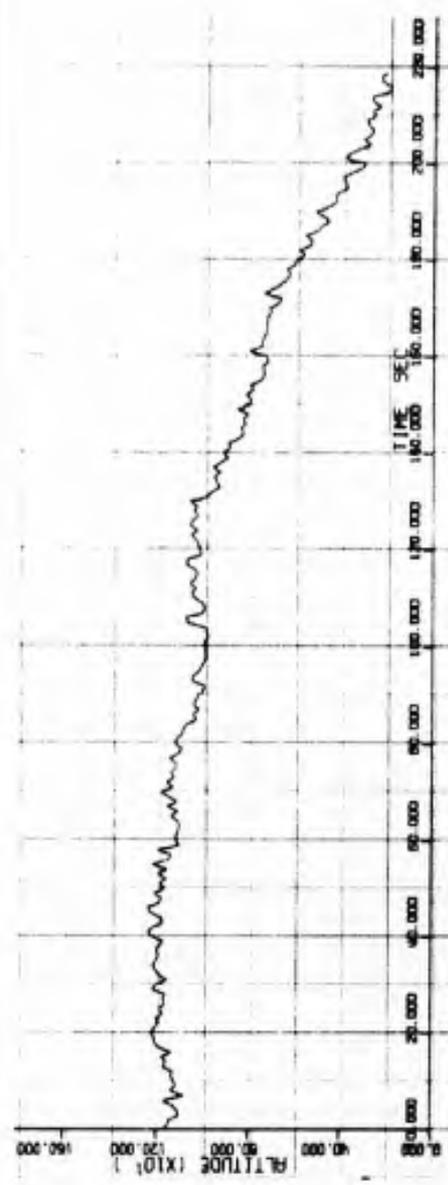
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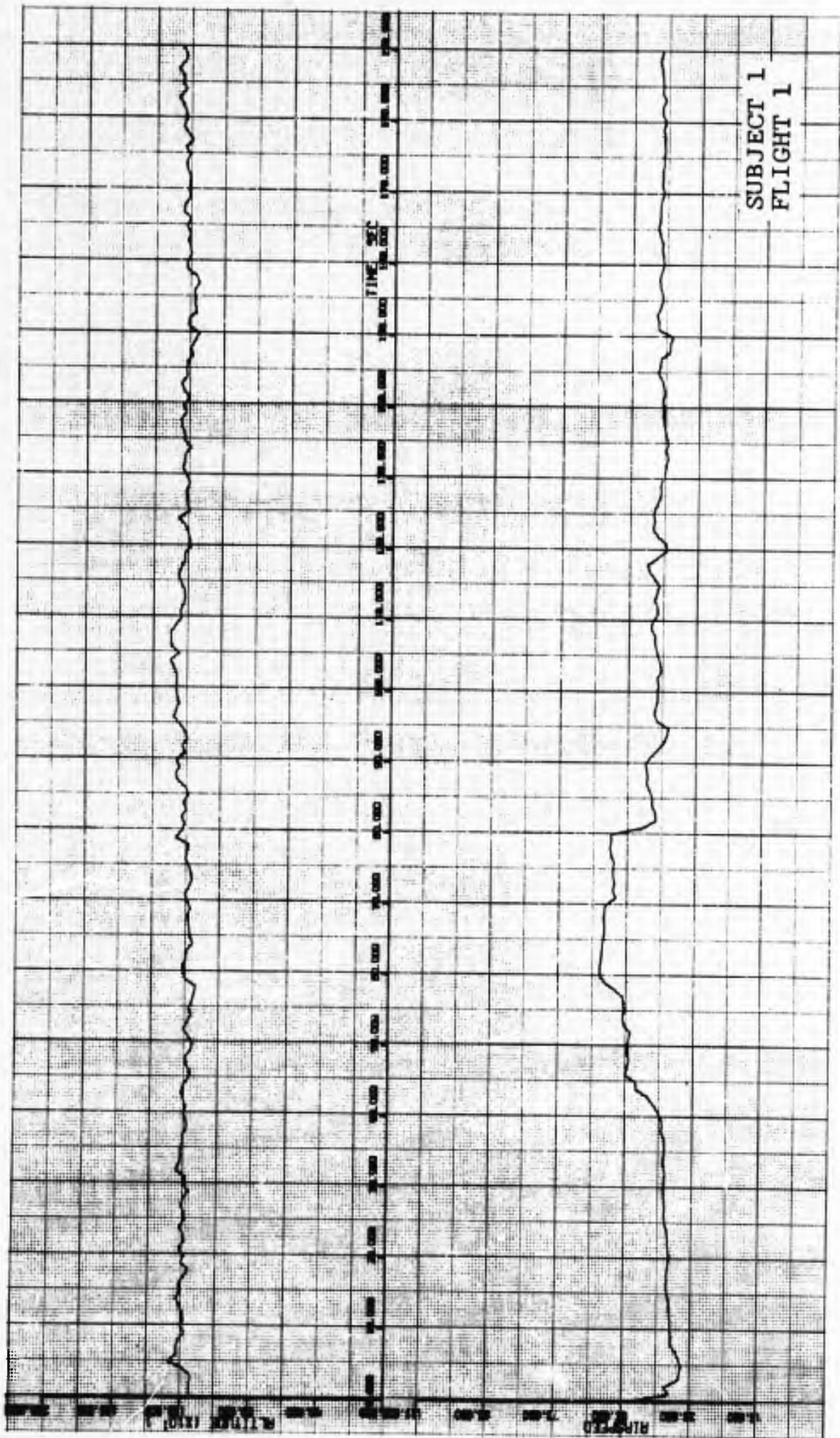
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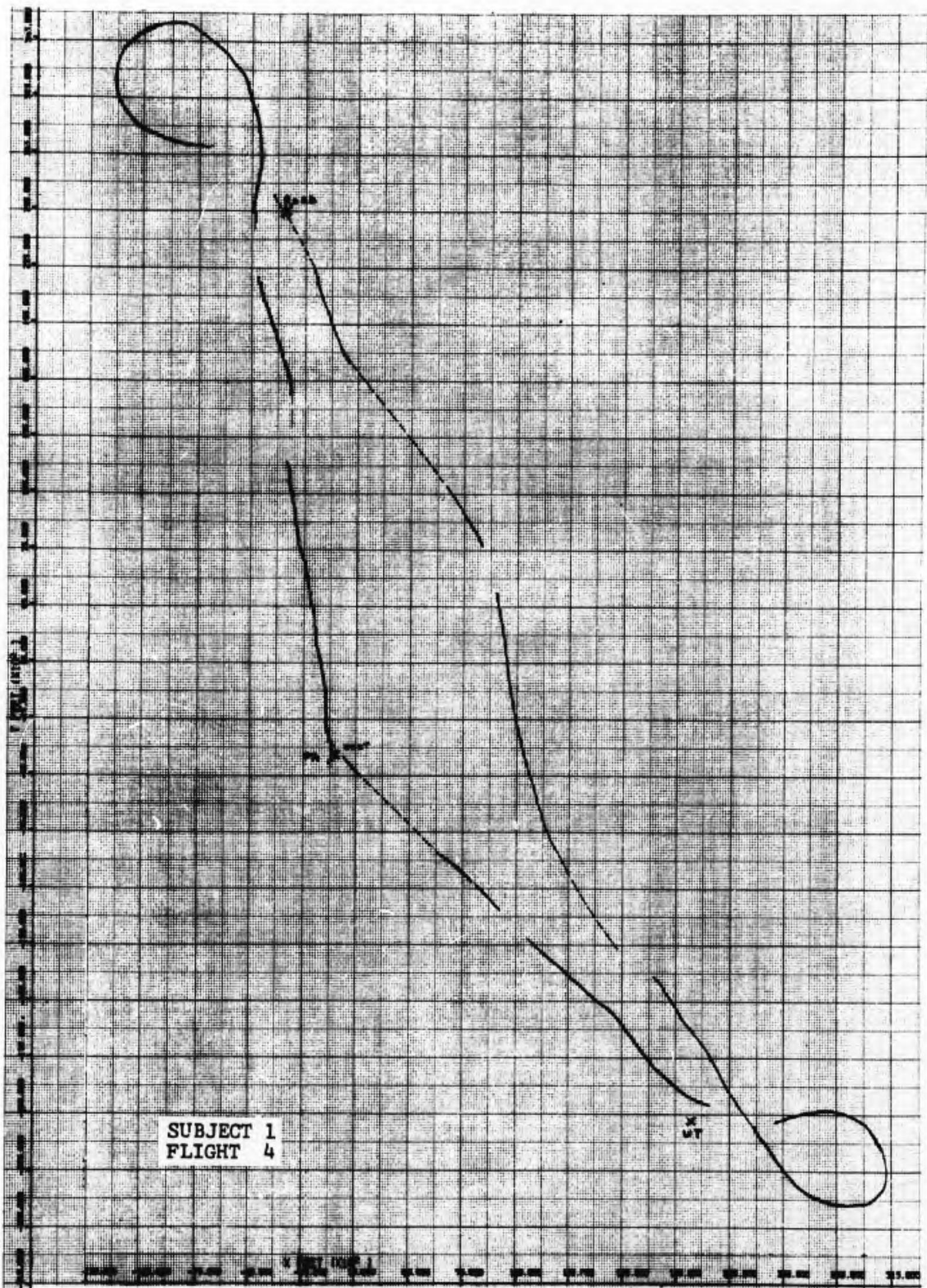
APPENDIX E





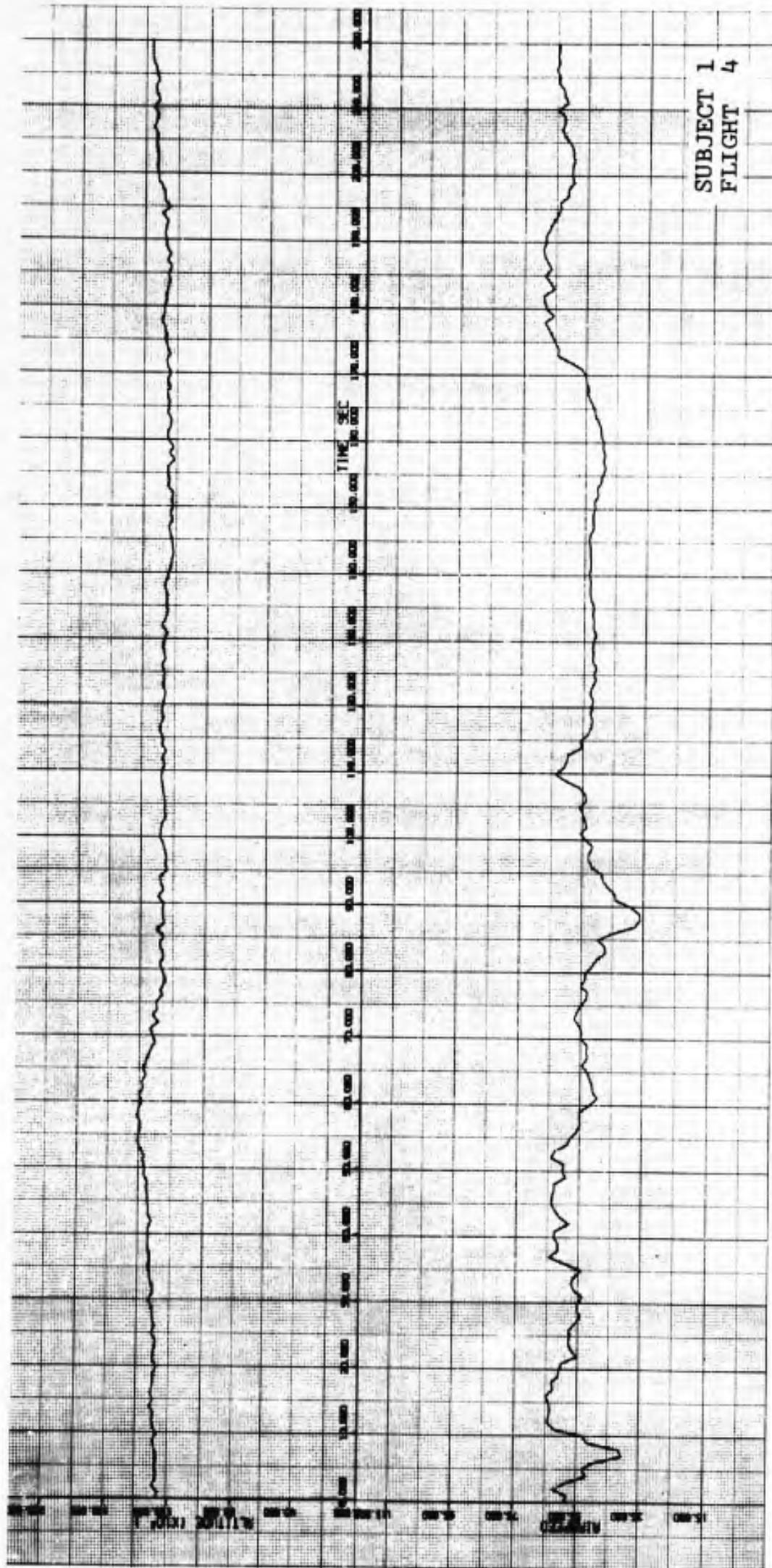
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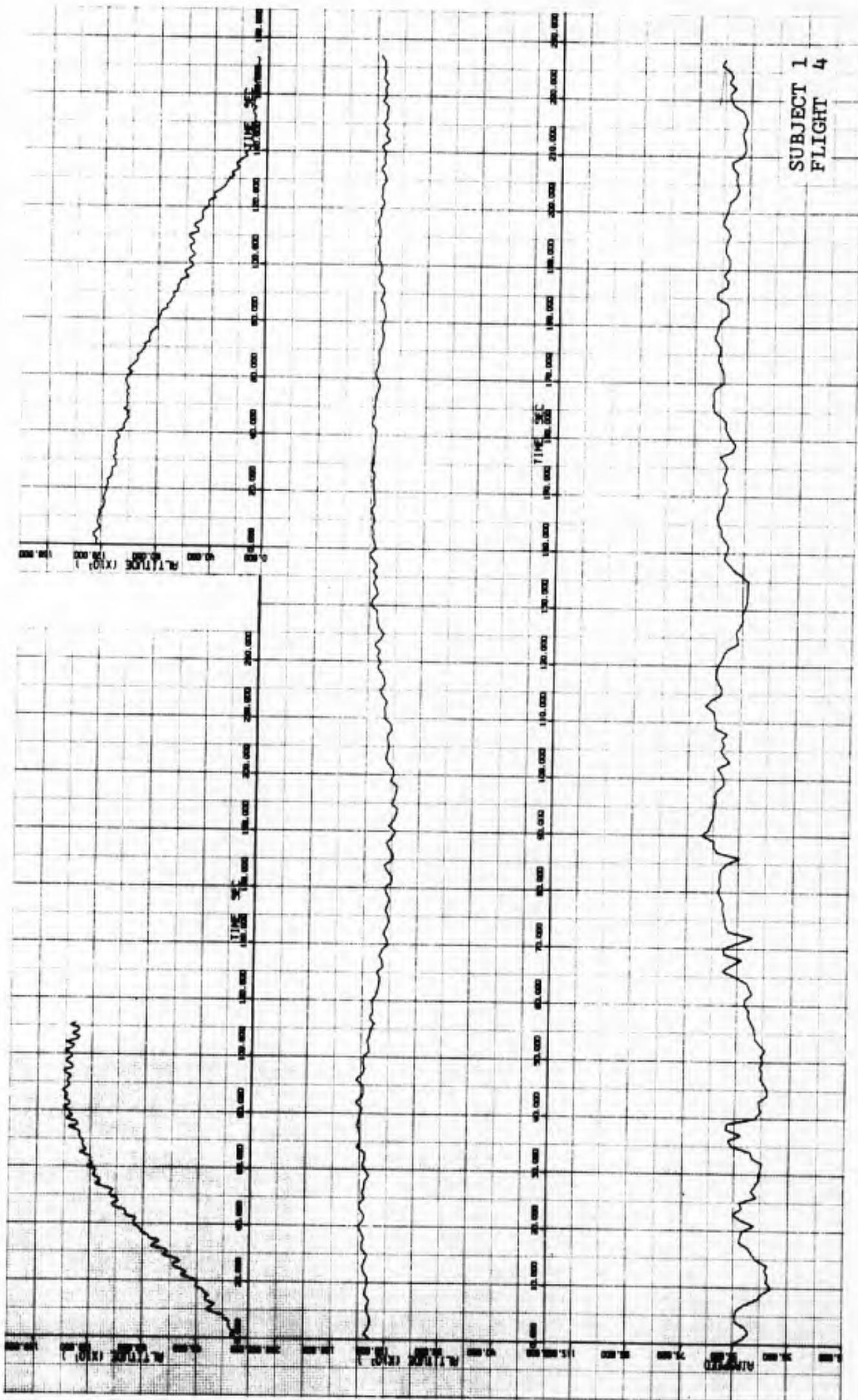


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FLIGHT 4

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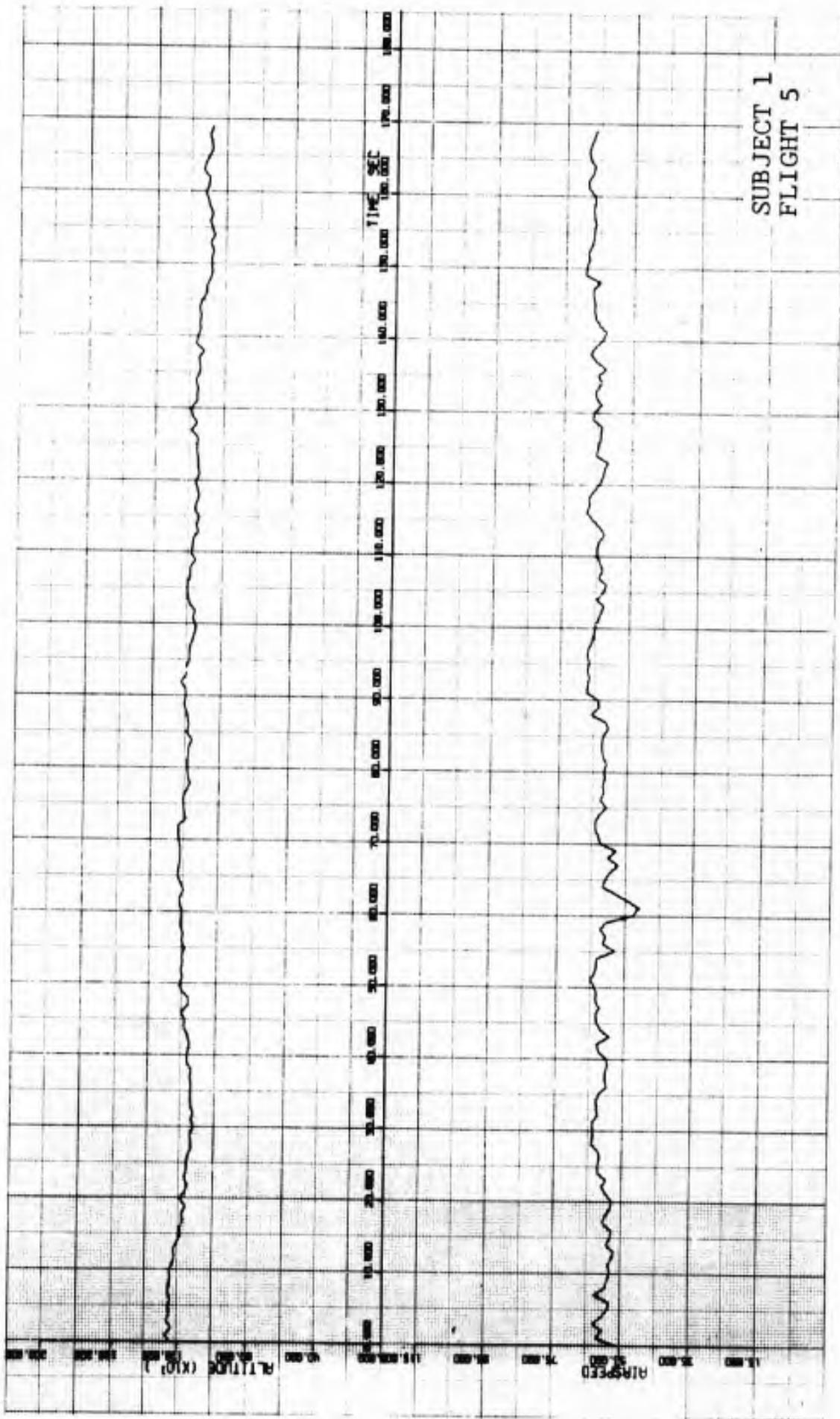


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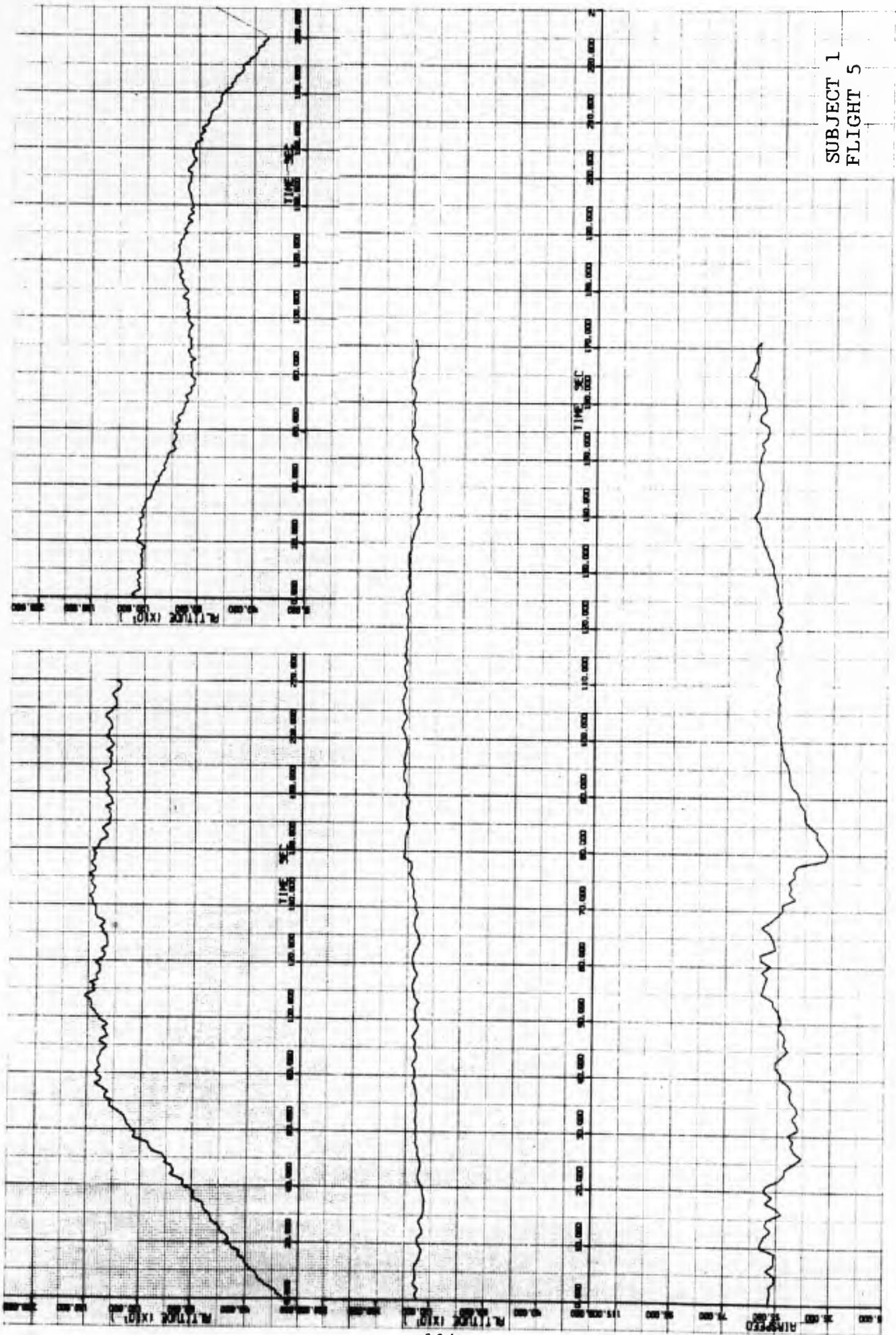


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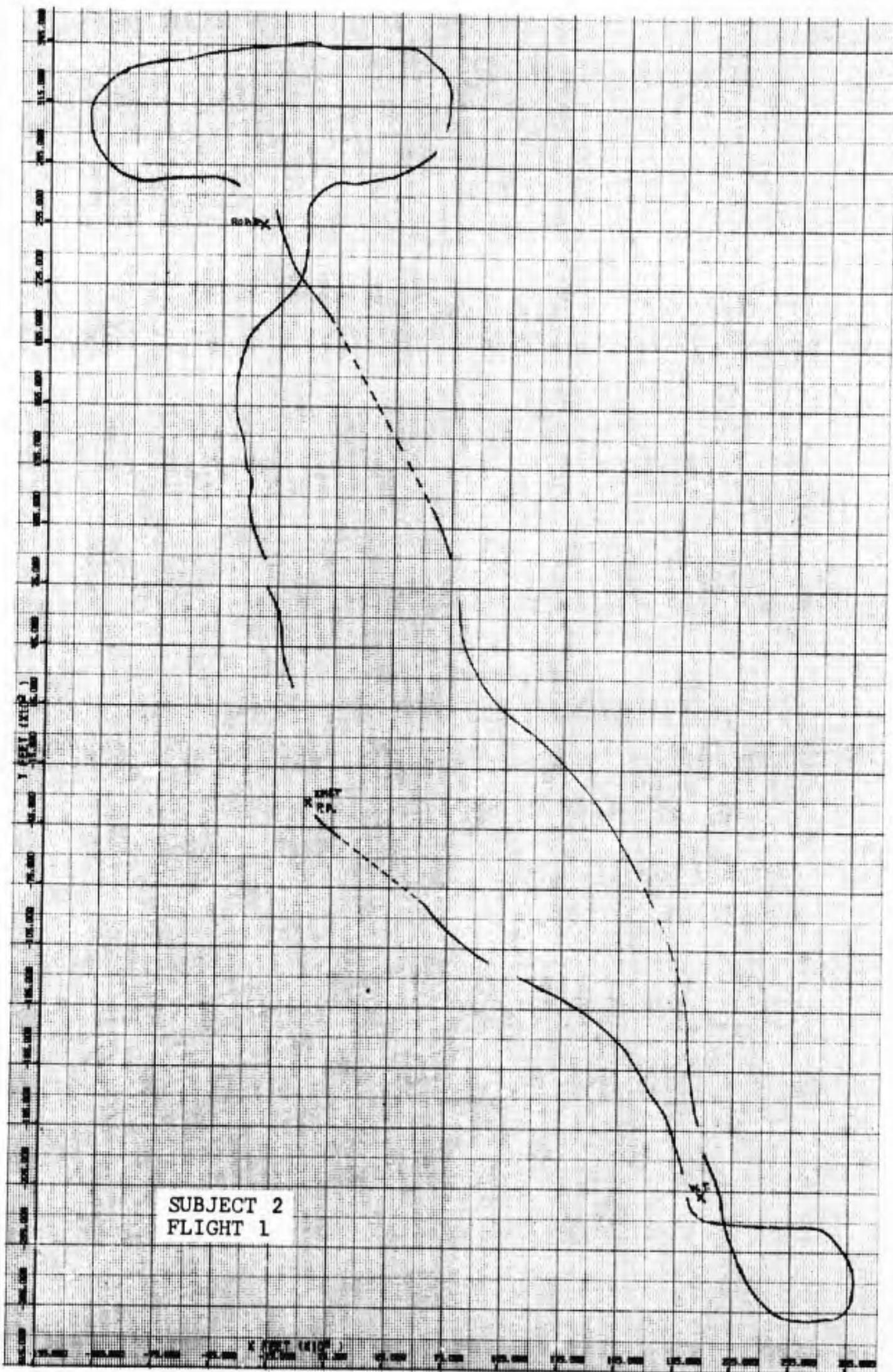


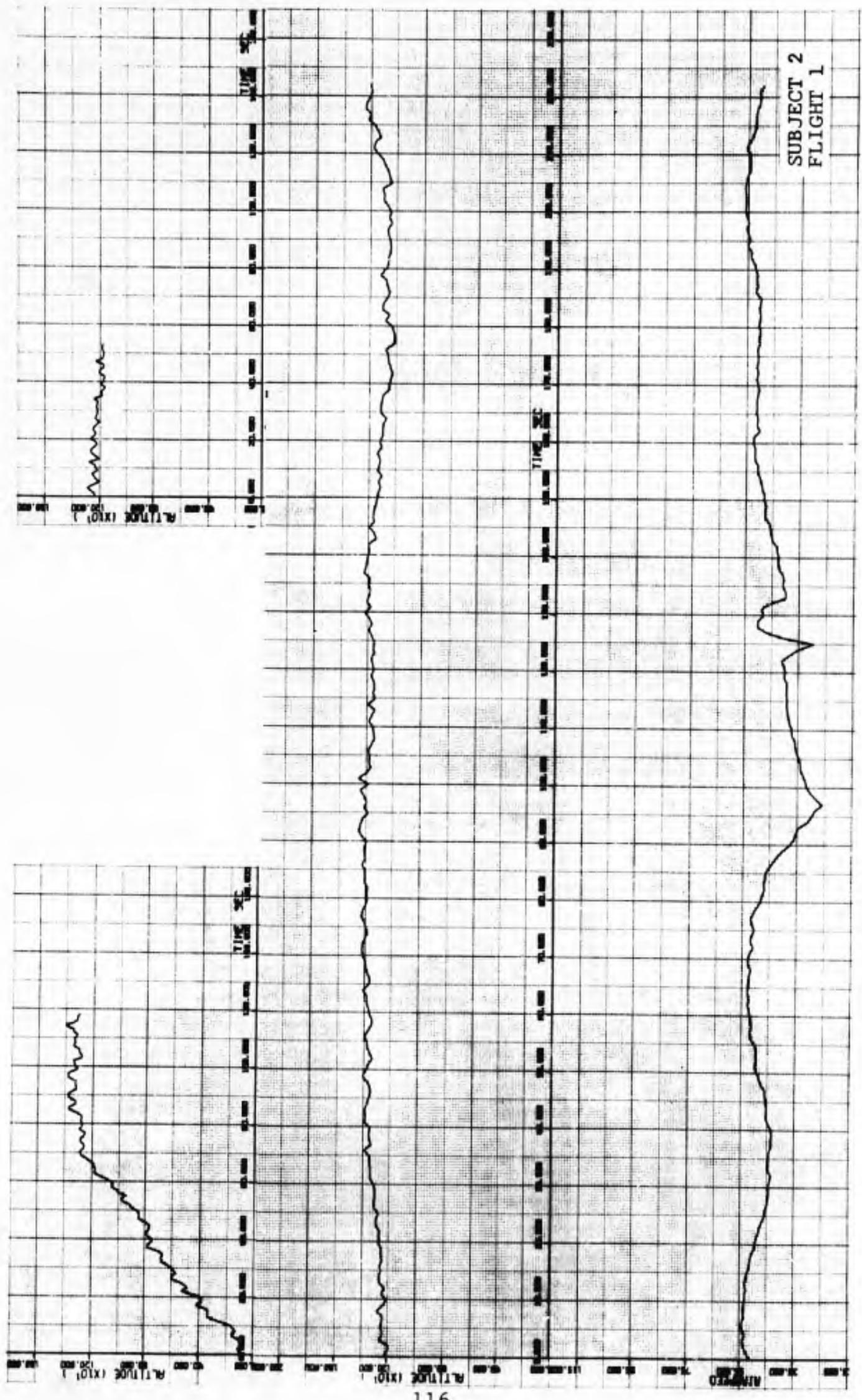


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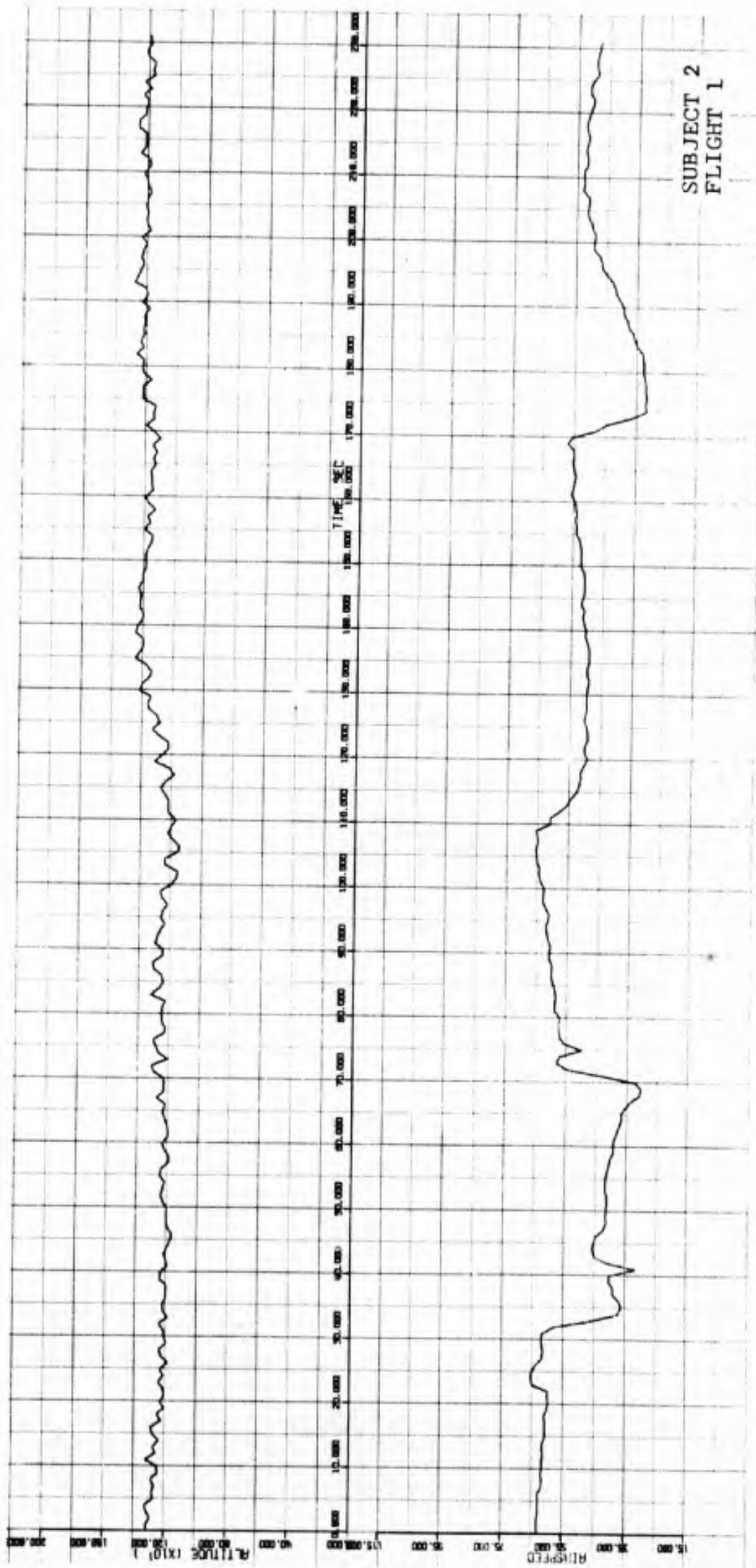


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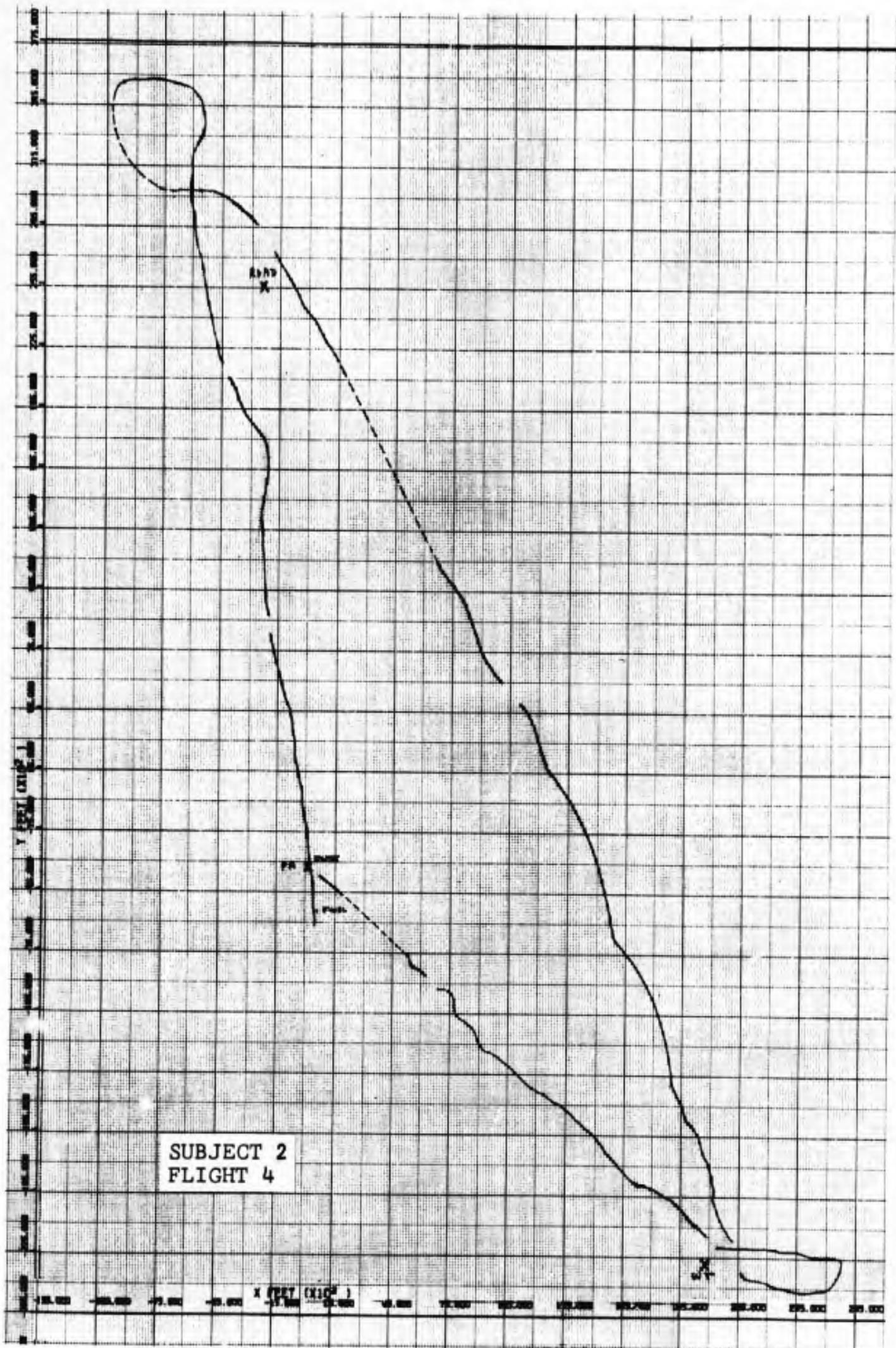


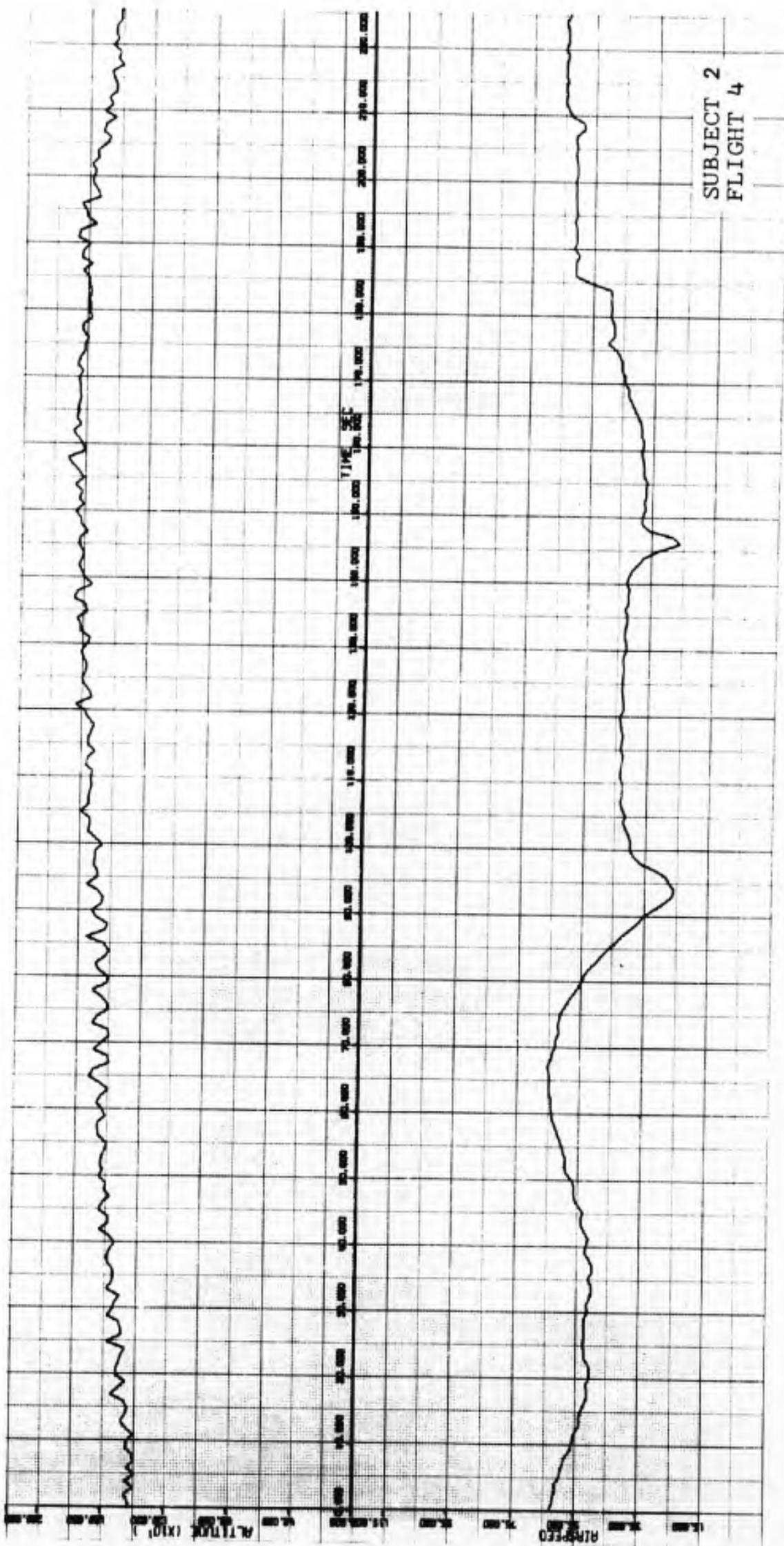


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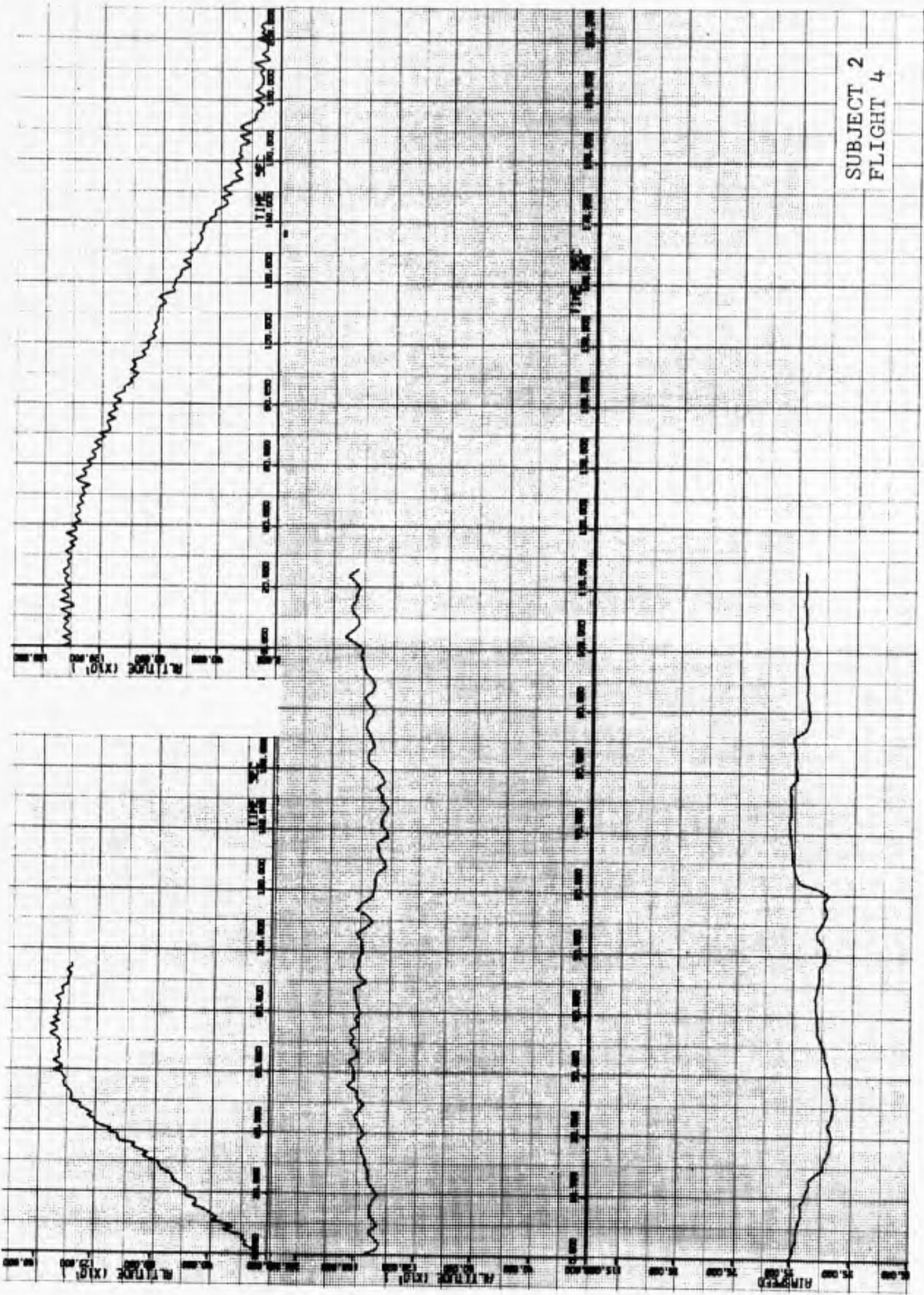


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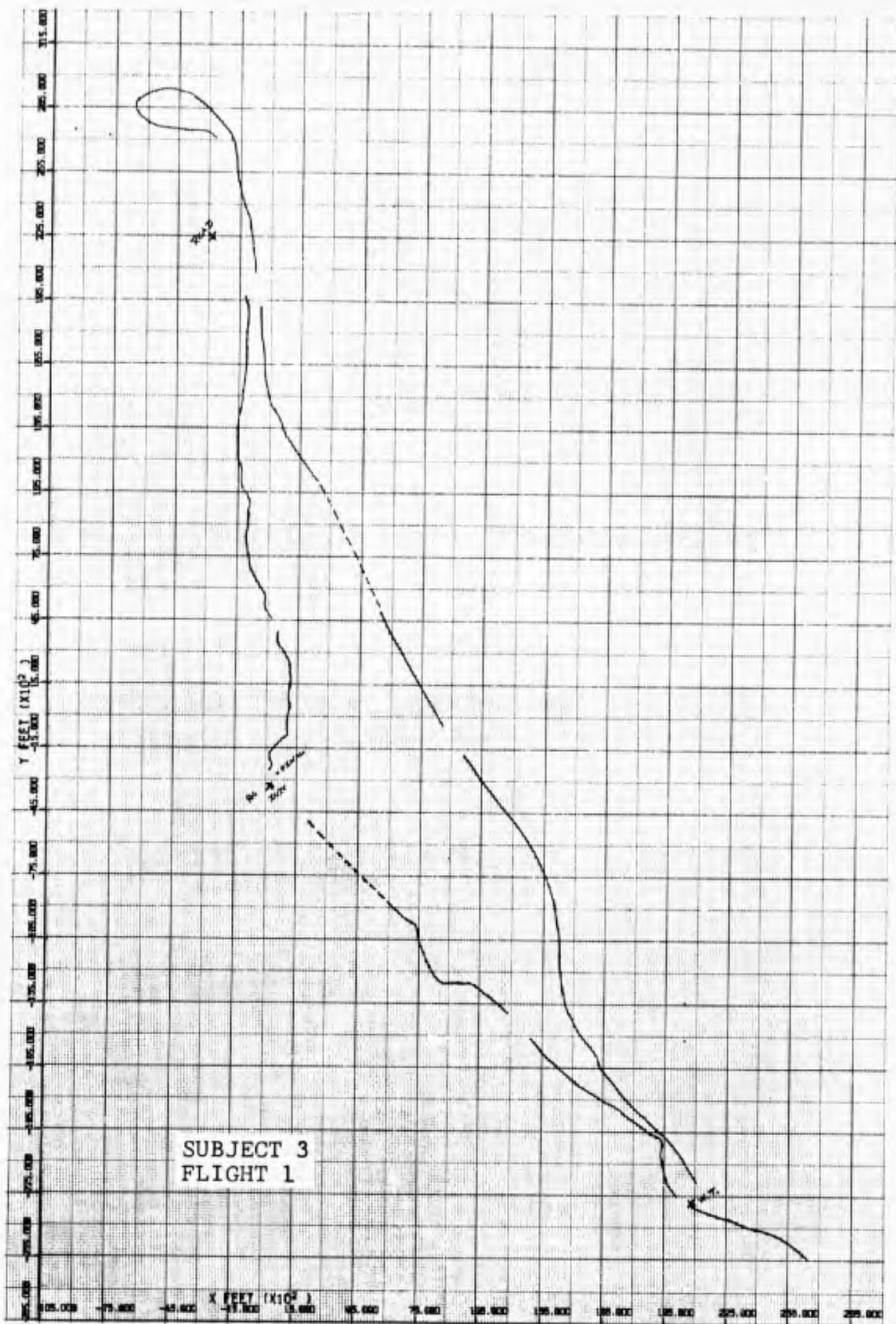


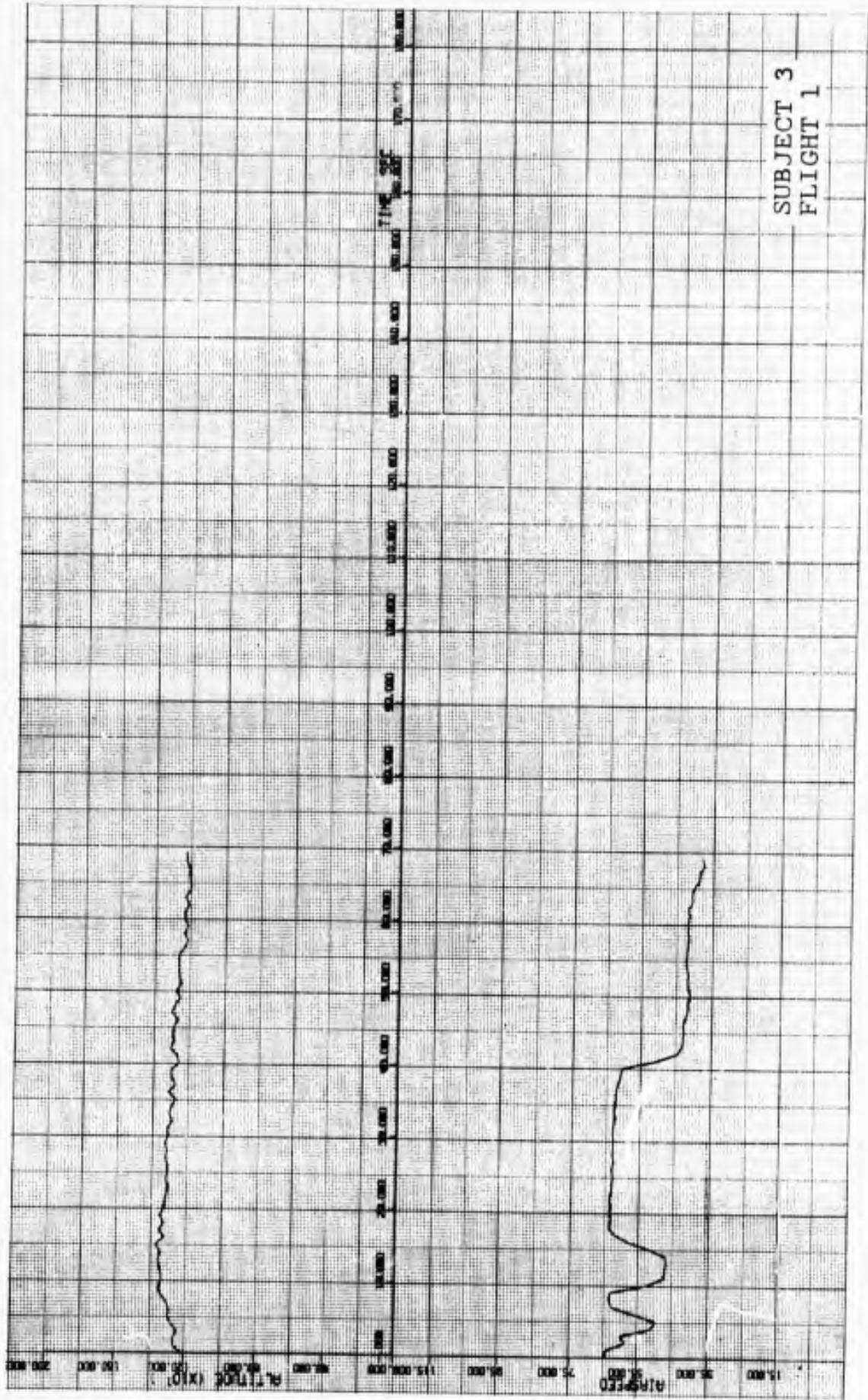


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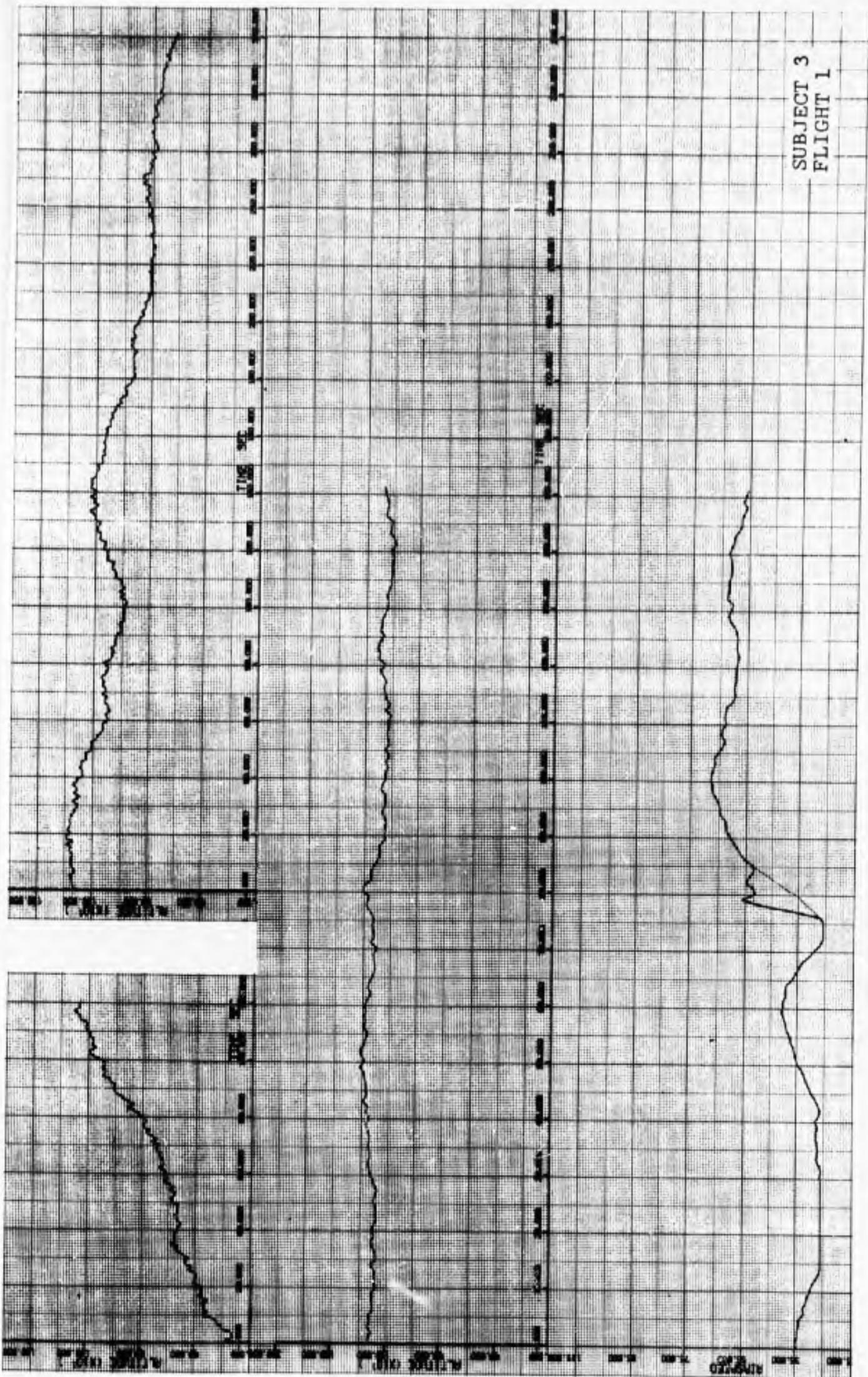
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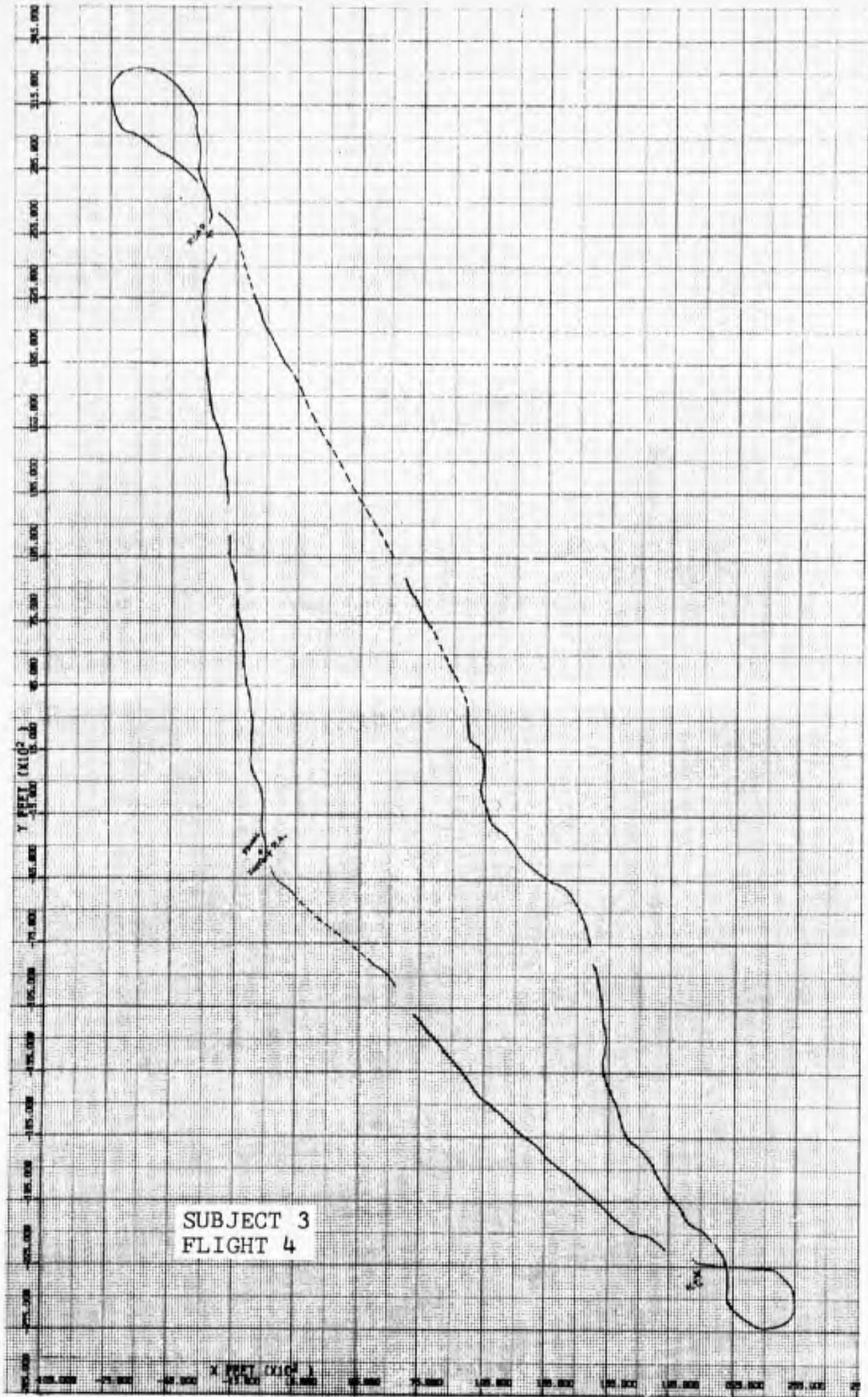


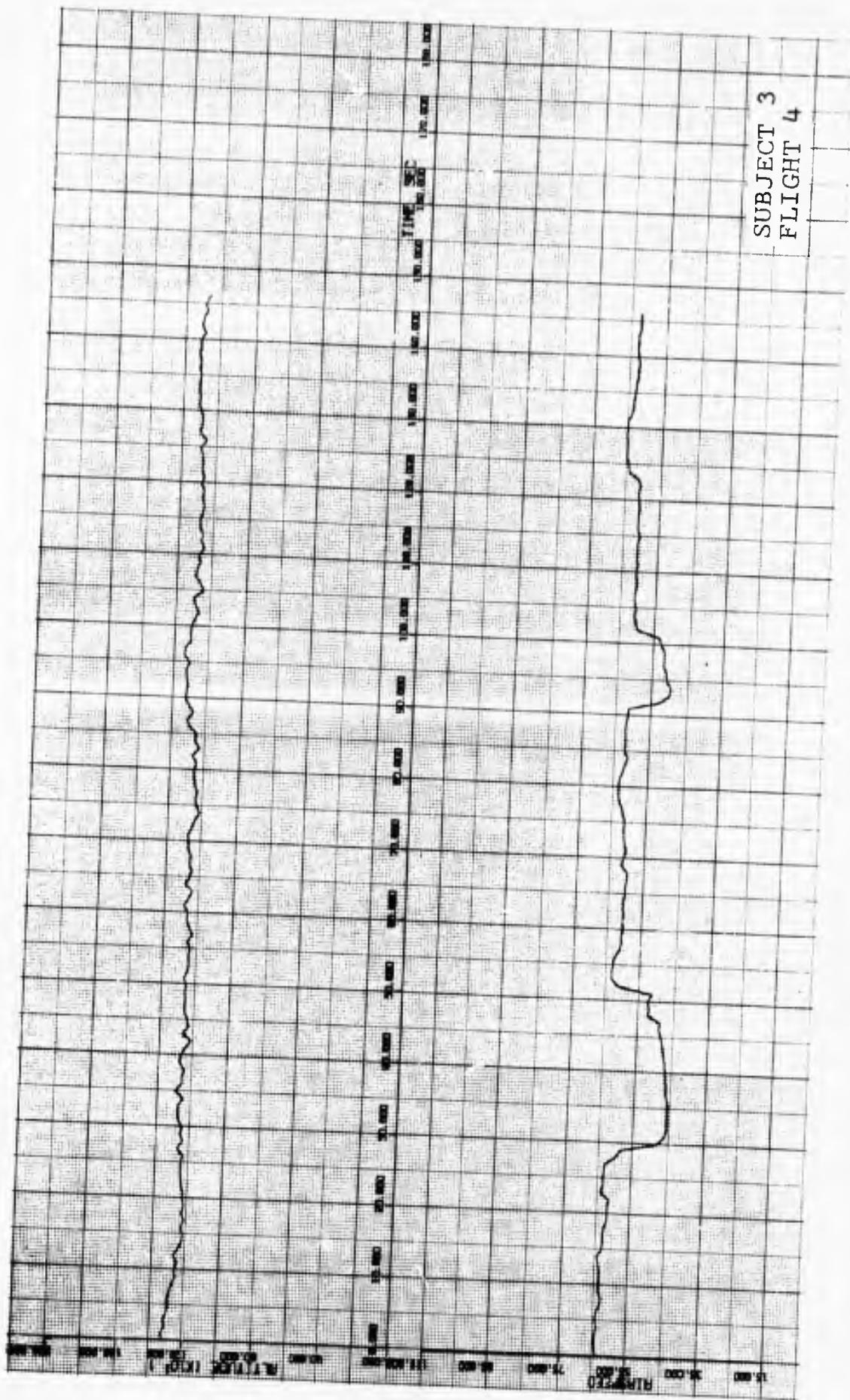


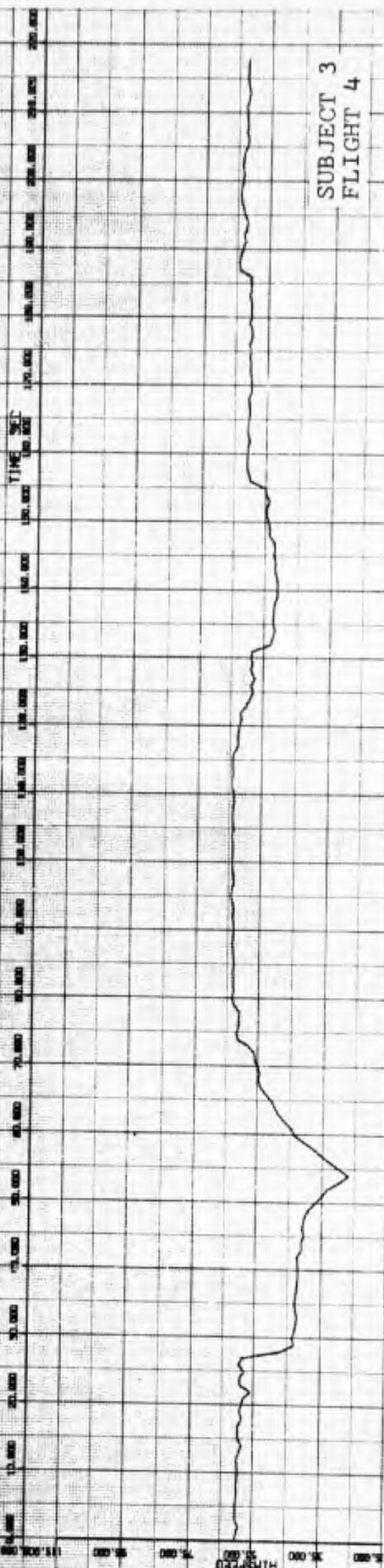
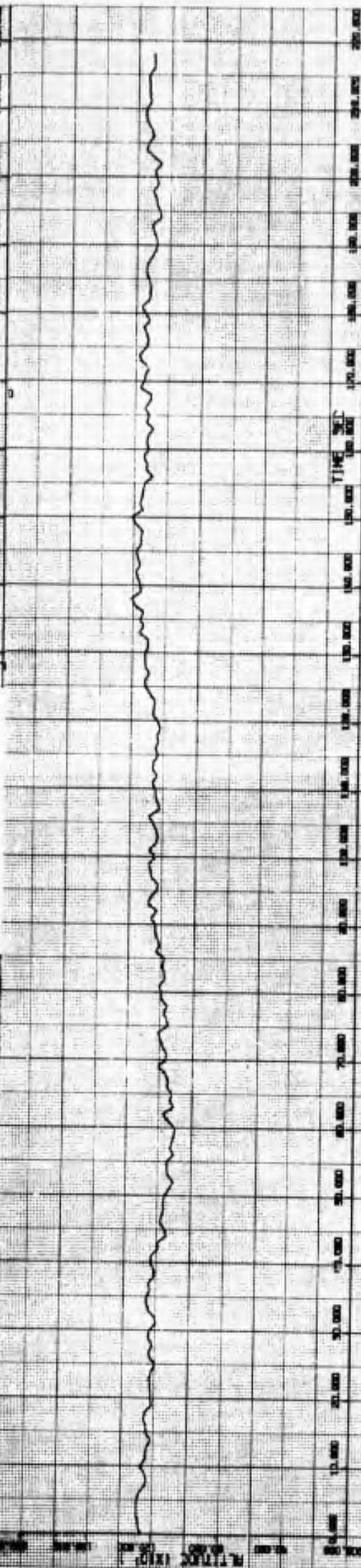
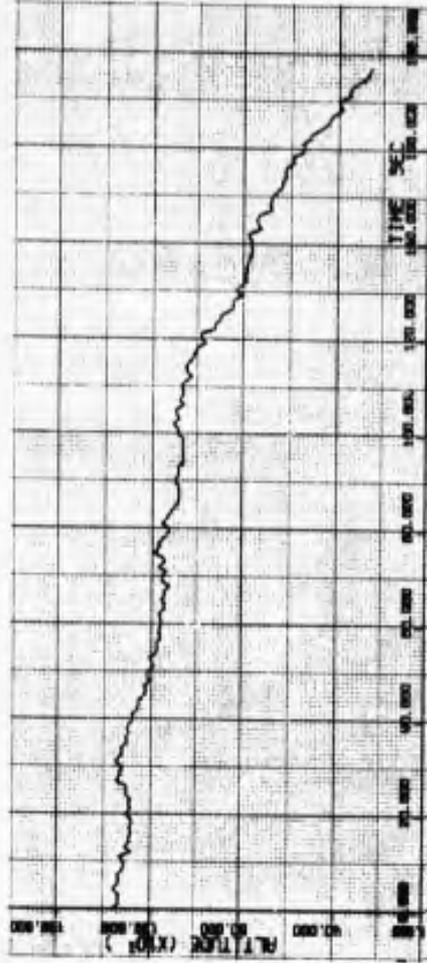
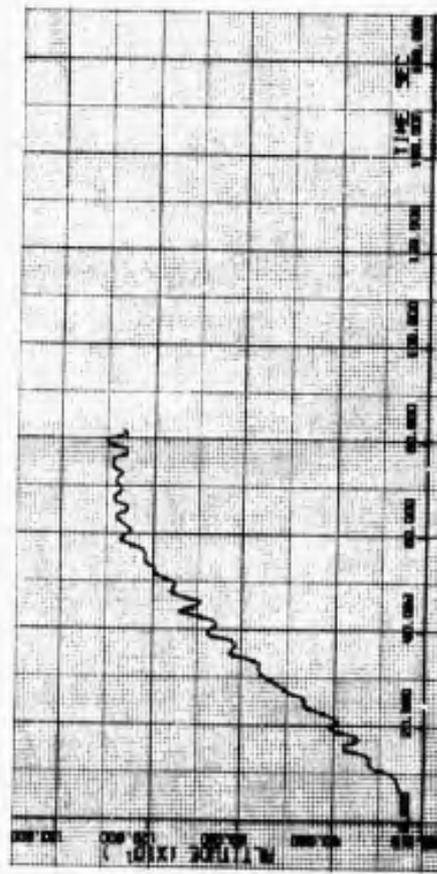
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FLIGHT 1

SUBJECT 3  
FLIGHT 1



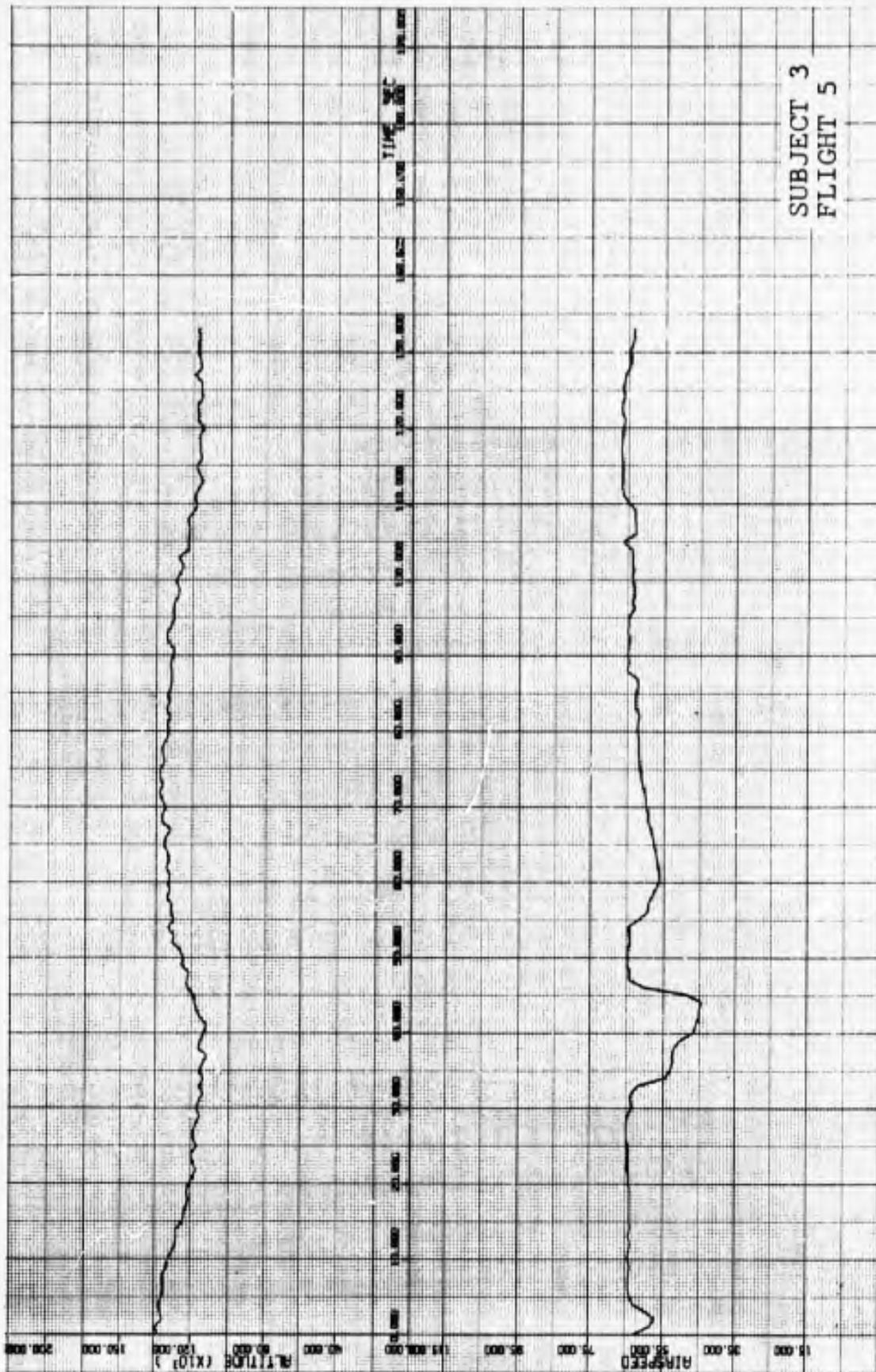




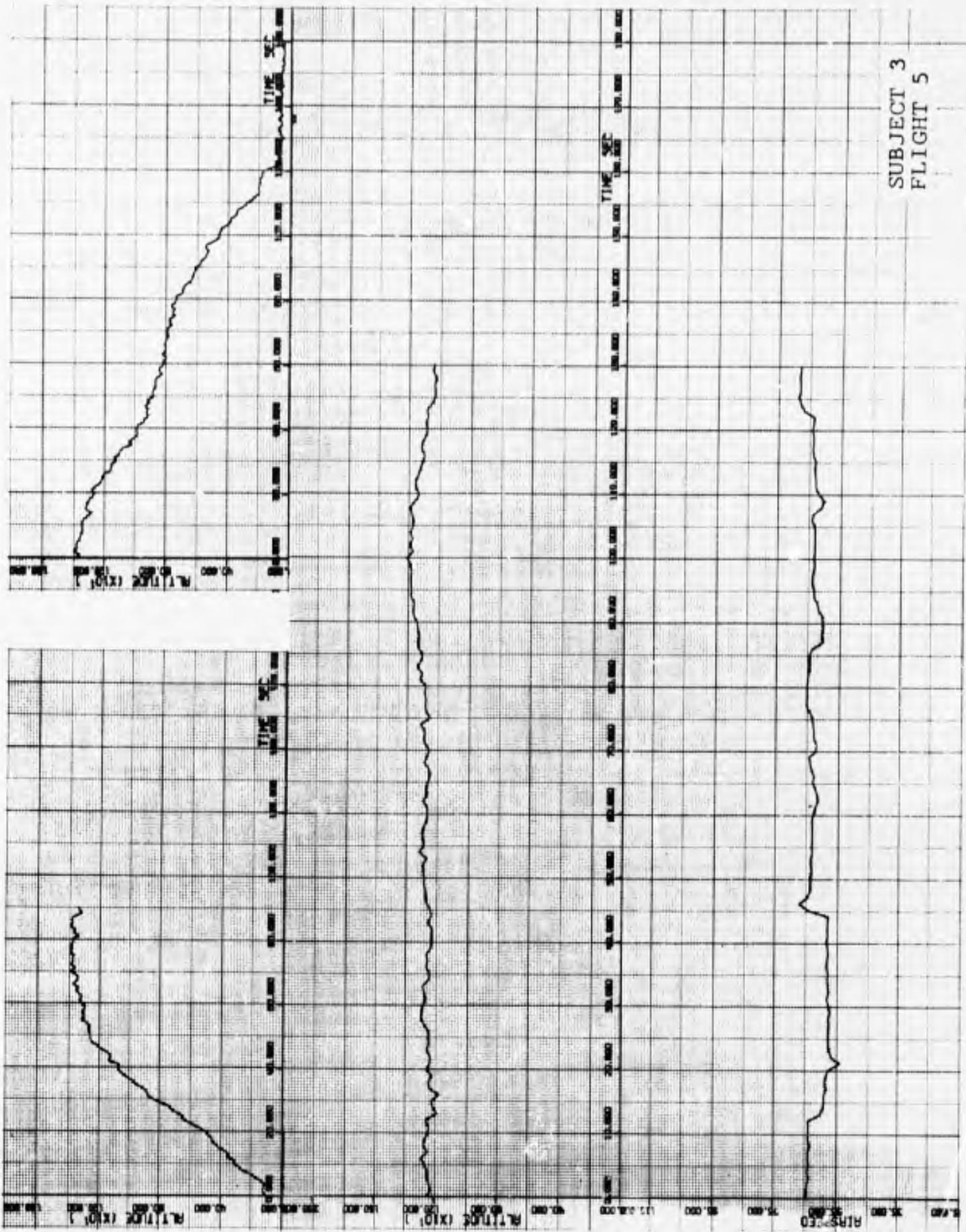


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FLIGHT 4

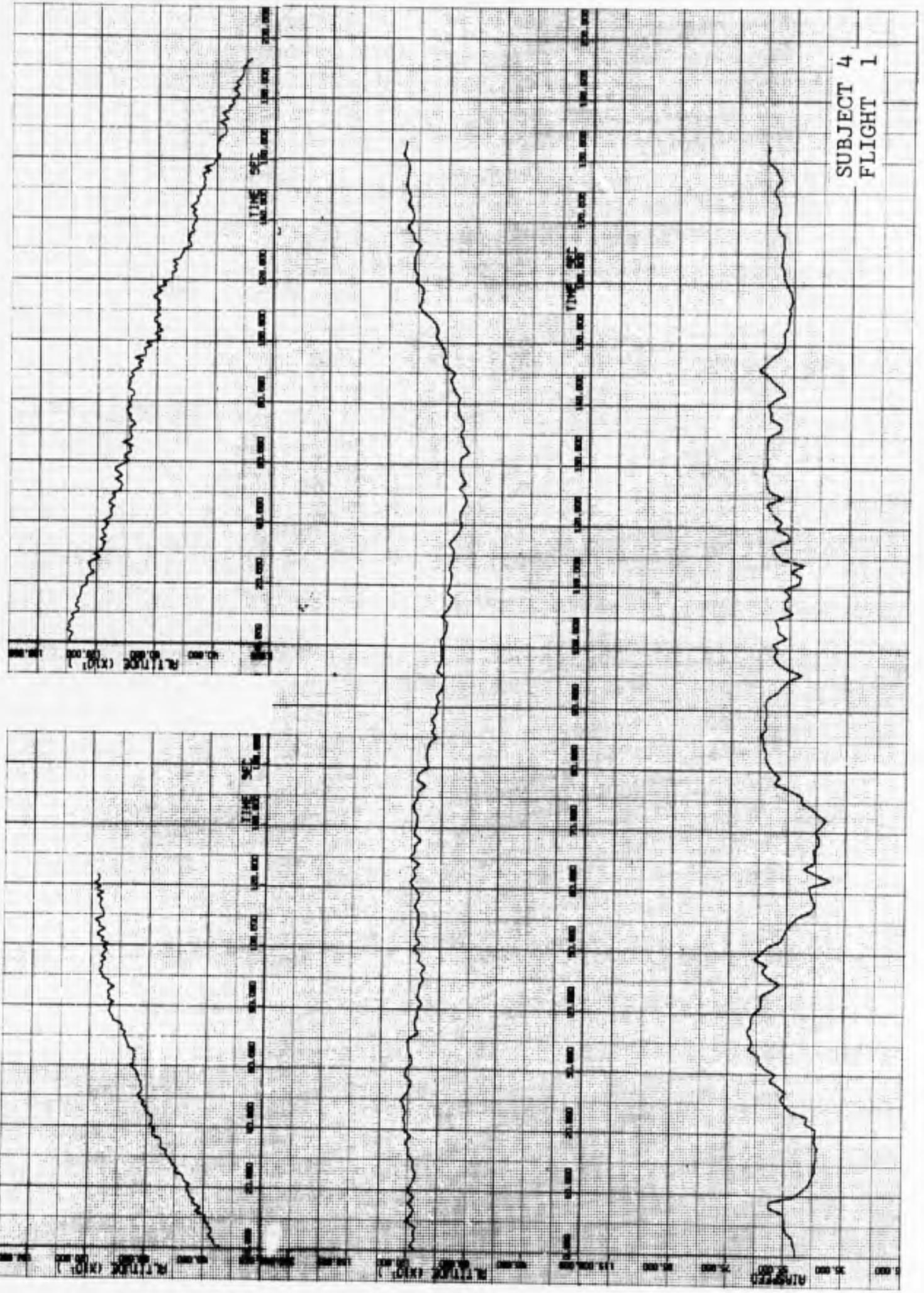




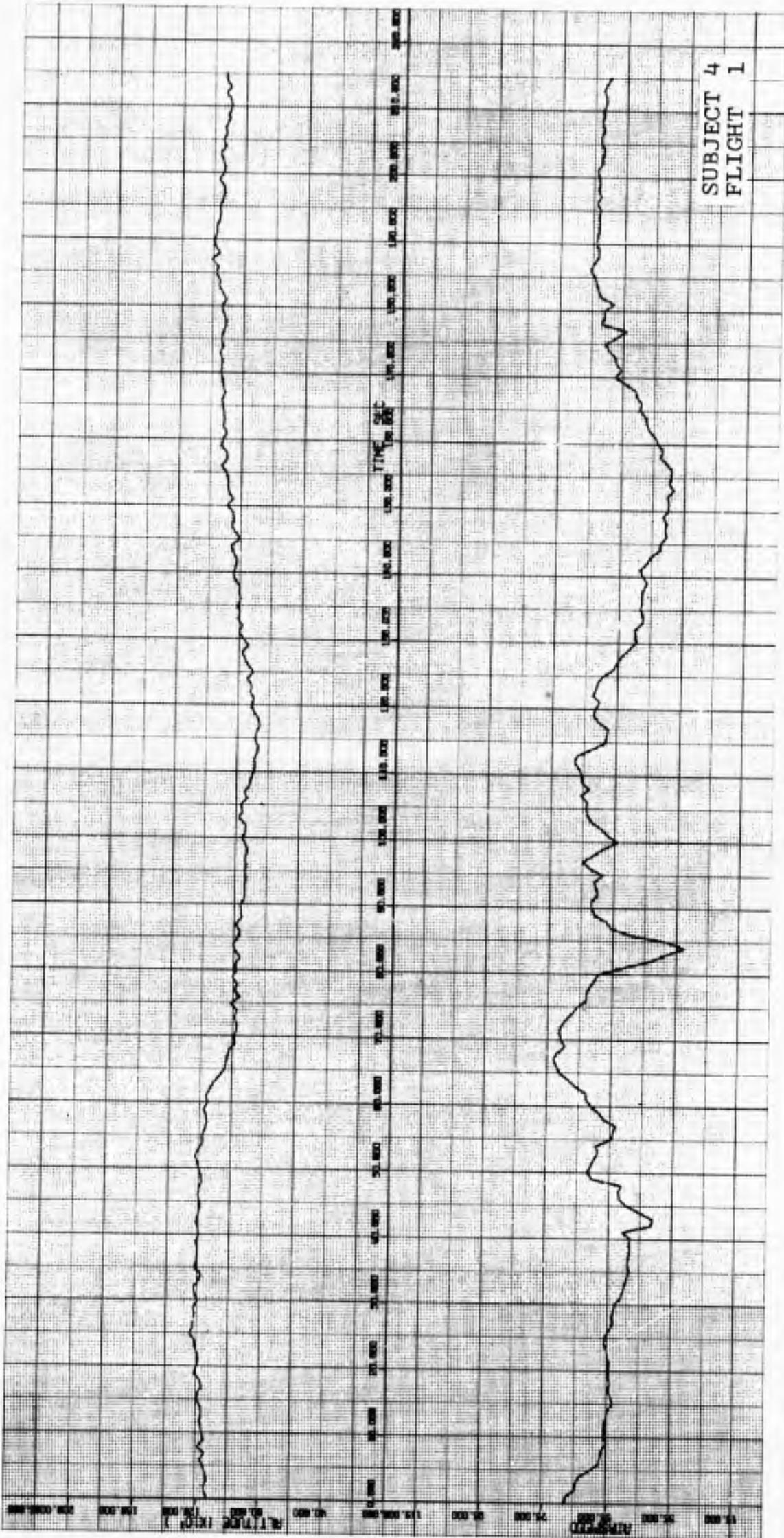
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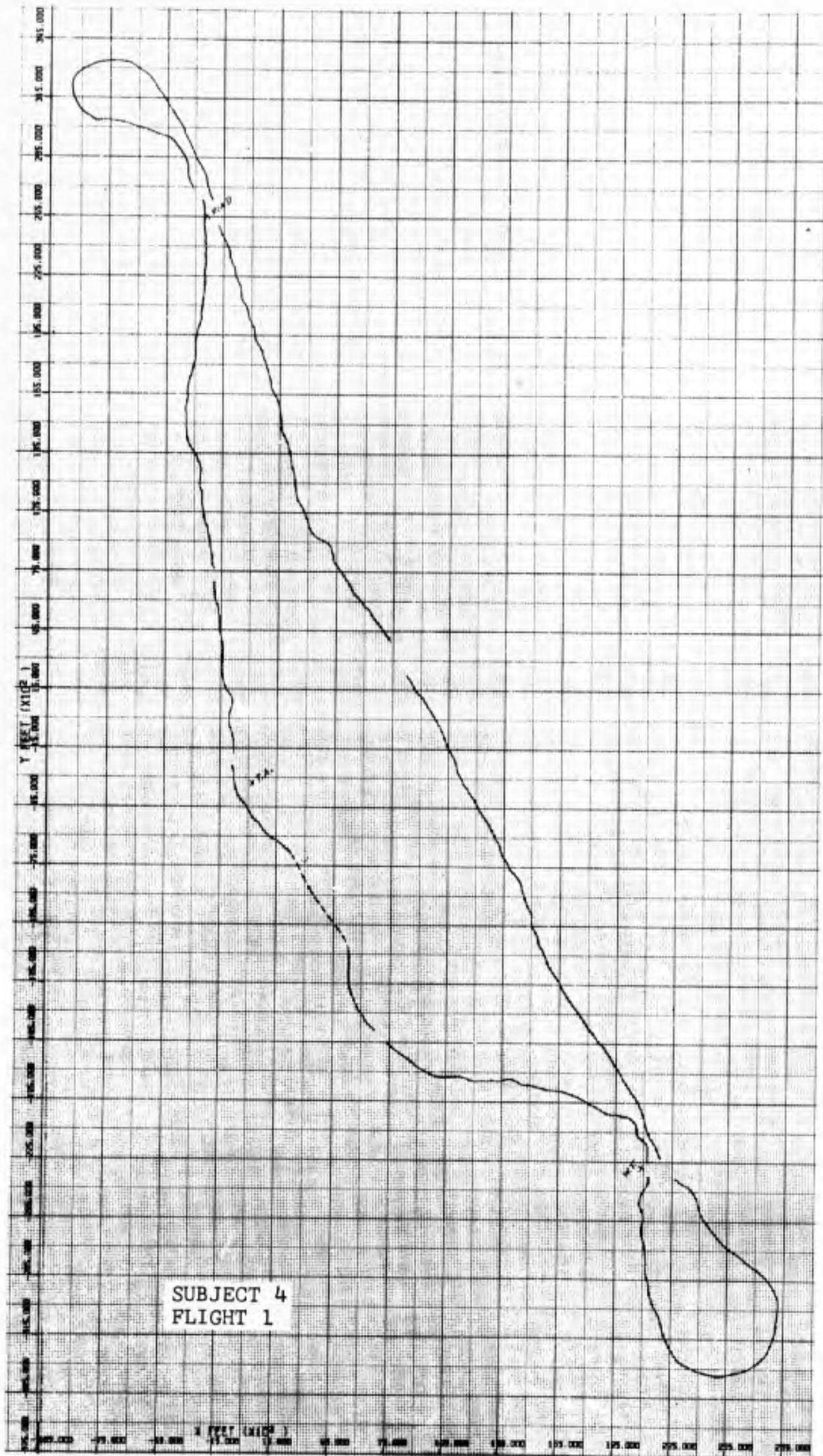
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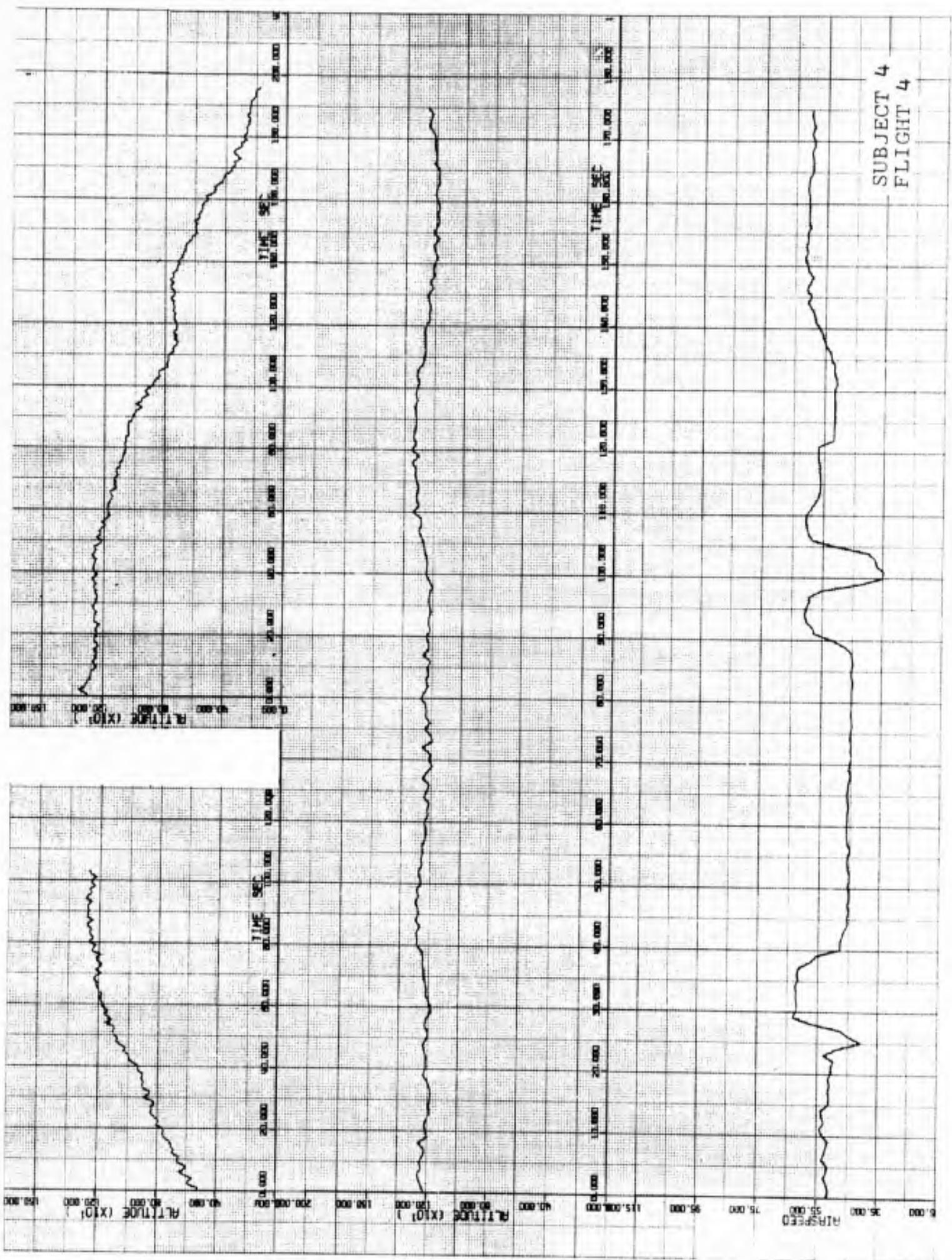
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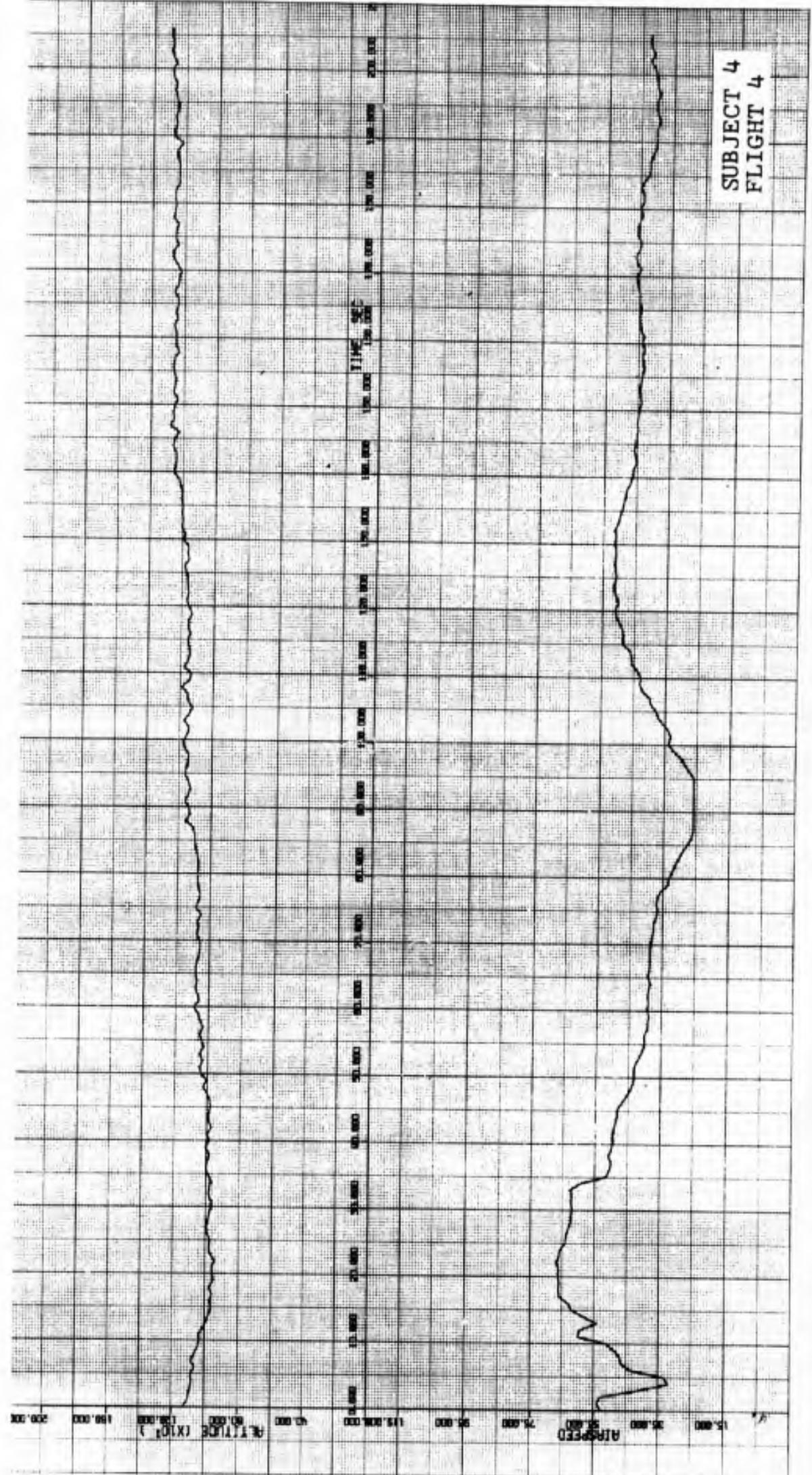


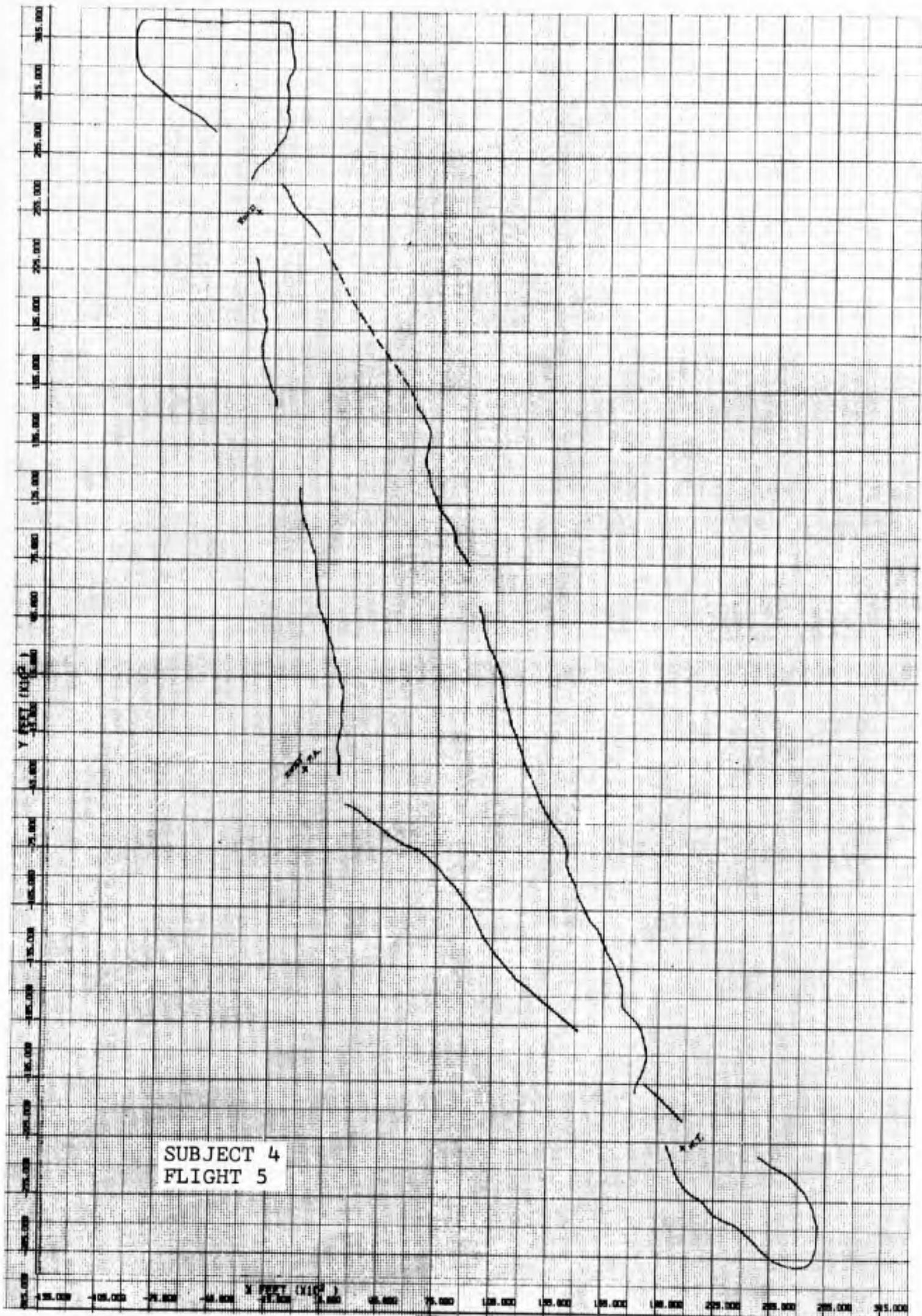
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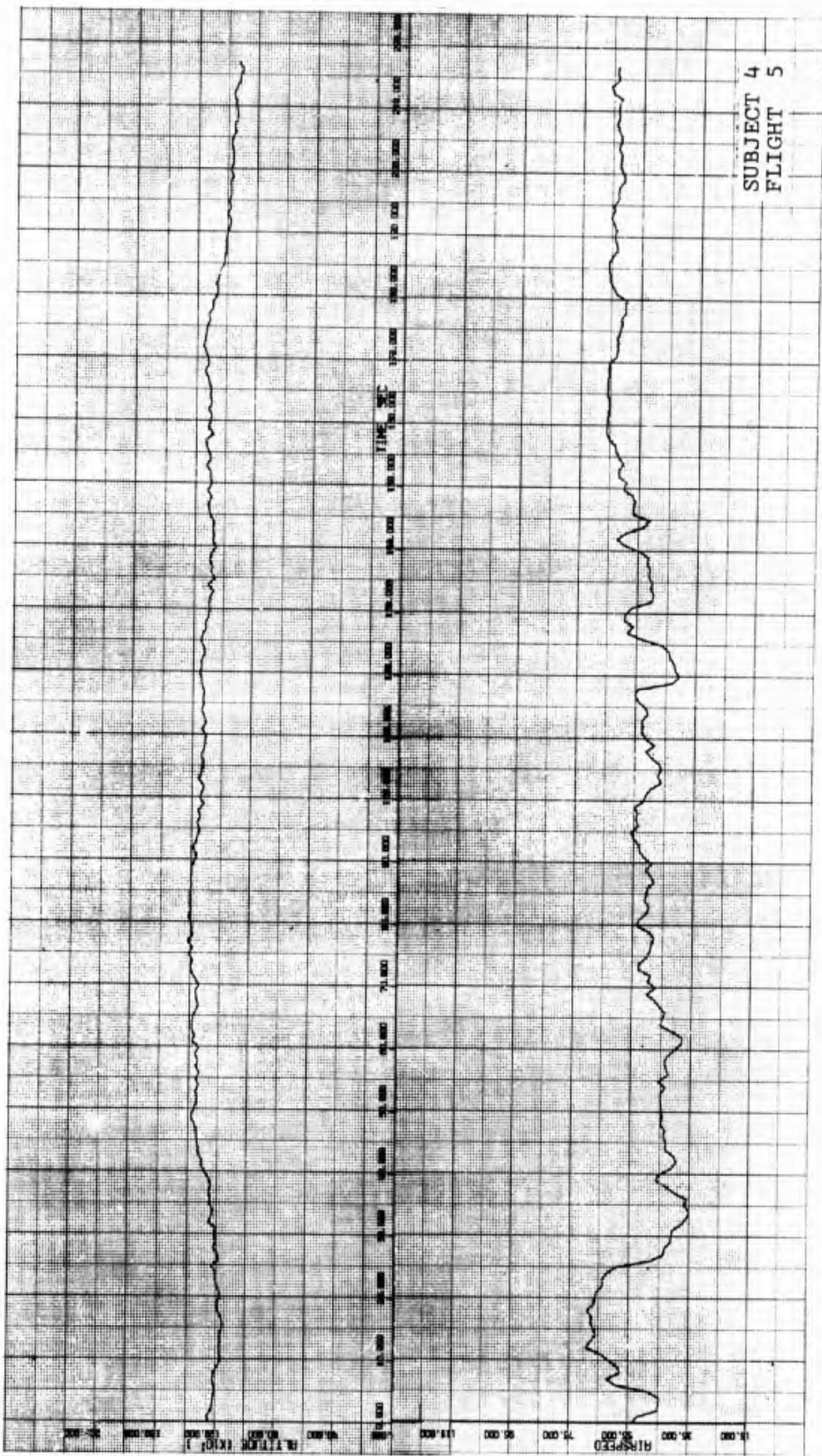






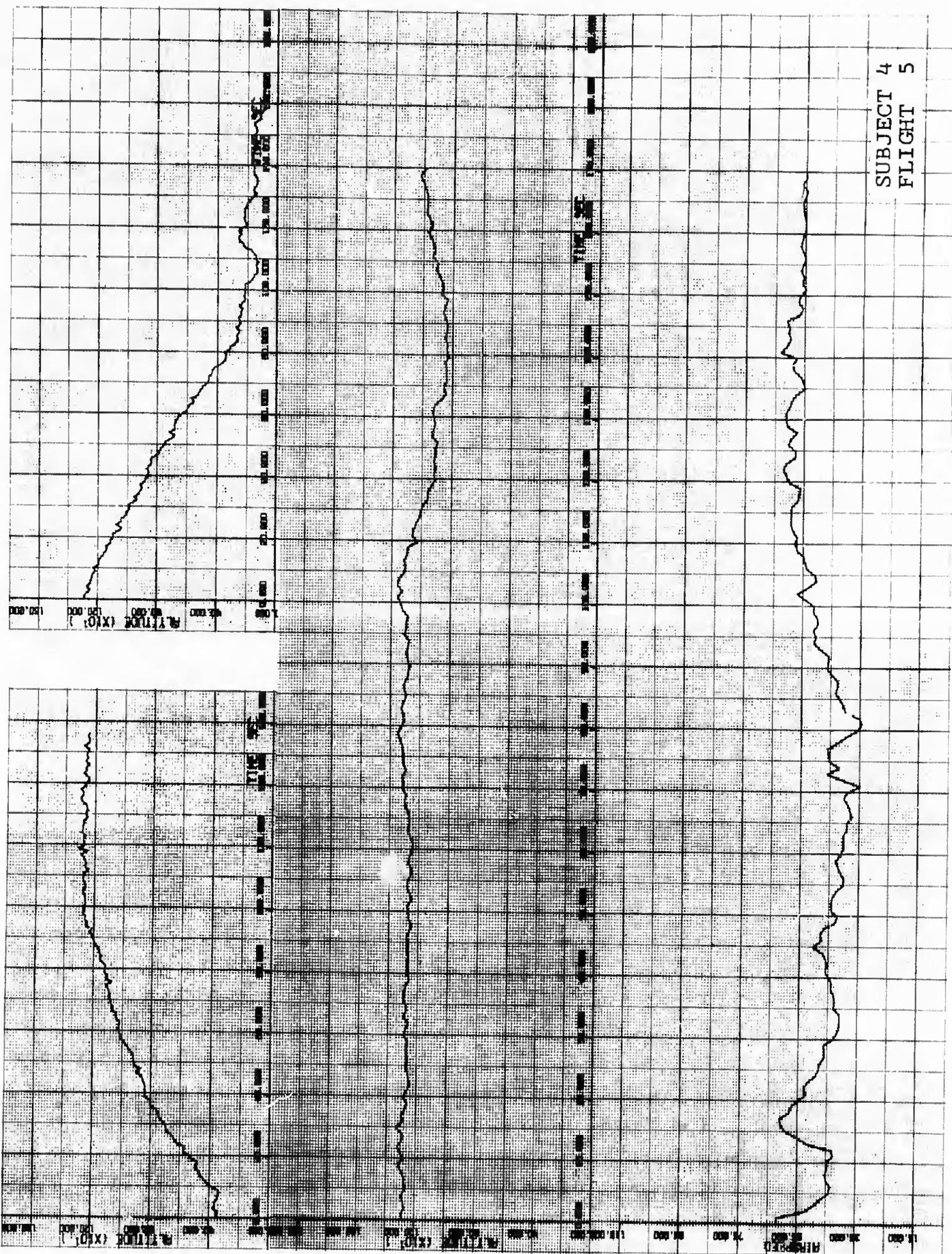


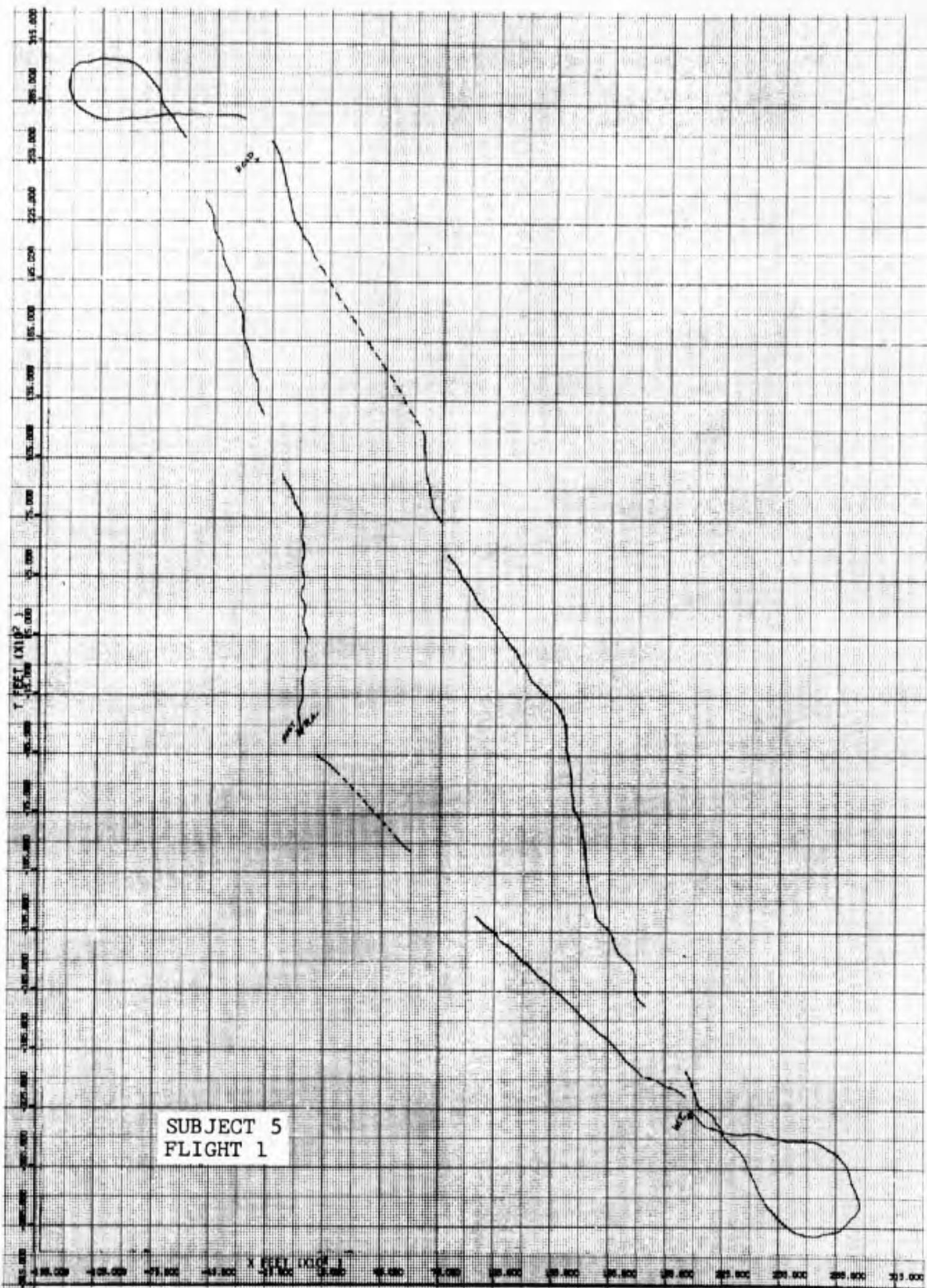


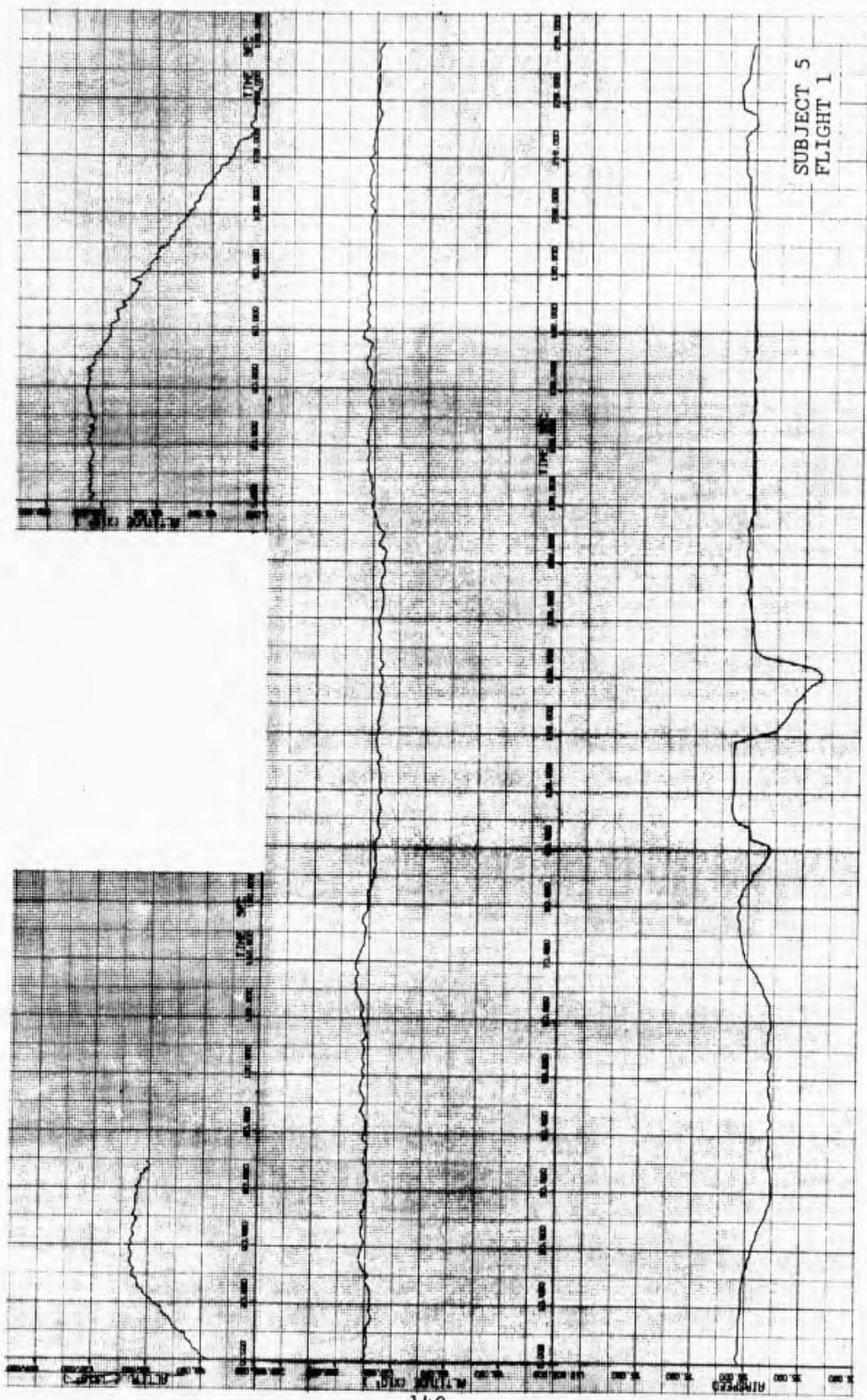


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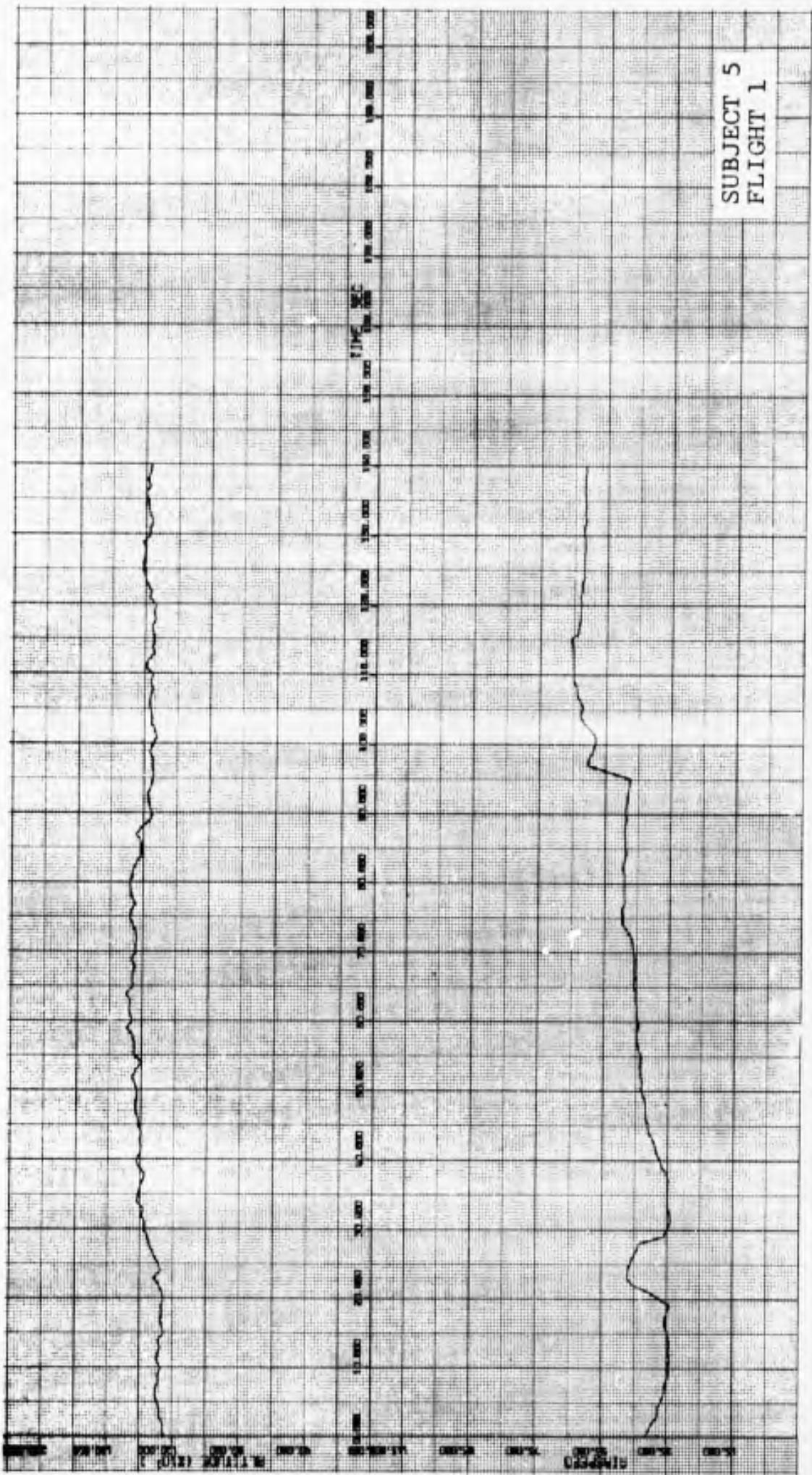
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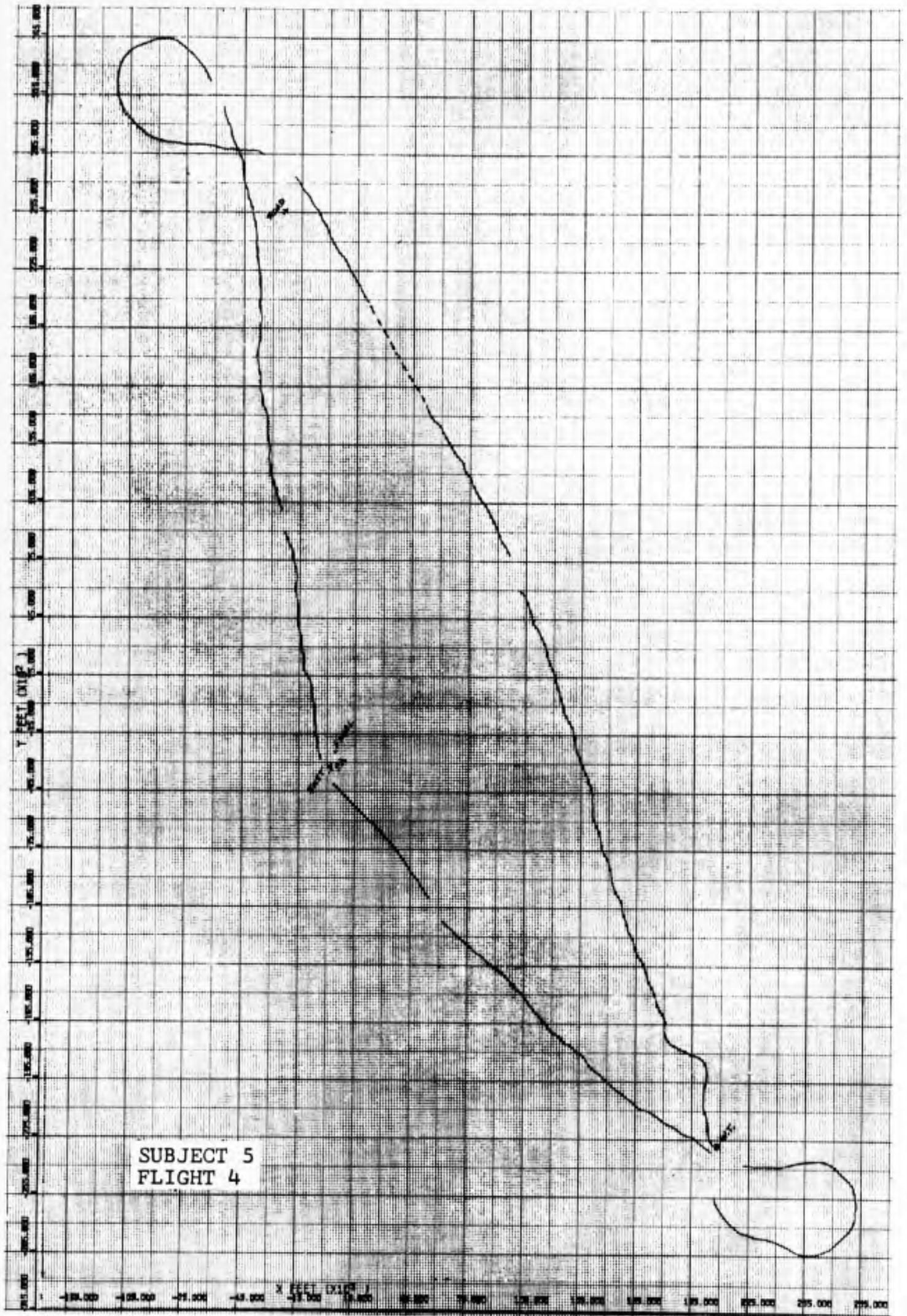


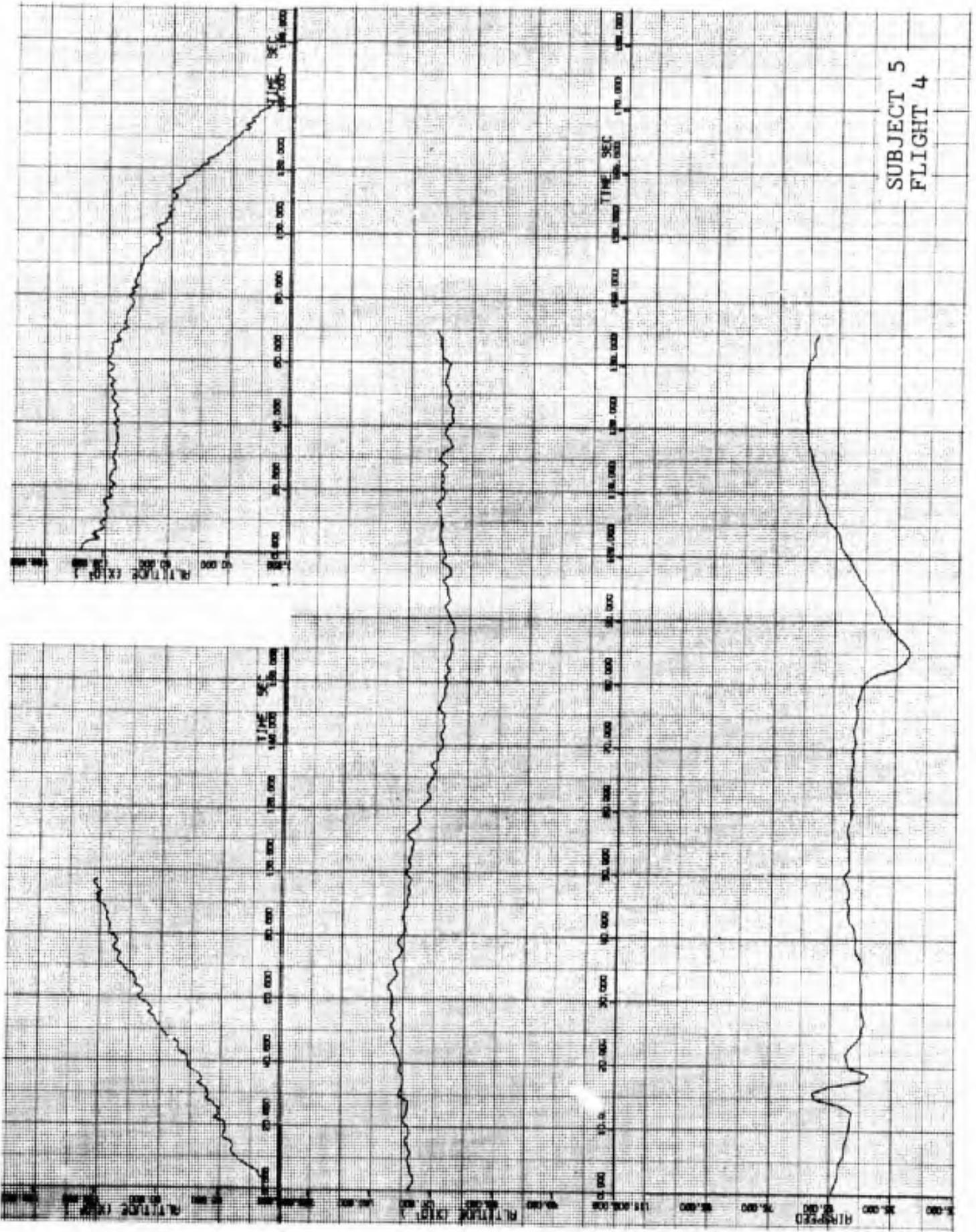




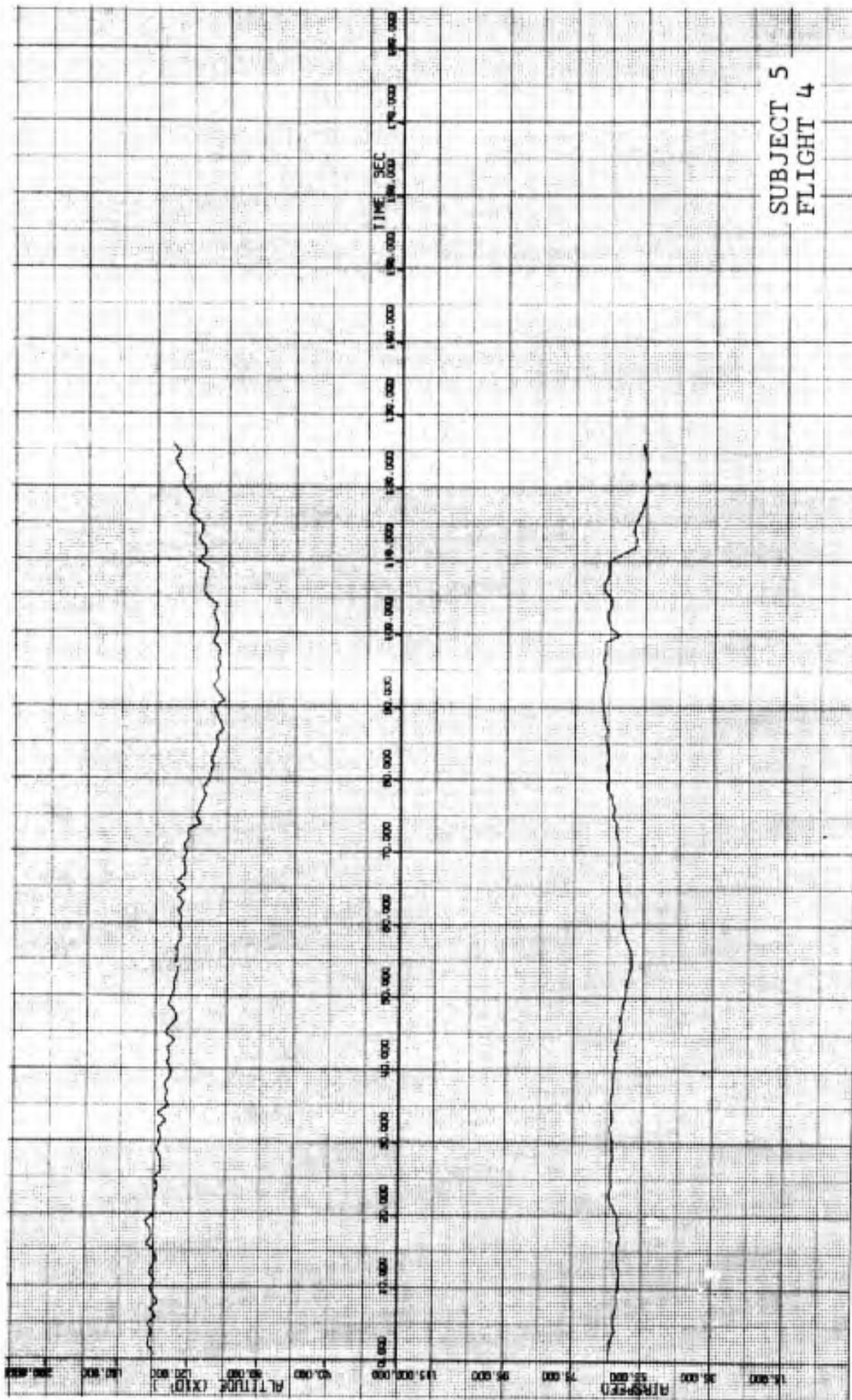
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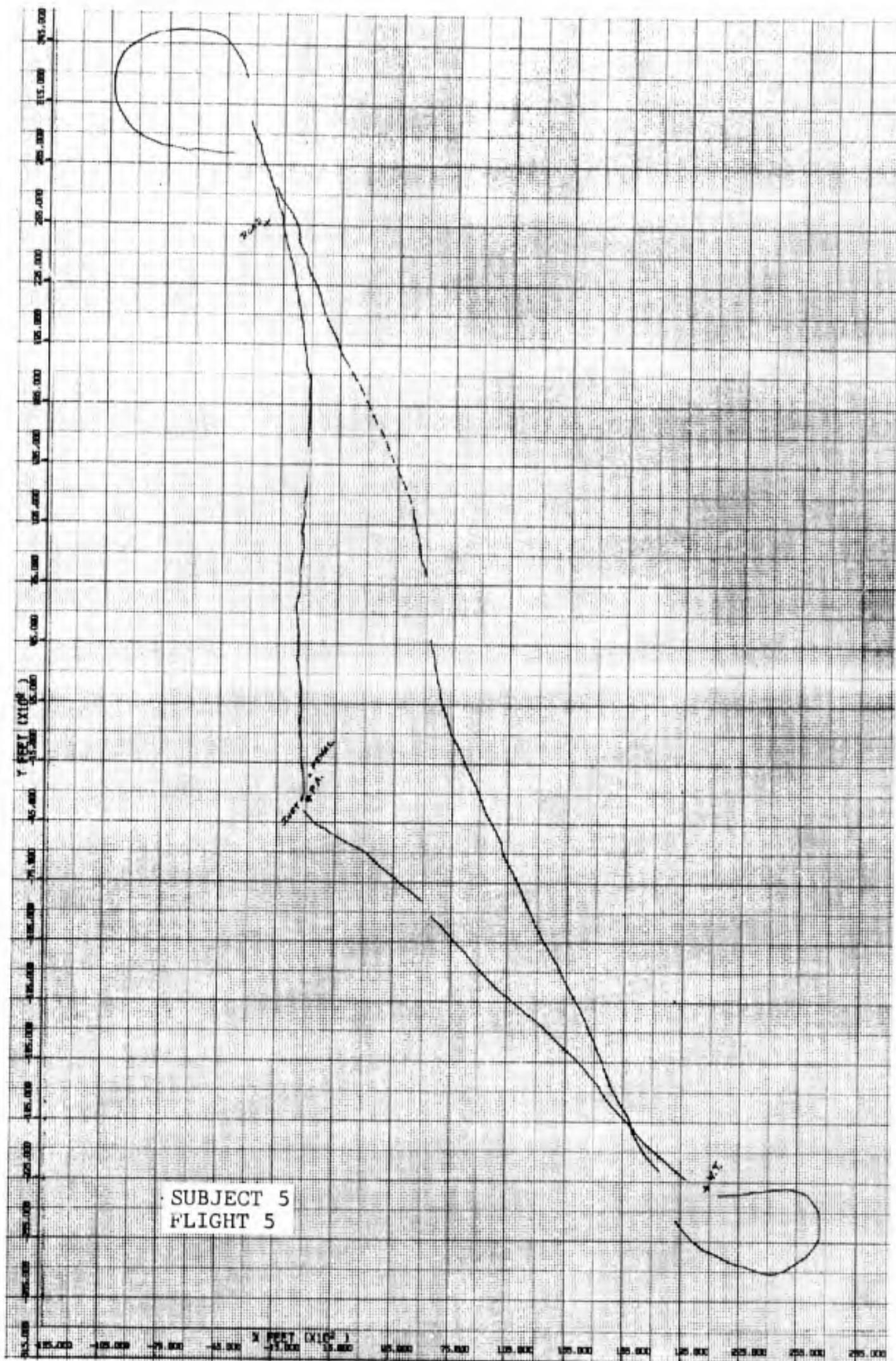


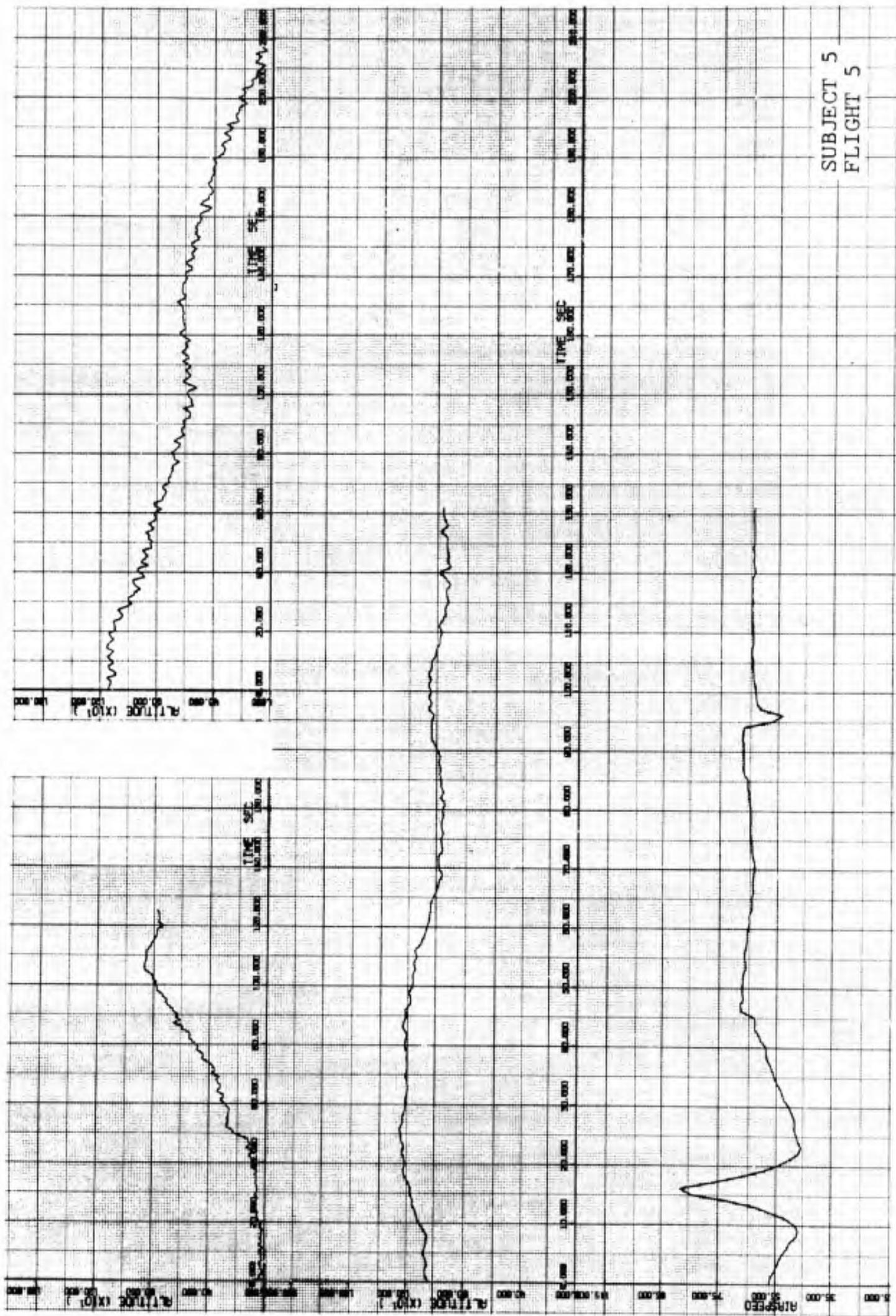


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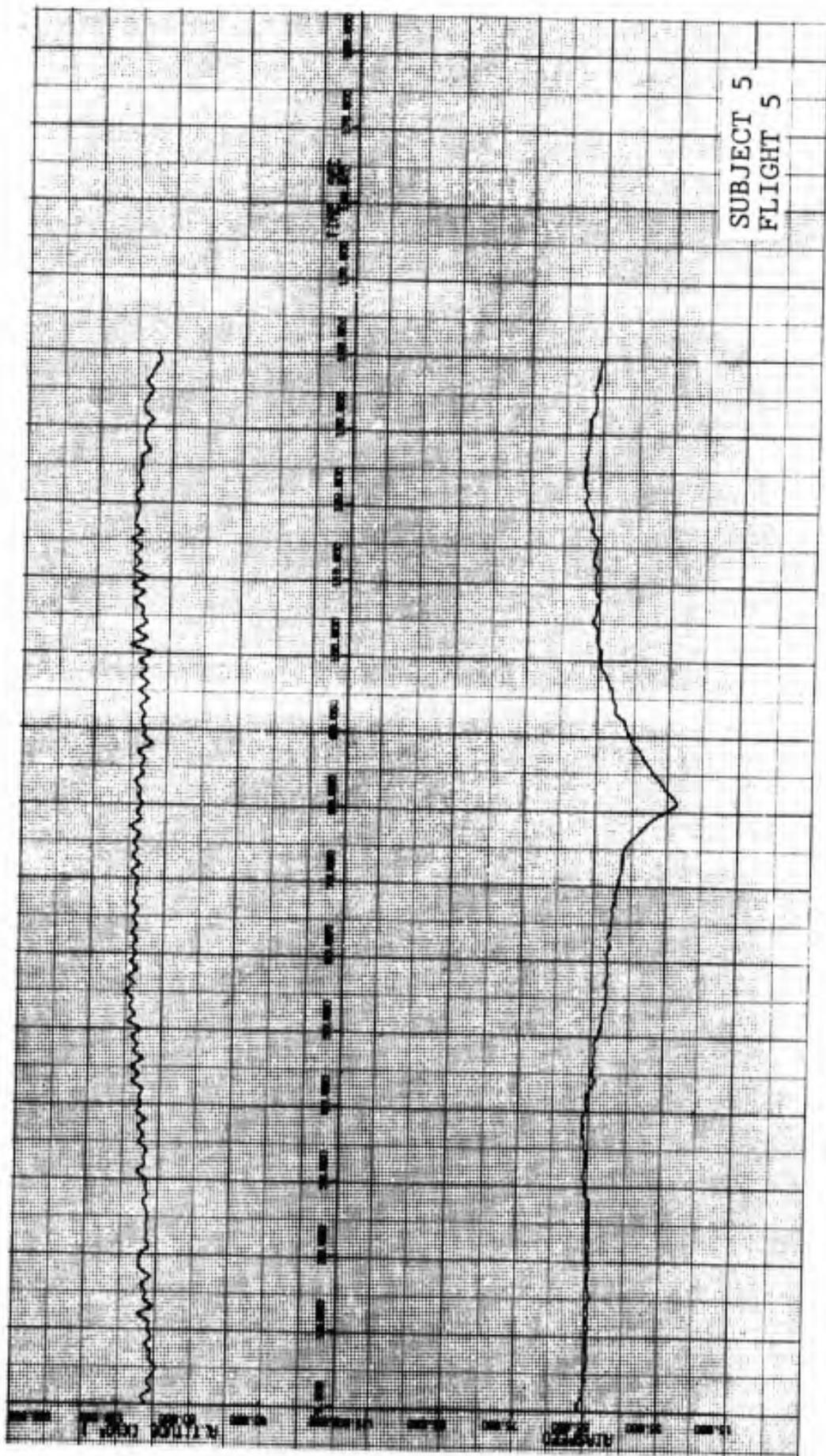


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SUBJECT 5  
FLIGHT 5



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APPENDIX F



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POST-FLIGHT DEBRIEFING (RH-2)

Subjects' Comments

REGARDING THE VERTICAL DISPLAY COMPONENTS

1. The Pathway Sensitivity:
  - a. No problems with this except as noted in #3 below.
  - b. Needs more stabilization
  - c. Too sensitive for normal control
  - d. Too sensitive at altitude you asked us to fly - easier to fly higher
  - e. Much too sensitive
2. Pathway Perspective When Aircraft Crabbed:
  - a. Depending on distance above pathway - disappears when too close
  - b. Inadequate; perspective gives appearance of proximity long before pathway is reached. Then when it is reached, the angle of interception has become acute
  - c. Crab angle difficult to establish - pathway direction seemed inappropriate
  - d. OK
  - e. Appeared to be all right, no annoyance
3. Interception of Pathway:
  - a. Sensitive - difficult to determine approach rate
  - b. See above
  - c. In flight, during most of my flights, the pathway performed in an unpredictable and erratic manner. Interception seemed difficult.
  - d. Normally can't see pathway coming in soon enough - result, overshoot every time.
  - e. Difficult because of sensitivity
4. Approach and Takeoff Phase on Pathway Angle:
  - a. Seemed a bit steep for me
  - b. All right after familiarization. On first try, it is deceptive.
  - c. During takeoff the pathway seemed to blank out too much of the ground plane for comfort. When used, I tried to stay just below. On approach, I never had one where pathway seemed to work as desired.
  - d. approach too steep and too fast.
  - e. Felt was too steep, very evident during approach.



5. Speed Markers
  - a. Did not use much.
  - b. I used them very little, relying primarily on my air-speed indicator.
  - c. Speed markers were difficult to see since they were on the pathway and most of the time I was not close enough to the pathway to see them. When seen, however, they were difficult to interpret and seemed to be moving in a direction opposite to that in which they should have moved.
  - d. Didn't use at all.
  - e. Of little value due to altitude above pathway I chose to fly.
  
6. Tarstrips
  - a. Nice to have, but became hypnotized after continuous cruise.
  - b. Same as #5.
  - c. During the flight on the XC mission, I do not recall ever using the tarstrips.
  - d. Couldn't see any advantage.
  - e. Most useful during approach.
  
7. Have you ever been bothered by viewing CRT for periods of flight?
  - a. Don't recall so.
  - b. Not consciously.
  - c. No.
  - d. Yes, sometimes felt borderline vertigo.
  - e. No, not during any flight.
  
8. How would you change grid? scales?
  - a. OK as is - might change scale to 100/1000/10000 ft.
  - b. Grid OK. Scales would be improved by numerical identification at bottom of screen. Also, transition period from one to another is upsetting.
  - c. I would like the scale more sensitive in the low altitude regime. If various scales are required, their limits should be easy to remember like 10, 100 etc.
  - d. OK.
  - e. Grid pattern I would not change; scales I would probably increase altitude of lower scale to 150 ft. or 200 ft.
  
9. Did you ever get confused in flight as to altitude scale in which you were operating?
  - a. No.
  - b. Yes.
  - c. No.
  - d. Yes, add some kind of symbol to show scale.
  - e. No.



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10. Do you know of any difference in position between simulator VD and RH-2VD? If so, what? Does placement change bother you?
  - a. RH-2 seemed lower.
  - b. No. I don't understand.
  - c. Yes. Sensitivity of the pathway -- jumping of grid when passing over gravel pits, RR tracks, etc.
  - d. No change.
  - e. RH-2 VD less stable. Placement change no problem.
11. Is there information not on VD that you would like to have displayed?
  - a. Heading information (compass ring).
  - b. Yes. A rate-of-climb indicator would be helpful. Also a larger altimeter.
  - c. Not particularly for the mission flown during this series of tests unless we would consider obstacle information.
  - d. Only as shown in #9 above.
  - e. I would like to have the following information: A/S and alt. quantitatively displayed.
12. The comparison of the flights with pathway vs flight(s) without the pathway?
  - a. More relaxed without pathway.
  - b. Easier with pathway.
  - c. I noticed very little difference since the pathway never seemed to perform in an optimal fashion.
  - d. Obviously more difficult to maintain track, but no change in ability to fly machine.
  - e. In the flight without the pathway, I had difficulty in establishing a correct ground track between checkpoints.

REGARDING PERTINENT CONTROL KNOBS, SELECTORS, READOUTS AND INSTRUMENTS

1. Pathway Bearing Knob
  - a. Rather small for fine adjustment with ease.
  - b. Calibration numbering too fine for easy reading.
  - c. Very difficult to read.
  - d. OK.
  - e. I did not have any problems with this knob other than poor lighting on occasion.
2. Buttons for Fix Insertion
  - a. Occasional confusion between enter and compute.
  - b. All right after familiarization.
  - c. No particular comment.
  - d. OK.
  - e. OK.



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3. Utility of Readout Information (Time and Distance to)
  - a. OK. Usable as is. Good information.
  - b. Additional cockpit familiarization would be helpful; also, a more concentrated time period of course continuity.
  - c. Very difficult to read. Full utilization of this time panel was not accomplished in this series of tests. ETA, for example, at a given fix was not requested en route such as would happen in an ATC flight problem.
  - d. Seemed to be too many readouts -- had difficulty casting eyes directly to one desired.
  - e. Very useful.
4. Turn and Bank Instrument (Below Vertical Display)
  - a. Need a turn needle in conjunction with.
  - b. Inadequate. Too small and not prominently displayed.
  - c. Very desirable to have the slip-skid indicator.
  - d. A necessity.
  - e. Would prefer a standard instrument.

#### REGARDING THE CONTROL SYSTEM

1. The Trim Button on the Side-Arm Cyclic Controller
  - a. Worked fine - relieved loads.
  - b. All right.
  - c. This seemed to be a desirable addition.
  - d. Didn't seem to operate at times and button too small and poorly located for my hand position.
  - e. Appeared to work intermittently.
2. The Comfort of the Air-Rest and Location (High or Low)
  - a. OK for height - cyclic stick did not fit my hand well.
  - b. OK.
  - c. OK.
  - d. OK.
  - e. Comfortable.
3. The Pressure Required for Control Input
  - a. Not coordinated between cyclic, collective and T/R.
  - b. OK.
  - c. OK.
  - d. OK, except diameter of side cyclic too small for comfort.
  - e. Good.
4. The reach required for the collective Decrease
  - a. Much too far.
  - b. Excessive.
  - c. I could not move the collective from a sitting position when holding onto the hand grip. I moved collective from a "choked down" position directly adjacent to the seat.



- d. OK.
  - e. Much too uncomfortable to use operationally, must lean forward in seat during approach.
5. Feedback From the Pedals
- a. Uncomfortable, even annoying at times, particularly on takeoff.
  - b. Not disconcerting.
  - c. No comment.
  - d. OK.
  - e. Did not notice any more than normal.
6. The Damper System (Contrast of Inflight vs Hover Characteristics)
- a. OK.
  - b. All right insofar as my own capabilities would allow.
  - c. This was highly desirable as opposed to no ASE.
  - d. OK.
  - e. Adequate.

REGARDING THE HORIZONTAL DISPLAY

1. The Map Scale(s) Used
- a. OK.
  - b. OK.
  - c. Remained on the XC scale due to inaccuracies introduced by the system in changing maps. Such a change would have been desirable.
  - d. OK.
  - e. Adequate.
2. The Indices for Bearing, Ground Track and Heading
- a. Never did use these much. Had most everything required on vertical display.
  - b. OK.
  - c. Very difficult to read with design of the map display. They were too small and masked by data on map.
  - d. Hardly used at all.
  - e. Difficult to see.
3. Present Position Symbol
- a. OK. Would like to see some kind of trace of ground track.
  - b. OK.
  - c. Symbol OK but difficult to read because of light focus from below display.
  - d. OK.
  - e. Good.



4. The Map Scale Selector
  - a. OK.
  - b. OK.
  - c. Adequate.
  - d. OK.
  - e. Good.
  
5. Map Content
  - a. OK.
  - b. Fixes should be marked more prominently.
  - c. Adequate in terms of past experience; however, it would have been nice to have a course line and a greater amount of terminal area position data, i.e., roads in landing area, edge of field, hedgerows and trees, and gravel pits in accurate position.
  - d. OK.
  - e. Adequate.
  
6. Map Color
  - a. OK.
  - b. OK.
  - c. Seemed desirable.
  - d. OK.
  - e. OK.
  
7. Desirability of Having a Line to Follow
  - a. Yes, (see 3 above), more a line to track than course.
  - b. Helpful.
  - c. Good.
  - d. Good idea - when pathway is not present, you must attempt to fly an imaginary line anyway - might be better than pathway.
  - e. It would be desirable to have ground track (command bearing) on this display.
  
8. Ability to Judge Area for Turn
  - a. Did not observe this.
  - b. OK.
  - c. Good - no problem recalled.
  - d. OK.
  - e. It was adequate if used in conjunction with the VD pathway.
  
9. Did you Participate as S in Nav Study in Simulator?
  - a. Yes.
  - b. I presume so.
  - c. As a pretest S.
  - d. Yes.
  - e. Yes.



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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Flight Displays Contact Analog Flight Evaluation Pictorial Displays Flight Television JANAIR						

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