**NASA
Technical
Paper
1936**

December 1981

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Scientific and Technical
Information Branch

SUMMARY

An analysis was conducted to investigate the differences in the techniques used by seven pilots to acquire information from an advanced display for instrument approaches to and landings on a runway. The study was conducted on a fixed-base simulator programmed with dynamics resembling Langley's terminal configured vehicle (TCV). It is shown that the seven pilots can be divided into two groups which used the display with distinctly different strategies for controlling the airplane. A clearly related pattern of performance differences resulted. Pilots who primarily used raw flight-path information experienced longitudinal oscillations; pilots using attitude information did not. Implications for future displays are discussed.

INTRODUCTION

The Terminal Configured Vehicle (TCV) Program at Langley Research Center includes investigation of displays for terminal area operation. One display which has evolved out of this program is an advanced electronic attitude director indicator (EADI), a vertical situation display. It provides situation and predictive guidance information during instrument approach and landing operations and replaces the conventional electromechanical flight director instrument.

To date, several studies sponsored by Langley Research Center have been completed which address the way pilots utilize the EADI, its operational effectiveness, and the definition of display information requirements. A discussion of what is perhaps the earliest of these appears in reference 1. It addresses the effects of providing inertial flight-path and track angles relative to a perspective runway. It concludes that including this information in the EADI improves the tracking performance of the instrument landing system (ILS) when compared to a similar display providing only raw glide-slope and localizer deviation indicators for ILS guidance. Aspects of a study to determine the effects of varying the manner in which information was presented in the display are addressed in references 2 to 4. That study included measurement of pilot scanning behavior in the display. The study in reference 5 involved a comparison of the EADI to a simulated, conventional flight-director instrument with glide-slope and localizer command information provided along the approach to the runway and also included measurement of scanning behavior. The results of that study indicated pilot preferences for the presentation of the perspective runway and flight-path-angle information with reference being made by the pilots to the presence of situation information in a natural format. They also indicated, however, that they liked the information provided in the command bars of the flight director. No significant difference in performance was measured when the effect of these two displays was compared. A recommendation was made that consideration be given to combining the information of the conventional flight-director instrument with the situation information of the advanced display.

Another study conducted at Langley involved analysis of pilot differences in using conventional displays (ref. 6) and suggested that measurement of pilot scanning behavior along with performance parameters and control activity provides an indication of individual pilot priorities and strategies. In that regard, this earlier study somewhat parallels the discussion to follow.

The data set under analysis in the present discussion was collected during a simulator-based investigation of certain parameters associated with the EADI display and with the level of detail and texture representation in the perspective runway drawing provided in the EADI. Pilot lookpoint was recorded with an oculometer system. The effects of the level of detail and texture representation were discussed in an earlier publication (ref. 2). In fact, it was reported in reference 2 that strong subject differences existed and that the several subjects of the study could be grouped according to how much time they spent looking at EADI runway details as opposed to the central area of that instrument. Therefore, a more detailed analysis was made to examine subject differences and their causes. That analysis is the subject of this paper.

SYMBOLS AND ABBREVIATIONS

A/C	aircraft symbol
c.g.	center of gravity
CRT	cathode-ray tube
EADI	electronic attitude director indicator
f_i	functions represented on analog function generators, $i = 1, \ldots, 25$
F_x	force at aircraft c.g. along x-axis, N
F_z	force at aircraft c.g. along z-axis, N
g	acceleration due to gravity, m/sec^2
h	altitude, m
IAS	indicated airspeed, knots
ILS	instrument landing system
K	constant
m	aircraft mass, kg
PIO	pilot induced oscillation
q	dynamic pressure, N/m^2
S	reference wing area, m^2
t	Student-t distribution test parameter
T_{total}	total thrust force, N
TCV	terminal configured vehicle

v	aircraft goundspeed, m/sec
X,Y,Z	body axes with origin at c.g.
α	angle of attack, rad
γ	flight-path angle, rad
δ_a	aileron deflection, deg
δ_e	elevator deflection, deg
δ_f	flap deflection, deg
δ_r	rudder deflection, deg
θ	pitch angle, rad
ψ	yaw angle, rad
ϕ	roll angle, rad

A dot above a symbol indicates its time derivative.

TEST EQUIPMENT

Simulator

The tests were conducted on a fixed-base simulator at the Simulations and Control Systems Department of the General Electric Corporation. The simulated aircraft dynamics of the system resembled those of the Langley Boeing 737 TCV airplane. Figure 1 is a photograph of the interior of the simulator cabin. The cabin was designed to simulate a jet transport flight deck and was adapted to represent the TCV by installing a CRT in the usual location of the attitude director indicator. An airspeed indicator was also on the panel. The computer display generation facility described in reference 7 was used to produce the EADI display.

Oculometer

An oculometer from the oculometer laboratory at the Langley Research Center was used in these studies to determine the pilot's lookpoint during the simulated landing approaches. The oculometer emits an infrared beam from an electro-optical package (fig. 2). The beam is reflected back from the retina and cornea of the eye (fig. 3) to a television (TV) camera. The area of the retina reflection is bounded by the pupil circumference. The relative positions of the two reflections is a function of the point of regard of the pilot's eye (the small area on the display which is imaged in the subject's central visual field - also called the lookpoint) with respect to the infrared light source. A minicomputer analyzes each TV frame and calculates the point of regard, pupil diameter, and voltage signals to drive mirrors in the electro-optical package to keep the eye centered on the TV camera. These signals were recorded for later analysis.

Primary Flight Display

The primary flight display was an electronic attitude director indicator (EADI, fig. 4) which provided most of the information needed by the pilot to control the aircraft during the final approach to the runway. It displayed altitude in a digital readout format, pitch and roll attitudes referenced to the stationary and centered aircraft symbol, deviation from the nominal glide path, inertial flight-path angle presented on a pair of wedges referred to as gamma wedges, and a perspective drawing of the runway which changed size to correspond to the distance from the runway. The flight-path wedges present the inertial flight-path angle and the magnetic track angle of the aircraft. Aligning these with an intended touchdown point on the perspective runway will cause the airplane to track to that point.

The EADI was presented on a CRT that was 20.96-cm high × 27.94-cm wide. The nominal eye position was 60.96 cm from the CRT. The displayed symbols represented a field of view of 25.4° (±12.7° of elevation angle) by 33.84° (±16.92° of azimuth angle). Thus, the effective magnification of the display was 0.8 (i.e. 0.8° of subtended angle referenced from the eye position represented 1.0° of simulated angular displacement).

Control System

The attitude control-wheel-steering mode of the TCV aircraft control system was simulated in this study. This is a rate-command, attitude-hold, manual control mode. Pilot control inputs through the column or wheel produce angular rates proportional to the input. When the input is removed, angular rates are reduced to zero and attitudes are maintained. Initial airplane response is what the pilot normally expects, and the stability augmentation relieves him of his usual attitude-stabilizing workload. The control system is a key element in understanding the conclusions reached in the discussions in this document. More complete details of the control system are documented in reference 8.

Simulated Aircraft Dynamics

The aircraft equations of motion were programmed on an analog computer and used function generators to represent the stability derivatives of the TCV in a linearized model. Neither steady winds nor turbulence were simulated. Verification of the model was carried out primarily by the subjective evaluation of two NASA test pilots currently qualified in this transport aircraft.

The following equations of motion were used:

$$\gamma = \theta - \alpha \tag{1}$$

$$\dot{v} = \frac{1}{m}(T_{total} - F_x) - g \sin \gamma \tag{2}$$

$$F_x = qS\left[(f_1(\alpha) + f_{16}(\delta_f)\right] \tag{3}$$

$$F_z = qS\left[f_{19}(\alpha) + f_{20}(\delta_f)\right] \tag{4}$$

$$\dot{\psi} = \left[f_3(\phi) + K\delta_r\right] f_5(\text{IAS}) \tag{5}$$

$$\dot{h} = v \sin \gamma \tag{6}$$

$$\dot{\phi} = f_6(\delta_a)\, f_7(\text{IAS}) \tag{7}$$

$$\dot{\theta} = f_8(\delta_e)\, f_9(\text{IAS}) \tag{8}$$

$$\dot{\alpha} = \left[-g\, f_{25}(\phi)\, f_{26}(\theta) + \frac{F_z}{m}\right] f_{23}(v) - \dot{\theta} \tag{9}$$

The complex relationship between α, γ, and θ, as implied by equations (1), (8), and (9), is an important feature of the present analysis. Specifically, the phase relationship between γ and θ is a function of the gains and functional values in these equations. The primary point to be made is that there is generally a phase difference between pitch and flight-path angle (i.e., flight-path angle lags pitch attitude).

Experiment

The test consisted of simulated, instrument approach and landing operations along a 3° glide slope flown without an out-of-the-window visual scene. The simulated flights were initiated from an altitude of approximately 160 m with random lateral deviation and with the airplane trimmed at an airspeed of 120 knots on the glide path. The pilot's task was to fly along the glide path to flare height at an altitude of about 18 m, flare the airplane, and touch down 305 m from the runway threshold. Each data run took approximately 50 sec for completion. The data set under analysis involved 180 runs consisting of two replications of the experiment for one pilot and three replications for the other six pilots. This difference is because of data loss in the experiment and was accounted for in the statistical analysis of the results. The experiment consisted of 9 data runs with variations in the details provided in the perspective runway presented on the EADI display.

Seven pilots participated in the study as test subjects. For convenience of discussion they will be referenced by numbers 1 to 7. Pilots 1 to 3 are general-aviation instructor pilots with experience flying military multiengine transports. Pilots 4 and 5 are commercial-airline jet transport captains, and pilots 6 and 7 are NASA test pilots. Only the NASA test pilots were initially familiar with the attitude-control-wheel steering mode and the EADI display. Each pilot flew two replications of the experiment for familiarization before data were taken for the experiment.

RESULTS

Essentially all of the pilot's time was spent observing the EADI. Included in table I are the total percent dwell on several of the EADI locations (i.e., percentage of the time looking at the EADI spent viewing a particular location), the number of control inputs, and the standard deviation of some aircraft attitudes and rates.

The appendix provides a description of the data recorded and its analysis. The entries in table I are average values for all of the runs made by each pilot and cover the flight from an altitude of 160 m down to 5 m. The standard deviation presented is the average of the standard deviations from the individual runs. "Total Gamma" and "Total A/C Symbol," shown in table I, are the sums of all dwell-time percentages involving the gamma wedges and the aircraft symbol, respectively. All of the locations occasionally getting some of the pilots' attention are not included in the table; also, there was time spent in the EADI when the lookpoint could not be determined, such as when the lookpoint was changing from one location to another.

When the total dwell times on the EADI display items were considered, it was found that pilots 1 and 7 used the gamma-wedge display of flight-path angle less than did the other five pilots. Pilots 1 and 7 used this display 28 and 25 percent of the time, respectively. The range of values of this parameter for the other pilots was from 47 to 56 percent. Pilots 1 and 7 also exhibited a greater use of the aircraft symbol, 35 and 46 percent. These measurements indicate that pilots 1 and 7 used the EADI display in a manner distinctly different from that of the other five pilots.

The other five pilots relied heavily on the gamma-wedge display of the flight-path angle. Their scan patterns were generally centered around this display symbol with varying use of the other displayed information.

Of the performance indicators measured, the only ones which seem to contribute to the differences between pilots 1 and 7 and the other five pilots are the standard deviations of pitch and roll angles along the flight path. This observation is believed connected to the fact that pilots 1 and 7 used the part of the EADI display associated with flying aircraft attitudes, the aircraft symbol and the pitch scale in the longitudinal axis.

Presented in table II are the data for the landing-flare segment of the flight, from an altitude of 21 m down to 5 m. The flare task is considerably different from the earlier phase of the ILS approach task (table I). However, the dwell-time percentage data show that the pilots used the same visual information throughout the approach including the flare.

It is interesting to note that the two NASA test pilots (pilots 6 and 7) are in different groups, exhibiting very different behavior in using the display. The performance of both of these pilots in terms of glide-slope and localizer deviation along the approach and in terms of location and decent rate near touchdown was within acceptable bounds. This finding led to discussions of the data set with these two pilots. This discussion resulted in an explanation of what was occurring between the two groups. One of the pilots suggested that the time histories of the aircraft longitudinal variables would show that the pilot using the gamma wedges as the major source of information for controlling flight along the glide path would induce longitudinal oscillations (PIO's). These oscillations would not be present for the pilots who relied heavily on attitude information.

Plots of the lookpoint and some longitudinal axis variables are provided in figures 5 to 10 for three sequential runs flown by each of the two test pilots. These runs include the display format found most desirable in reference 2. A key to the ordinate scale of the lookpoint plots is presented in table III. In each of these figures, a time history of the pilot's lookpoint during the run is provided at the top of the page. The second plot is of the flight-path angle, followed by the pitch angle, stick position, glide-slope deviation, and altitude, which is plotted at the bottom of the page.

Figures 5 to 7 are plots for runs made by pilot number 6. Studying the plots of the lookpoint versus time, it is observed that this pilot did indeed use the gamma wedges heavily. Roughly 65 percent of the EADI viewing time is spent viewing the gamma wedges or the gamma wedges in combination with some other pieces of information in the display. Note the clearly observable low-frequency oscillations present in the longitudinal axis variables.

Plots from runs made by pilot number 7 are presented in figures 8 to 10. The lookpoint plots confirm that this pilot concentrated more heavily on the attitude information provided in the vicinity of the aircraft symbol, spending approximately 50 percent of his time on the aircraft symbol or viewing it in combination with other displayed information. Oscillations (PIO's) are either nonexistent or greatly reduced for this pilot as compared with the other test pilot who concentrated his attention on the gamma wedges.

The analysis of the results from the two NASA test pilots shows that pilot 6 used the gamma wedges heavily and developed PIO's, while pilot 7 combined heavy use of the attitude information in the display with use of the display of flight path and avoided the oscillations. This leads to the question of whether similar behavior was observed in the remainder of the pilots in the two groups identified earlier.

Time histories of the lookpoint and the relevant longitudinal variables for pilot number 1 are provided in figures 11 to 13. This is the other pilot whose scanning behavior was identified as resembling that of pilot 7. He used the attitude information in the vicinity of the aircraft symbol heavily, and PIO's rarely occurred in time histories of the runs for this pilot.

Time histories of the same variables are provided in figures 14 to 25 for the other four pilots who have already been identified as heavy users of the flight-path-angle display, the gamma wedges. Inspection of these figures support the previous conclusion regarding their scanning behavior and shows a tendency of each of these pilots to induce oscillations.

CONCLUDING REMARKS

Compatibility between the display and the control system of an airplane is an important issue to consider in designing a flight system. This study has demonstrated an adverse effect on performance because of the lack of such compatibility in a simulated aircraft where a rate-command, attitude-hold control system was coupled with a display which allowed the pilots a choice of information. Electing to fly the flight-path angle information resulted in pilot induced oscillations (PIO's) since flight-path angle lags the aircraft pitch angle. The pilots who elected to fly attitude (pitch) information in conjunction with the flight-path angle were able to avoid such PIO's.

The results of this study imply that raw flight-path angle should not be presented alone in vertical situation displays. Although providing flight-path angle in vertical situation displays is a desirable innovation based on previous research at Langley Research Center, it is recommended that researchers and designers consider providing this information in some quickened format to prevent the adverse effects demonstrated in the present study. The Terminal Configured Vehicle (TCV) Program has already taken such an approach.

The PIO's identified in the present study do not fall into the dramatic category discussed in much of the literature on the subject; however, they do comply well with generic definitions. There is evidence, in addition, that some previously held concepts concerning the nature of PIO's might be enhanced by considering the present results. Although longitudinal-axis PIO's may not be observable in some fixed-base simulators, the present study presents data representing such an occurrence.

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October 9, 1981

APPENDIX

DATA REDUCTION AND ANALYSIS

A list of the time-history signals recorded on FM wide-band magnetic-tape recorders is presented in the table which follows. Included are aircraft state variables, pilot control inputs, and oculometer measurements of the pilots' lookpoints and related parameters. These analog signals were subsequently digitized and recorded on computer-compatible magnetic tape to facilitate data reduction. The means and standard deviations of each data channel were calculated as well as the instrument dwell times and an eye point-of-regard transition matrix. These data were recorded for subsequent summarizing by a special-purpose statistical analysis program. This program computed the means and variances of specified groups of data and the t-value to test the means between groups.

SIGNALS RECORDED ON FM MAGNETIC TAPE

Time, sec
X-lookpoint coordinate
Y-lookpoint coordinate
Pupil diameter
Oculometer tracking state
Oculometer lateral-mirror drive-servo signal
Oculometer vertical-mirror drive-servo signal
Aircraft roll angle and rate
Control-wheel displacement
Aircraft yaw angle and rate
Rudder-pedal displacement
Aircraft pitch angle and rate
Column displacement
Column trim-tab deflection
Altitude
Vertical speed
Airspeed
Throttle-lever displacement
Localizer error
Range

The number of control inputs considered in the main text is generally regarded as at least a part of pilot workload. Additionally, it provides a clue to what the pilot is doing with information obtained from the display. The number of control inputs provided in the tables of the main text are based on an algorithm which analyzes the continuous signal from each of the control-lever potentiometers. Basically, the analyst decides on a number of units change in the signal per second to trigger a counter. Actually, the algorithm is quite complex in attending to a large number of possibilities. In interpreting this measure, one should recognize that any activity of the subject control lever in a single direction and in excess of the user-specified amplitude triggers the counter. Thus, when a roll to the right is executed, followed by a return of the wheel to detent, the counter will be incremented twice. Two distinct movements of the control lever in a single direction will result in two counts added, etc.

APPENDIX

LOOKPOINT COMPUTATION

The dynamic position of each symbol in the EADI was determined from the recorded state variables of the airplane. These position coordinates were checked against the lookpoint coordinates as supplied by the oculometer. In practice, a circular disc about 2.54 cm in diameter was constructed with the lookpoint coordinates as center. The area of this disc represented the approximate measurement accuracy of the oculometer. When any part of an EADI display item fell within the interior of this circle, the lookpoint data-reduction algorithm indicated that the subject was looking at that item. Additional checking continued until each display item had been checked and, if the subject was determined to be looking at additional items in the display, the algorithm indicated the combination of items being viewed (e.g., both the gamma wedges and the horizon). The maximum number of items which could be reported by the algorithm as being viewed simultaneously was three. However, in most situations only one or two items were identified during a given $\frac{1}{32}$-sec sample period.

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TABLE I.- SUMMARY OF RESULTS FROM ALTITUDE OF 160 m DOWN TO 5 m

Measured quantities	Pilot						
	1	2	3	4	5	6	7
Display items	Total percent dwell on EADI locations						
Localizer deviation	0	0	0	0	0	0	0
Glide slope	12	3	2	5	4	12	7
A/C symbol	20	8	9	9	6	2	36
Speed error	0	5	9	0	3	6	2
Altitude box	2	1	2	2	2	2	4
Gamma	2	2	2	1	1	5	5
A/C symbol and gamma	0	0	1	0	0	0	0
A/C symbol and horizon	6	2	7	4	4	1	7
A/C symbol and R_WC_L	10	7	3	13	7	1	1
Gamma and 1000-ft line	20	50	35	38	44	43	10
Gamma and horizon	4	1	5	3	3	5	10
R_WC_L and 1000-ft line	1	1	6	4	4	0	0
Horizon	7	3	3	4	3	3	2
Total gamma	28	56	47	47	52	56	25
Total A/C symbol	35	22	29	27	21	10	46
Controls	Number of control inputs, average counts						
Stick (pitch)	10	22	17	16	15	17	8
Wheel (roll)	10	28	12	15	10	6	9
Rudder (yaw)	4	0	8	9	13	1	1
Throttle	2	3	4	0	3	5	2
Attitudes and rates	Standard deviations (SD) of attitudes and attitude rates averaged over all runs						
SD roll angle, deg	1.4	2.2	2.0	1.5	2.3	1.5	1.4
SD roll rate, deg/sec	1.0	1.7	1.1	1.0	1.0	.7	.7
SD pitch angle, deg	1.2	1.3	2.3	1.4	1.6	1.6	1.1
SD pitch rate, deg/sec	.8	.9	1.1	1.0	1.1	1.1	1.0

TABLE II.- SUMMARY OF RESULTS FROM ALTITUDE OF 21 m DOWN TO 5 m

Measured quantities	Pilot						
	1	2	3	4	5	6	7
Display items	Total percent dwell on EADI locations						
Localizer deviation	0	0	0	0	0	0	0
Glide slope	4	3	1	1	0	3	0
A/C symbol	23	3	3	4	1	1	59
Speed error	0	2	2	0	0	0	0
Altitude box	8	6	6	0	6	6	7
Gamma	1	0	1	3	0	0	0
A/C symbol and gamma	0	0	0	0	0	0	0
A/C symbol and horizon	5	0	2	2	1	1	3
A/C symbol and R_WC_L	11	1	3	6	2	1	0
Gamma and 1000-ft line	19	67	44	60	66	66	2
Gamma and horizon	2	0	3	3	0	2	4
R_WC_L and 1000-ft line	4	3	9	4	9	0	0
Horizon	4	1	1	1	0	2	2
Total gamma	26	72	60	71	69	76	6
Total A/C symbol	39	5	10	12	5	3	62
Controls	Number of control inputs, average counts						
Stick (pitch)	0.9	3.0	2.9	1.4	1.5	3.2	2.4
Wheel (roll)	.4	3.5	1.6	.9	.2	.5	1.2
Rudder (yaw)	.4	.0	1.3	.8	.9	.2	.3
Throttle	.9	1.0	.5	.0	.1	.9	.2
Attitudes and rates	Standard deviations (SD) of attitudes and attitude rates averaged over all runs						
SD roll angle, deg	0.14	1.11	0.65	0.48	0.15	0.38	0.30
SD roll rate, deg/sec	.11	1.69	.43	.35	.06	.33	.36
SD pitch angle, deg	.53	1.01	1.31	.87	1.2	1.12	1.19
SD pitch rate, deg/sec	.56	.72	.84	.75	1.2	.68	.46

TABLE III.- KEY TO ORDINATE SCALE OF LOOKPOINT TIME HISTORIES

(FIGS. 5 TO 25)

Scale position	Lookpoint
0	Undetermined location
1	Altitude box (ALT)
2	Localizer
3	Glide-slope indicator (GS)
4	Speed error indication (SPD)
5	Runway centerline (R_WC_L)
6	1000-ft line (1K)
7	Flight-path acceleration (VDOT)
8	Gamma wedges (GW)
9	Gamma wedges and VDOT
10	Gamma wedges and 1000-ft line (GW/1K)
11	Gamma wedges and horizon (GW/HRZ)
12	Gamma wedges and runway centerline (GW/CL)
13	Pitch reference
14	VDOT and runway centerline
15	1000-ft line and centerline
16	A/C symbol and gamma wedges (AC/GW)
17	A/C symbol and horizon (AC/HRZ)
18	A/C symbol and runway centerline (AC/CL)
19	A/C symbol and VDOT
20	A/C symbol (AC)
21	Horizon (HRZ)
22	Pitch reference
23	1000-ft line and localizer
24	Centerline and localizer
25	VDOT and 1000-ft line
26	Horizon and VDOT
27	Speed error and VDOT
28	Pitch scale (pitch)
29	A/C symbol, VDOT, and gamma
30	Track symbol (TRK)
-1	Lost track

Note:

γ = Total percent time spent viewing flight-path-angle information
A/C = Total percent time spent viewing aircraft symbol

L-78-5040

Figure 1.- Aircraft simulator cabin.

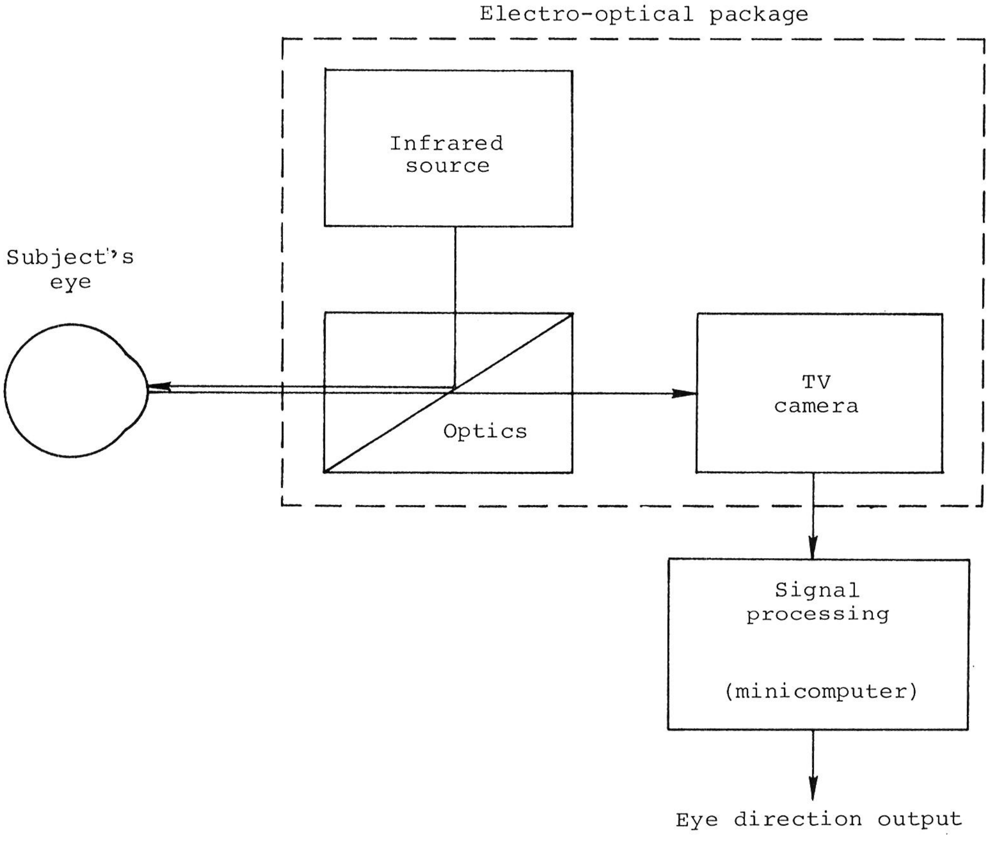

Figure 2.- Simplified schematic diagram of oculometer system.

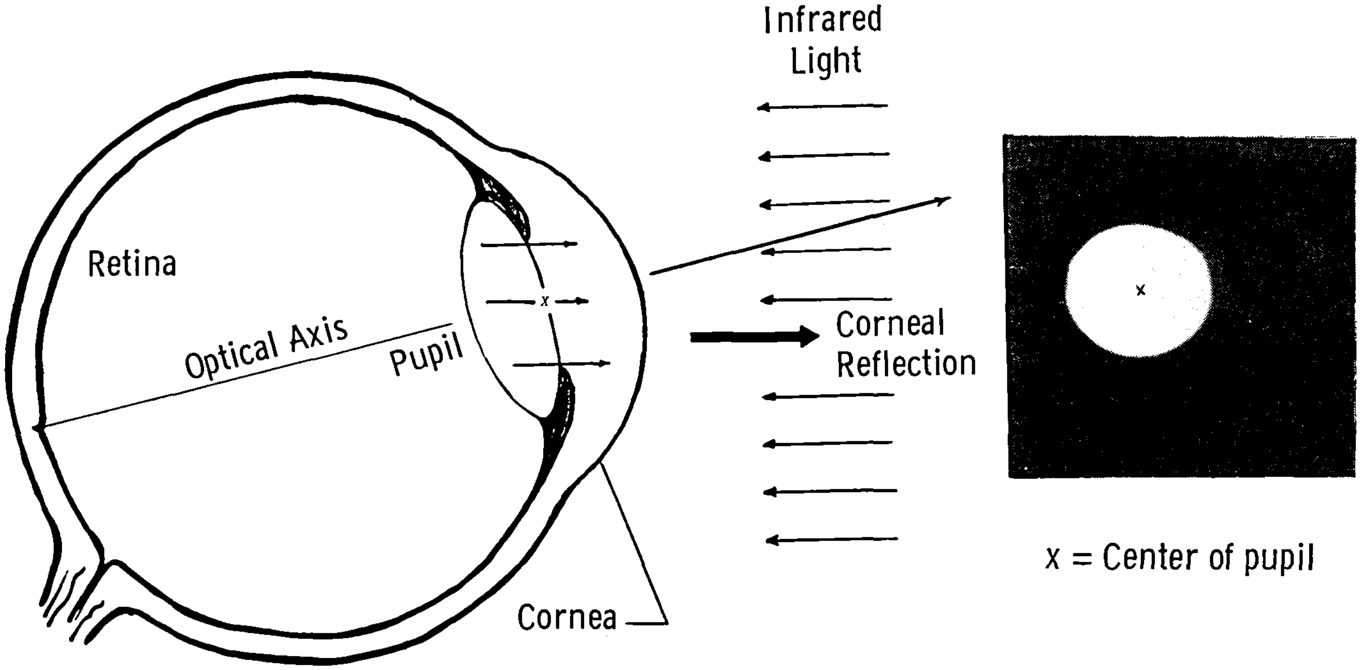

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Figure 3.- Basic sensing principle.

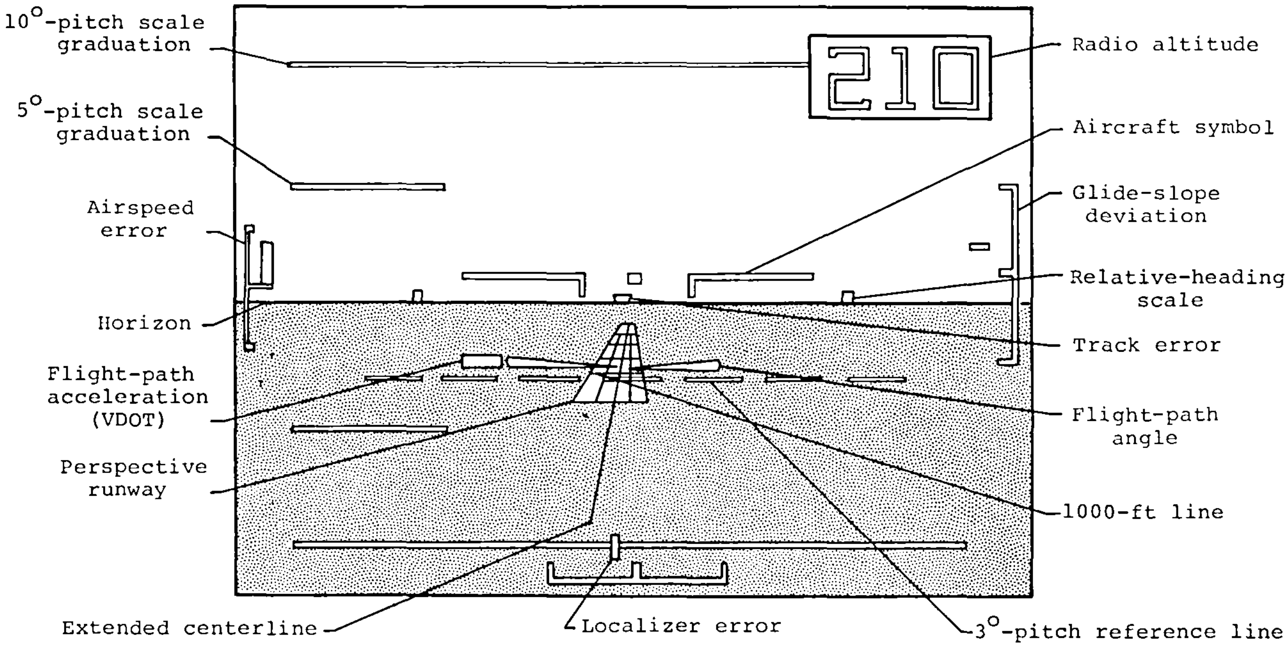

Figure 4.- EADI display symbology.

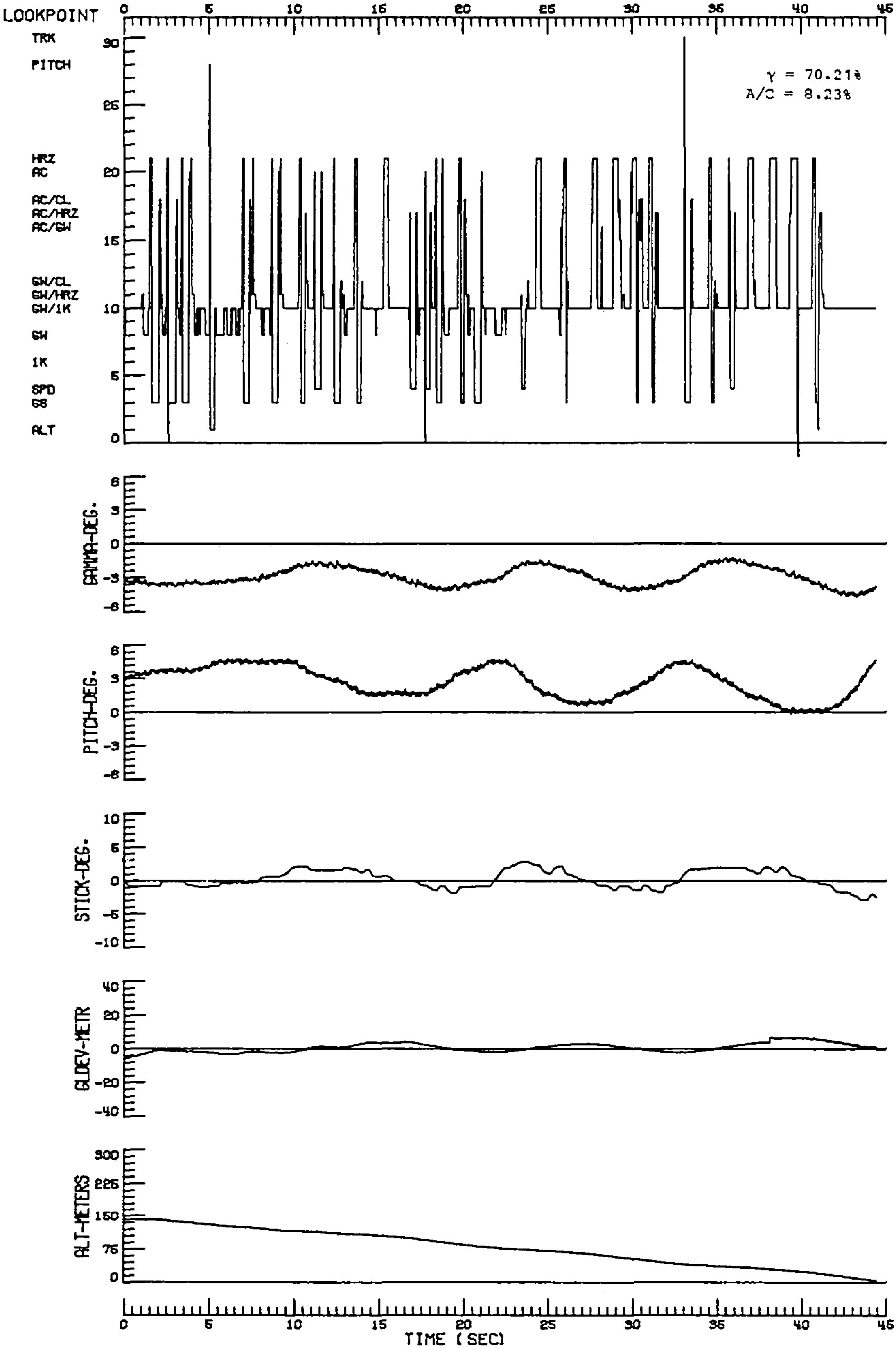

Figure 5.- Time histories: lookpoint and longitudinal variables for pilot 6. (See table III for key.)

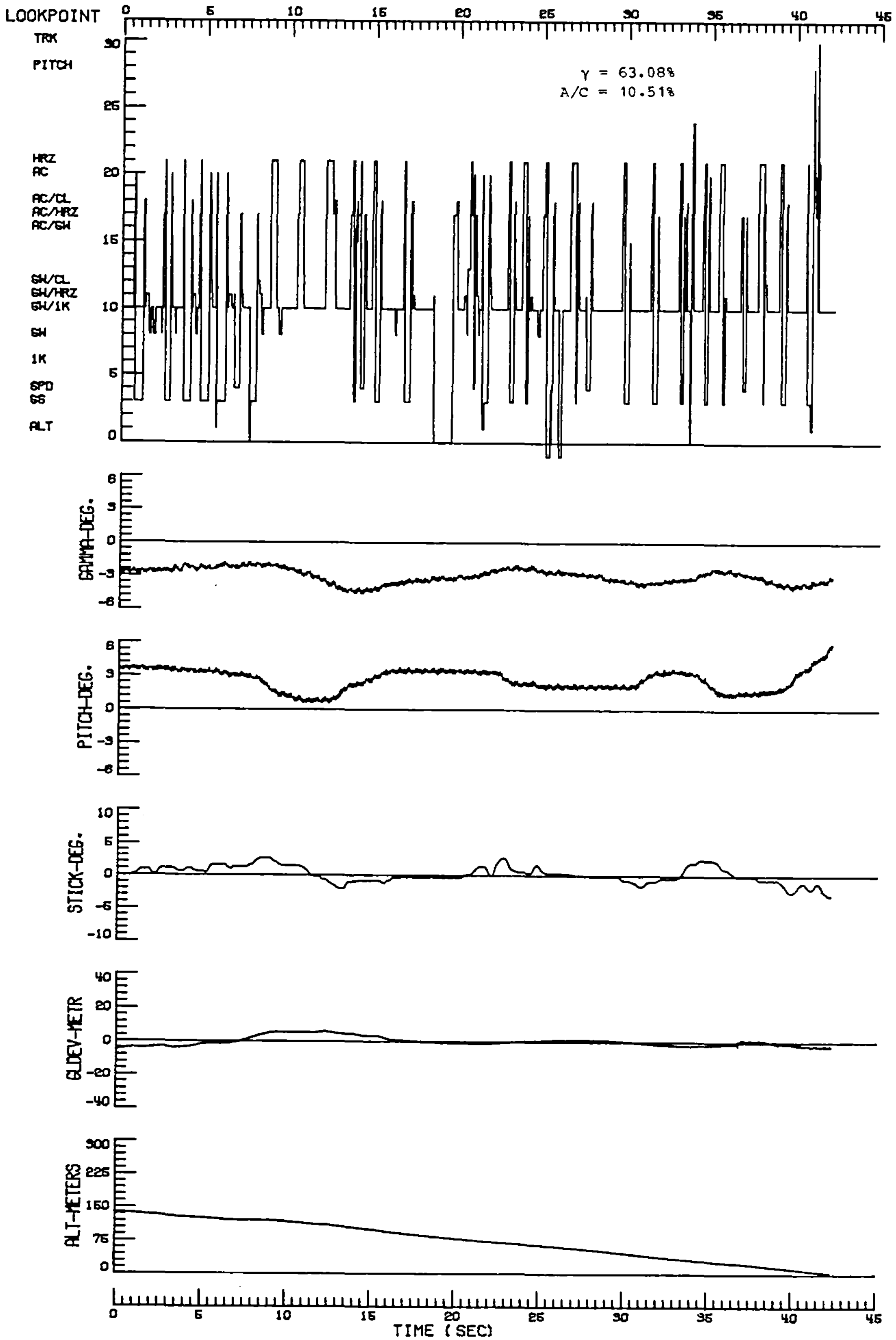

Figure 6.- Time histories: lookpoint and longitudinal variables for pilot 6. (See table III for key.)

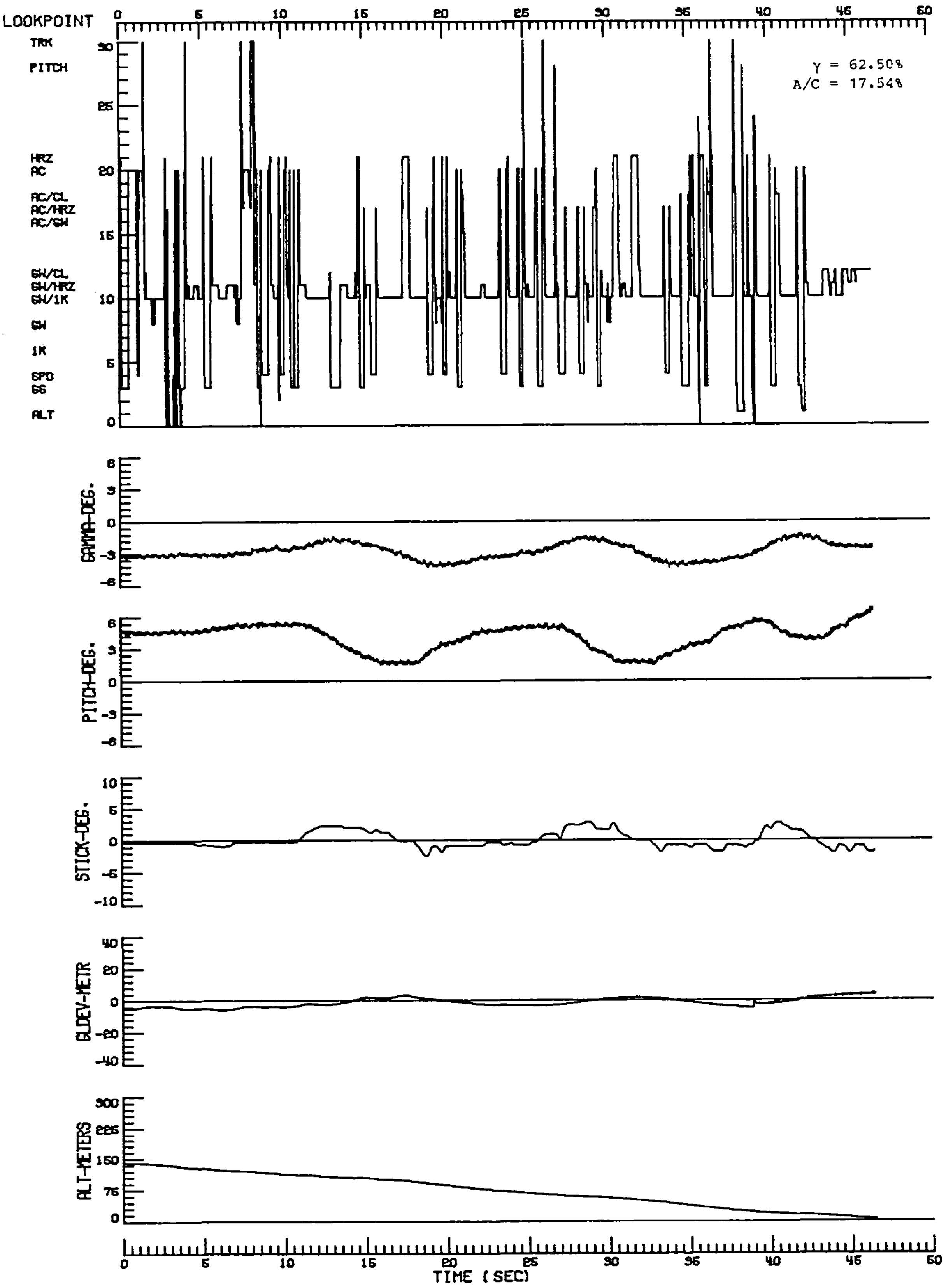

Figure 7.- Time histories: lookpoint and longitudinal variables for pilot 6. (See table III for key.)

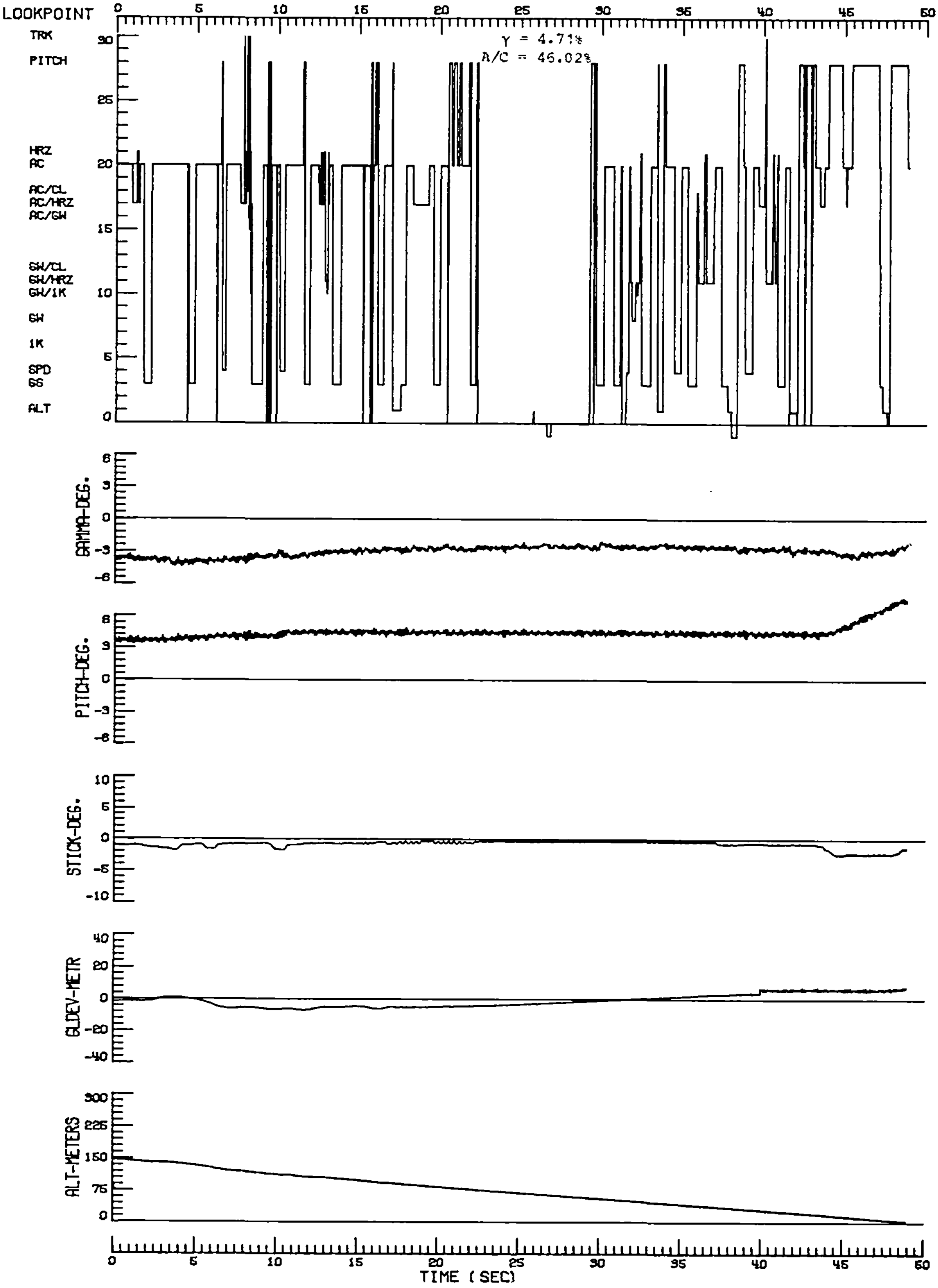

Figure 8.- Time histories: lookpoint and longitudinal variables for pilot 7. (See table III for key.)

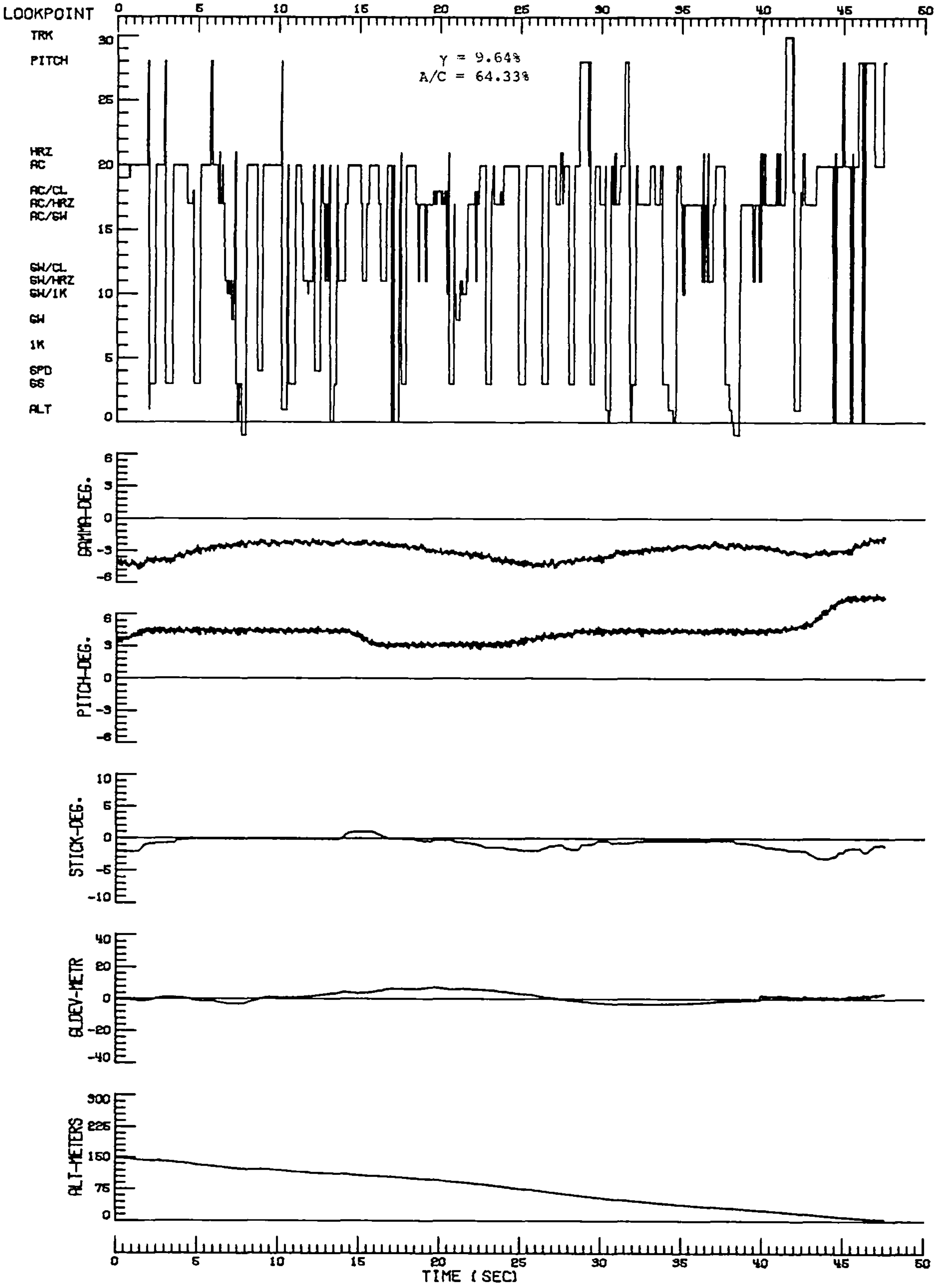

Figure 9.- Time histories: lookpoint and longitudinal variables for pilot 7. (See table III for key.)

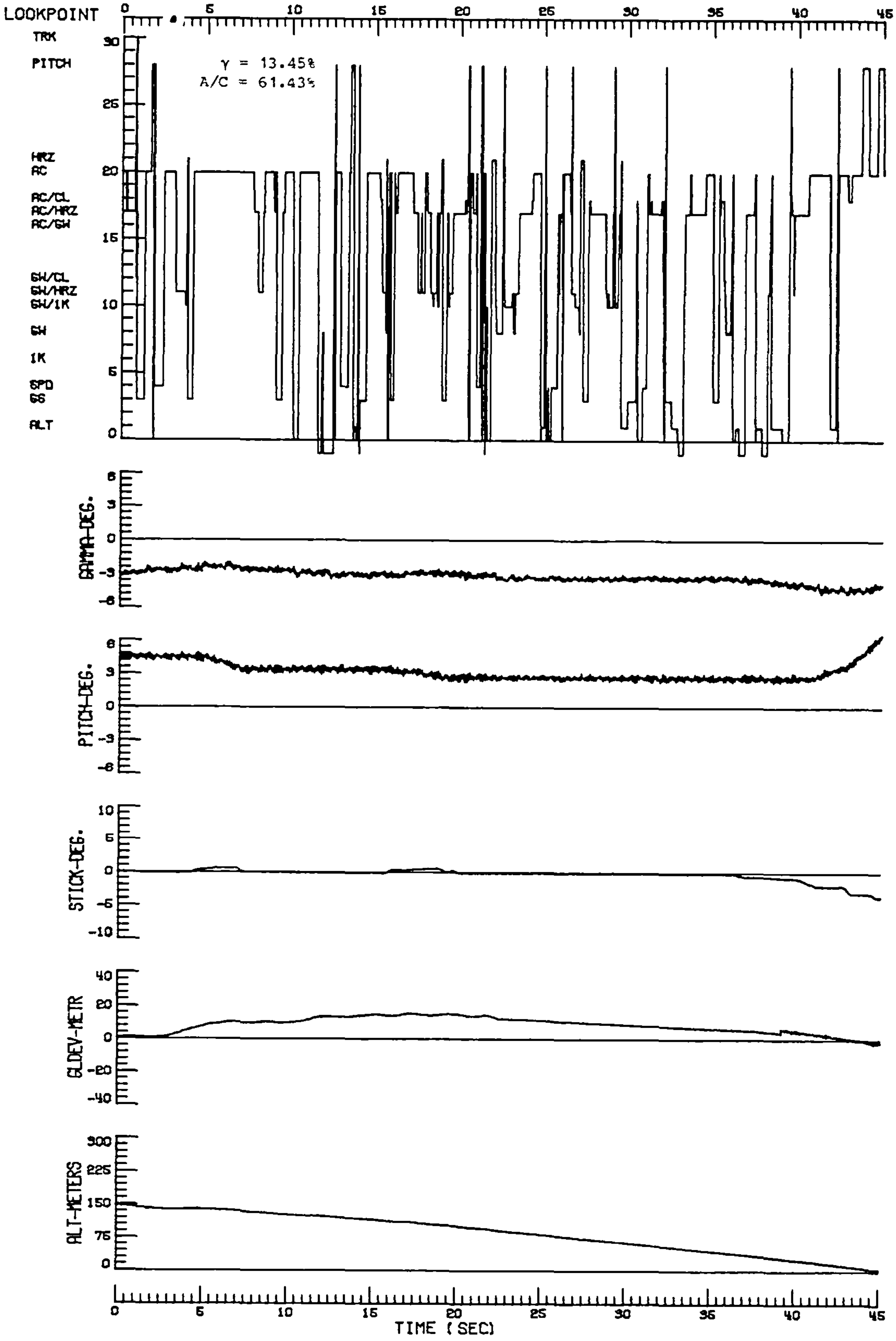

Figure 10.- Time histories: lookpoint and longitudinal variables for pilot 7. (See table III for key.)

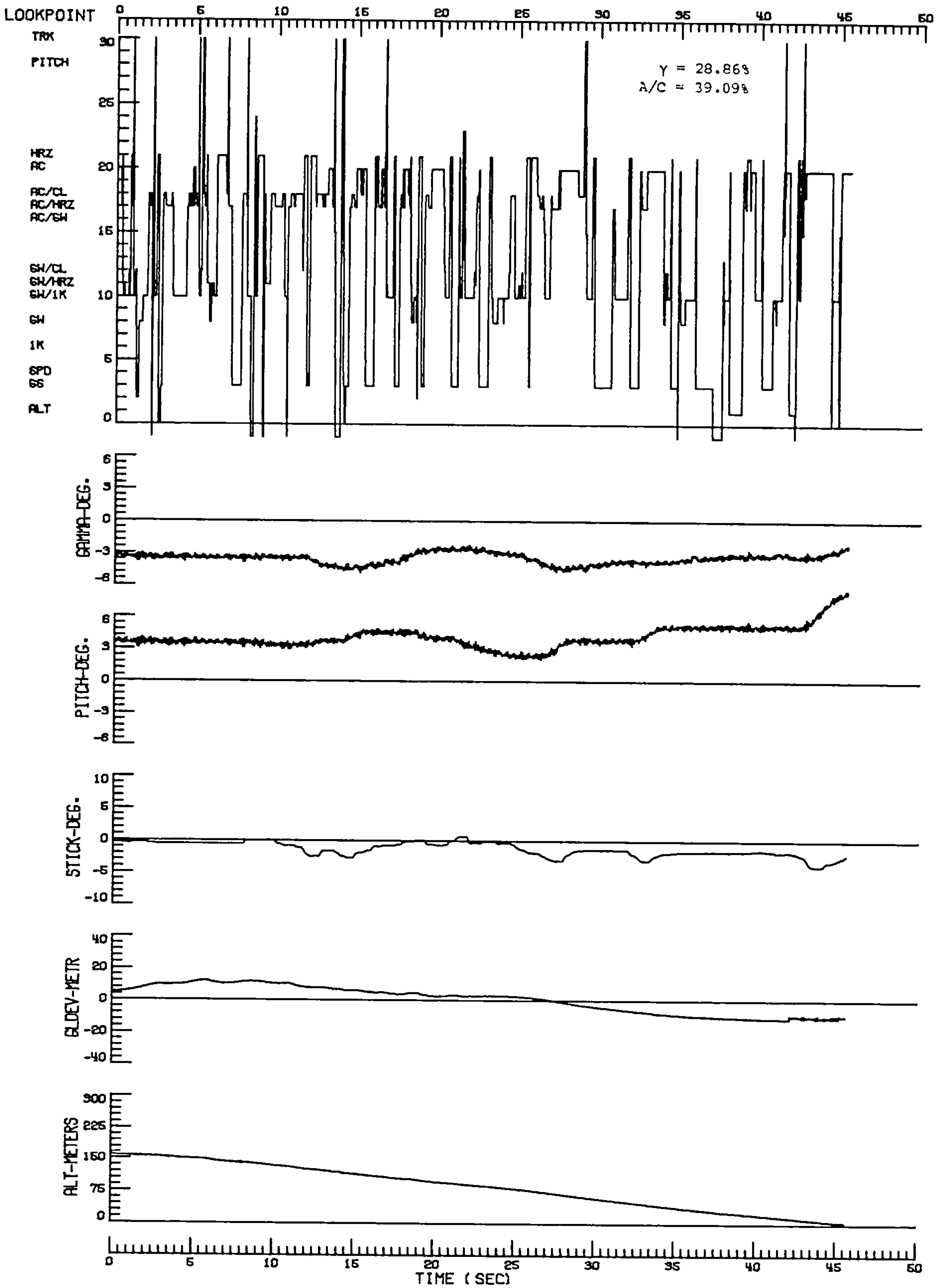

Figure 11.- Time histories: lookpoint and longitudinal variables for pilot 1. (See table III for key.)

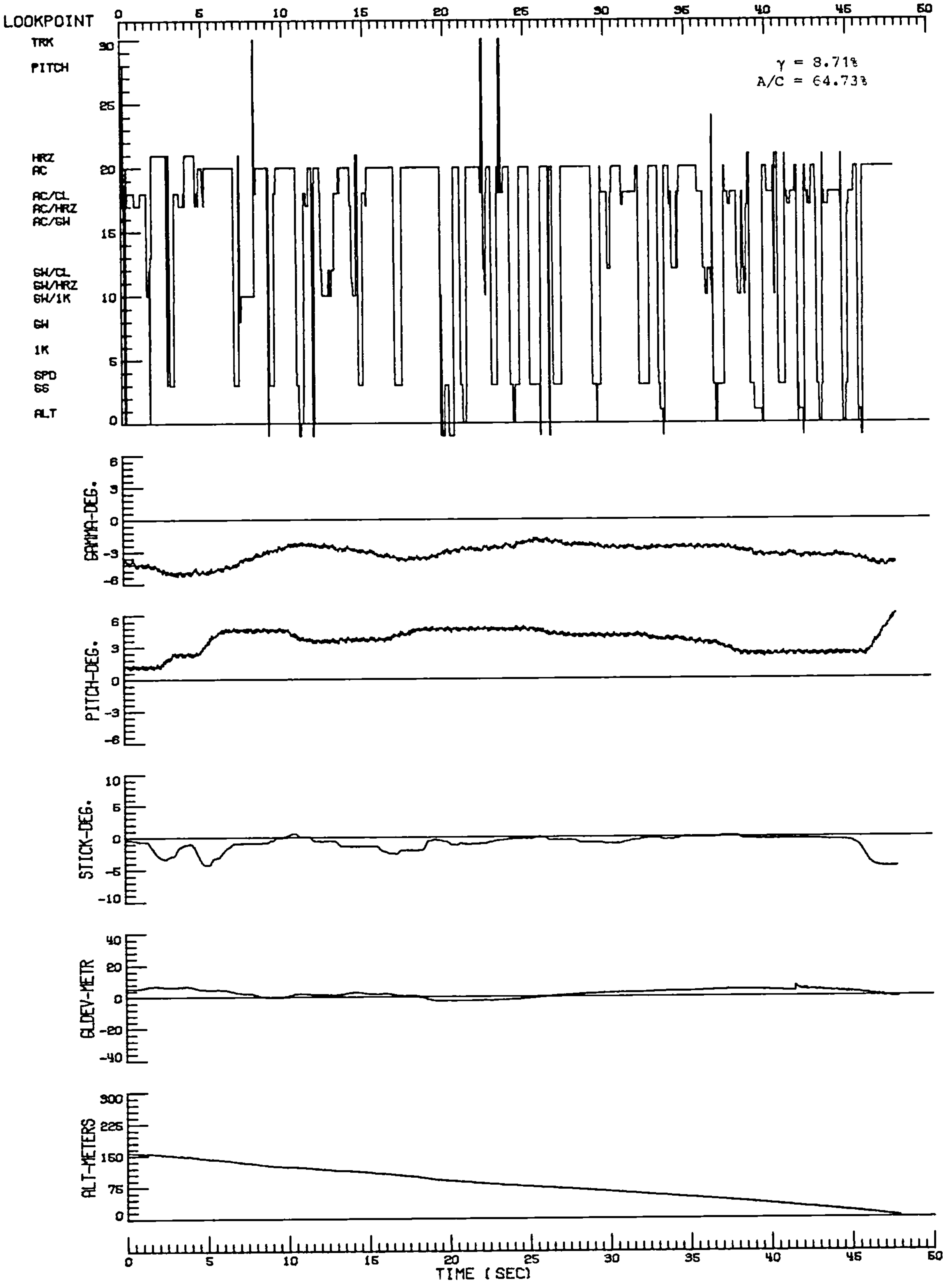

Figure 12.- Time histories: lookpoint and longitudinal variables for pilot 1. (See table III for key.)

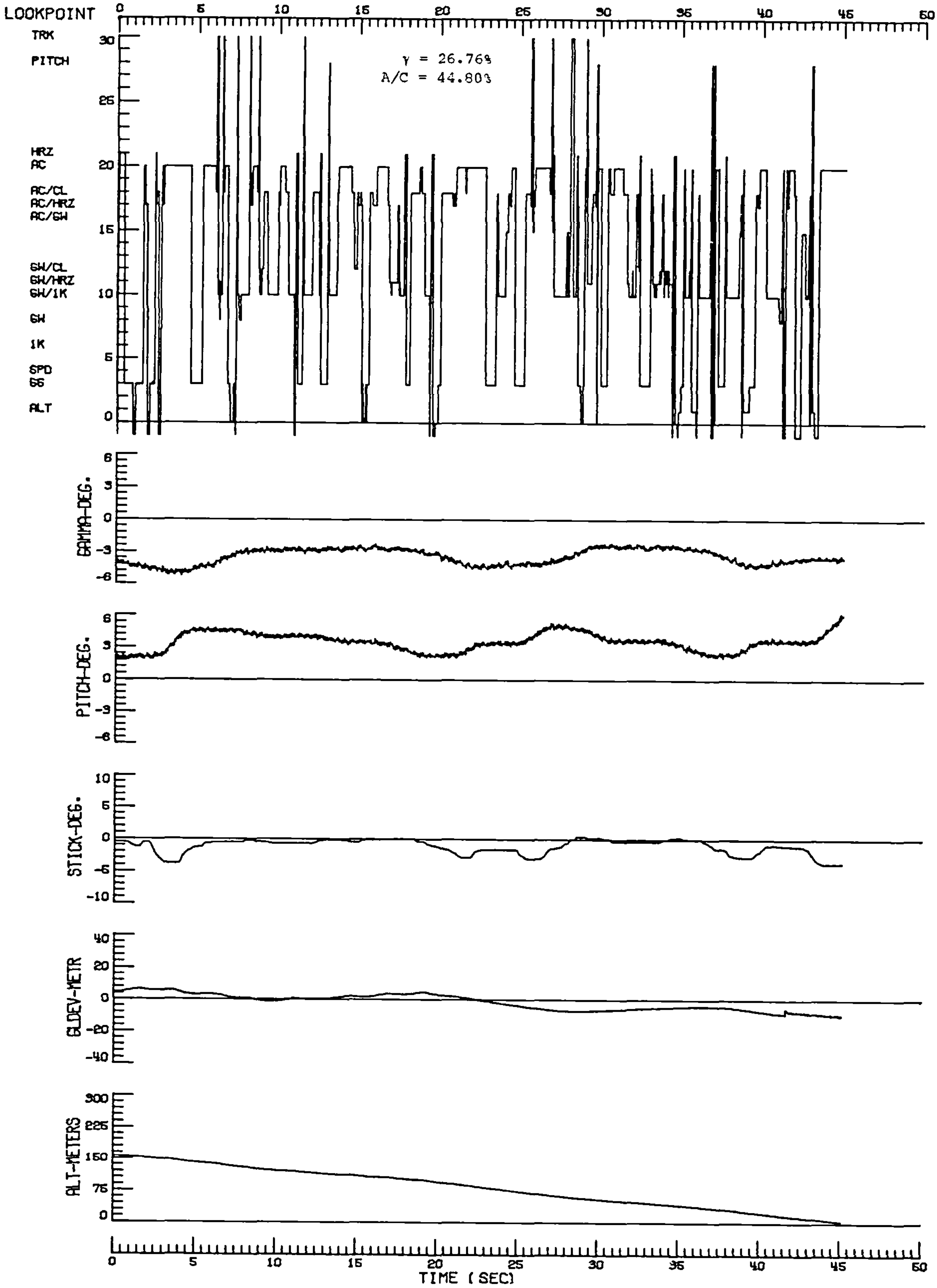

Figure 13.- Time histories: lookpoint and longitudinal variables for pilot 1. (See table III for key.)

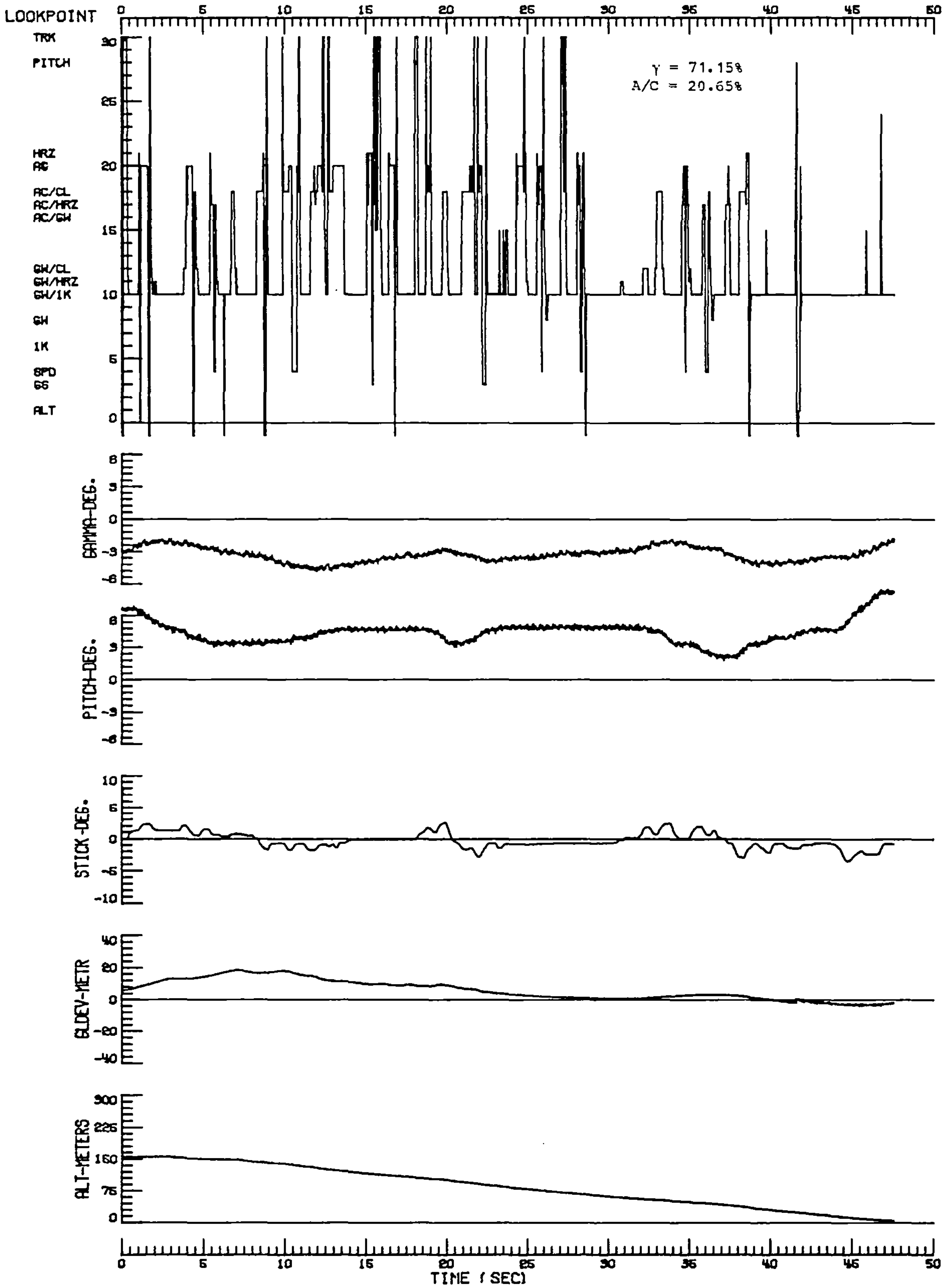

Figure 14.- Time histories: lookpoint and longitudinal variables for pilot 2. (See table III for key.)

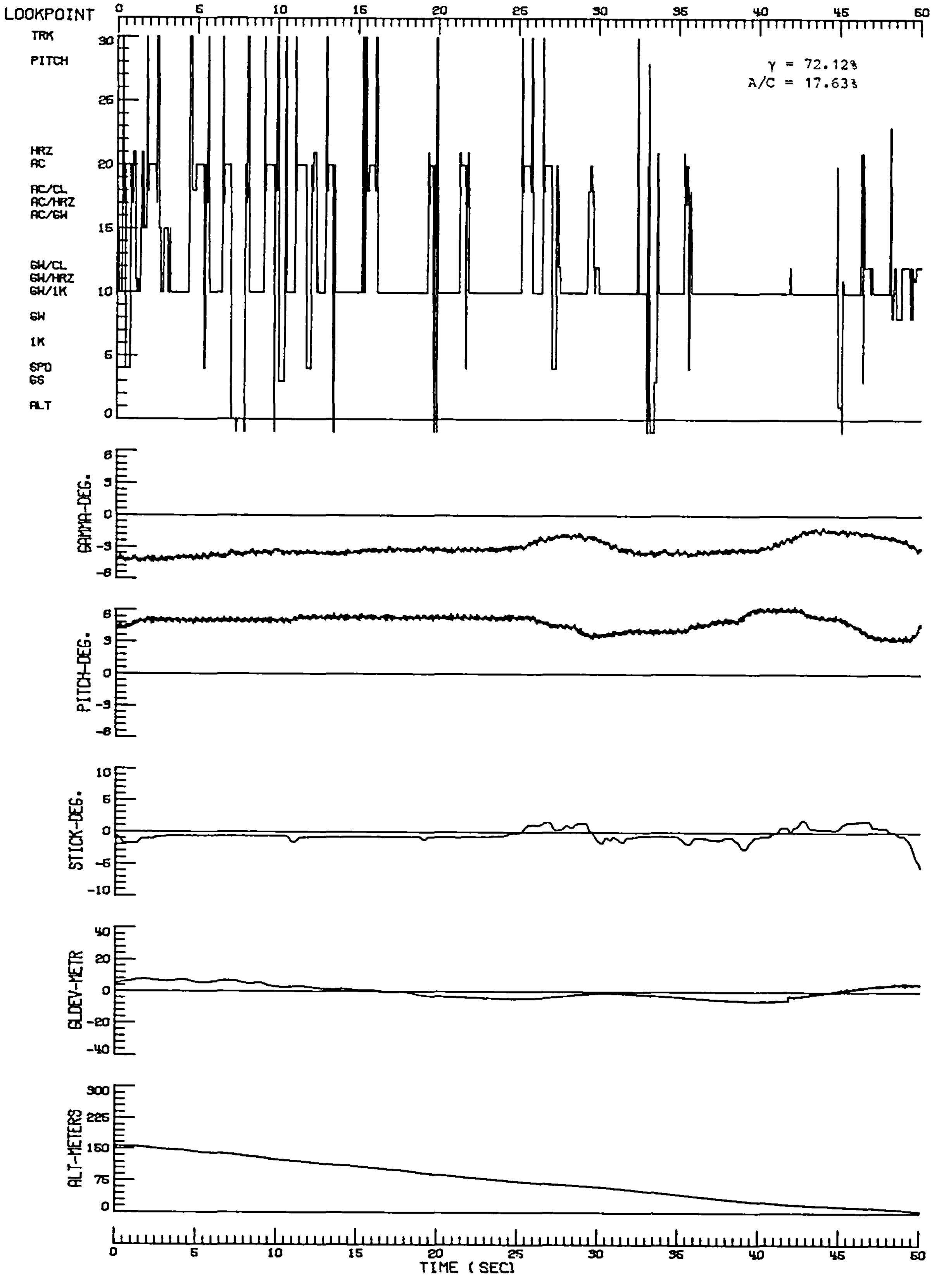

Figure 15.- Time histories: lookpoint and longitudinal variables for pilot 2. (See table III for key.)

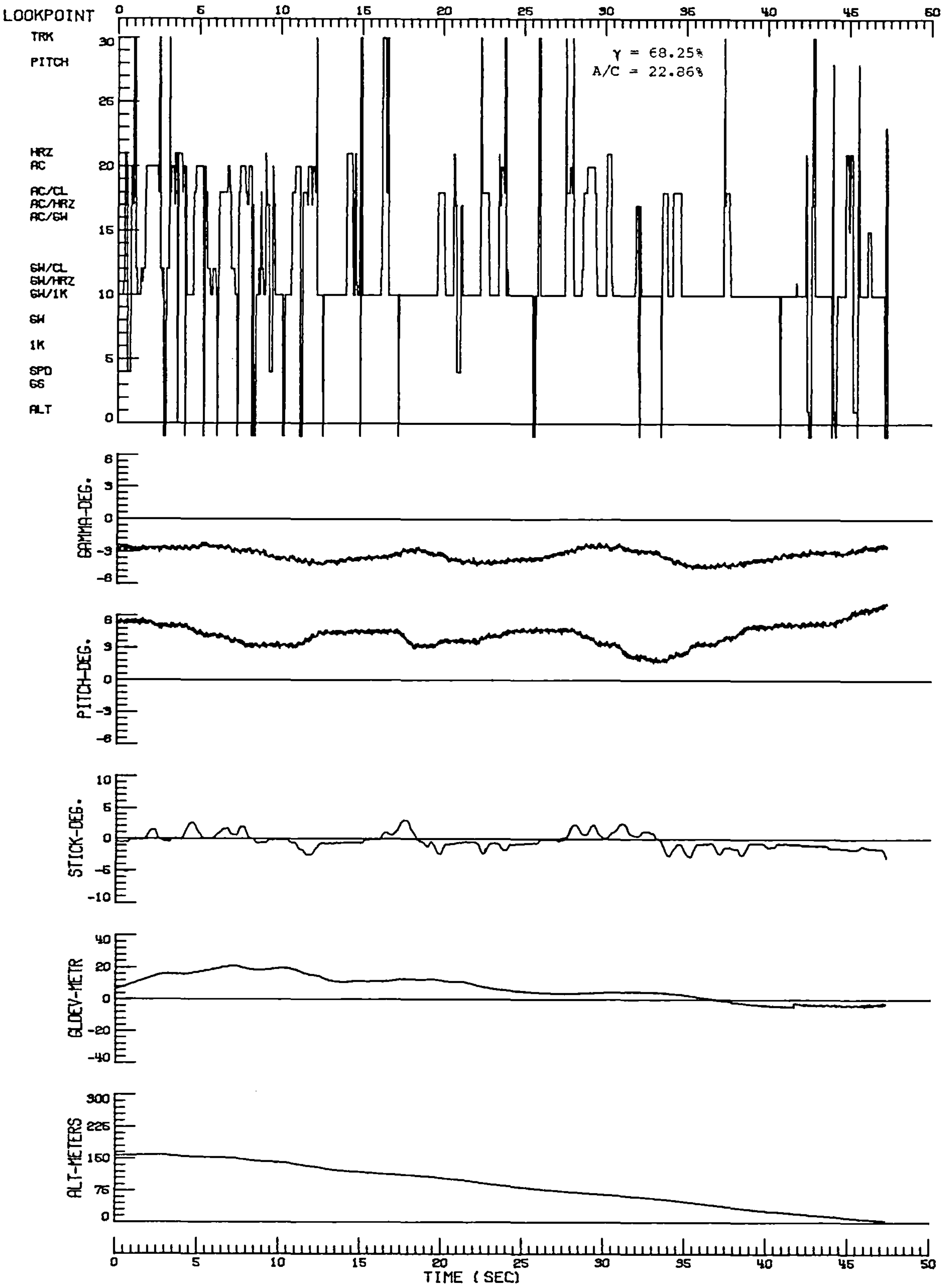

Figure 16.- Time histories: lookpoint and longitudinal variables for pilot 2. (See table III for key.)

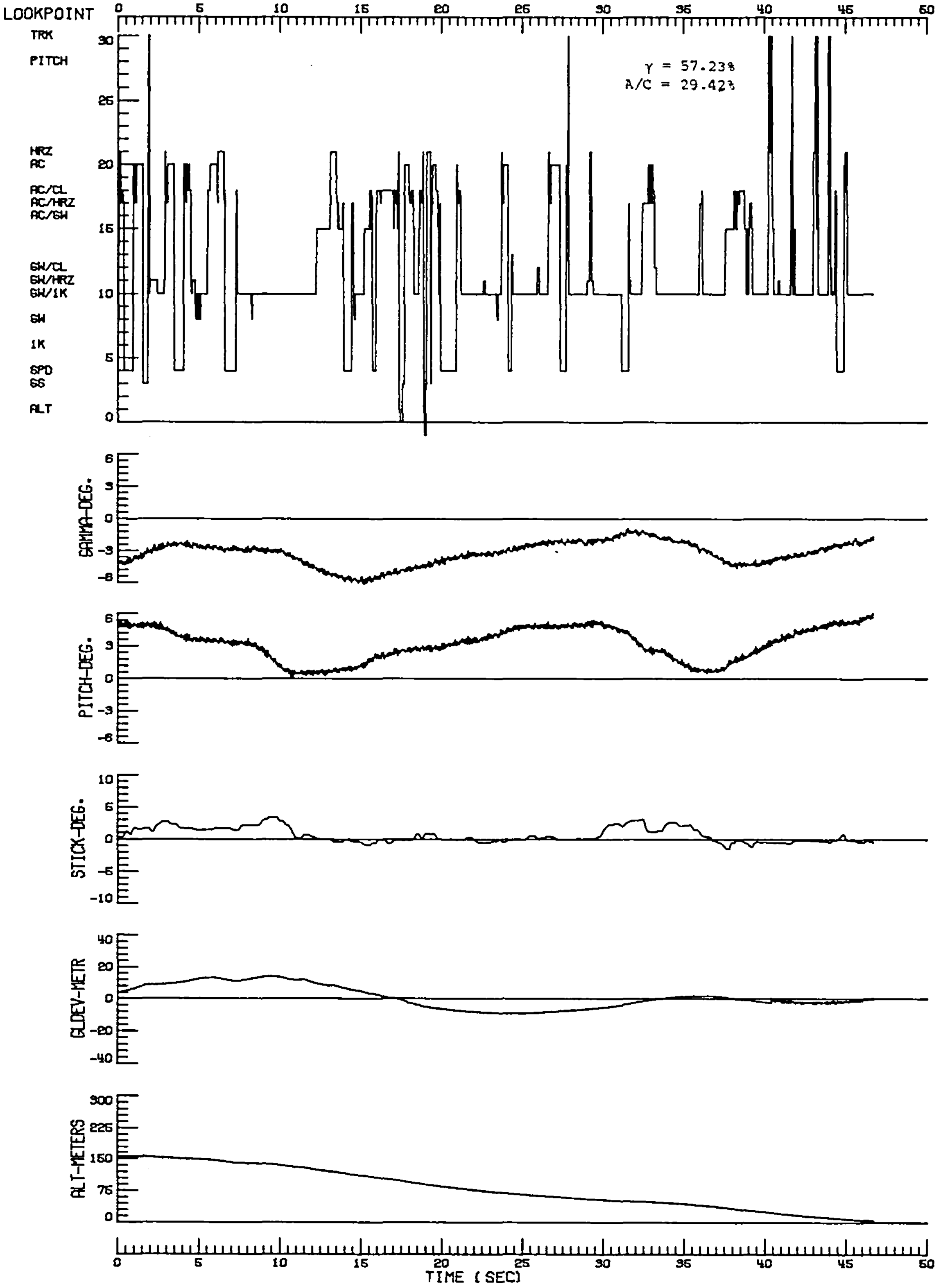

Figure 17.- Time histories: lookpoint and longitudinal variables for pilot 3. (See table III for key.)

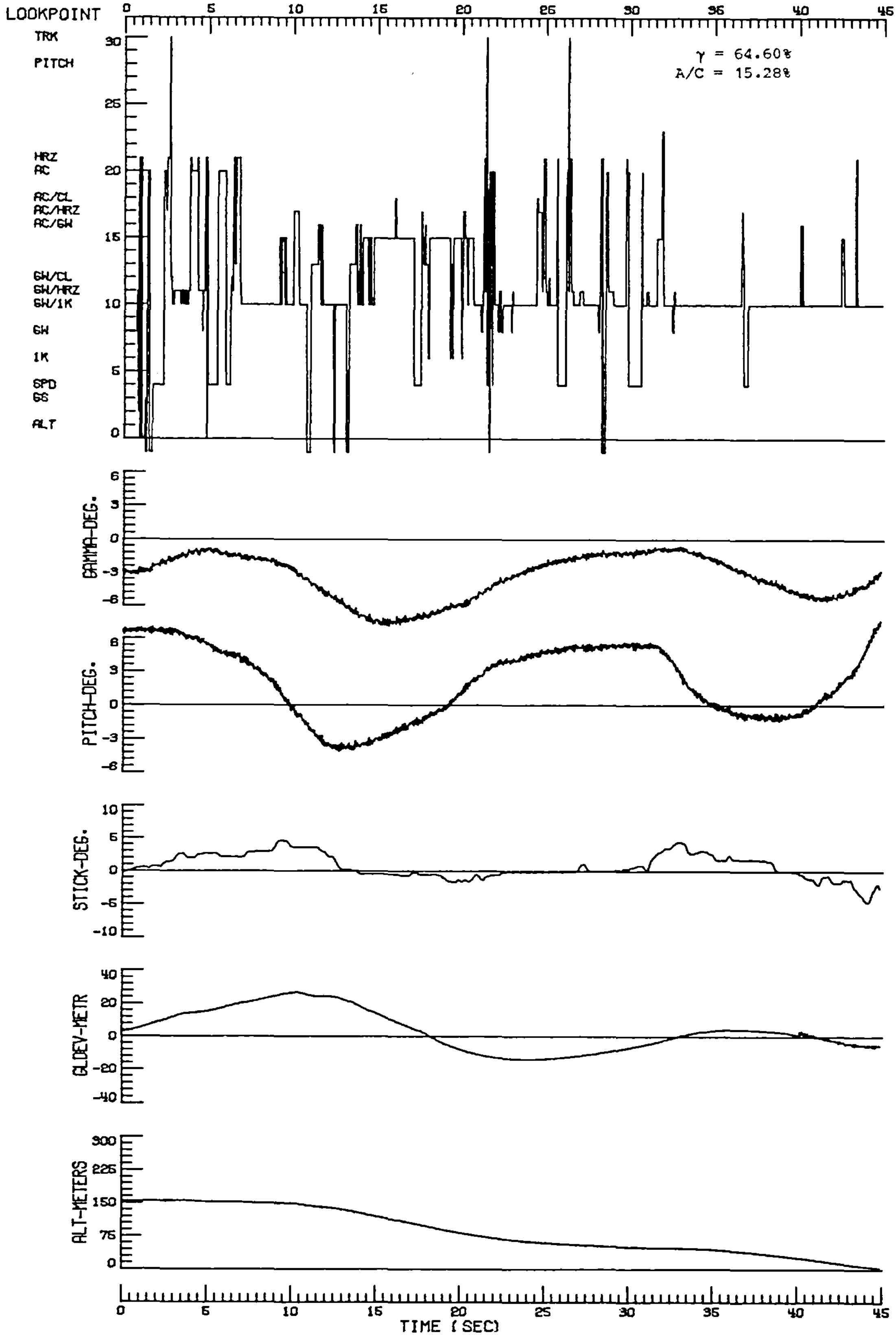

Figure 18.- Time histories: lookpoint and longitudinal variables for pilot 3. (See table III for key.)

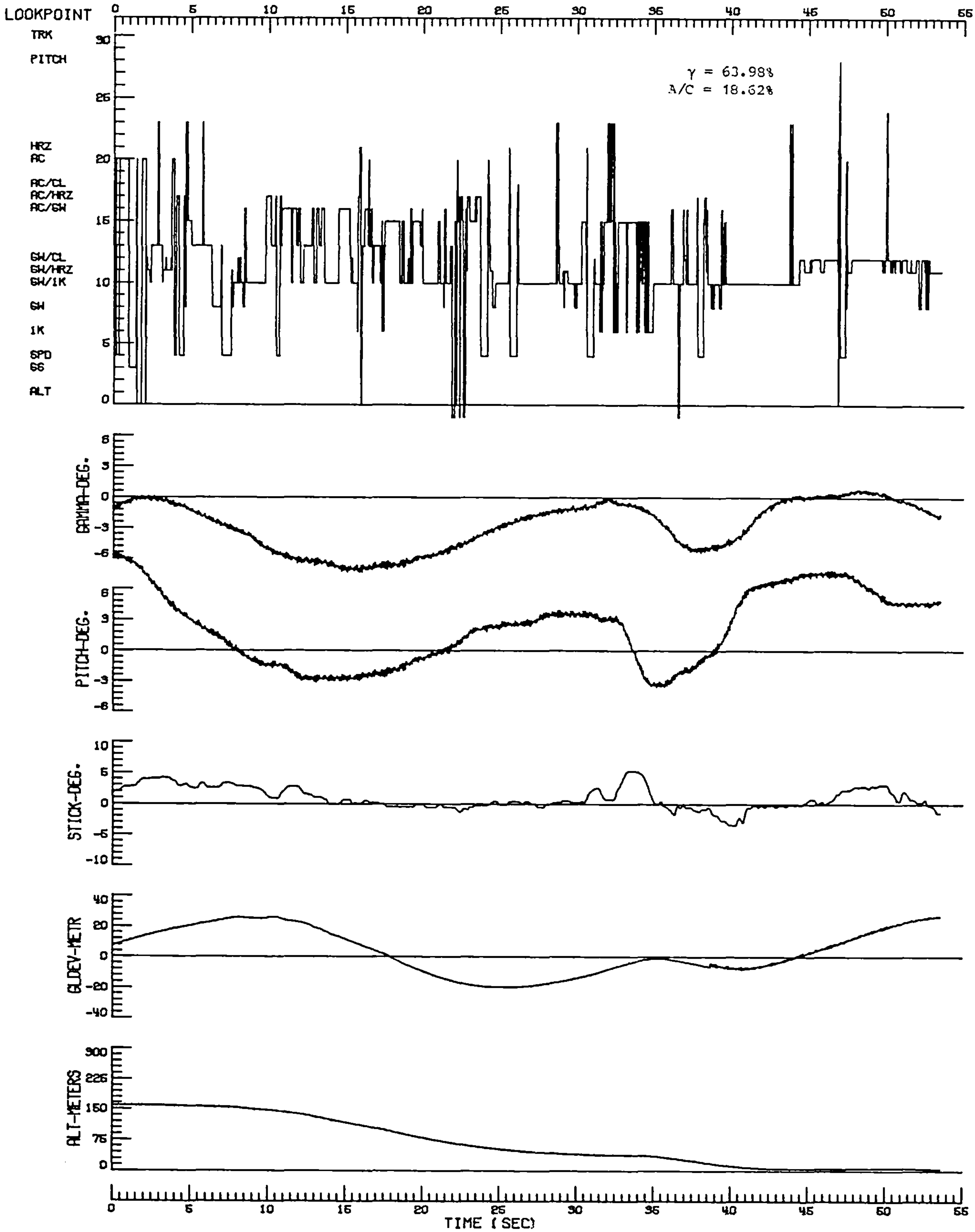

Figure 19.- Time histories: lookpoint and longitudinal variables for pilot 3. (See table III for key.)

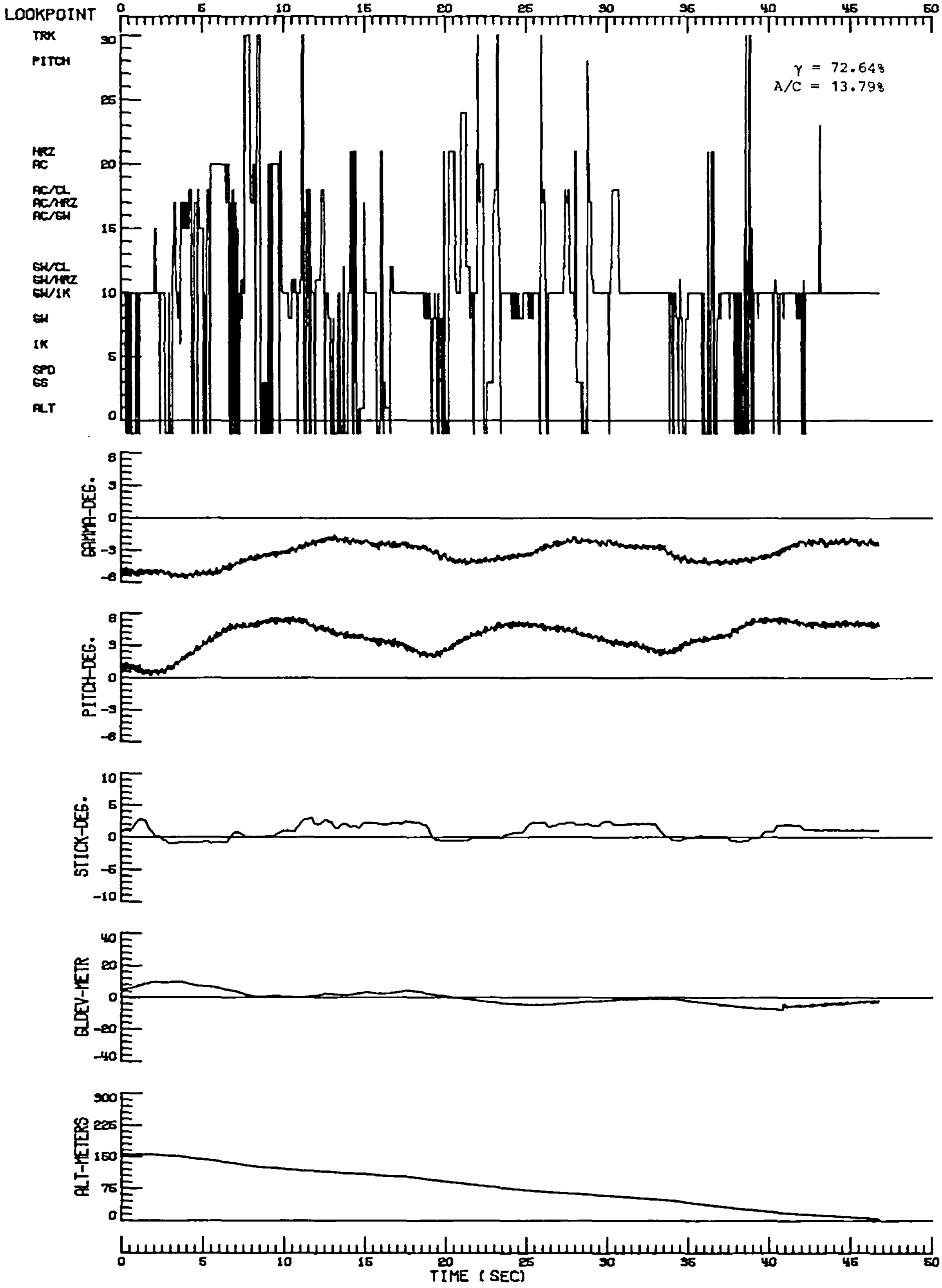

Figure 20.- Time histories: lookpoint and longitudinal variables for pilot 4. (See table III for key.)

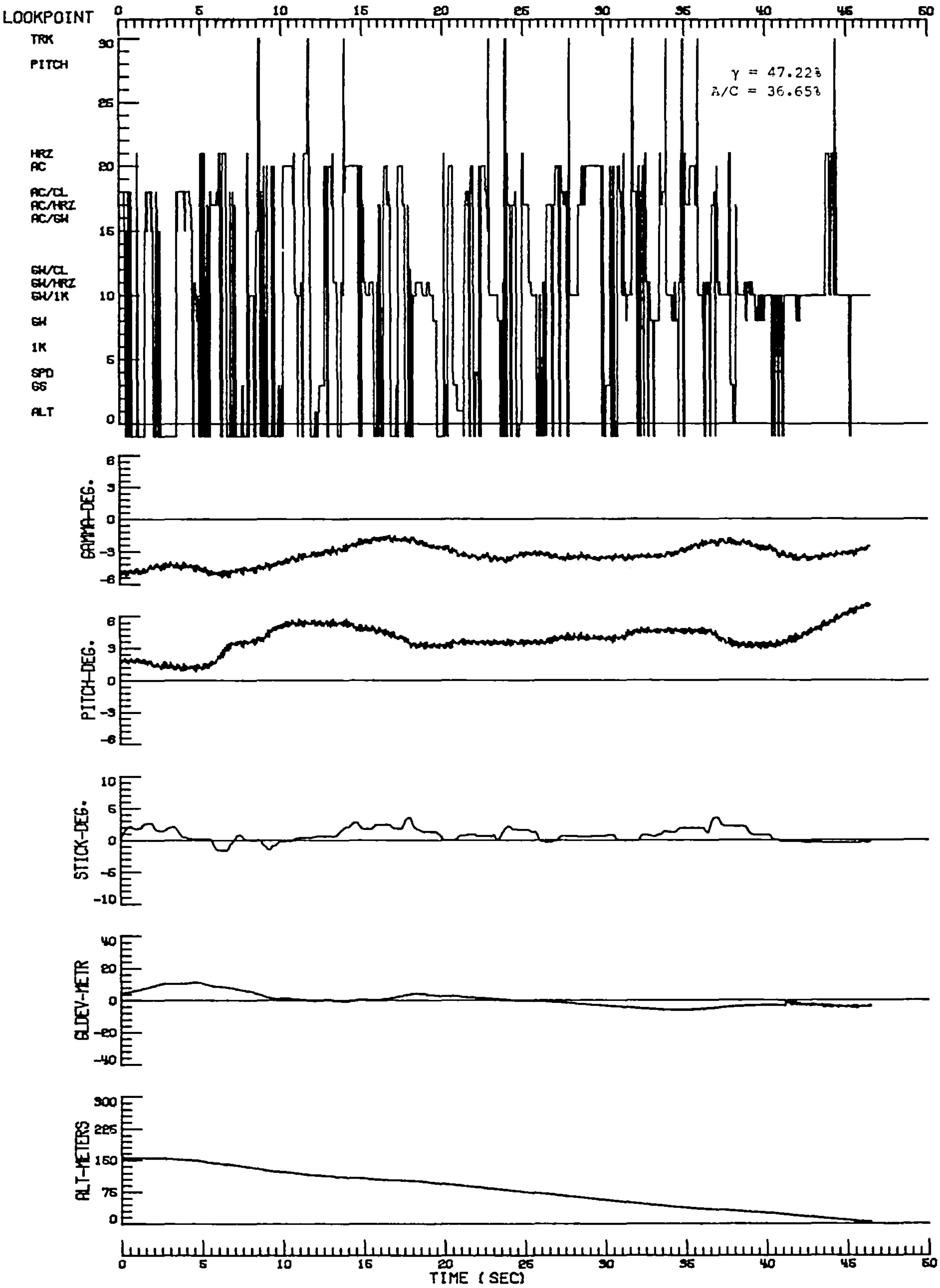

Figure 21.- Time histories: lookpoint and longitudinal variables for pilot 4. (See table III for key.)

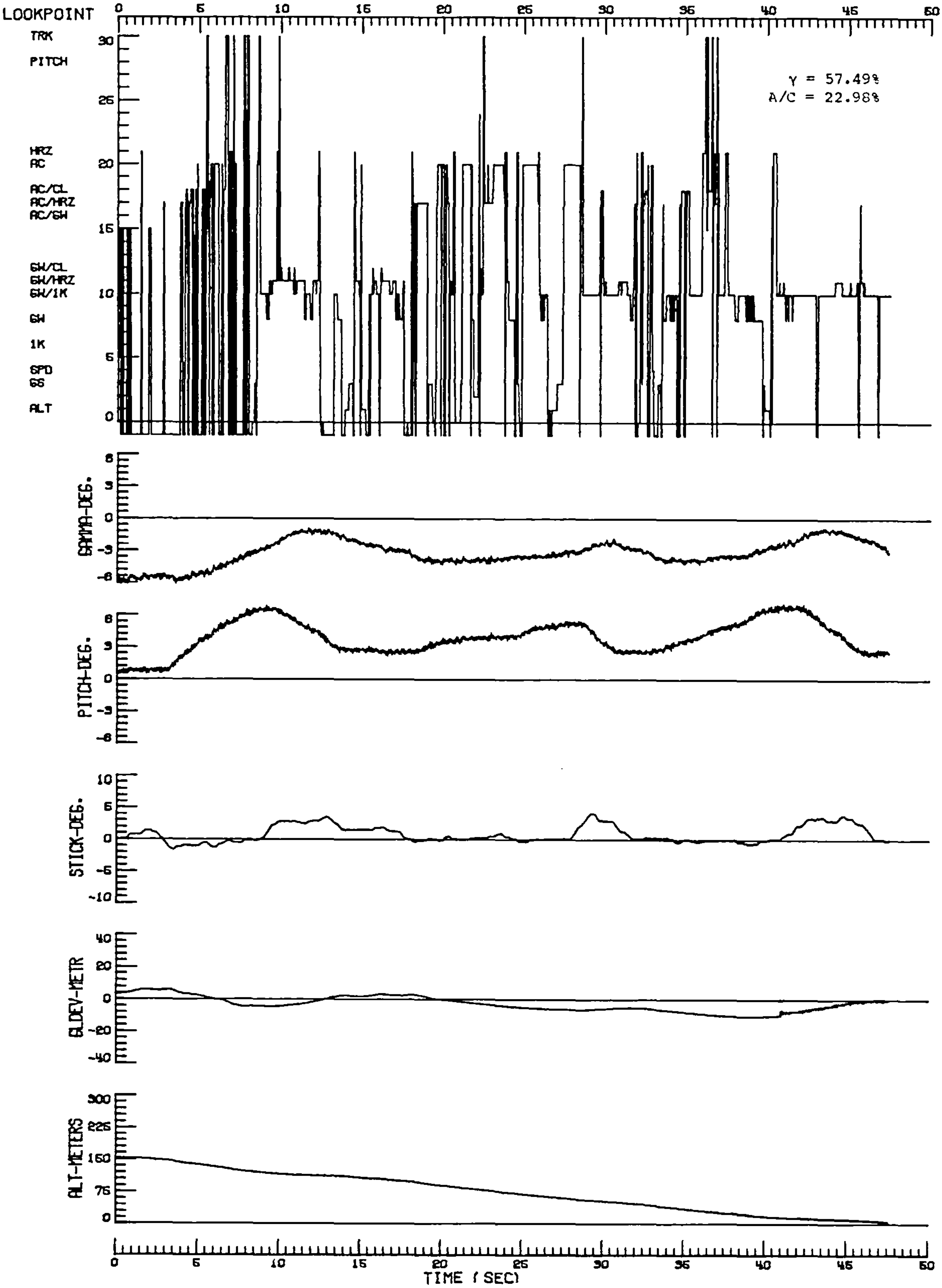

Figure 22.- Time histories: lookpoint and longitudinal variables for pilot 4. (See table III for key.)

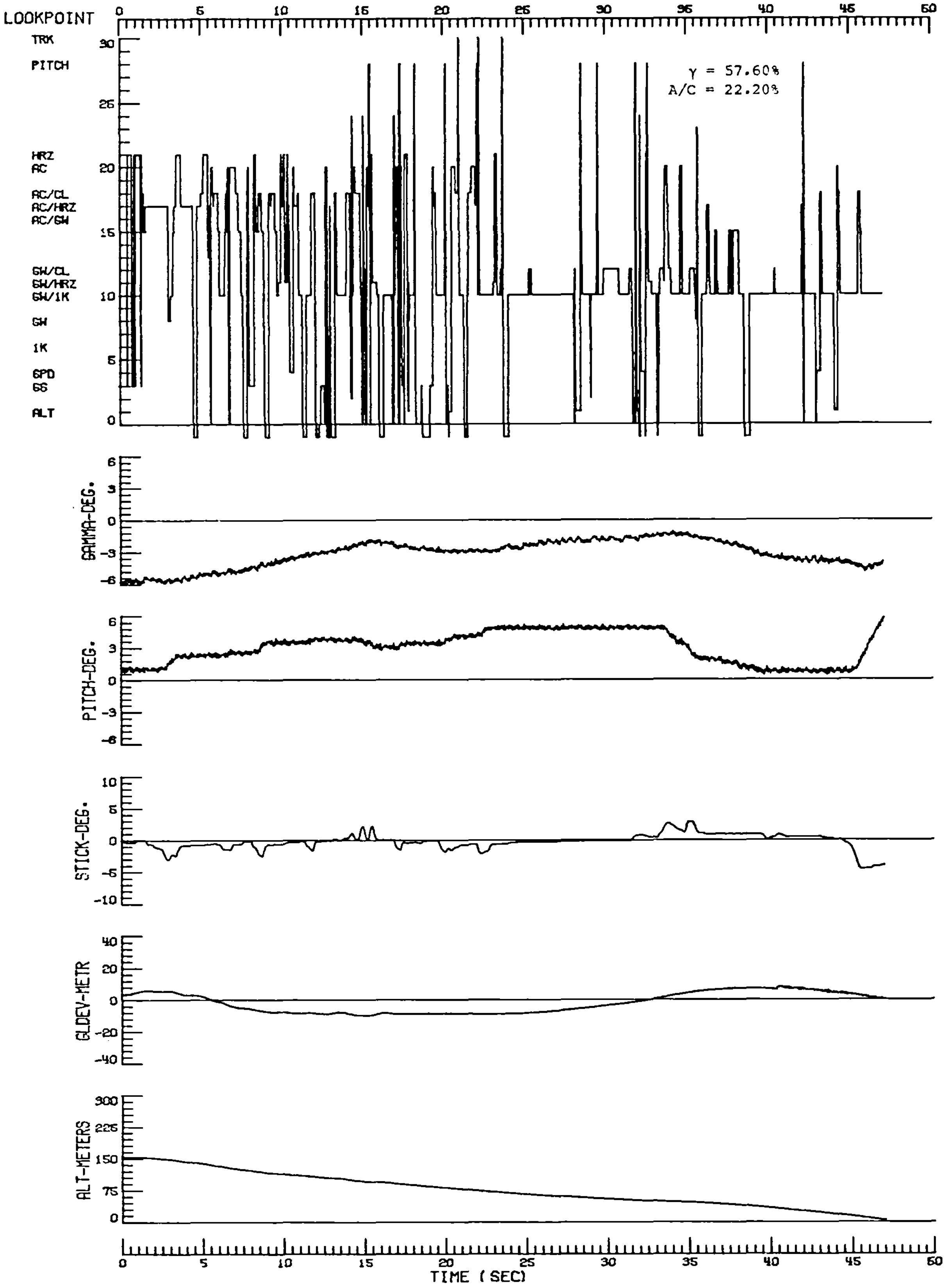

Figure 23.- Time histories: lookpoint and longitudinal variables for pilot 5. (See table III for key.)

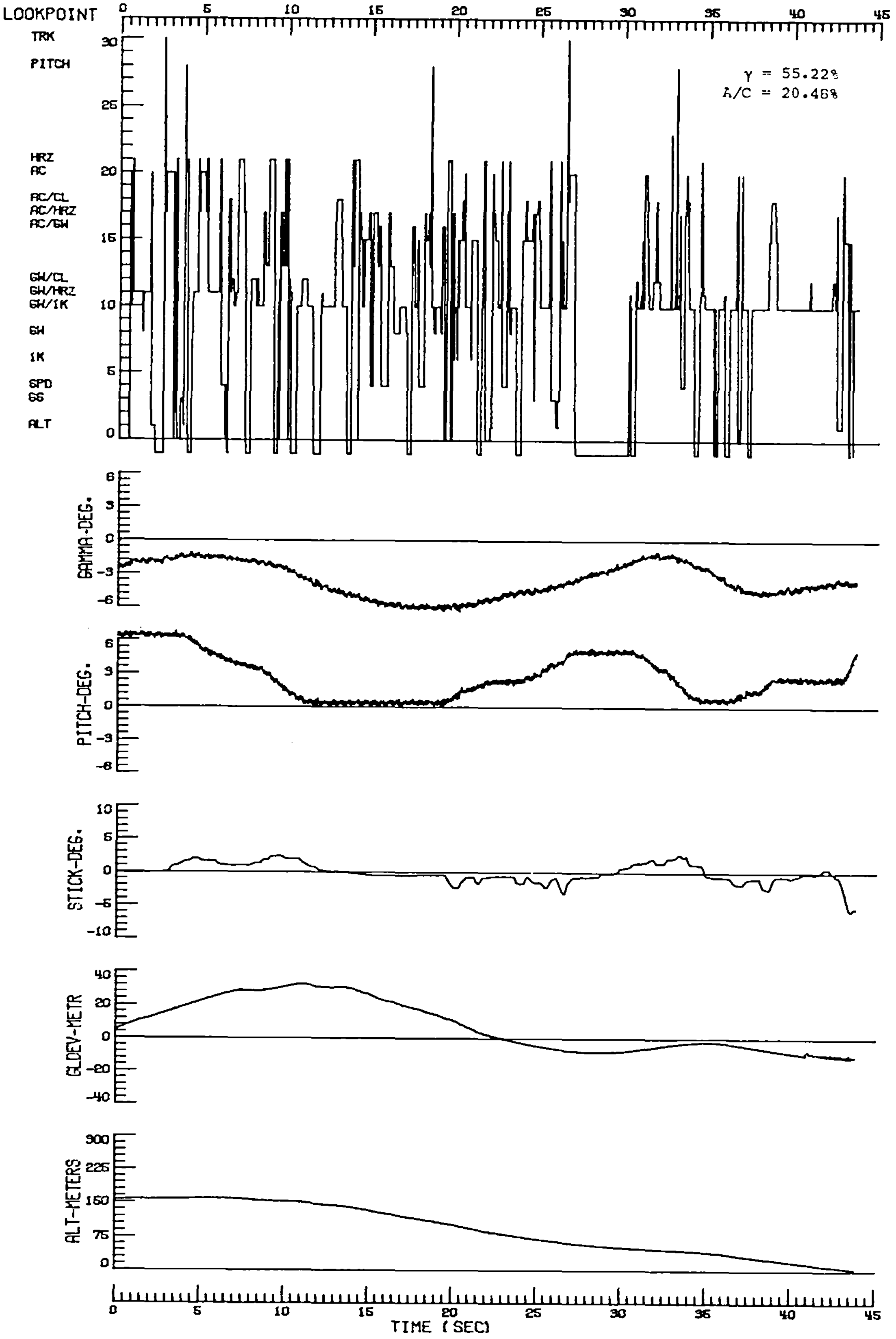

Figure 24.- Time histories: lookpoint and longitudinal variables for pilot 5. (See table III for key.)

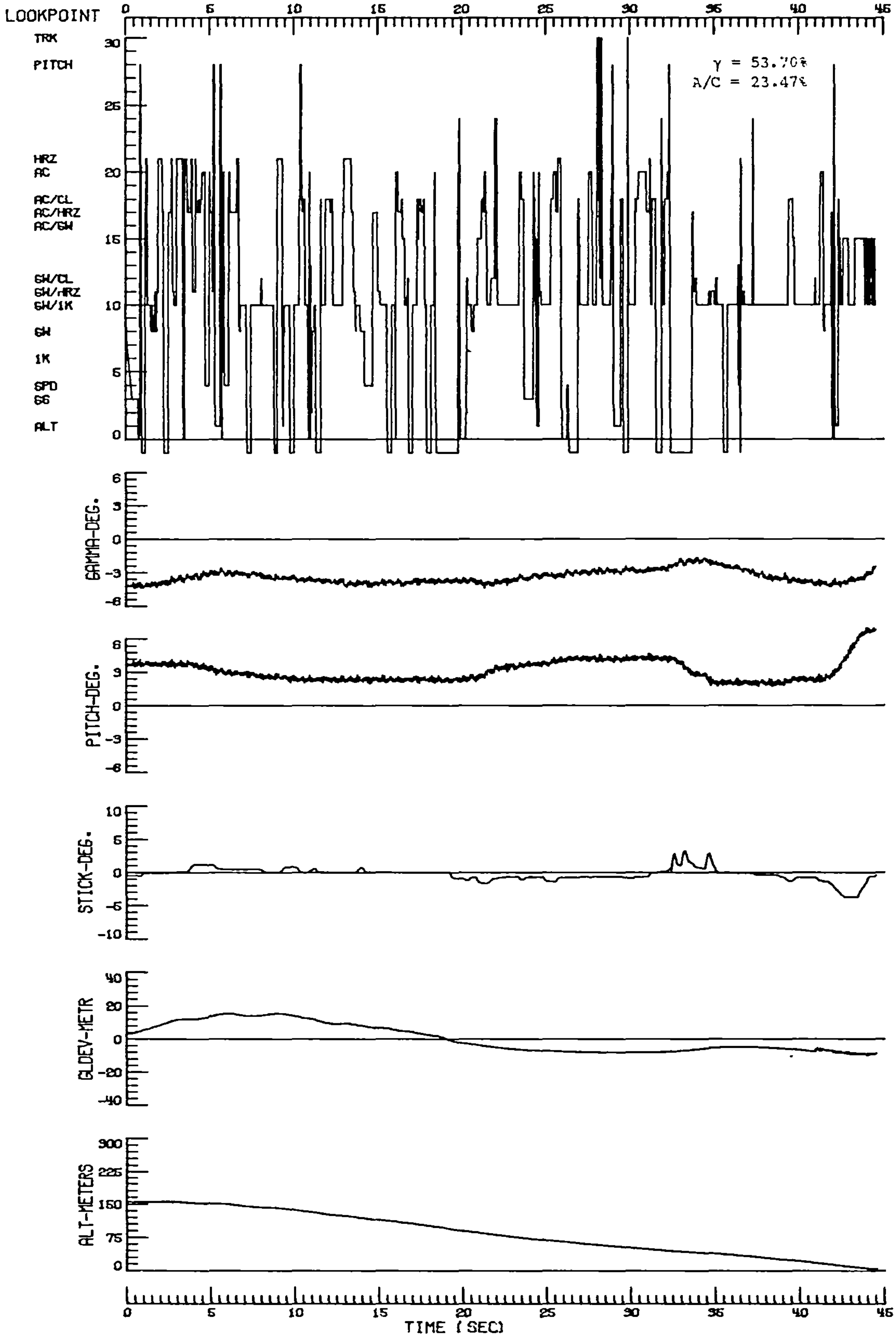

Figure 25.- Time histories: lookpoint and longitudinal variables for pilot 5. (See table III for key.)

1. Report No. NASA TP-1936	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle INFLUENCE OF DISPLAY AND CONTROL COMPATIBILITY ON PILOT-INDUCED OSCILLATIONS		5. Report Date December 1981
		6. Performing Organization Code 534-04-13-53
7. Author(s) Marvin C. Waller, Randall L. Harris, Sr., and Lee H. Person, Jr.		8. Performing Organization Report No. L-14364
9. Performing Organization Name and Address NASA Langley Research Center Hampton, VA 23665		10. Work Unit No.
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546		13. Type of Report and Period Covered Technical Paper
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

An analysis was conducted to investigate the differences in the techniques used by seven pilots to acquire information from an advanced display for instrument approaches to and landings on a runway. The study was conducted on a fixed-base simulator programmed with dynamics resembling Langley's terminal configured vechicle (TCV). It is shown that the seven pilots can be divided into two groups which used the display with distinctly different strategies for controlling the airplane. A clearly related pattern of performance differences resulted. Pilots who primarily used raw flight-path information experienced longitudinal oscillations; pilots using attitude information did not. Implications for future displays are discussed.

17. Key Words (Suggested by Author(s)) Vertical situation displays Display system compatibility Pilot induced oscillations Terminal configured vehicle	18. Distribution Statement Unclassified - Unlimited Subject Category 53

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	38	A03

For sale by the National Technical Information Service, Springfield, Virginia 22161 NASA-Langley, 1981

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