General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Produced by the NASA Center for Aerospace Information (CASI)

AMT File Copy
Do Not Distribute

PM-64

THE USE OF AUTOMATIC CONTROL THEORY AND A PILOT MATH MODEL IN HELICOPTER MANUAL CONTROL SYSTEM SYNTHESIS

FACILITY FORM 602

N71-12224	
(ACCESSION NUMBER)	(THRU)
18	G-3
(PAGES)	(CODE)
TMX-66492	01
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

DEC 1970
RECEIVED
NASA STI FACILITY
INPUT BRANCH

ELECTRONICS RESEARCH CENTER

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

PM-64

THE USE OF AUTOMATIC CONTROL THEORY AND A PILOT MATH MODEL IN HELICOPTER MANUAL CONTROL SYSTEM SYNTHESIS

By Paul S. Rempfer, Lloyd Stevenson,
and Dennis Collins

Guidance and Control Research Directorate
Electronics Research Center

October 1968

This publication contains information prepared in the interest of rapid dissemination to a select distribution. The reader is cautioned that the information contained herein is preliminary in nature and subject to change. It is not considered a formal referenceable document.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

INTRODUCTION

During the month of July, 1968, a brief one-week investigation into the use of automatic control theory with a simple pilot model for synthesizing helicopter landing approach flight director control laws was made. This preliminary memorandum documents the work of that investigation. The synthesis technique was quite successful and was subsequently used to define flight director control laws for the Langley Research Center CH-46C tandem rotor helicopter.

THE MISSION

The mission of the helicopter system was IFR landing approach. It was assumed that the pilot had already acquired the glide slope. His task was to fly down a fixed-glide slope at constant forward velocity, V_x, until, at a range to touchdown of X_o, a decceleration command was given with V_x programmed on range so that hover was achieved at zero range.

THE HELICOPTER SIMULATION

The helicopter model simulated was the Vertol CH-46C tandem rotor. The simulation was non-linear, accounting for dynamic variations with helicopter airspeed. This permitted a good simulation over the aircraft flight envelope. These dynamics were then tied to the ERC fixed-base simulator. The control system on the simulator had two modes, one for hover and one for cruise (TAS > 35 kts). In hover, the pilot commanded pitch attitude (θ) with longitudinal stick, roll attitude (ϕ) with lateral stick, and yaw rate (r) with pedals. There was no control system on the collective input (δ_c) for altitude. In cruise the pitch and plunge axes remained the same, while the pilot commanded a co-ordinated turn with lateral stick and commanded side slip, β, with pedals. The mode-select was manual with a toggle switch on the instrument panel.

THE FLIGHT DIRECTOR

The flight director used was an ARU-2B/A made by Sperry. It displayed two axes of attitude (pitch and roll), had a turn and bank indicator, and had three command functions. For command there was a vertical needle, a horizontal needle, and a vertical "bug" running up and down the left side of the instrument. In the system simulation, the vertical needle addressed localizer error with lateral stick, the horizontal needle addressed forward velocity error with longitudinal stick, and the vertical "bug" addressed the glide slope error with collective stick.

THE SYNTHESIS TECHNIQUE

The technique is simple. The basic underlying assumption is that when a man is operating from a flight director, he is performing a task similar to a servo actuator in an automatic system. With this the case, then a math model of the man may be introduced, just as one would introduce the math model of an actuator, and then the loops about the man may be synthesized as if it were an automatic system. If the system is defined so as to be insensitive to the pilot model, then a very simple model may suffice. When a good automatic system is defined by analysis and simulation, then a real pilot may be introduced into the system via fixed-base simulation for final gain adjustments. It is this procedure that was used in this investigation.

THE SYSTEM CONTROL LAWS

Since the investigation was limited to one week, only a sketchy analysis was done on the automatic system before it was simulated. In a real design this should not be the case. It is safe to say--the better the analysis, the better the final system.

Figure 1A shows the automatic pitch loop used to control forward velocity, V_x. For a range to touchdown greater than X_O, the velocity command was V_{x_O} = 75 fps. Within X_O the helicopter was commanded to decelerate to hover at zero range. An integral bypass was used in the velocity loop to give proper trim θ command for zero steady state error. The pilot model was a simple first-order lag, but the time constant was varied from zero up to 0.5 sec.

Figure 1B shows the manual pitch loop resulting from the automatic system study. The gain k_θ was found by simulation.

Figure 2A shows the automatic roll loop used to control localizer error. Derived cross range rate was assumed available. The $T_{\dot{y}}$ time constant is smoothing on the derived rate. This system was used for the whole speed range for both flight control modes. The pilot switched the mode from cruise to hover at 35 kts and nulled any heading error with pedals. The same simple pilot model was used.

Figure 2B shows the manual roll loop resulting from the automatic system study. The gain k_ϕ was found by simulation.

Figure 3A shows the automatic altitude loop used to control glide slope error. The range to touchdown was processed through tangent of commanded flight path angle of 6 degrees to give an altitude command. Altitude error gave an error rate of descent command in addition to the steady-state rate of descent command. An integral by-pass was inserted before collective command to account for trim changes at steady state. Again the same simple pilot model was used.

Figure 3B shows the manual altitude loop resulting from the automatic system study. The gain k_{δ_c} was found by simulation

AUTOMATIC SYSTEM RESULTS

Figures 4A and 4B show the automatic system with the pilot model inserted into the pitch loop only, with $T_p = 0.5$ sec. For this case $X_o = 3500$ ft. The initial conditions were with zero localizer and glide slope error and zero rate of descent (intercept). The aircraft overflew the glide slope and then settled down until, at X_o, it under flew for a few seconds because of the deceleration command. Near touchdown, a forward step gust of 5 kts from behind was inserted. The run was terminated at zero altitude. Overall system performance was considered good.

Figures 5A and 5B show the automatic system with the pilot model inserted into the roll loop only, with $T_p = 0.5$ sec. For this case $X_o = 3500$ ft. The initial conditions were with zero localizer and glide slope error with zero rate of descent (intercept). The aircraft overflew the glide slope and then settled down on the beam. With cruise control mode on ($V_x > 60$ fps) a lateral step gust of 5 kts was inserted. At $X_o = 3500$ ft deceleration was initiated. With hover control mode on ($V_x < 60$ fps) a lateral step gust of 10 kts was inserted. The run was terminated at zero altitude. Overall system performance was considered good.

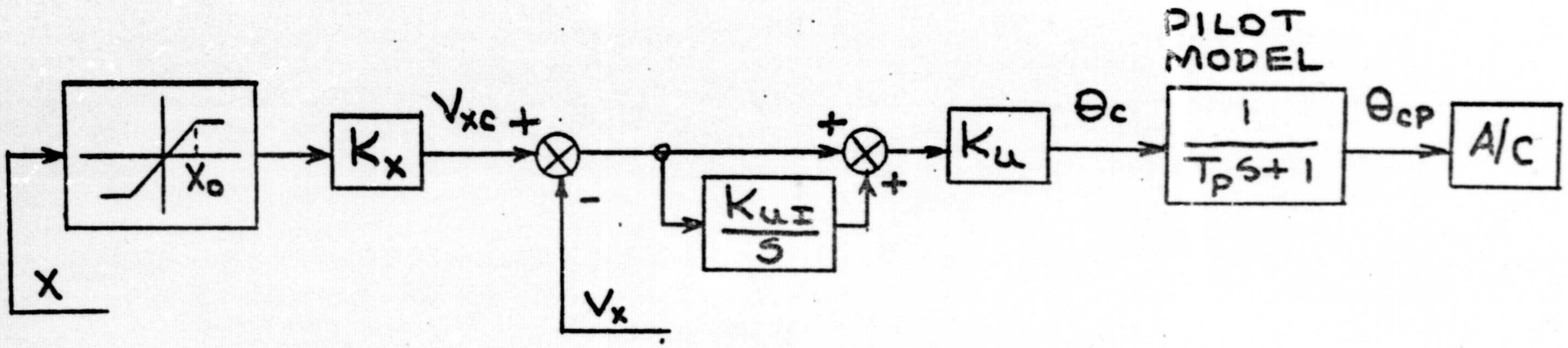
Figures 6A and 6B show the automatic system with the pilot model inserted into the altitude loop only, with $T_p = 0.5$ sec. For this case $X_o = 3500$ ft. The initial conditions were as before at intercept. System behavior began as on the prior runs. A vertical step gust of 5 kts from above was inserted. The system corrected for the resulting glide slope error. The run was terminated at zero altitude.

MANUAL SYSTEM RESULTS

When an acceptable automatic system with the pilot model was defined, manual control simulations were carried out. A pilot was introduced into the system one loop at a time and the flight director command needle sensitivities (k_θ, k_ϕ, k_{δ_c}) were found. The pilot was an untrained subject being a research engineer. In spite of this, the pilot was able to do a good job on each axis individually and on the pitch and altitude loops together. All three axes of command were not tried together in this study because of a time constraint on simulator use. Figures 7A and 7B show the manual system in pitch and altitude, with roll automatic. The performance was not so smooth as with the automatic system but was considered good.

CONCLUSIONS

Automatic control system synthesis techniques were used in conjunction with a simple mathematical pilot model to design flight director control laws for the manual landing approach of a helicopter. The technique was quite successful and is recommended by the authors. Subsequent to the study documented herein, this technique was used successfully to define flight director control laws for landing approach of the Langley Research Center CH-46C helicopter.



$K_{uI} = 0.01$

$K_u = 0.5$ DEG/FPS

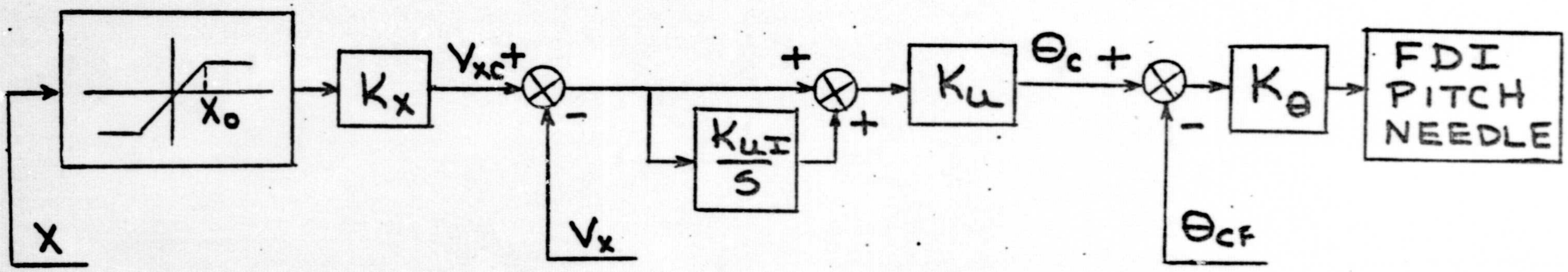
$0 < T_p \leq 0.5$ SEC

$K_x = \frac{V_{x_o}}{X_o}$ FPS/FT

$X_o = 3600, 1800, 900$ FT

$V_{x_o} = 75$ FPS

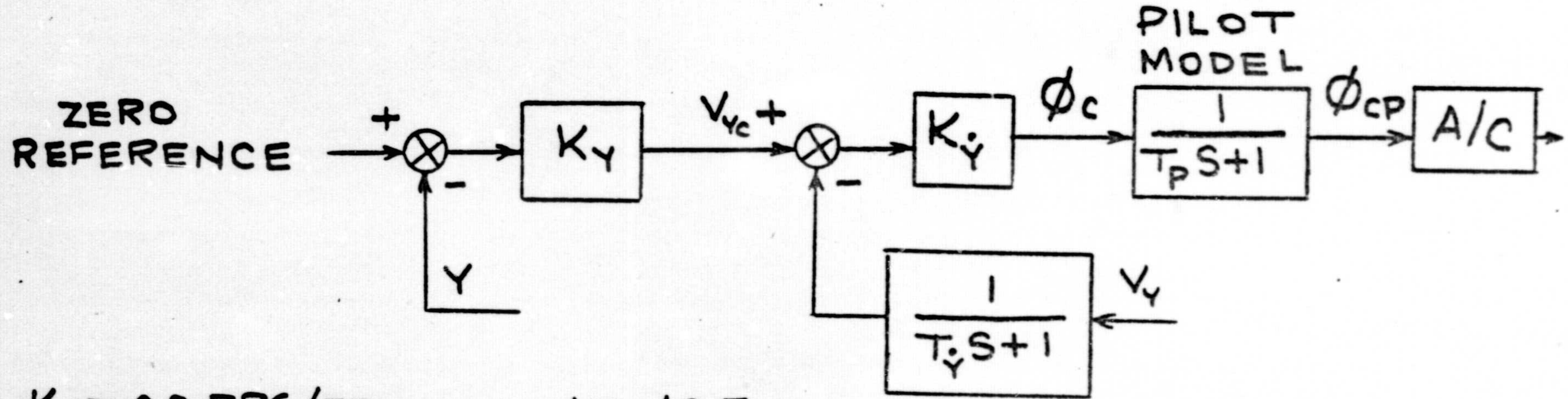
Figure 1A.- Automatic pitch loop with pilot model



$K_\theta = 0.25$ VOLTS/DEG

FDI PITCH NEEDLE IS 2.6 VOLTS FULL SCALE

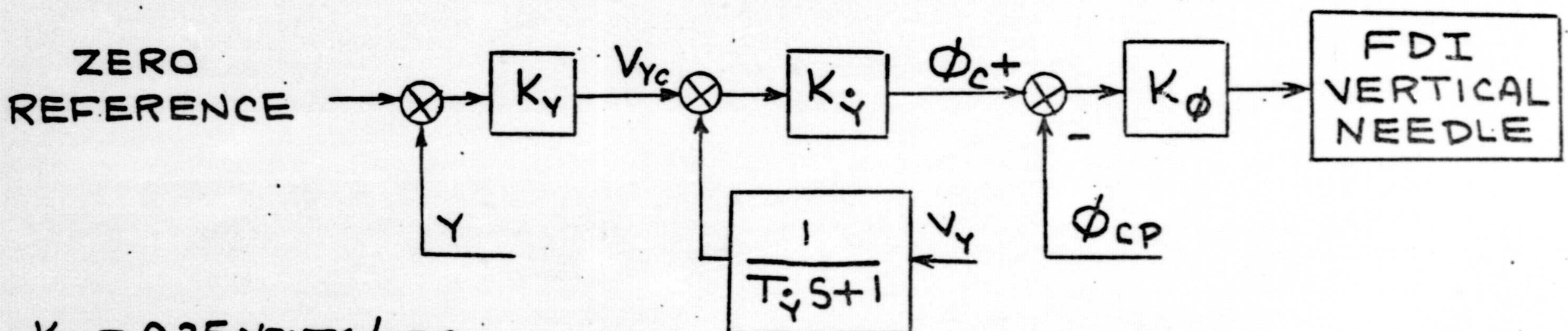
Figure 1B.- FDI manual pitch loop



$K_Y = 0.2$ FPS/FT $\quad 0 < T_P \leq 0.5$ SEC

$K_{\dot{Y}} = 0.5$ DEG/FPS $\quad T_{\dot{Y}} = 0.5$ SEC

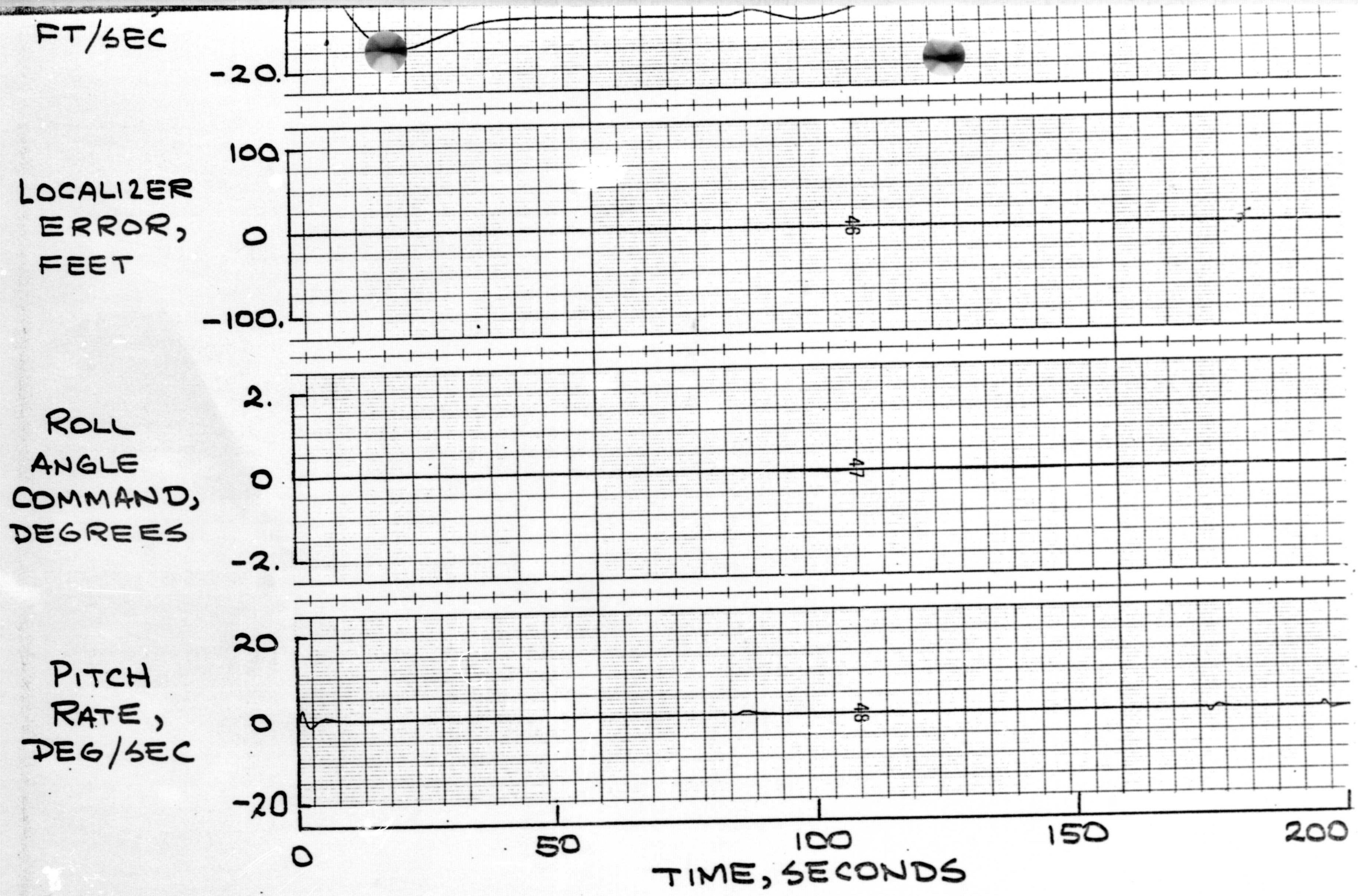
Figure 2A.- Automatic roll loop with pilot model



$K_\phi = 0.25$ VOLTS/DEG

FDI VERTICAL NEEDLE IS 2.6 VOLTS FULL SCALE

Figure 2B.- FDI manual roll loop


FT/SEC
-20.
100
LOCALIZER
ERROR,
FEET
0
-100.
46
2.
ROLL
ANGLE
COMMAND,
DEGREES
0
-2.
47
20
PITCH
RATE,
DEG/SEC
0
-20
48
0
50
100
150
200
TIME, SECONDS

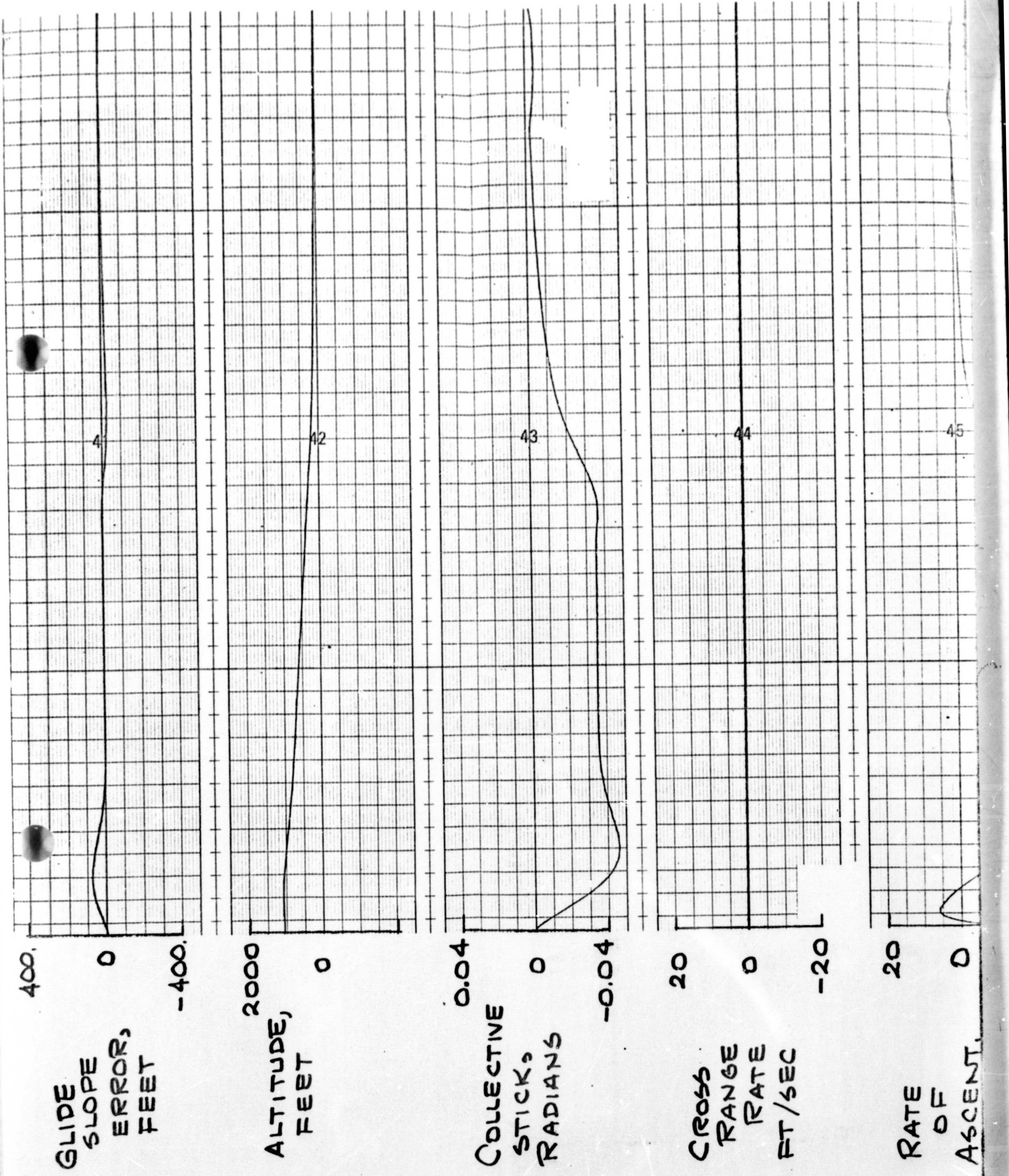
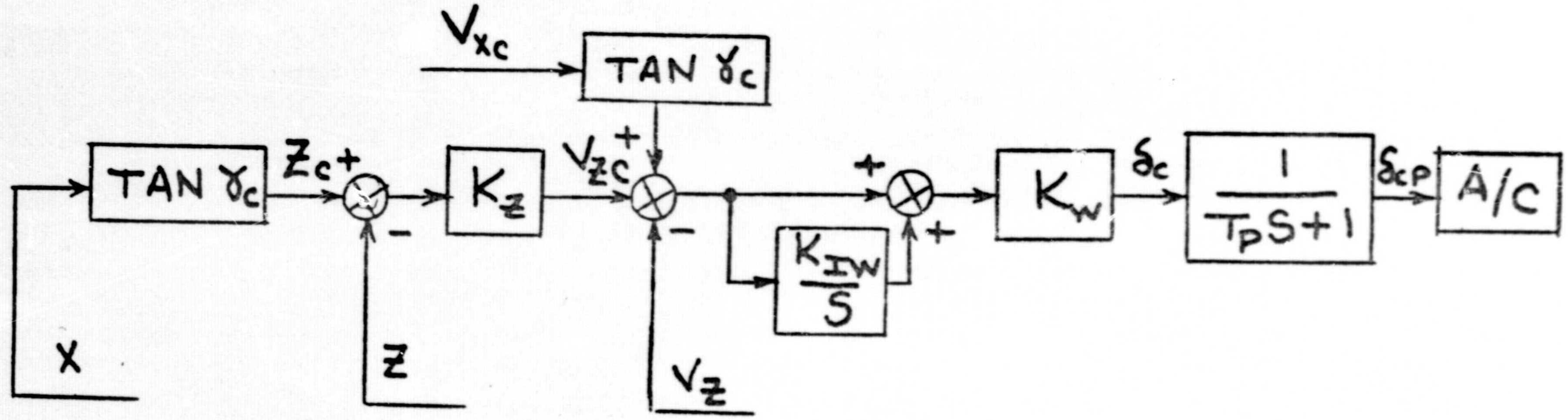


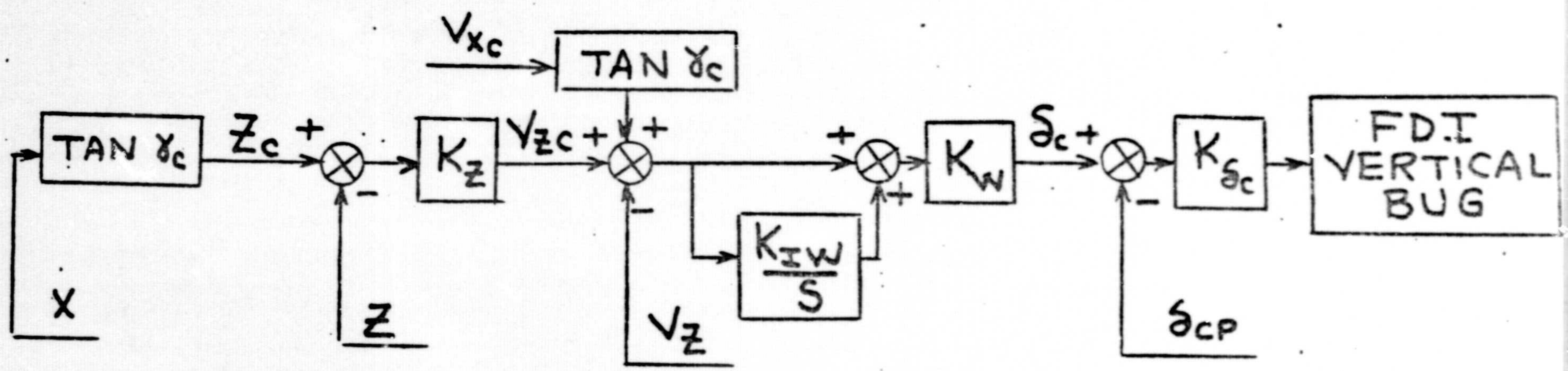
Figure 4A.- Automatic system with pilot model in pitch loop only (T_p = 0.5 sec)



$K_W = 0.3$ IN/FPS $\quad K_Z = 0.1$ FPS/FT $\quad 0 < T_P \leq 0.5$ SEC

$K_{IW} = 0.1 \quad \gamma_c = 6$ DEGREES

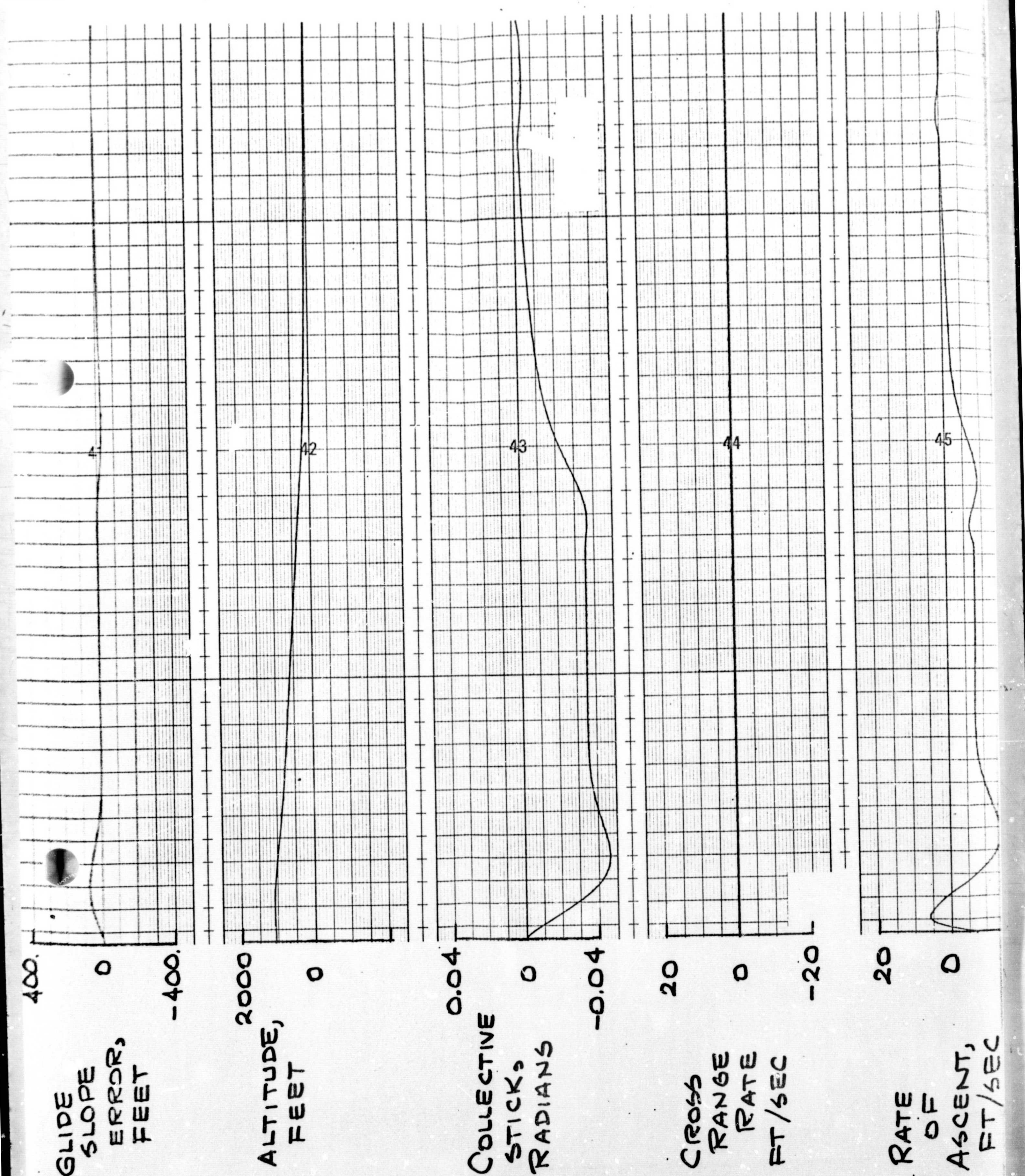
Figure 3A.- Automatic altitude loop with pilot model



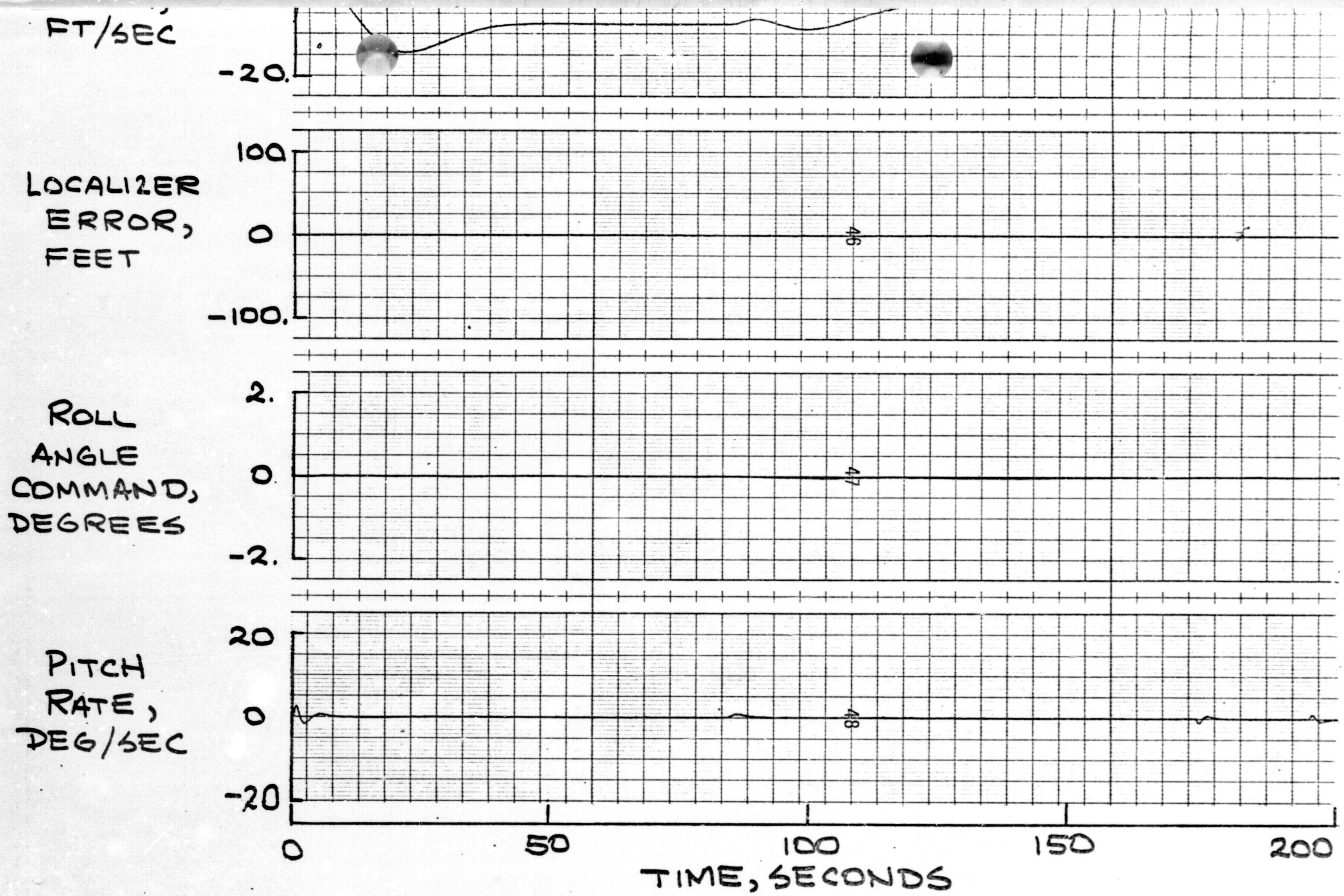
$K_{\delta_c} = 50$ VOLTS/RAD

FDI VERTICAL BUG IS 14.7 VOLTS FULL SCALE

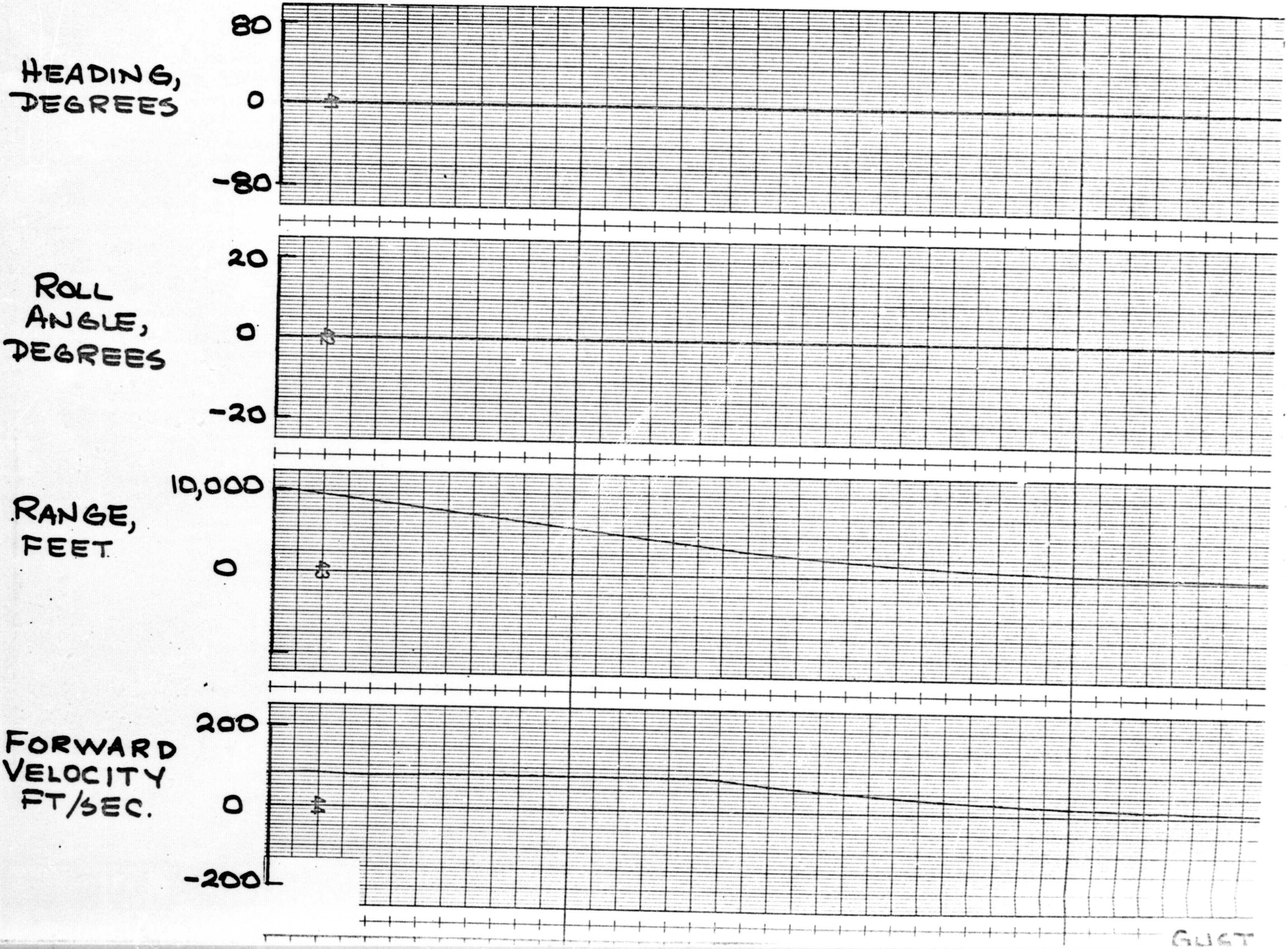
Figure 3B.- FDI manual altitude loop



gure 4A.- Automatic system with pilot
del in pitch loop only (T_p = 0.5 sec)



FT/SEC
-20.
LOCALIZER
ERROR,
FEET
100
0
-100.
46
ROLL
ANGLE
COMMAND,
DEGREES
2.
0
-2.
47
PITCH
RATE,
DEG/SEC
20
0
-20
48
0
50
100
150
200
TIME, SECONDS


HEADING, DEGREES
80
0
-80
ROLL ANGLE, DEGREES
20
0
-20
RANGE, FEET
10,000
0
FORWARD VELOCITY FT/SEC.
200
0
-200
GUST

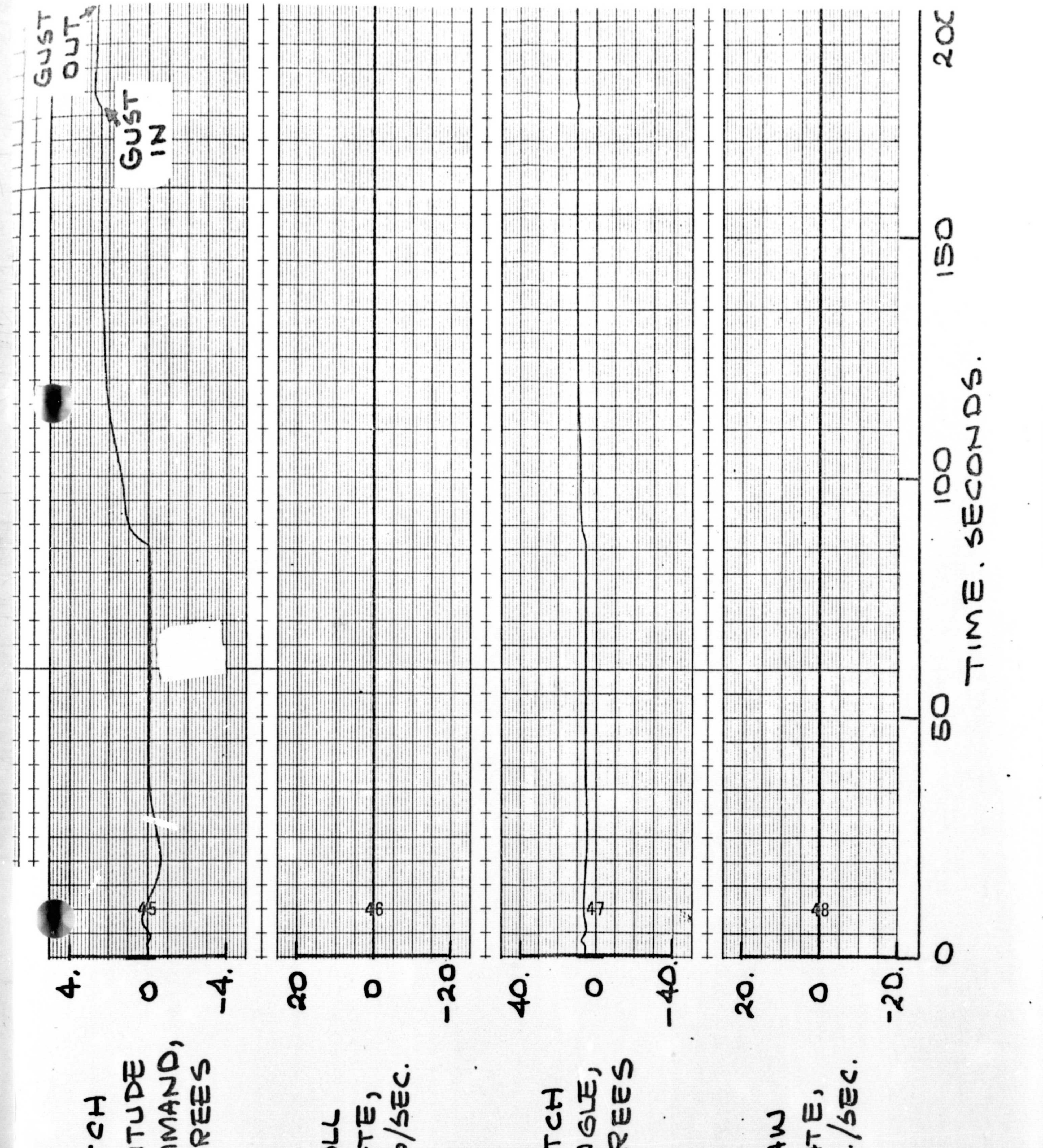
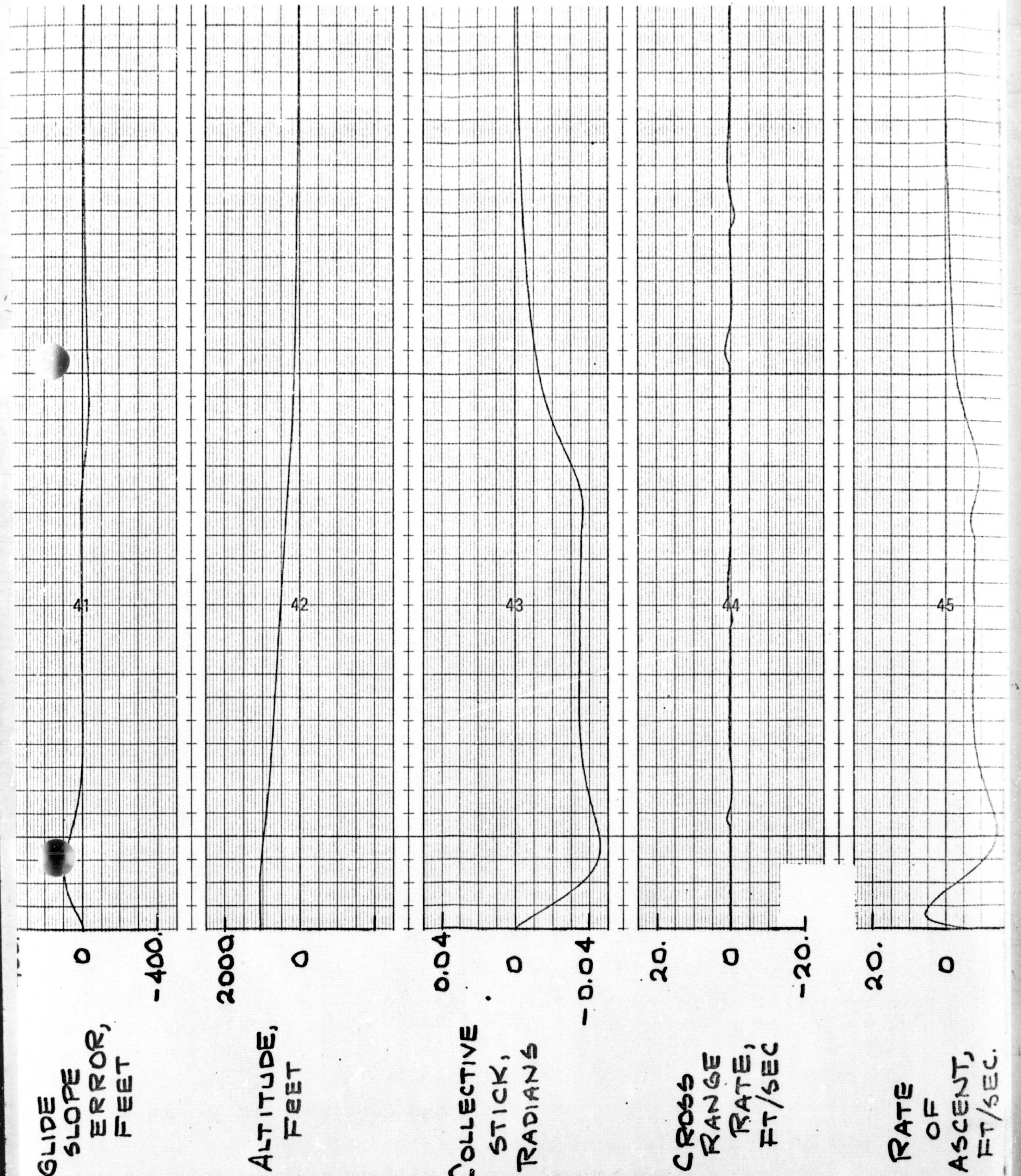
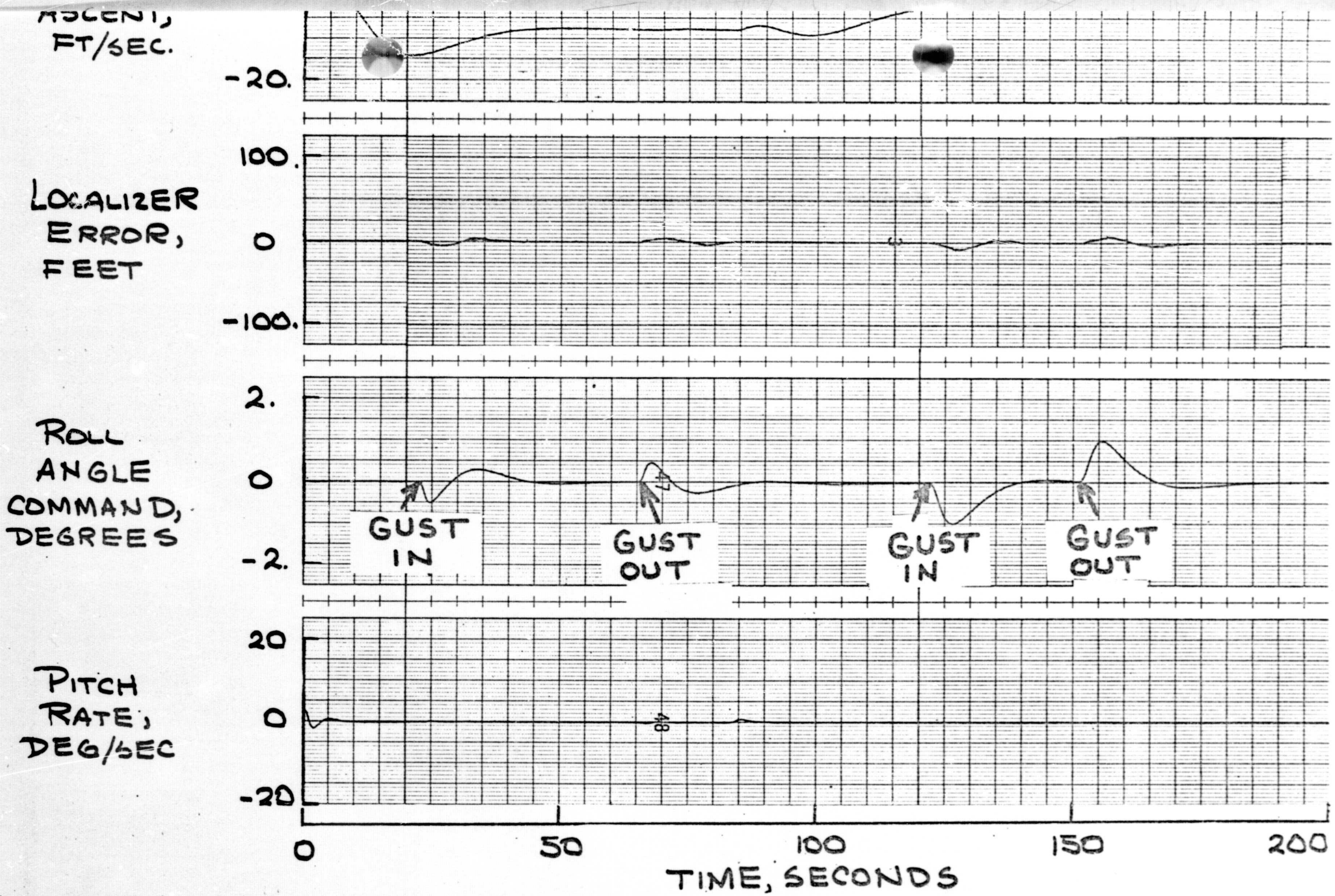
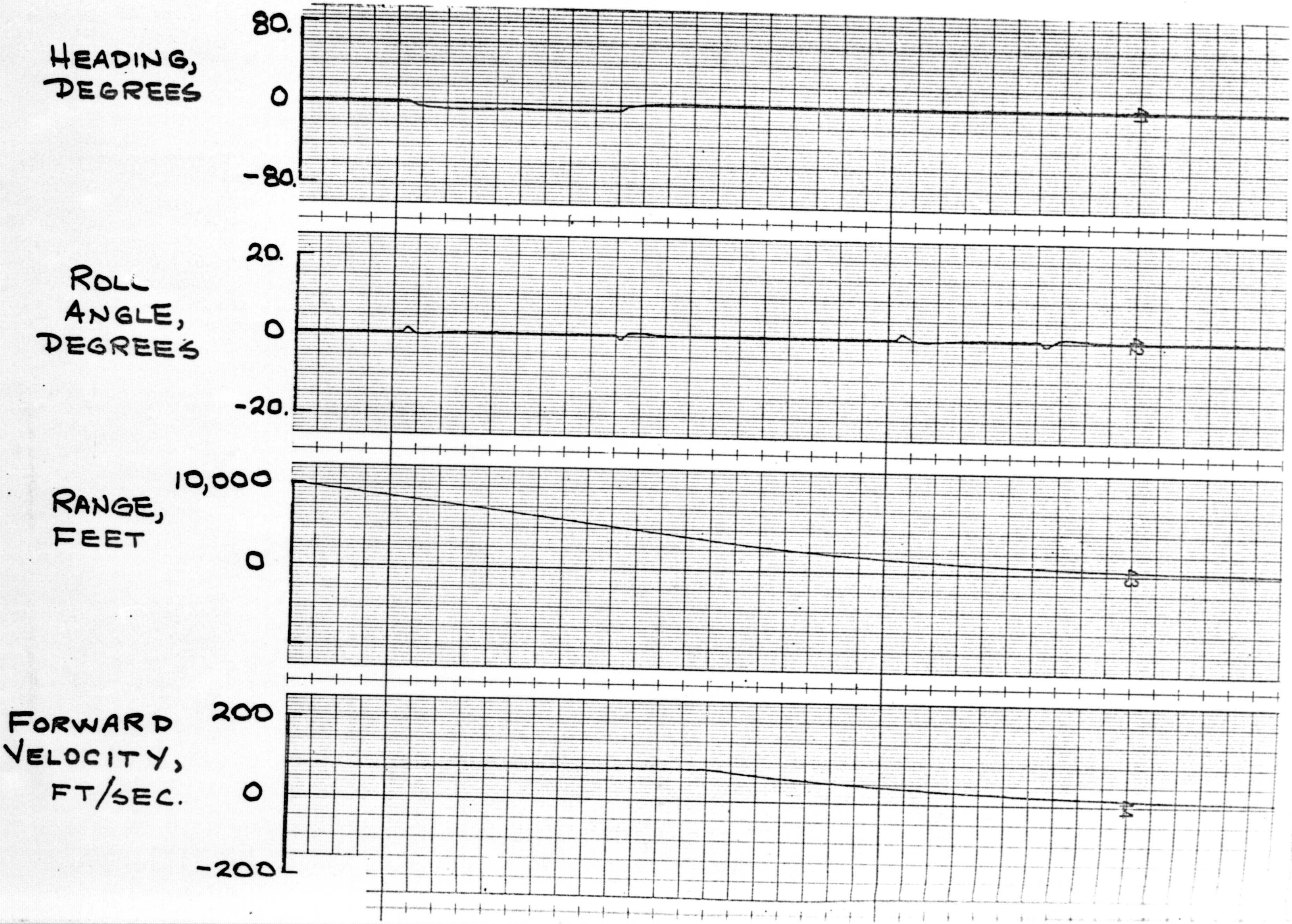


Figure 4B.- Automatic system with pilot model in pitch loop only (T_p = 0.5 sec)



e 5A.- Automatic system with pilot in roll loop only (T_p = 0.5 sec)


FT/SEC.
-20.
100.
LOCALIZER
ERROR,
FEET
0
-100.
2.
ROLL
ANGLE
COMMAND,
DEGREES
0
-2.
GUST IN
GUST OUT
GUST IN
GUST OUT
20
PITCH
RATE,
DEG/SEC
0
-20
0
50
100
150
200
TIME, SECONDS


HEADING, DEGREES
80.
0
-80.
ROLL ANGLE, DEGREES
20.
0
-20.
RANGE, FEET
10,000
0
FORWARD VELOCITY, FT/SEC.
200
0
-200

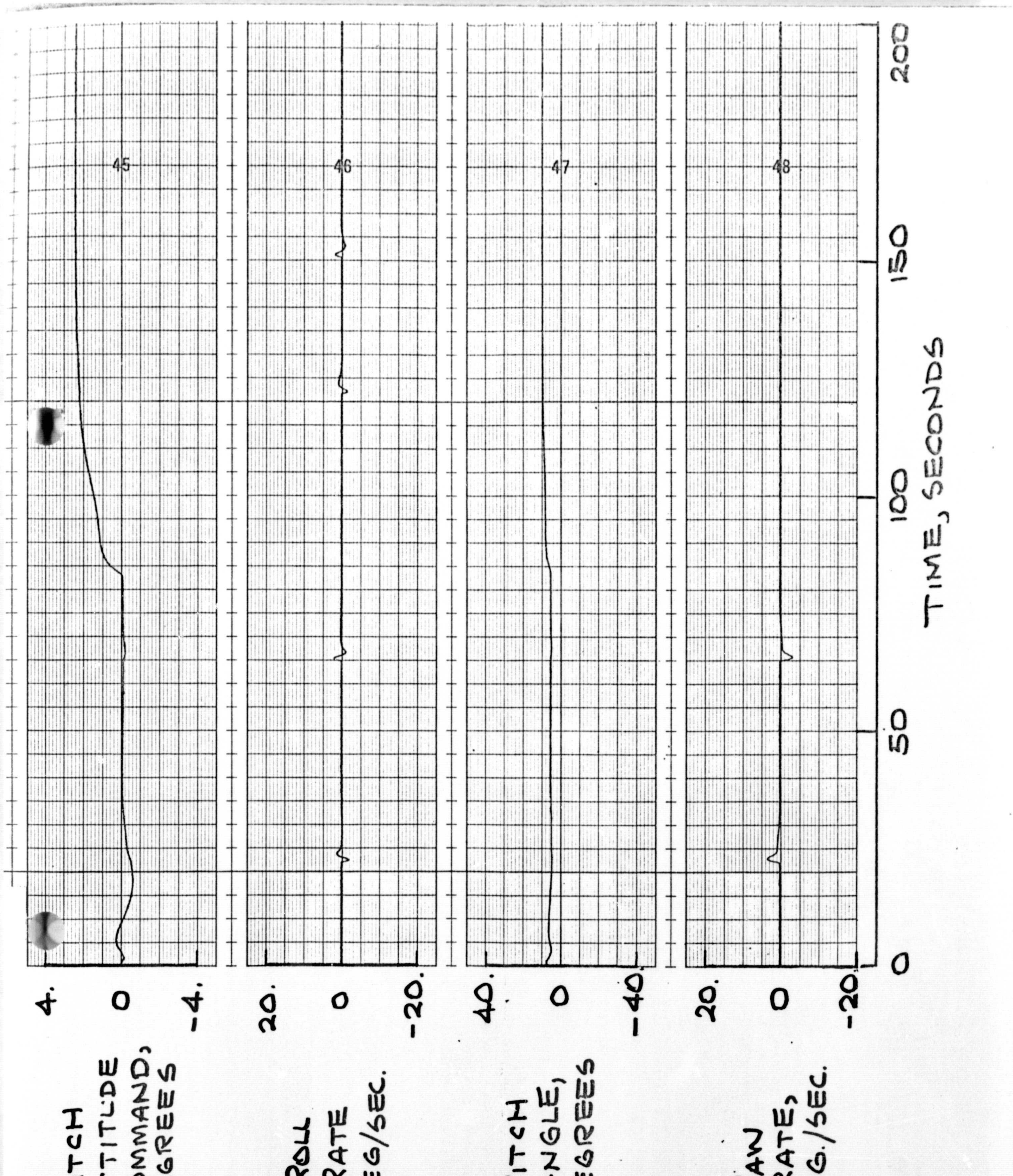
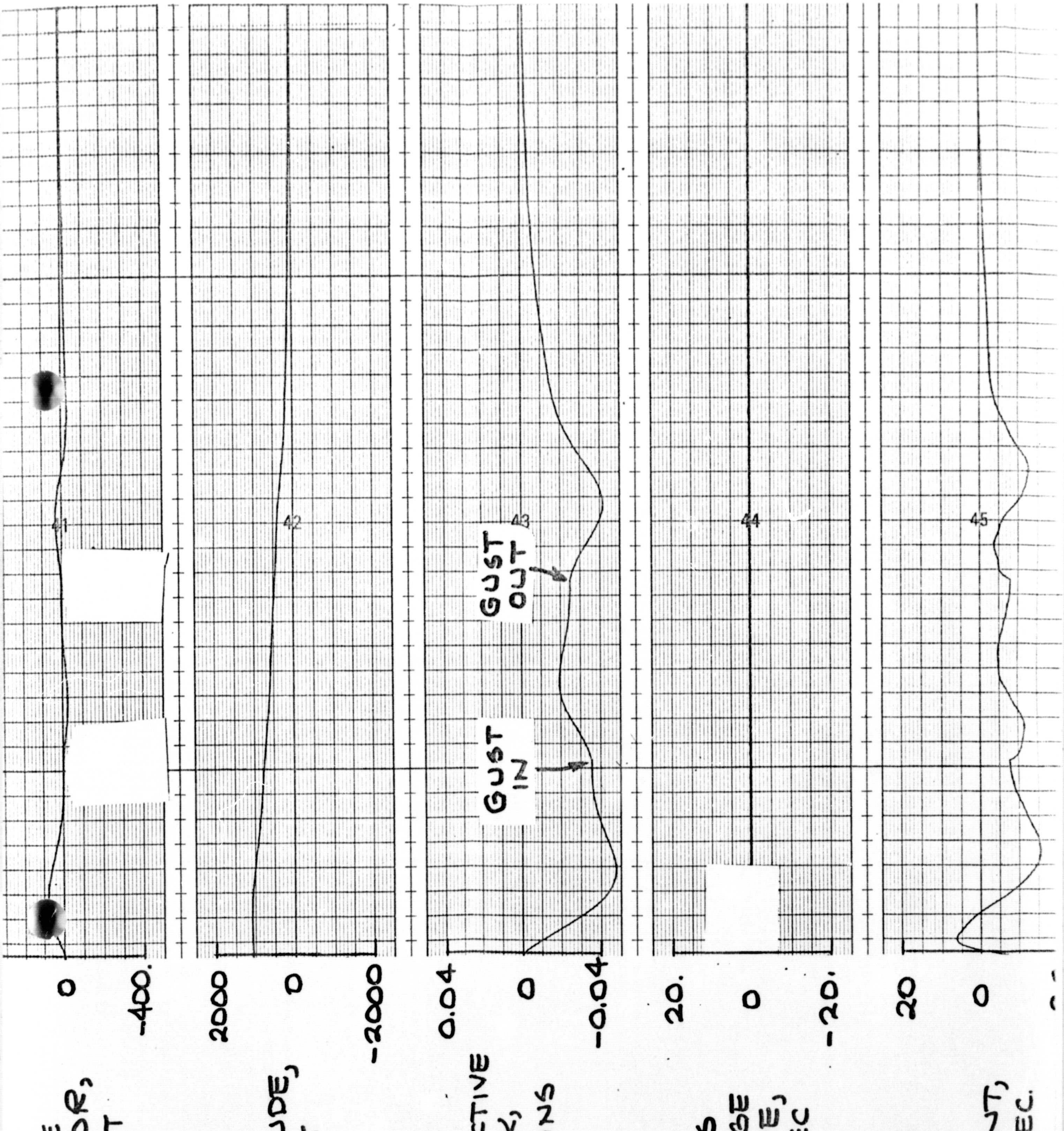
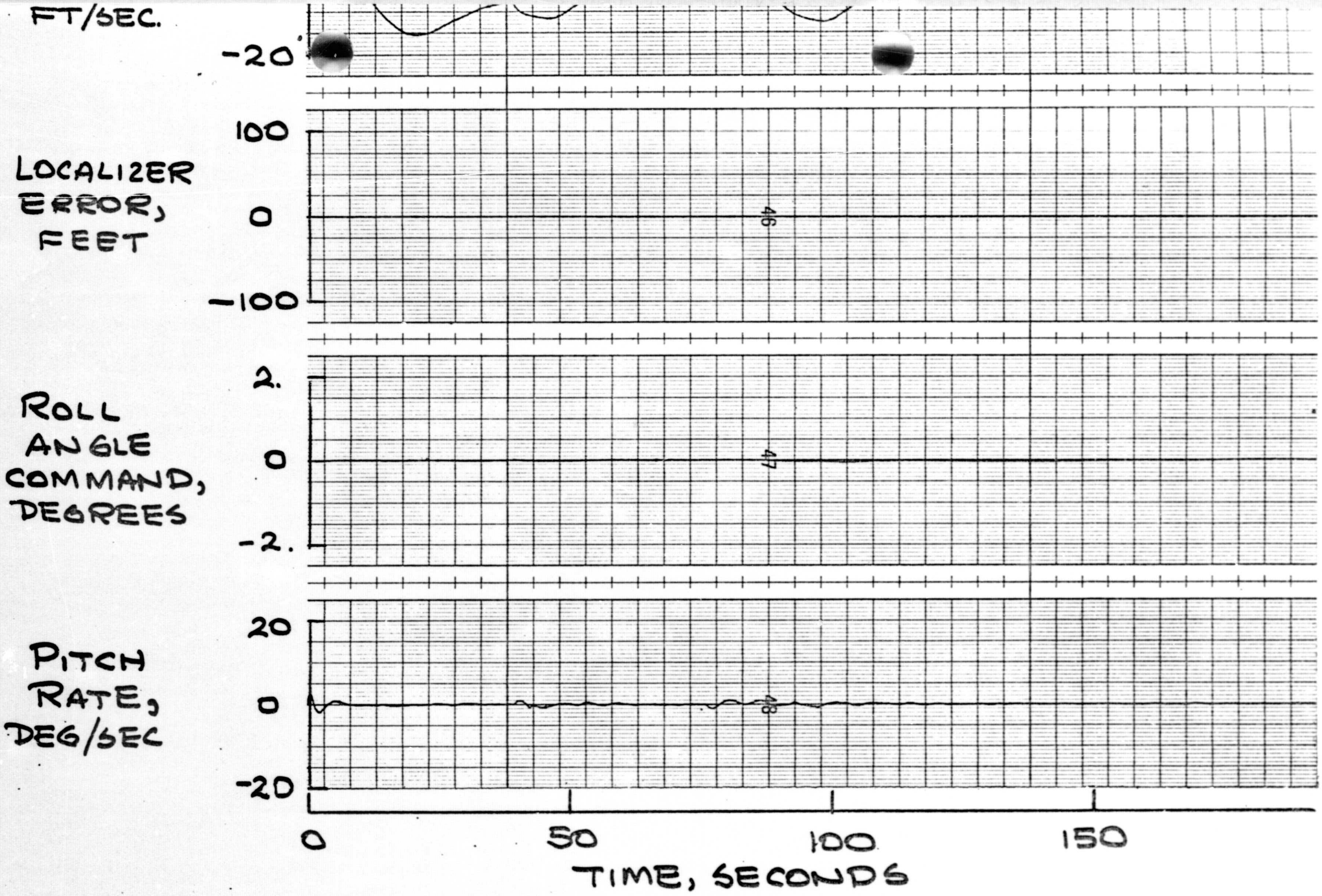
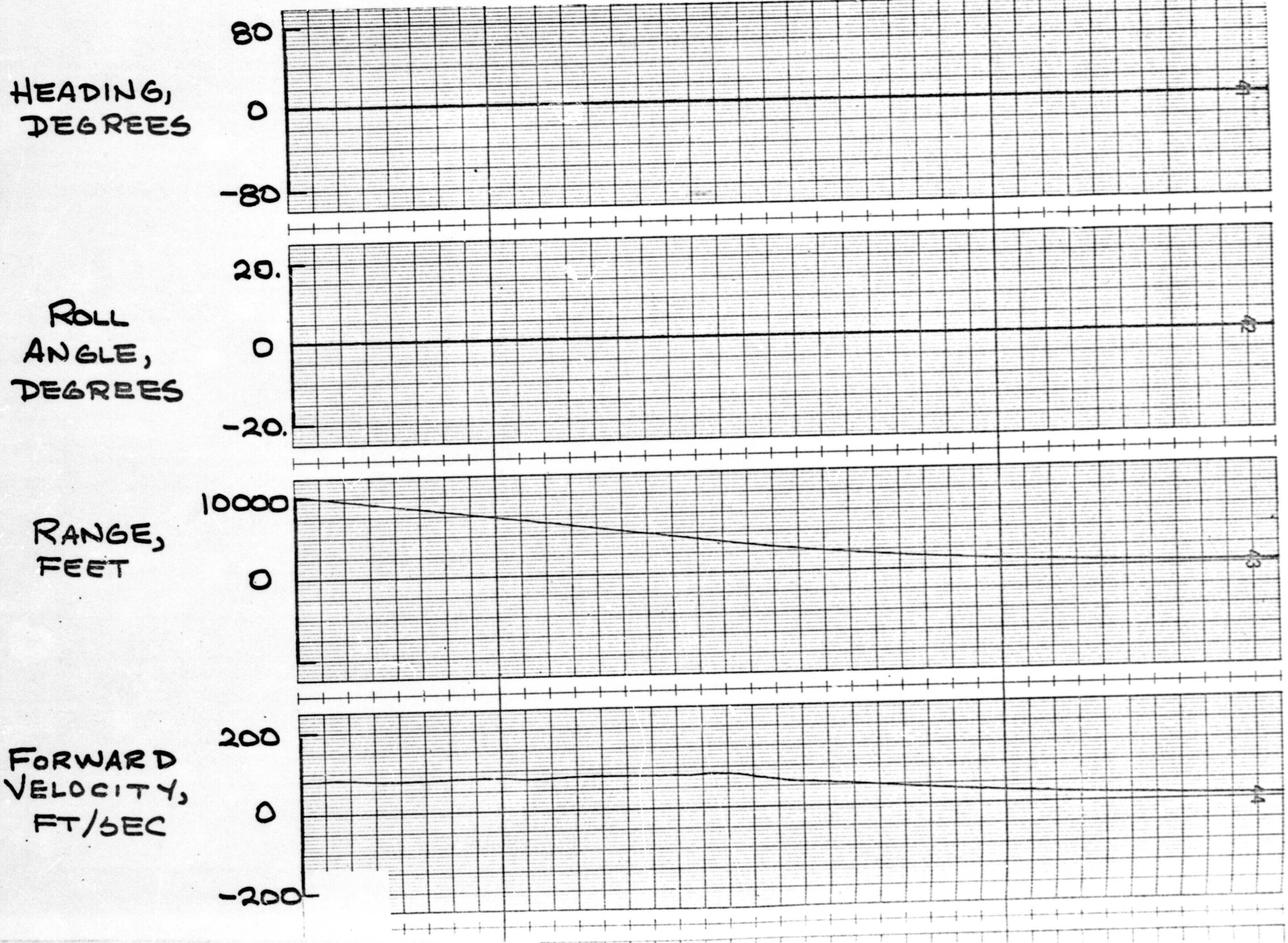


Figure 5B.- Automatic system with pilot model in roll loop only (T_p = 0.5 sec)



e 6A.- Automatic system with pilot
in altitude loop only (T_p = 0.5 sec)


FT/SEC.
-20
LOCALIZER ERROR, FEET
100
0
-100
ROLL ANGLE COMMAND, DEGREES
2.
0
-2.
PITCH RATE, DEG/SEC
20
0
-20
46
47
48
0
50
100
150
TIME, SECONDS


HEADING, DEGREES
80
0
-80
ROLL ANGLE, DEGREES
20.
0
-20.
RANGE, FEET
10000
0
FORWARD VELOCITY, FT/SEC
200
0
-200

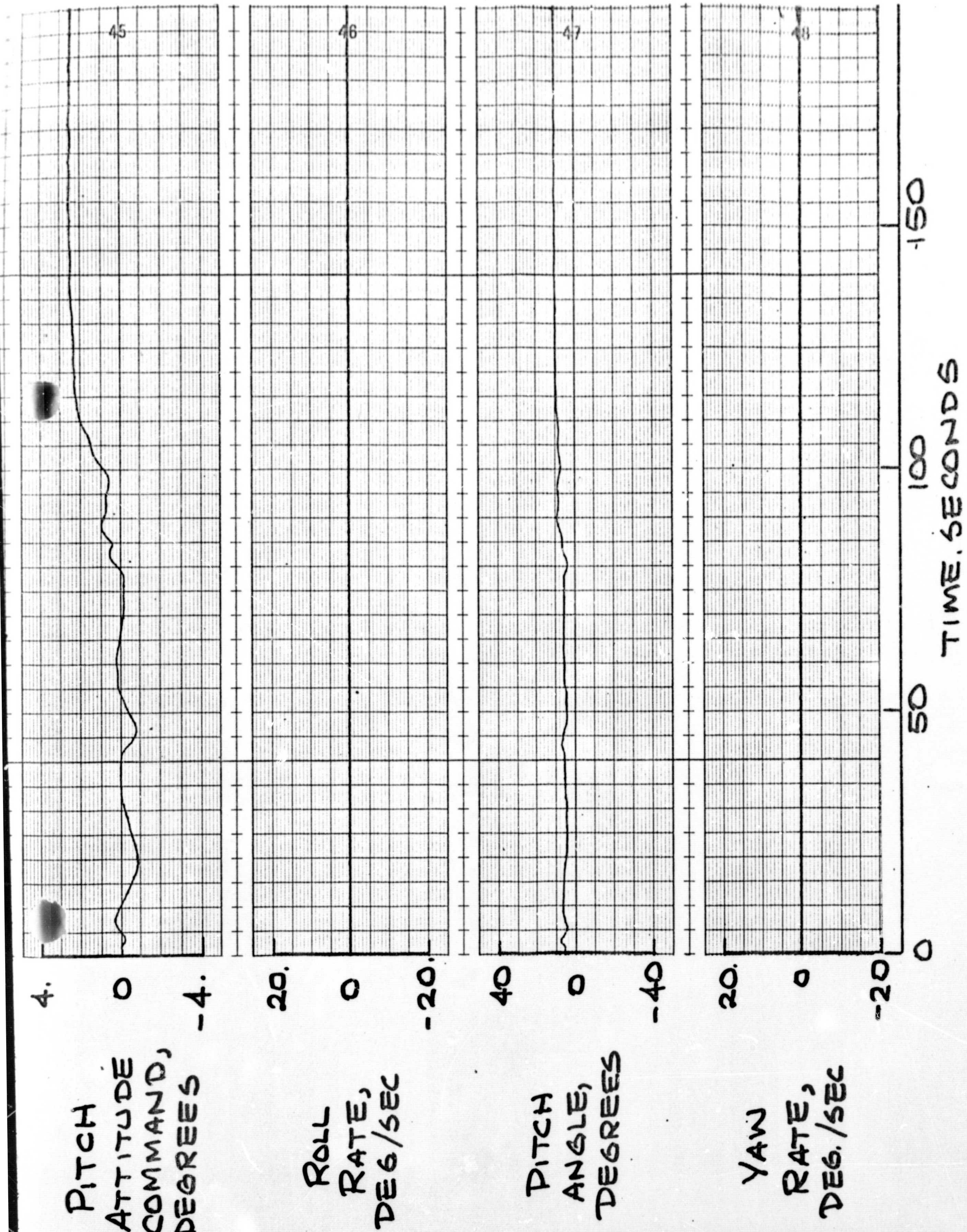
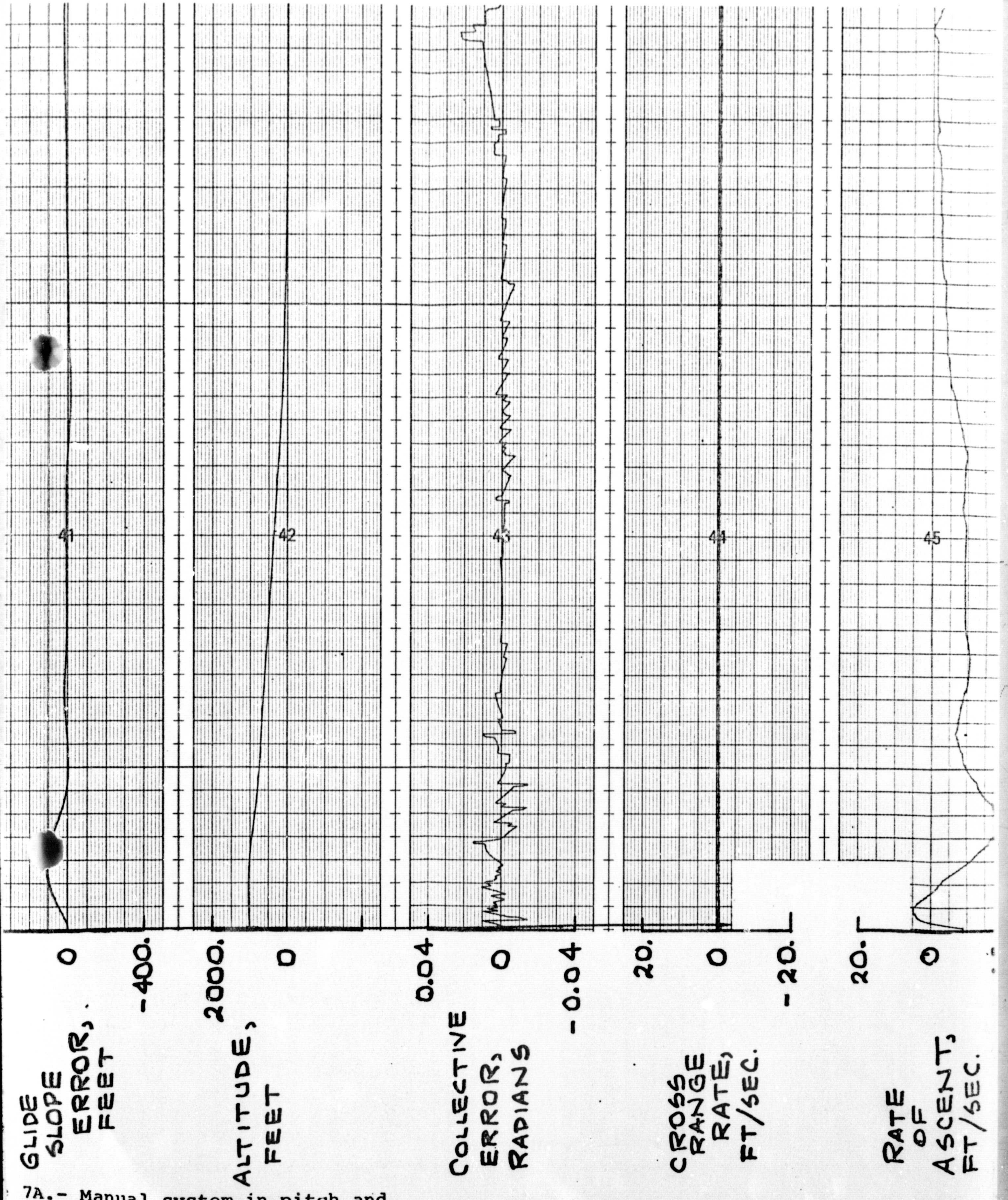
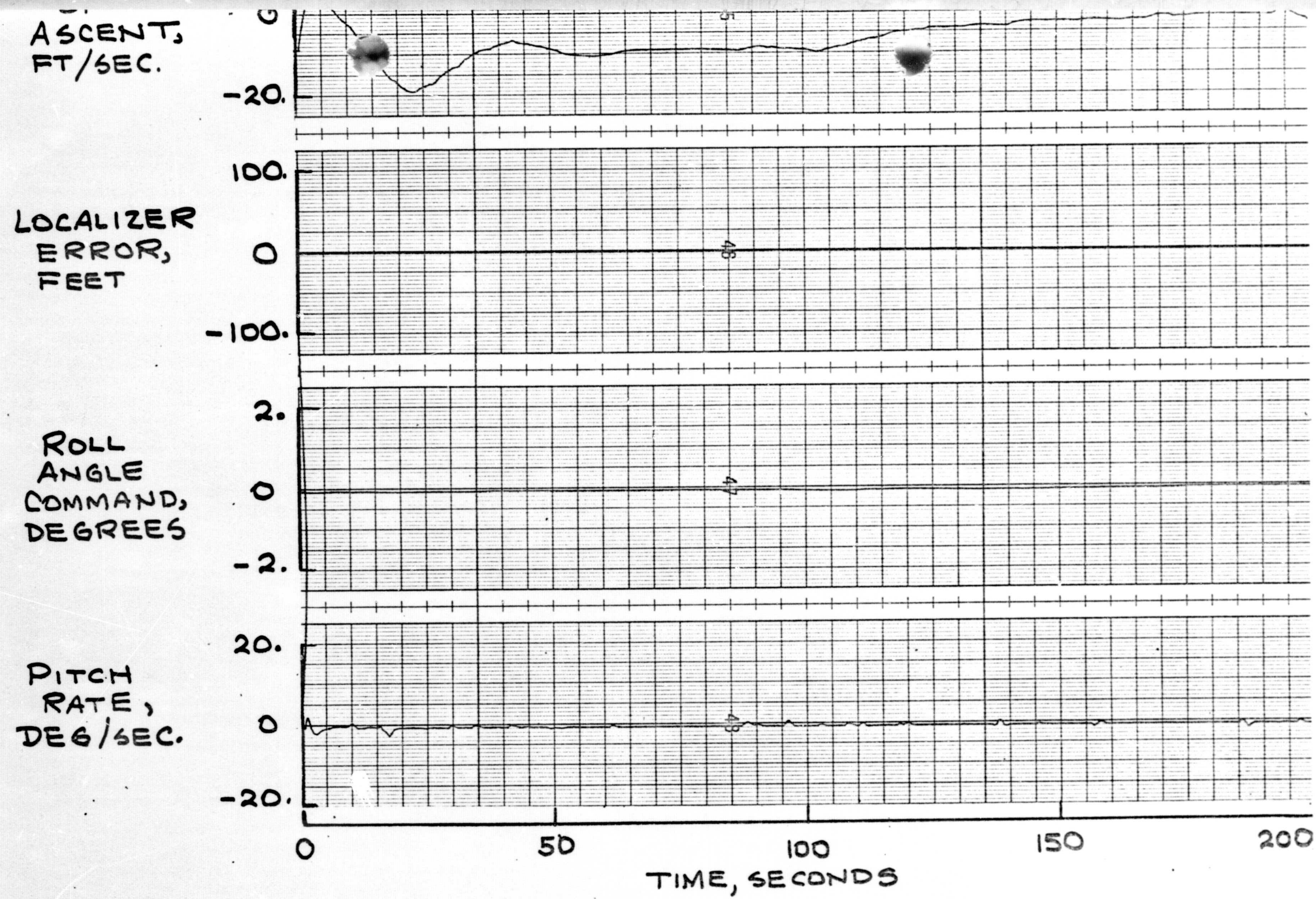


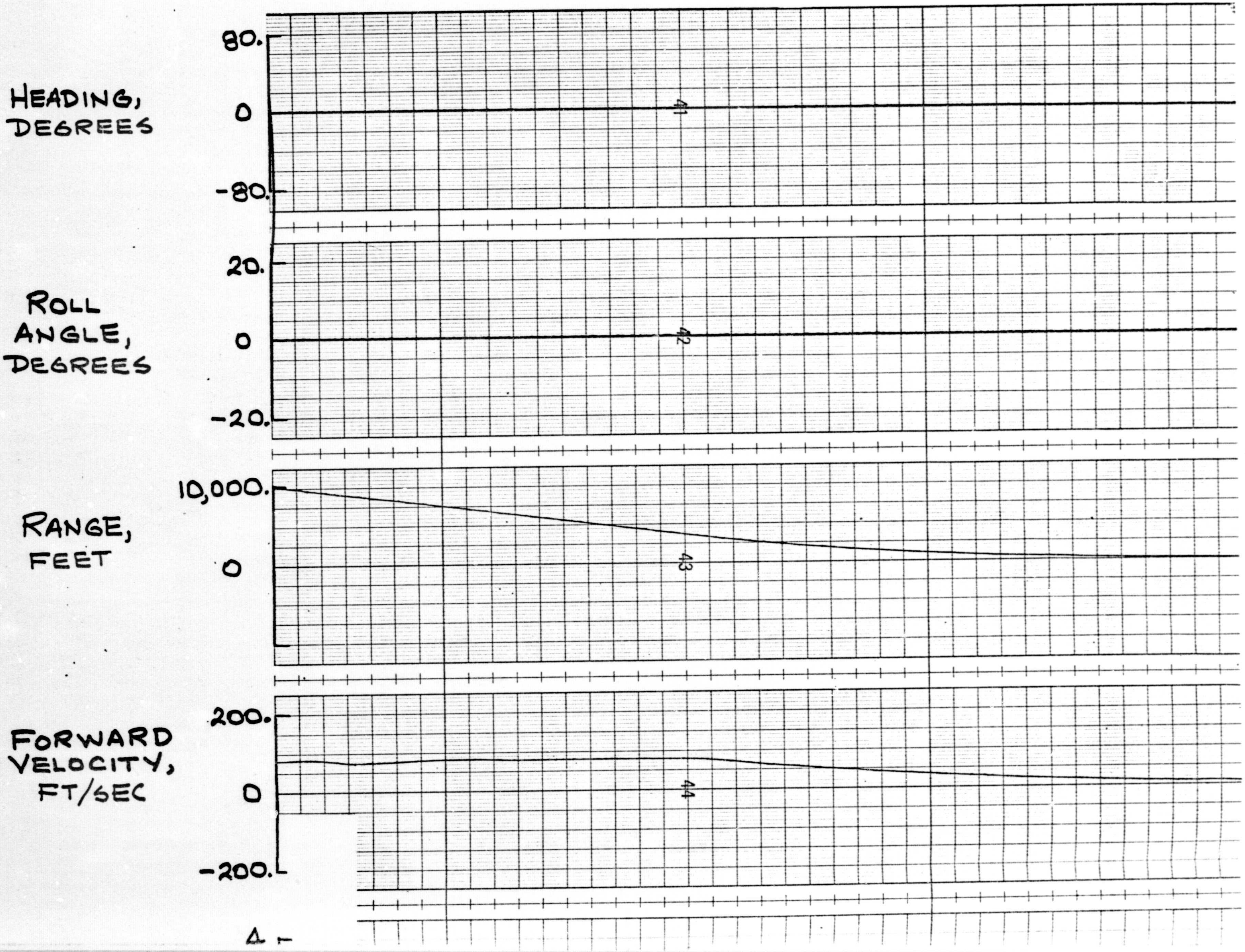
Figure 6B.- Automatic system with pilot model in altitude loop only (T_p = 0.5 sec)



7A.- Manual system in pitch and
itude with roll automatic



ASCENT,
FT/SEC.
0
-20.
LOCALIZER
ERROR,
FEET
100.
0
-100.
ROLL
ANGLE
COMMAND,
DEGREES
2.
0
-2.
PITCH
RATE,
DEG/SEC.
20.
0
-20.
0
50
100
150
200
TIME, SECONDS


HEADING, DEGREES
80.
0
-80.
41
ROLL ANGLE, DEGREES
20.
0
-20.
42
RANGE, FEET
10,000.
0
43
FORWARD VELOCITY, FT/SEC
200.
0
-200.
44
4

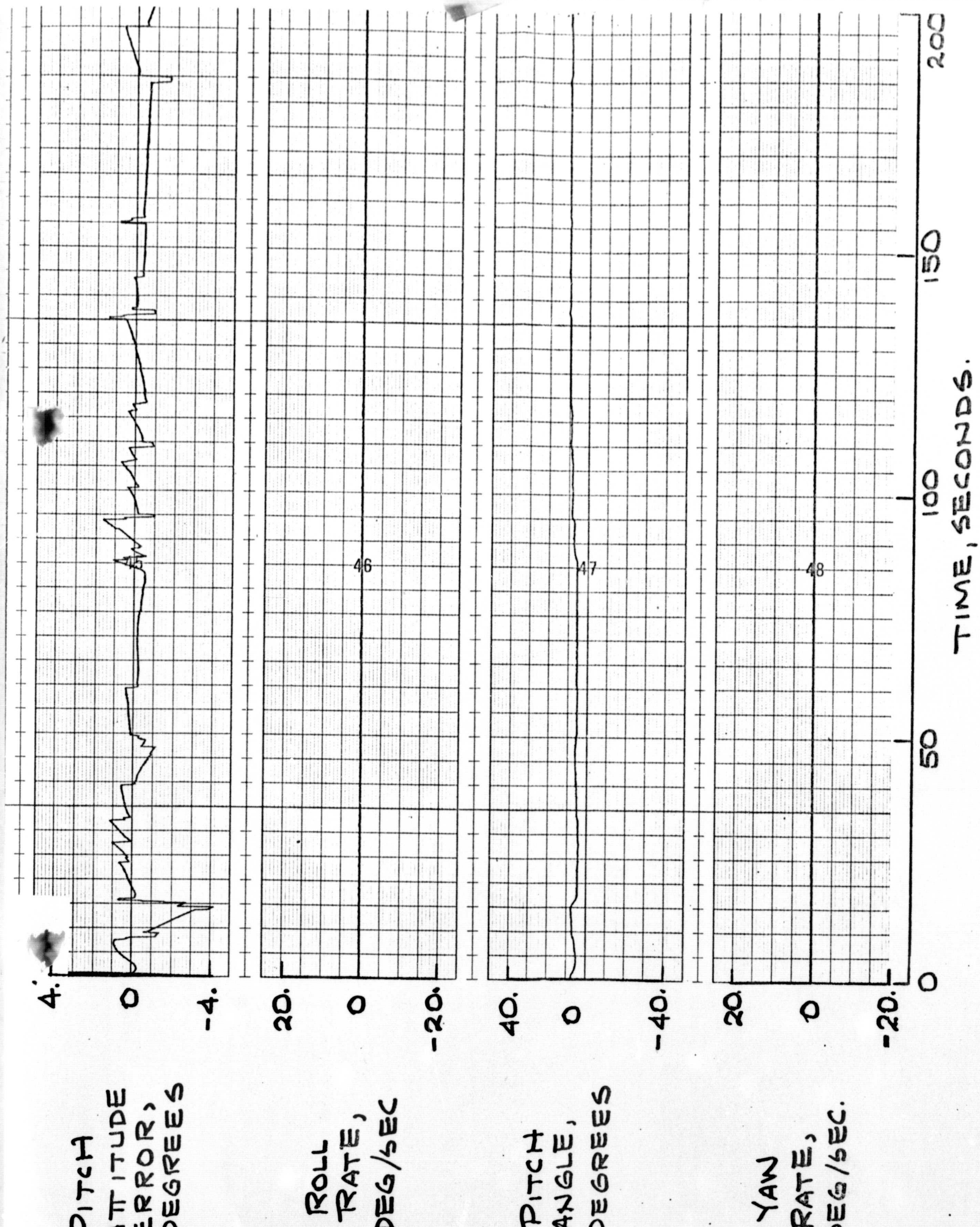


Figure 7B.- Manual system in pitch and in altitude with roll automatic