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DATA PRESENTATION FROM AIR-TO-AIR COMBAT MANEUVERING BETWEEN AN S-76 AND A UH-60A

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September 1985

AVIATION APPLIED TECHNOLOGY DIRECTORATE
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This report presents data measured during one-on-one air-to-air maneuvering tests involving Army UH-60A and Sikorsky S-76 helicopters. The engagements included preplanned maneuvering engagements as well as unstructured engagements in which both helicopters were maneuvered aggressively to gain a tactical advantage. The test program was conducted during July, 1983 at the Naval Air Test Center, Patuxent River, Maryland, and included the OH-58A in addition to the two helicopters mentioned above. This report contains data only on the S-76 and UH-60A; data from the OH-58A has been published in two separate reports. The data for each helicopter are presented in the form of time histories of the various parameters as measured during the maneuvers. The parameters for which data are presented include aircraft position in space, pitch, roll, and sideslip attitudes, pitch, roll, and yaw rates, control positions, load factor, airspeed, rotor speed, altitude, and engine torque. In addition to the time histories, several of the parameters are cross-plotted using time as the associating variable. These cross-plots permit a ready assessment of the flight envelope utilized by each helicopter during the air combat maneuvering.

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INTRODUCTION

The Army has developed an interest in air-to-air combat between helicopters due to the increased potential of such engagements in future conflicts. This increased potential is due to the vast number of armed helicopters now in production throughout the world, including the Soviet bloc countries. Therefore, the US Army helicopter research and development (R&D) community has initiated a program which addresses the necessity of providing future Army helicopters with the maneuverability and agility to meet this potential threat.

The goals of this program are to investigate the maneuvering capabilities of current rotary-wing aircraft and to develop the requirements for future aircraft maneuverability. To achieve these goals, a series of flight tests was conducted placing various state-of-the-art helicopters in a one-on-one air-to-air combat environment. The key parameters of each aircraft were recorded during the combat to form a data base of current maneuvering capability.

To build this data base, several phases of tests were conducted. The beginnings of this data base, including flying qualities, performance, and structural conditions, were created in the April 1983 air-to-air combat tests (AACT I). This phase was conducted at the Patuxent River Naval Air Test Center (NATC) utilizing an OH-58A and an AH-1S aircraft. In addition to acquiring the data base on these aircraft, another objective of AACT I was to emerge from the tests with proven techniques for airborne instrumentation, aircraft radar tracking, data processing, and evasive maneuvering. Having achieved these objectives, the second phase of the air-to-air tests (AACT II) at the NATC was conducted in July 1983 involving an OH-58A, a UH-60A, and the militarized version of an S-76.

This report presents data collected during the AACT II tests involving the S-76 and the UH-60A. The report also includes a brief summary and description of the participants (Appendix A), the aircraft, the maneuvers, and the data acquisition methods. However, no data analysis is included. Also presented is a discussion of the limitations placed on the tests as well as a description of each type of plot presented in the appendixes. A more detailed description of the manner in which these tests were conducted is available in Reference 1.

METHOD OF TEST

The S-76 and UH-60A engagement required approximately 1.5 flight hours of test range time under day visual meteorological conditions (VMC). The limits contained in the S-76 Operator's Manual[2] and the UH-60A Flight Manual,[3] and the special operating limits presented for the S-76 (Appendix B) and the UH-60A (Appendix C) were used as the limiting factors for the tests. These limits were monitored via strip-chart recorder at the Real-Time Telemetry Processing Station (RTPS) throughout the tests. No predetermined attempt was made to exceed the maximum allowable maneuver capability of either helicopter. For safety-of-flight requirements, the minimum indicated altitude planned for this flight was 500 feet above ground level (AGL). Minimum planned separation for all engagements based on pilot visual estimates and radar tracking was 500 feet except for the aft quadrant maneuvers in which the minimum separation distance decreased to 200 feet.

The flight scenarios executed during this project consisted of the basic Maneuver Criteria Evaluation Program (MCEP) agility maneuvers, Marine Air Weapons Tactics Squadron (MAWTS) evasive maneuvers, and free engagement evasive maneuvers. The basic MCEP agility maneuvers are single aircraft maneuvers defined as:

a. Cruise
b. Acceleration/deceleration at constant altitude
c. Climb/descent at constant airspeed
d. Dive/rolling pullout
e. Turn at constant airspeed and altitude
f. Climbing/descending turn at constant airspeed
g. Return to target at constant altitude
h. Climbing return to target
i. Pullup/pushover at desired load factor
j. Collective pop-up at constant attitude and low airspeed
k. Pedal turn at hover
l. Sideward acceleration/deceleration
m. Sideward acceleration/pedal turn into the wind

Data from these maneuvers will be used to verify the MCEP analysis. The MCEP computer code, from which the flight profiles for these basic maneuvers were extracted, is described in detail in Reference 4.

The two other scenarios, MAWTS and free engagements, were dual aircraft engagements involving evasive maneuvering (EVM), simulating air-to-air combat. The MAWTS maneuvers, which are described briefly here and in detail in the MAWTS Helicopter Evasive Maneuvering Procedure Guide,[5] consisted of the high yo-yo, wing-over, scissors, and low yo-yo. In these structured maneuvers one aircraft is designated as the aggressor and the other as the bogey. The bogey plays a passive or defensive role and flies a predetermined route. The aggressor, meanwhile, performs only one of the MAWTS maneuvers to gain an advantage on the bogey.

The high yo-yo maneuver is used when the aggressor attacks the bogey's rear quadrant and maneuvers to prevent overshooting or flying past the bogey in a turn (see Figure 1). This maneuver is performed by rolling to wing's level from a turn, then gaining altitude and losing airspeed, thus preventing an overshoot of the bogey.

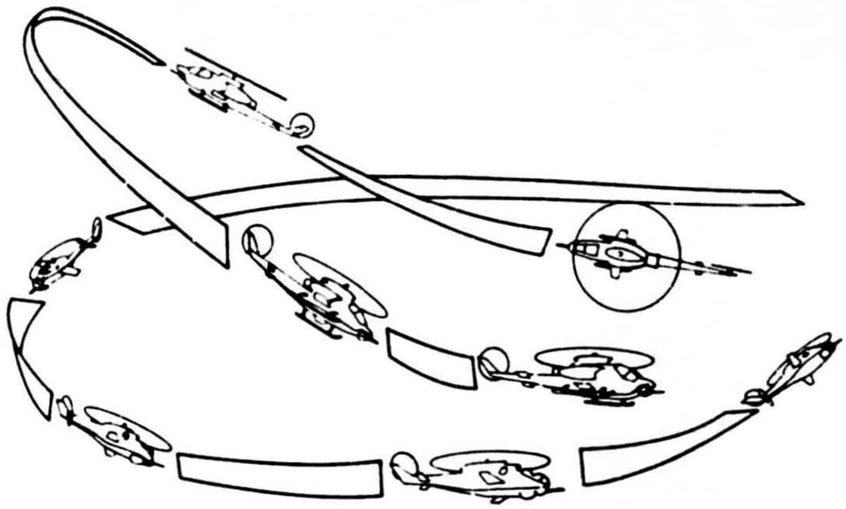

Figure 1. High yo-yo.

The wing-over maneuver is used when the aggressor approaches the bogey head-on from a high angle and long range (see Figure 2). It is performed by pitching the nose up, gaining altitude, and then rolling toward the enemy, thus attacking from the side. The level turn and 45-degree pitch pop-up maneuvers were used as training or preliminary maneuvers for the wing-over.

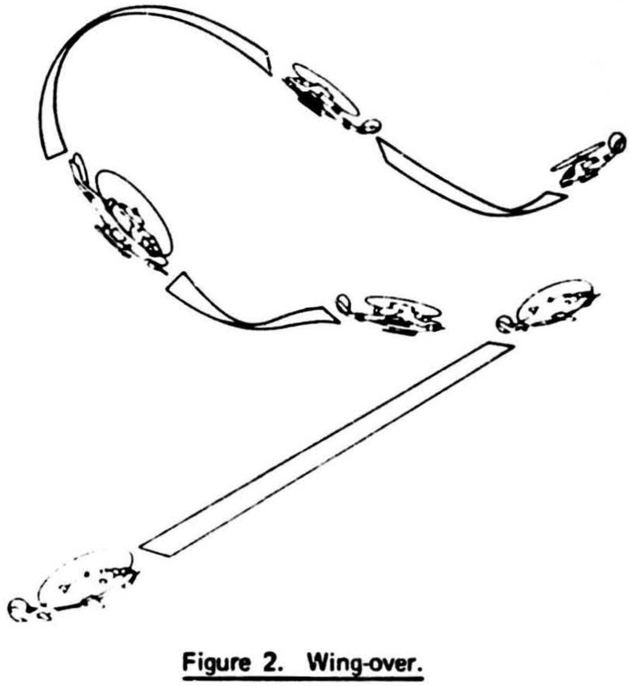

Figure 2. Wing-over.

The scissors maneuver is used when the aggressor is attacking the bogey's rear quadrant (see Figure 3). In a defensive maneuver the bogey performs a series of roll reversals and turns to force the aggressor to overshoot. The aggressor follows, trying to stay in an advantageous position behind the bogey.

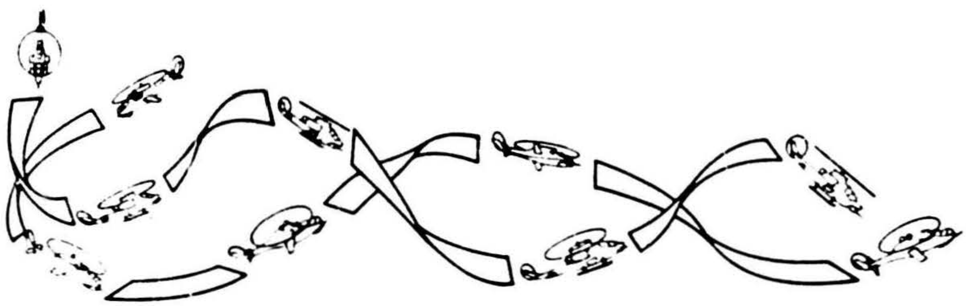

Figure 3. Scissors.

The low yo-yo is used when the aggressor is attacking the bogey's rear quadrant and maneuvers to decrease the range between the two aircraft (see Figure 4). It is performed by lowering the nose, thus increasing airspeed and decreasing altitude and turning to the inside of the bogey's turn.

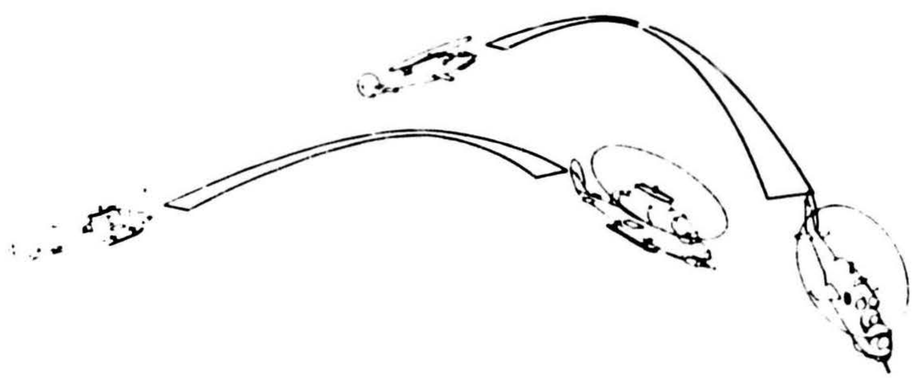

Figure 4. Low yo-yo.

In the free engagement scenario each aircraft could be both aggressive and defensive and each could perform any combination of maneuvers in an effort to gain an advantage over the opposing aircraft. However, before beginning each free engagement maneuver, the aircraft was placed in a prescribed location. This placement varied the quadrant of the attack (forward, abeam, aft) and also varied the relative altitude of the aircraft (high, level, low). These free engagement maneuvers permitted a less structured application of the MAWTS maneuvers, and allowed any maneuvering the test pilots could devise within approved aircraft and safety limits.

LIMITATIONS AND ASSUMPTIONS DURING TESTING

Some limitations were inherent with the test from both a flight-safety aspect and a subjective weapons aiming aspect which restricted the test from achieving a true simulation of the air-to-air environment. Also, since helicopter air-to-air combat has rarely been seen on a battlefield, some assumptions were required relating to the setup of the air-to-air combat scenarios. However, in the following discussion it will be shown that in some cases these limitations and assumptions actually created a scenario which required a greater amount of maneuverability than might be expected in actual air-to-air combat.

One of the limitations was that the aircraft were restricted to fly no less than 500 feet AGL. This restriction was due to a safety-of-flight requirement and a data recording limitation. The radar tracking units at the test facility were able to track only above 500 feet AGL; any flight under this limit would cause the radar track to be lost. This precluded low-level flight and nap-of-the-earth testing, wherein terrain masking is an important consideration.

Two other limitations that restricted the engagements from reproducing a more realistic air-to-air engagement were the requirements for simultaneous aircraft visual detection and day VMC. Early sighting, by chance or design, may dilute the importance of great maneuvering capability, especially if first shot probability of kill is high. The simultaneous visual aircraft detection requirement restricted the use of surprise engagements but was necessary to prevent a possible midair collison. The day VMC restriction also limited the engagements from encountering real battle settings (bad weather, low visibility) but was used so that visibility would be at a safe level during the tests.

One other limitation was that there was no means used to simulate weapons firing and thus no means to conclude which aircraft "won" the engagement. Since there was no gun firing simulator, the only means of determining weapons firing opportunities was pilot judgement. This method was found to be highly unsatisfactory since there was no means of validating these opportunites. There was also no incentive for the pilot to maintain the advantageous position to allow time to acquire the target and fire the weapon. Therefore, no data exist as to whether the pilot could have maintained the opportunity long enough to fire. There is also no data as to where the rounds would have gone and thus no means of predicting the probability of rounds hitting the adversary aircraft (P_h) or the probability of kill (P_k).

The limitation discussed above is also related to one of the important assumptions made for these tests. It was assumed that these aircraft were equipped solely with fixed guns; therefore, the pilot was in a position to fire only when the aircraft's nose was pointed directly at the other aircraft; thus, a line of sight had to be achieved. This assumption, however, requires the utmost maneuverability from the aircraft, since the pilot was not able to move his guns as with turreted weapons.

Another important assumption in these tests was that the flying was done in a single threat area. That is, there were no other aircraft or any antiaircraft weapons assumed to be in the area where the engagement took place. The pilots, therefore, were not concerned with fire from any source other than the adversary helicopter. Therefore, there was no limit as to how high or how slow the helicopter could fly. The tactics often used by the pilots were to gain an altitude advantage and a turn rate advantage by decreasing airspeed. Serious doubts were raised as to whether this was a realistic tactic since a slow-moving, high-altitude helicopter becomes a likely target for other threat weapon systems because of its high visibility. It should be pointed out, however, that although the pilot may be aware of other threat weapons in his operating area, he will likely be most concerned with his most immediate threat, the adversary helicopter. Therefore, he will do what is required to defeat that foe by using the best available tactics and maneuvers.

The simultaneous visual detection limitation and the fixed gun and single threat assumptions prevent investigation of all realistic conditions for future air-to-air combat. However, these limitations and assumptions are not unduly restrictive since they have the effect of creating a scenario which would require the greatest amount of maneuverability, thus requiring the utmost in performance from both the aircraft and the pilot.

TEST AIRCRAFT AND EQUIPMENT

The S-76 (see Figure 5) had a takeoff gross weight of 8925 pounds. A detailed description of the commerical version of the S-76 aircraft is contained in the Flight Manual.[2] It was further modified with an external motion picture camera, a nose-mounted boom with sideslip vane, two laser reflectors, two transponders, and two Telemetry (TM) antennae. The aircraft was instrumented with both a flying qualities and performance pulse code modulation (PCM) instrumentation package, and a structural frequency modulation (FM) instrumentation package.

Figure 5. Militarized version of the Sikorsky S-76 helicopter.

A detailed description of the UH-60A helicopter (see Figure 6) is contained in the Operator's Manual.[3] This aircraft had a takeoff gross weight of 14,685 pounds. It was modified with an external motion picture camera; a nose-mounted boom with a yaw, angle of attack, Pitot-static (YAPS) head; two laser reflectors; one transponder; and two TM antennae. The aircraft was instrumented with both a flying qualities and performance PCM instrumentation package and a structural FM instrumentation package.

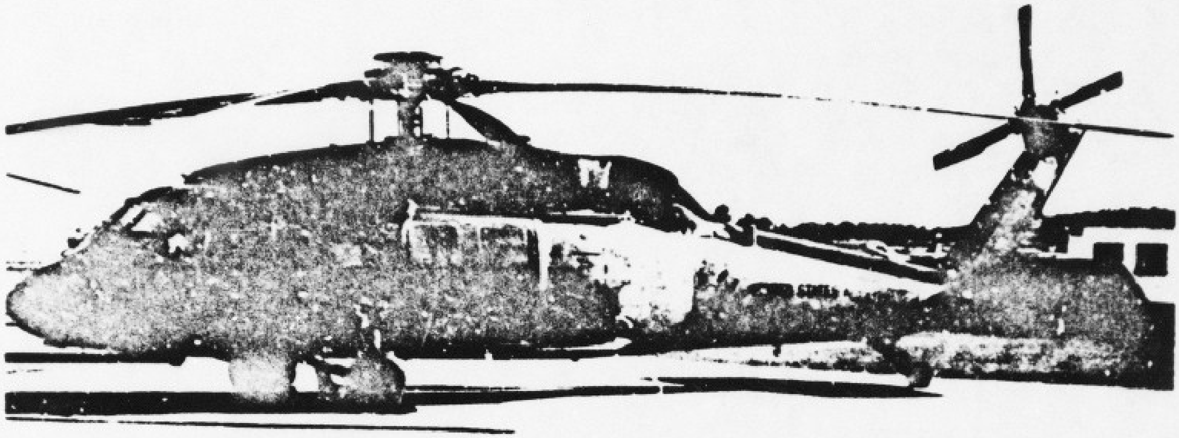

Figure 6. US Army UH-60A helicopter.

DATA ACQUISITION AND ANALYSIS METHODS

The test instrumentation consisted of the PCM parameters listed in Appendixes D and E for the S-76 and UH-60A aircraft, respectively. All PCM parameters and FM structural parameters were recorded on the aircrafts' magnetic tape recorders. In addition, all PCM parameters were telemetered to the RTPS facility where the data were recorded on magnetic tape and displayed on strip-chart recorders.

All data flights recorded real-time space position data, which were obtained by radar tracking and received by the Chesapeake Test Range (CTR). The data collected, consisting of both radar and telemetry data, were merged and stored on magnetic tape. Thus, at each 0.2-second time interval during the flight the aircraft state in terms of rates and accelerations, its inertial position in space, and its position relative to the adversary aircraft were measured.

The data on the magnetic tapes were converted to a format compatible with the Data from Aeromechanics Test and Analytics Management and Analysis Package (DATAMAP). DATAMAP was then used to access and plot the data via an interactive graphics terminal. The data time histories and space positions shown in Appendix F and the cross plots shown in Appendix G were all plotted using this program. A complete description of the DATAMAP program may be found in Reference 6.

TEST DATA DESCRIPTION

The test data collected from the evasive maneuvering (EVM) scenarios between the UH-60A and the S-76 are presented in Appendixes F and G. The data are from eight separate free engagement maneuvers. Appendix F consists of space position data and time histories of the various parameters as measured during each maneuver. Appendix G contains cross plots of selected parameters from the free engagement maneuvers. No MCEP or MAWTS maneuvers are included in this report.

SPACE POSITION AND TIME HISTORY DATA

The presentation of the space position and time history data consists of eleven figures (a through k) for each of the eight maneuvers.

Figure (a) is an X-Y plot of the flight paths of both aircraft where X was measured positive east and Y was measured positive north (relative to a point located at the CTR). This plot shows a view of the flight path from above the two aircraft. The abscissa and ordinate are divided by an equal interval to show a true representation of the flight path. The solid line and circles represent the flight path of the UH-60A while the dashed line and triangles represent that of the S-76. Whenever possible, data from the entire maneuver are shown, but in some cases part of the data from the entry and/or exit portion of the flight path was truncated so that the actual engagement could be enlarged and studied more readily. The square symbol at one end of the plot represents the common time point of 2 seconds and the beginning of the maneuver. Each circle or triangle symbol thereafter represents the next time point, with the interval between the symbols being equal for both aircraft. Numerical time points are shown on the plot to define the marking interval.

Figure (b) shows three plots of the S-76 flight path. These are the X-Y, the X-Z, and the Y-Z space position plots, where Z is defined as positive up from ground level, disregarding the curvature of the earth. The scaling between the three plots is always held constant, as is the scaling between the abscissa and ordinate axes of each individual plot. The square symbol again represents the time point at 2 seconds and the marking interval afterward is shown by the successively numbered circles on each plot.

Figure (c) shows the three flight path plots for the UH-60A. The scaling between the plots is again held constant although the scaling is not necessarily the same as that used on Figure (b). The fourth plot shown on this page in the bottom right corner is a time history plot of the longitudinal separation of the two aircraft during the maneuver.

Figures (d) through (k) contain the time history plots of parameters recorded and plotted for the duration of a maneuver. The first four of these figures (d, e, f, and g) contain the parameters for the S-76 and the second four (h, i, j, and k) contain the same parameters for the UH-60A. For comparison purposes the same scaling is used for both aircraft for any one parameter. In this way an accurate visual comparison can be made between the two aircraft in each maneuver.

Figures (d) and (h) consist of the time histories of the attitudes and heading angles for the S-76 and UH-60A, respectively. The pitch and roll attitudes are Euler angles and follow the traditional sign conventions associated with the body fixed axis system. Pitch is positive nose up and roll is positive right wing down. Sideslip is the angle measured between the velocity vector and the longitudinal axis of the aircraft. The sideslip angle is positive when the nose is to the left of the velocity vector (i.e., the wind "strikes" the right side of the nose). The heading angle is the angle between the velocity vector and true north. The heading is measured between 0 and 360 degrees with a heading of north equal to 0 or 360 degrees and east equal to 90 degrees. Yaw angle was not measured but can be determined by subtracting the sideslip angle from the heading angle.

Figures (e) and (i) consist of the pitch, roll, and yaw rates and load factor for the S-76 and UH-60A, respectively. The sign of the pitch and roll rates is positive in the same sense as the attitudes discussed above, with the yaw rate being positive for nose right motion. The aircraft load factor is given in G's of acceleration and was measured by an accelerometer located as close to the center of gravity as possible.

Figures (f) and (j) consist of the plots of four control positions for the S-76 and the UH-60A, respectively: collective, longitudinal cyclic, lateral cyclic, and pedal. These are all measured in percent as defined below:

Collective	0% = Full down	100% = Full up
Longitudinal Cyclic		
S-76	0% = Full aft	100% = Full forward
UH-60A	0% = Full forward	100% = Full aft
Lateral Cyclic	0% = Full left	100% = Full right
Pedal	0% = Left Pedal + low collective	100% = Right pedal + high collective

Figures (g) and (k) consist of four time history parameters for the S-76 and UH-60A, respectively: airspeed, rotor speed, altitude, and engine torque. Airspeed for both the S-76 and the UH-60A was recorded through the Pitot-static system of each aircraft. Rotor speed was measured in percent rpm, with 100 percent being equivalent to 293 rpm for the S-76 and 258 rpm for the UH-60A. Altitude was measured from the aircraft Pitot-static systems. Finally, engine torque was measured in percent and can be converted to shaft horsepower using the following equation:

$$Eshp = Kq\ (Q)\ (Nr)$$

where Eshp = engine shaft horsepower
Kq = torque constant = 0.0650 (S-76) or 0.1400 (UH-60A)
Q = engine torque (percent per engine)
Nr = rotor speed (percent rpm)

The engine torque plot has two lines, one for each engine of the respective aircraft.

PARAMETER CROSS PLOTS

Appendix G contains cross plots showing two parameters plotted against each other with time as the associating variable. The parameters are cross-plotted over the entire time history of each maneuver, resulting in a graphic representation of the envelope flown by the aircraft.

Each plot of Appendix G is a compilation of several separate maneuvers, providing a better overall representation of how the aircraft was flown. Data from the free engagement maneuvers were used exclusively, as these scenarios prompted the most aggressive maneuvering and resulted in the largest envelopes. These envelopes were plotted for both aircraft using the same maneuvers.

For all but the lateral versus longitudinal stick position cross plot, the parameters are plotted against airspeed. Airspeed was chosen as the independent variable since for most performance parameters the aircraft limitations are at least partially dependent on airspeed. The lateral versus longitudinal stick position plot is set up to provide a view from above the stick, tracing the path of the stick through the maneuvers. The other parameters, all plotted against airspeed, include load factor, pitch attitude, pitch rate, roll attitude, roll rate, sideslip, and yaw rate.

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LIST OF ACRONYMS AND ABBREVIATIONS

AACT	Air-to-air combat tests
AGL	Above ground level
AATD	Aviation Applied Technology Directorate
CTR	Chesapeake Test Range
DATAMAP	Data from Aeromechanics Test and Analytics - Management and Analysis Package
EVM	Evasive maneuvering
FM	Frequency modulation
GPM	Gallons per minute
GW	Gross weight
H_D	Density altitude
KCAS	Knots calibrated airspeed
KIAS	Knots indicated airspeed
MAWTS	Marine Air Weapons Tactics Squadron
MCEP	Maneuver Criteria Evaluation Program
NATC	Naval Air Test Center
NL	Nose left
NOE	Nap of the earth
NR	Nose right
PCM	Pulse code modulation
P_h	Probability of hit
P_k	Probability of kill
PSIA	Pounds per square inch-absolute
RPM	Revolutions per minute
RTPS	Real-Time Telemetry Processing Station
TM	Telemetry
USNTPS	United States Naval Test Pilot School
V_H	Maximum speed in level flight
VMC	Visual meteorological conditions
YAPS	Yaw, angle of attack, Pitot static

APPENDIX A
PARTICIPANTS

The major participants in the AACT II program and their primary contributions were as follows:

a. Aviation Applied Technology Directorate (AATD)
US Army Aviation Research and Technology Activity (AVSCOM)
Fort Eustis, Virginia
provided the DATAMAP computer code, engineering support, project pilot, and overall management.

b. US Naval Test Pilot School (USNTPS)
Patuxent River, Maryland
provided aircraft (OH-58A), maintenance support, instrumentation, engineering support, test coordination, and two test pilots.

c. Marine Aviation Weapons and Tactics Squadron 1 (MAWTS 1)
Yuma, Arizona
provided two weapons tactics instructor pilots.

d. Rotary Wing Aircraft Test Directorate
Naval Air Test Center (NATC)
Patuxent River, Maryland
provided engineering support.

e. Sikorsky Aircraft Division
United Technologies Corporation
Stratford, Connecticut
provided aircraft (S-76 and UH-60A), operational and maintenance support, instrumentation, and two project pilots.

APPENDIX B
SAFETY PRECAUTIONS/OPERATING LIMITATIONS FOR THE S-76 HELICOPTER[1]

1. All limits of the operator's manual apply except as noted within this document.

2. Airspeed Limits

   a. Maximum - 170 KIAS
   b. Level flight - 155 KIAS
   c. Autorotation - 155 KIAS (Gear up)
   d. Sideward - 40 KIAS
   e. Rearward - 40 KIAS

3. Altitude Limits

   Minimum recovery for area flights - 500 ft AGL minimum

4. Attitude Limits

   a. Pitch: ±60 deg absolute; commence recovery at 45 deg or less if rate is excessive.

   b. Roll: ±140 deg absolute (load factor within V-n diagram); commence recovery at 60 deg or less if rate is excessive.

5. Angular Rates

   Roll - 75 deg/sec left
   110 deg/sec right

   Pitch - ±35 deg/sec

   Yaw - ±40 deg/sec

6. Normal Acceleration Limits

   See Figure B-1

7. Sideslip Angle Limits

   See Figure B-2

8. Rotor Speed Limits

   a. Maximum continuous - 100%-107%
   b. Minimum continuous - 100%
   c. Maximum transient - 115%
   d. Minimum transient - 87%

e. Maximum auto (steady) - 115%

f. Maximum auto (transient) - 121%

g. Normal maneuvering - 107%

9. Torque Limits

a. Maximum continuous (twin engine) - 100%

b. Maximum continuous (30 min) - 100%

c. Maximum transient (twin engine) - 120% for 30 sec per occurrence

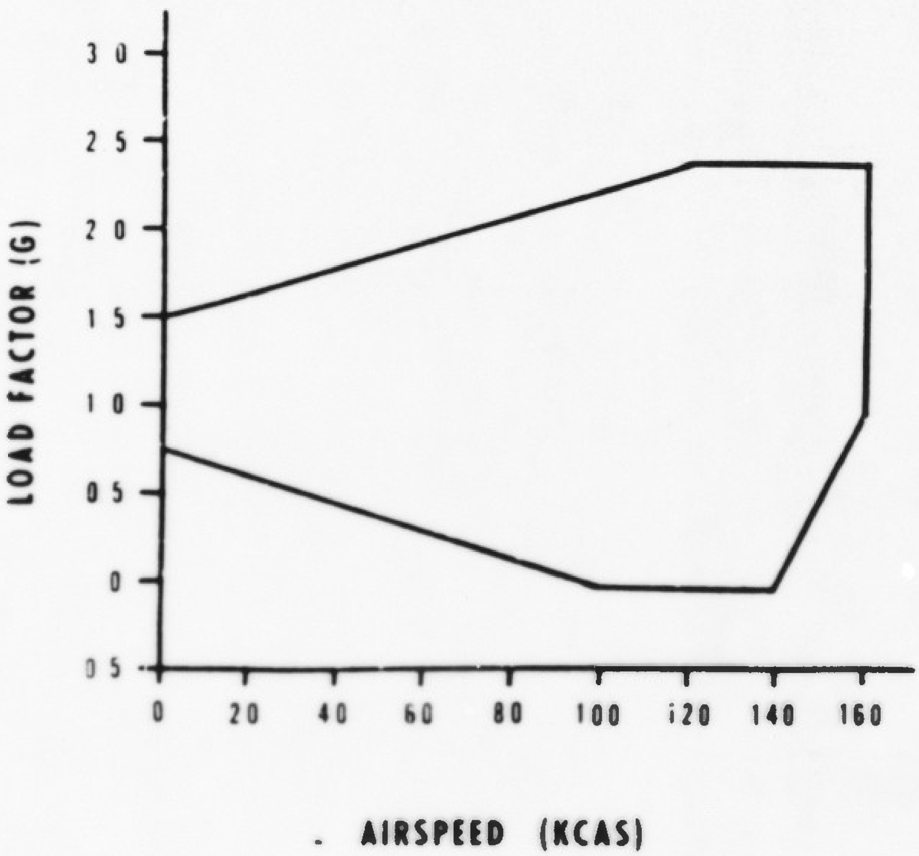

Figure B 1. S 76 normal acceleration limits.

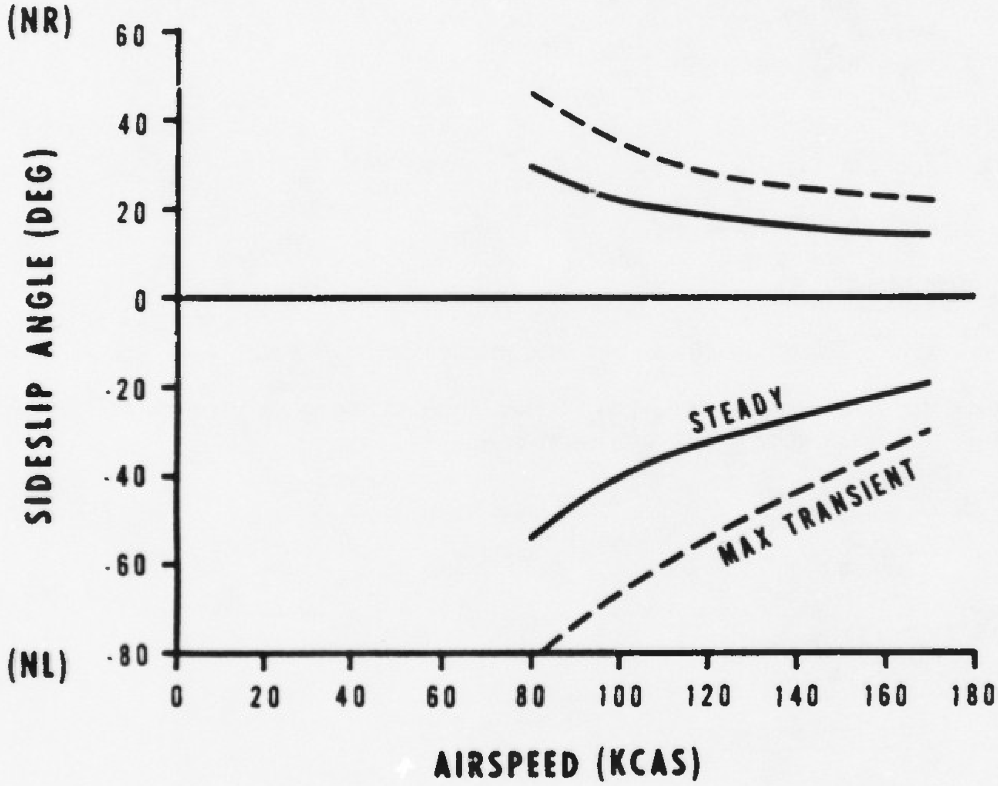

Figure 8-2. S-76 sideslip angle limits.

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APPENDIX C
SAFETY PRECAUTIONS/OPERATING LIMITATIONS FOR THE UH-60A HELICOPTER[1]

1. All limits of the operator's manual TM-55-1520-237-10 apply except as noted within this document.

2. Airspeed Limits

   a. Maximum (dive) - 193 KIAS
   b. Level flight - Per Figure 5-3 of operator's manual
   c. Autorotation - 150 KIAS
   d. Sideward - 55 KIAS
   e. Rearward - 55 KIAS
   f. Maximum, one engine inoperative - 130 KIAS

3. Altitude Limits

   Minimum recovery for area flights - 500 ft AGL minimum

4. Attitude Limits

   a. Pitch: ±60 deg absolute; commence recovery at 45 deg or less if rate is excessive.

   b. Roll: ±140 deg absolute (load factor within V-n diagram); commence recovery at 60 deg or less if rate is excessive.

5. Angular Rates

   Roll - 75 deg/sec left
   120 deg/sec right
   Pitch - ±45 deg/sec
   Yaw - ±60 deg/sec

6. Normal Acceleration Limits

   See Figure C-1

7. Sideslip Limits

   See Figure C-2

8. Rotor Speed Limits

   a. Maximum continuous - 95%-101%
   b. Minimum continuous - 95%
   c. Maximum transient - 107%
   d. Minimum transient - 91%

e. Maximum auto (steady) - 110%
f. Maximum auto (transient) - 120%
g. Normal maneuvering - 100%-101%

9. Engine Limits

a. Maximum continuous - 105%
b. Minimum continuous - 91%
c. Maximum transient - 105%-107% for 12 sec

10. Torque Limits

a. Maximum continuous dual engine - 100%
b. Maximum continuous dual engine (30 min) - 100%
c. Maximum continuous single engine only - 100%-110%
d. Transient: dual engine - 100%-125% for 10 sec
single engine - 110%-135% for 10 sec

11. Stabilator

Phase I (MCEP) - automatic
Phase II (EVM) - locked (manual at 2 deg TE down)

12. SAS Configuration

SAS on, FPS on, PBA off and centered

13. Parachutes

Not required.

14. Unusual Attitude Recovery

Unusual attitude recovery from both high attitude pitch and roll maneuvers will be practiced during the instruction/demonstration flights at the beginning of this project. Unusual attitude recovery procedures will be thoroughly covered during the preflight brief of every subsequent data flight.

15. Hazards

During all EVM and MCEP maneuvers, the effect of horizontal tail (stabilator) position and motion upon control margins and controllability will be monitored closely by the crew. The aircraft is to be flown with the horizontal tail in the "automatic" mode for the MCEP maneuvers and "locked out" for all EVM flights.

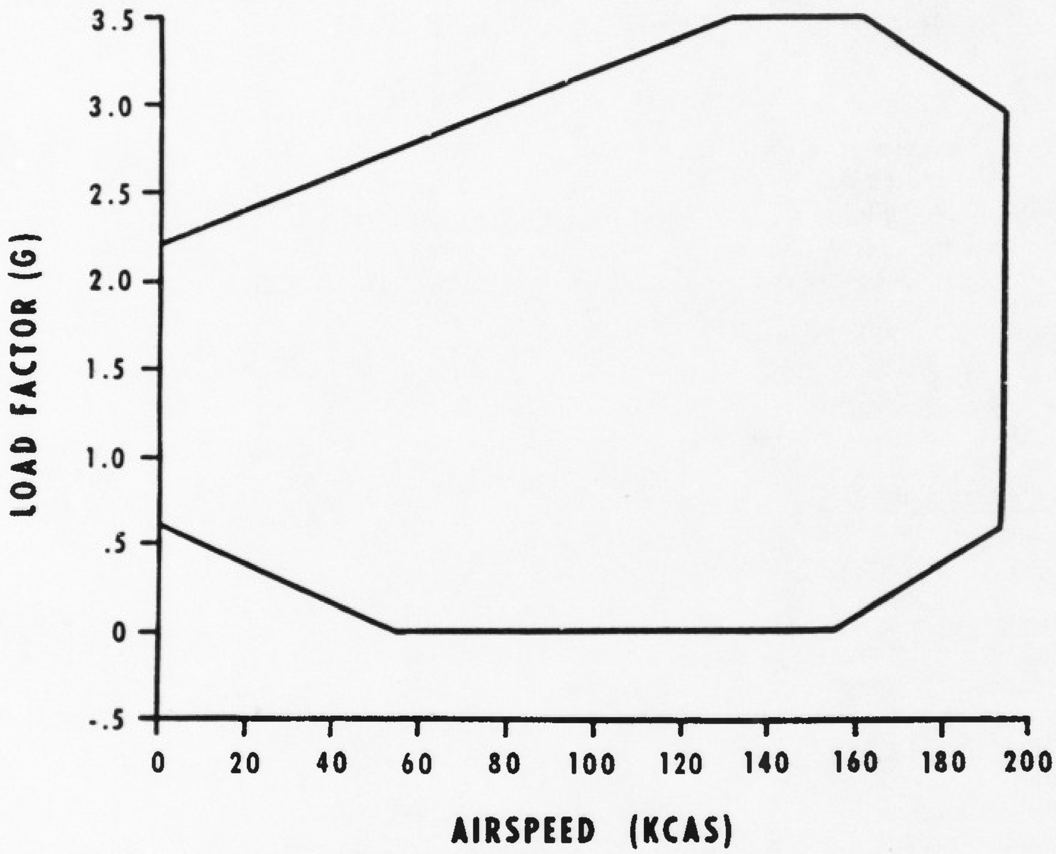

Figure C-1. UH-60A normal acceleration limits.

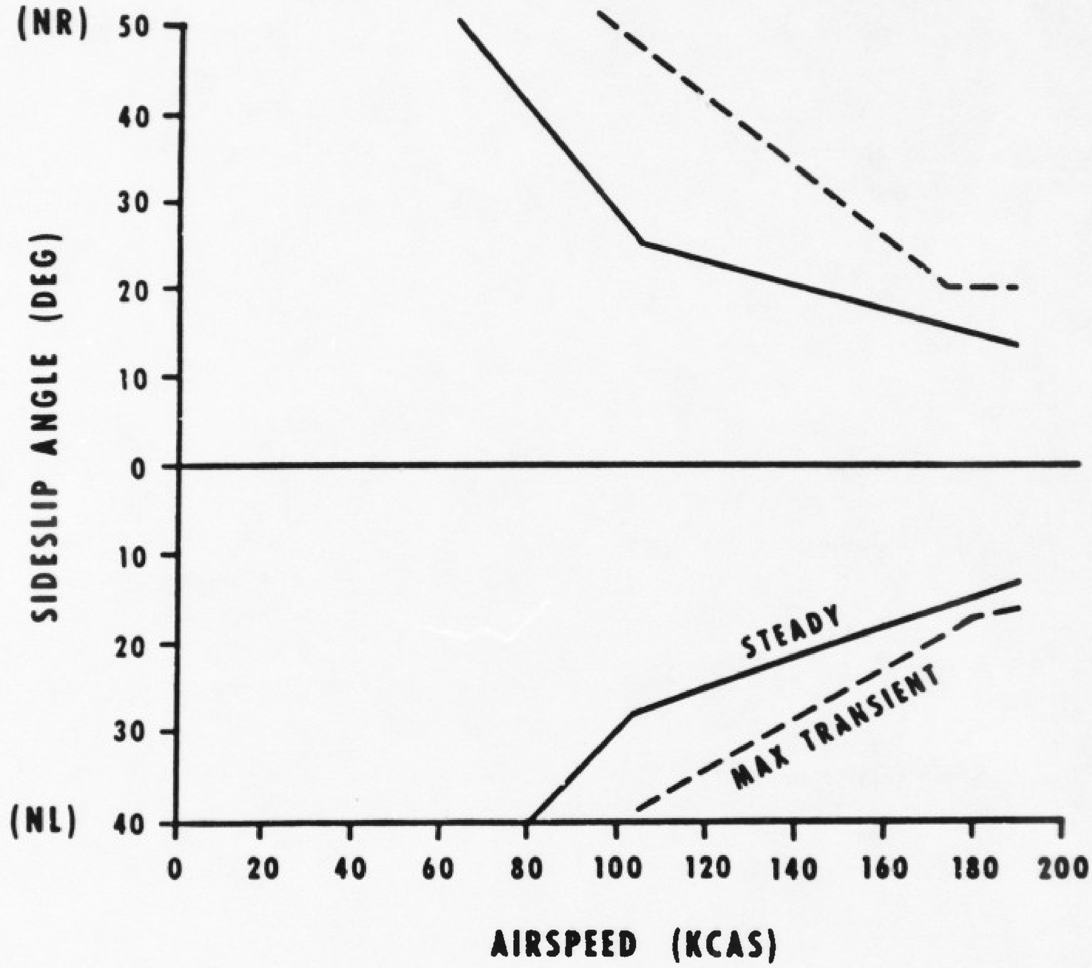

Figure C-2. UH-60A sideslip angle limits.

APPENDIX D
S-76 INSTRUMENTATION

PARAMETER	FULL-SCALE RANGE
Pitch attitude	±70 deg
Roll attitude	±130 deg
Pitch rate	±50 deg/sec
Roll rate	±90 deg/sec
Yaw rate	±45 deg/sec
Sideslip	±45 deg
Longitudinal cyclic	0–100%
Lateral cyclic	0–100%
Collective position	0–100%
Pedal position	0–100%
Load factor	+3.0 to -0.5 G
Rotor speed	80%-125%
Velocity	0–190 kt
Pressure altitude	-1000 to +3000 ft
Outside air temperature	0–40°C
No. 1 engine torque	0–130%
No. 2 engine torque	0–130%
No. 1 engine T_5	0–1000°C
No. 2 engine T_5	0–1000°C
Event marker	–
Gun camera synch	–

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APPENDIX E
UH-60A INSTRUMENTATION

PARAMETER	FULL SCALE RANGE
Pitch attitude	±70 deg
Roll attitude	±130 deg
Pitch rate	±50 deg/sec
Roll rate	±90 deg/sec
Yaw rate	±45 deg/sec
Sideslip	±45 deg
Longitudinal cyclic	0-100%
Lateral cyclic	0-100%
Collective position	0-100%
Pedal position	0-100%
Load factor	+3 to -0.5 G
Rotor speed	80%-125%
Velocity	0-190 kt
Pressure altitude	-1000 to +3000 ft
Outside air temperature	0-40°C
No. 1 engine torque	0-130%
No. 2 engine torque	0-130%
No. 1 engine T_5	0-1000°C
No. 2 engine T_5	0-1000°C
Event marker	–
Gun camera synch	–
Stabilator angle	–

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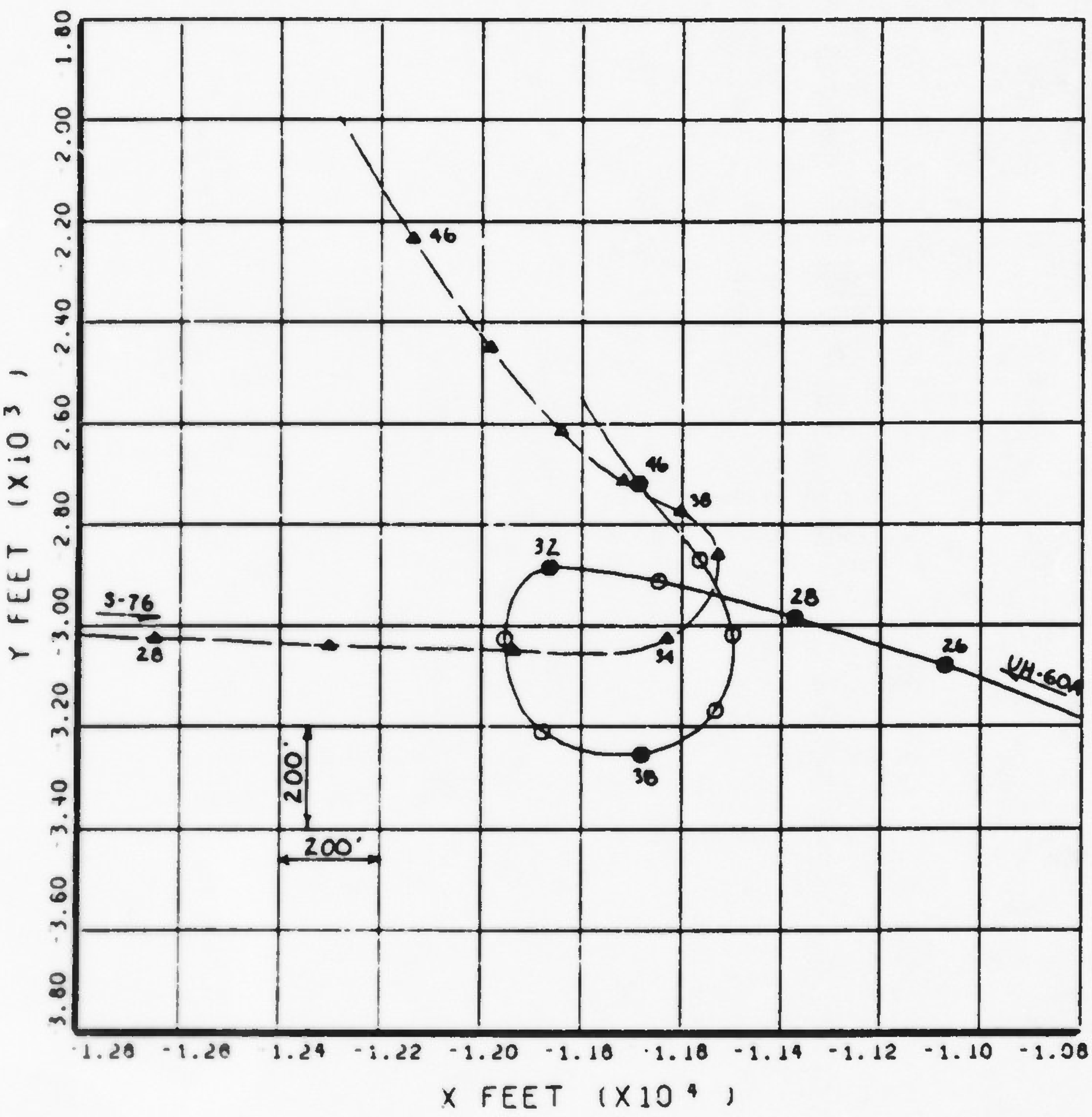
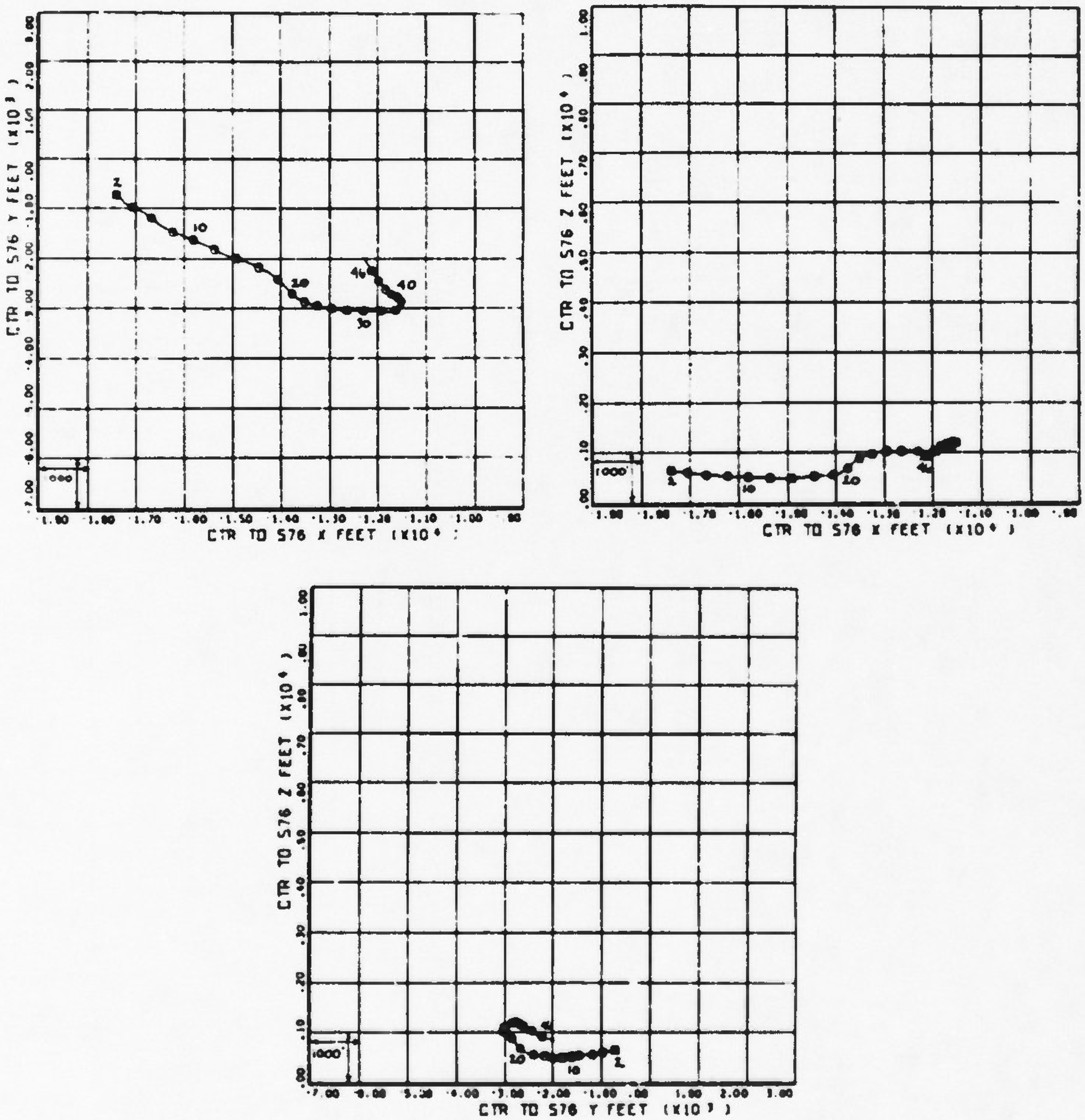
APPENDIX F
S-76 VERSUS UH-60A FLIGHT TEST DATA



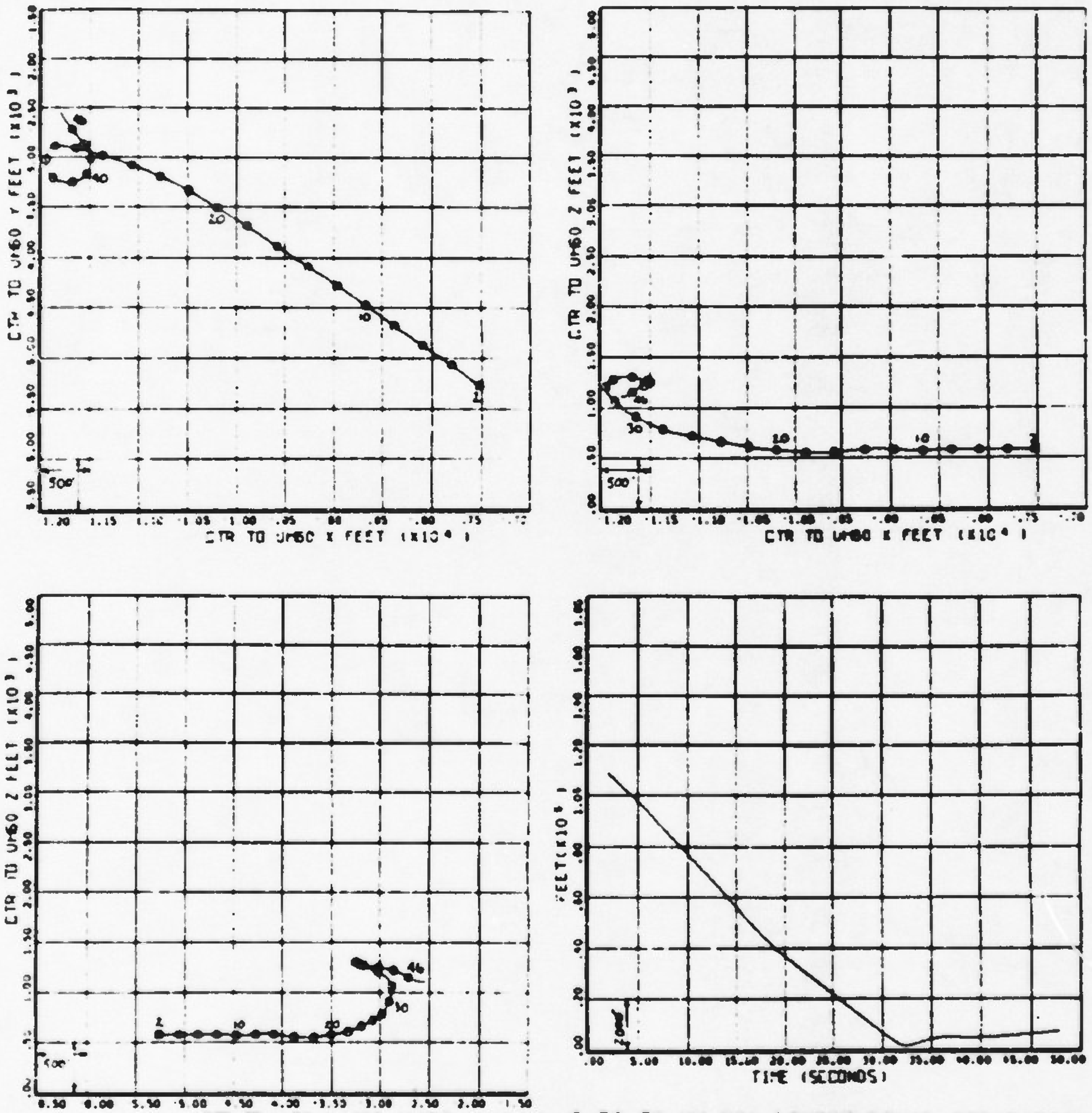
(a)
Figure F-1. Free engagement — head to head (level).

S-76
FLIGHT PATH PLOTS



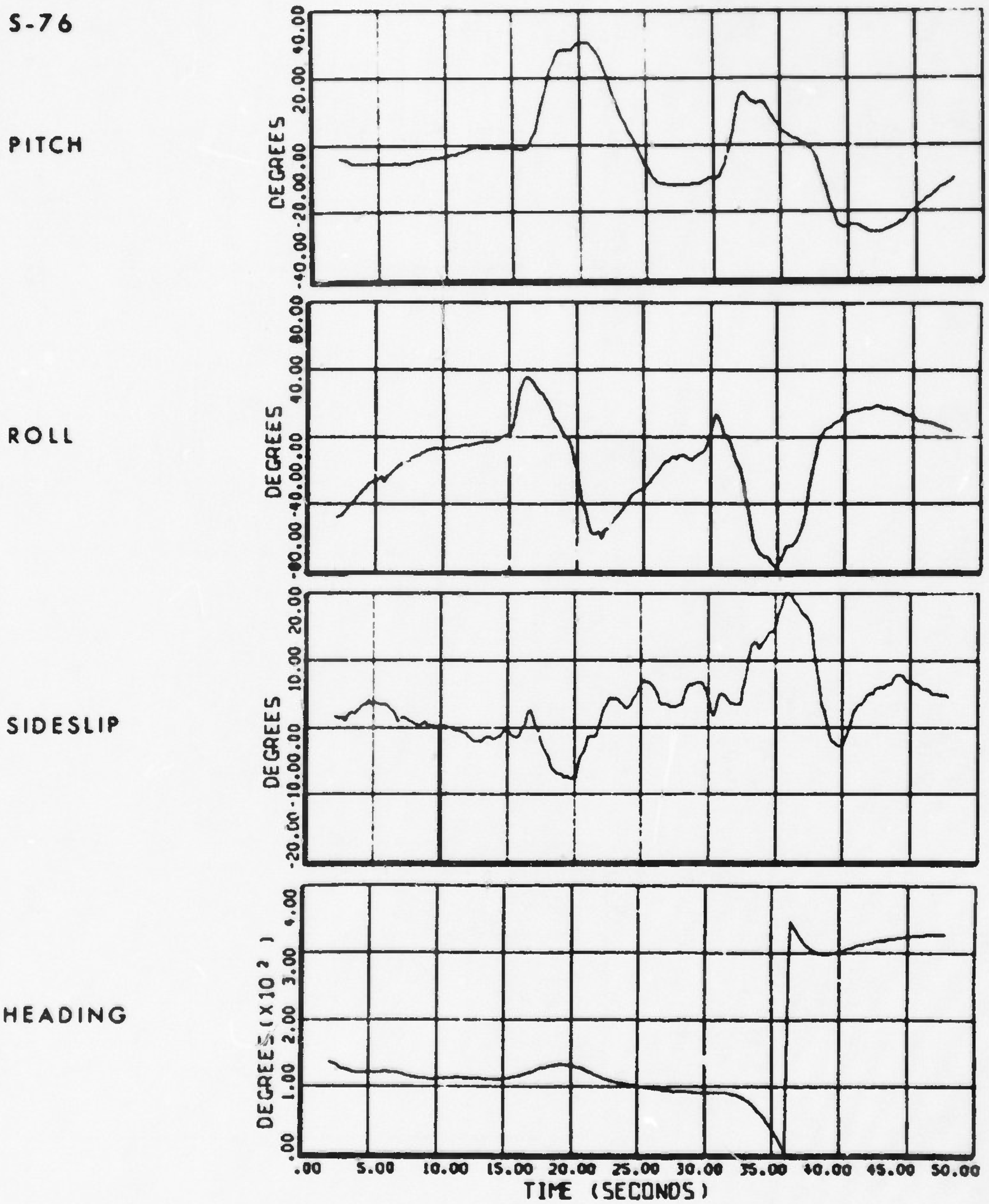
(b)
Figure F-1. Continued.

UH-60A
FLIGHT PATH PLOTS

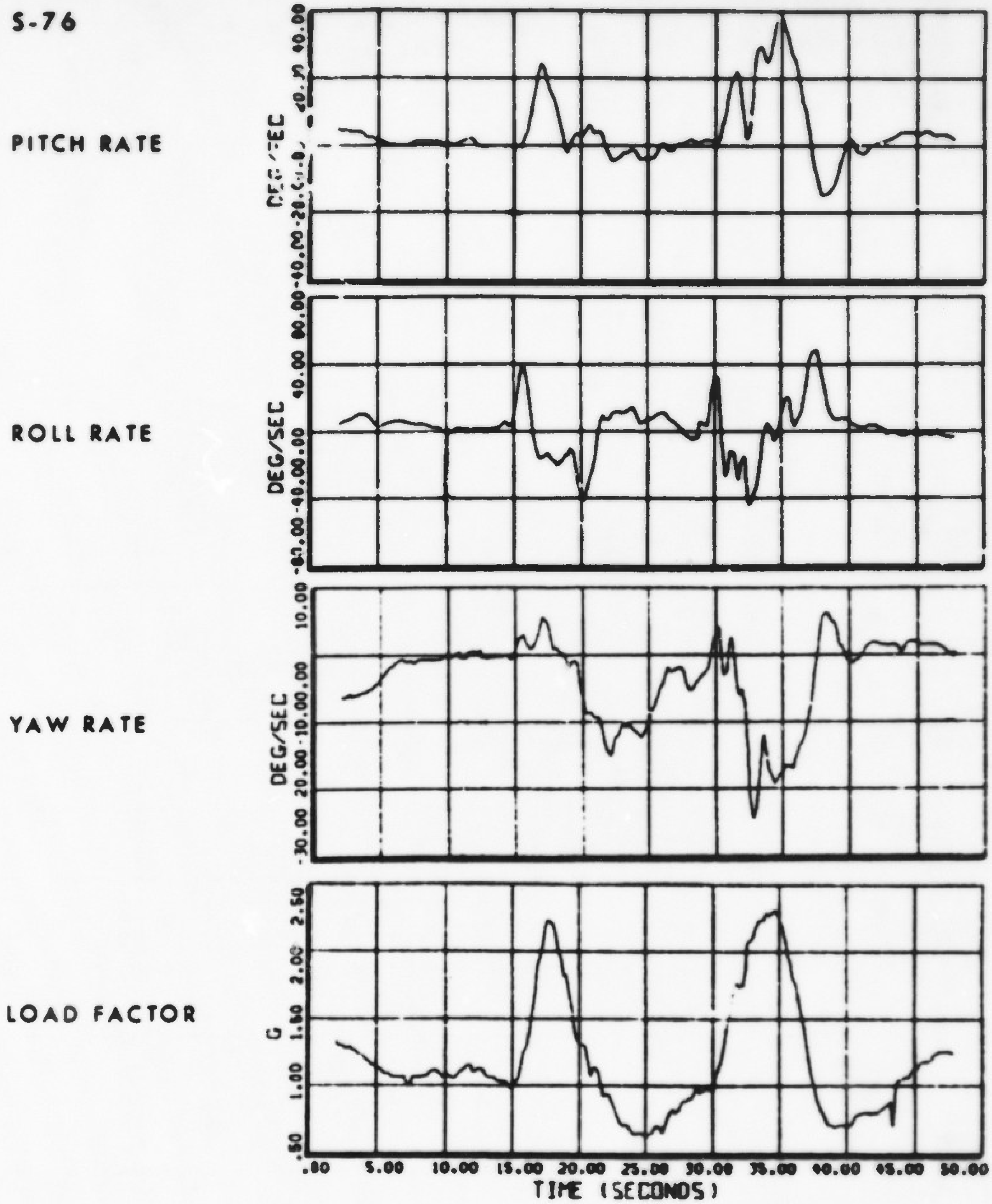


S-76 TO UH-60A LONGITUDINAL SEPARATION

(c)
Figure F-1. Continued.



(d)
Figure F-1. Continued.



(e)

Figure F-1. Continued.

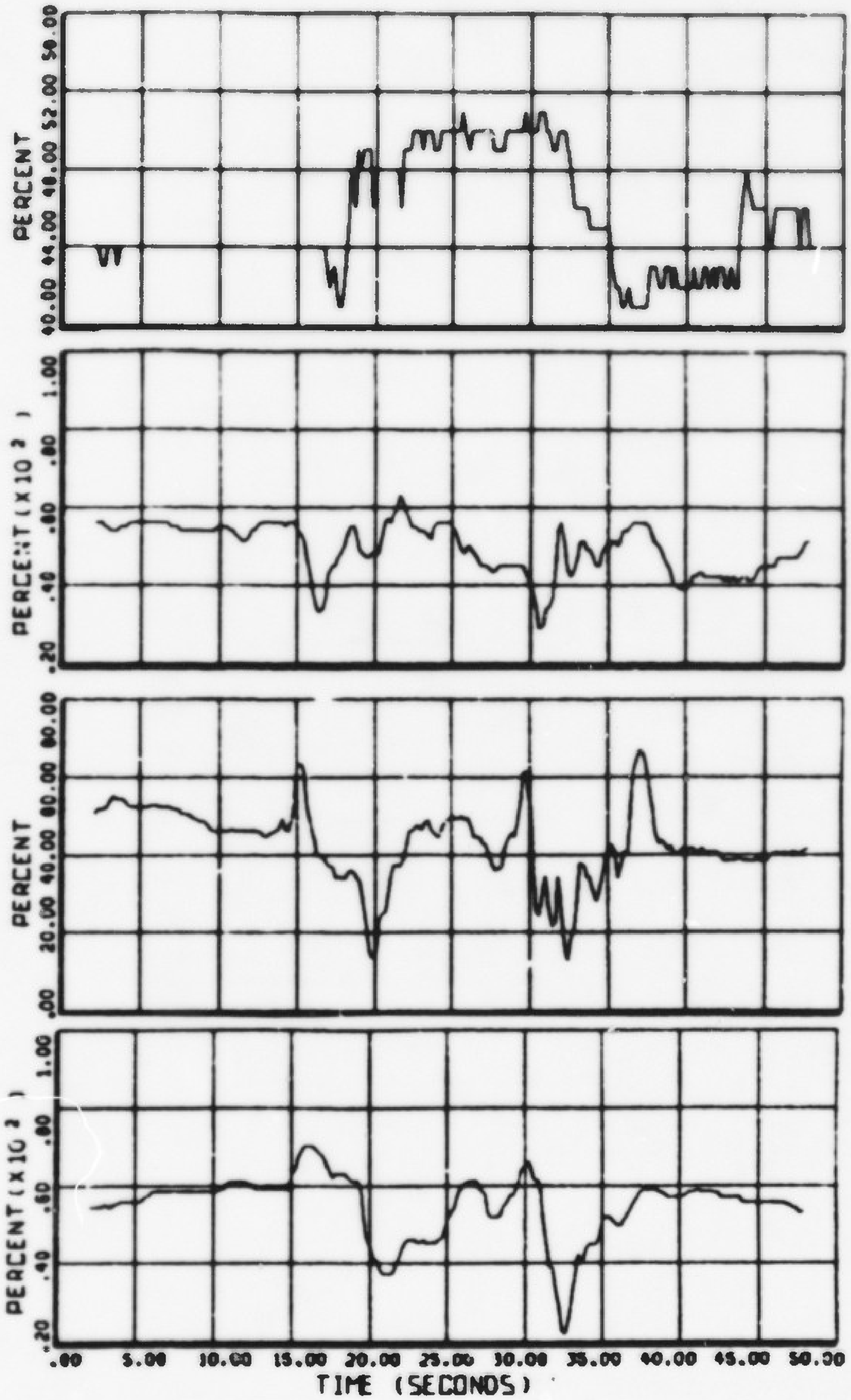
S-76

COLLECTIVE

LONGITUDINAL STICK

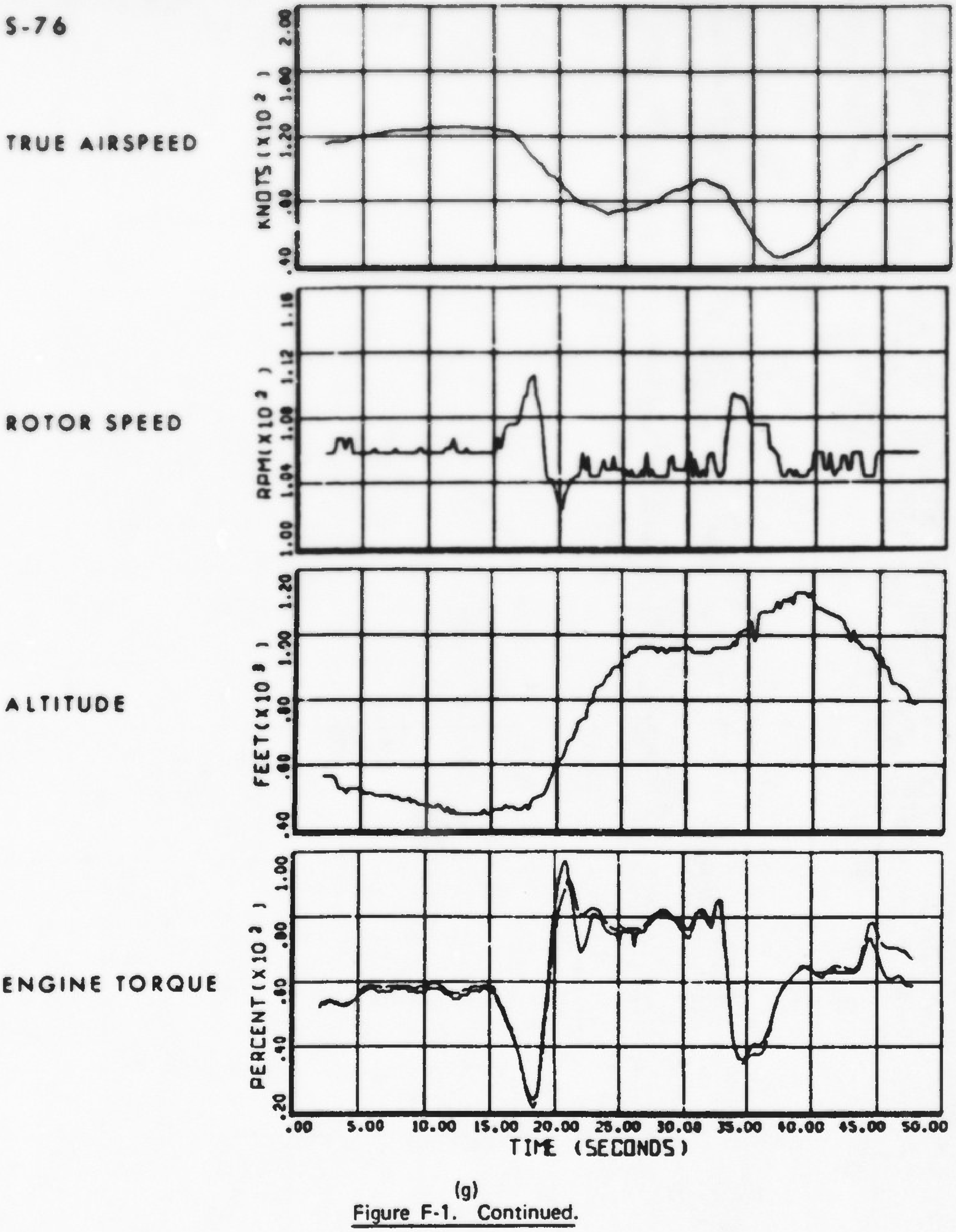
LATERAL STICK

PEDAL

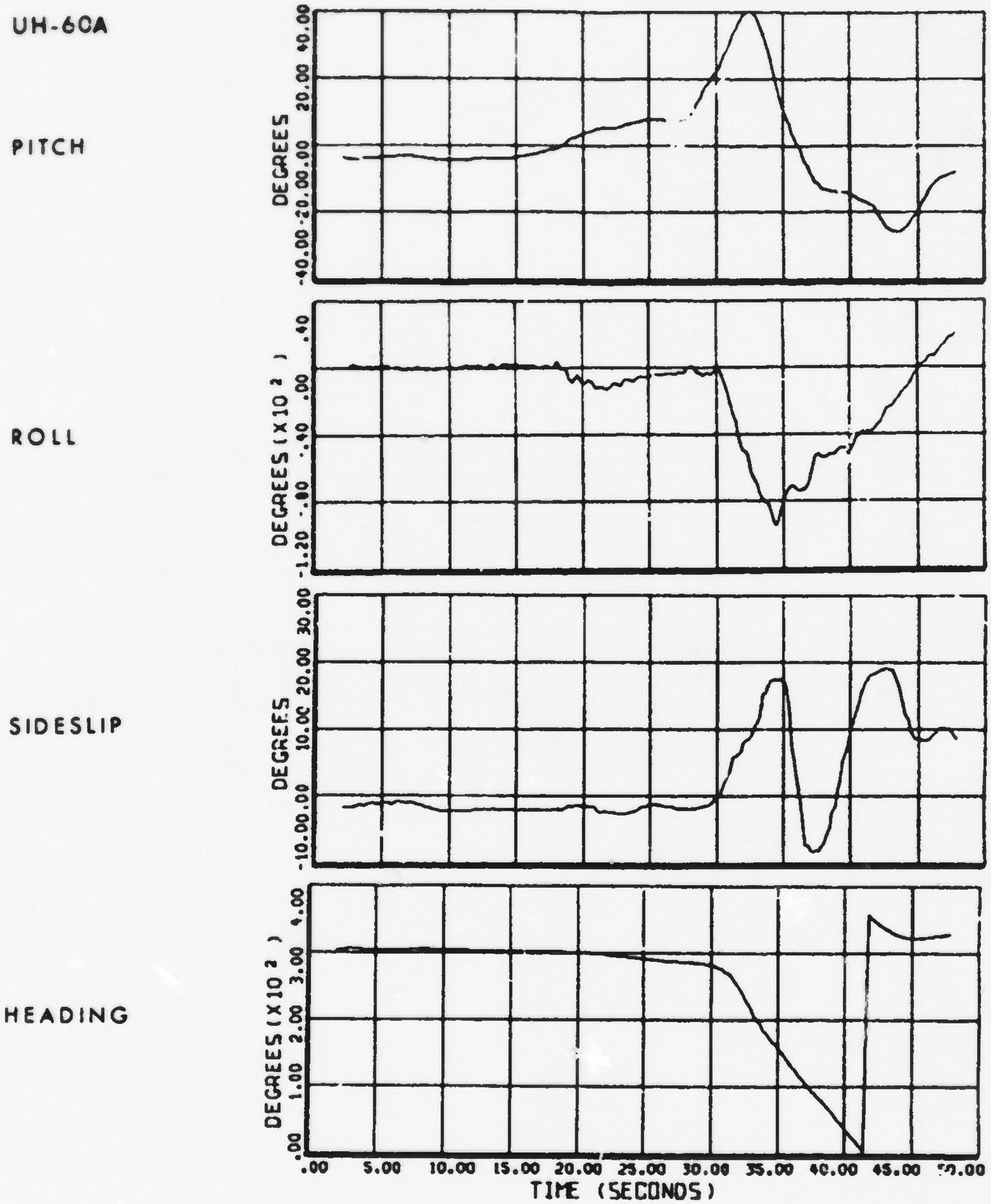


(f)
Figure F-1. Continued.

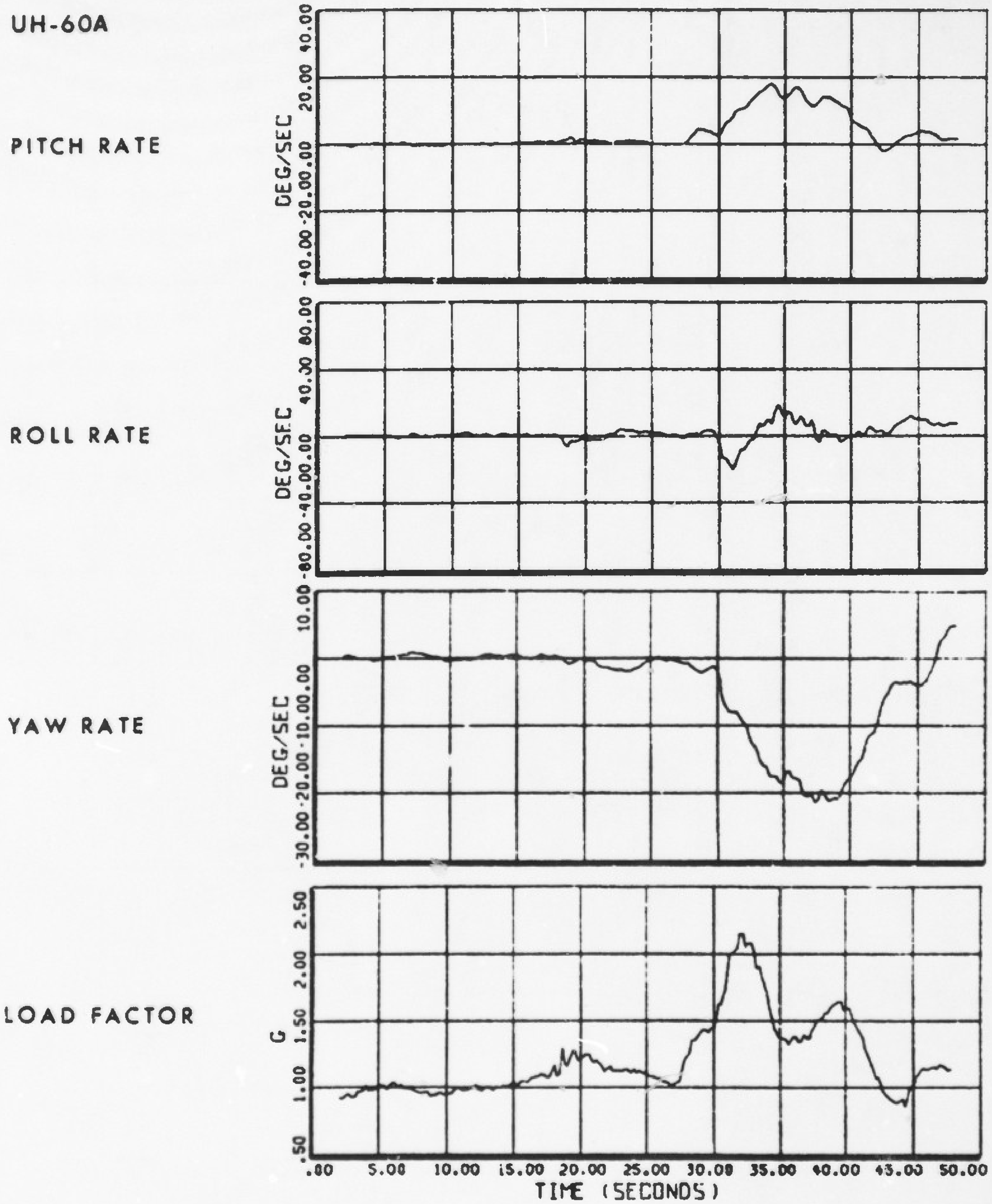
S-76



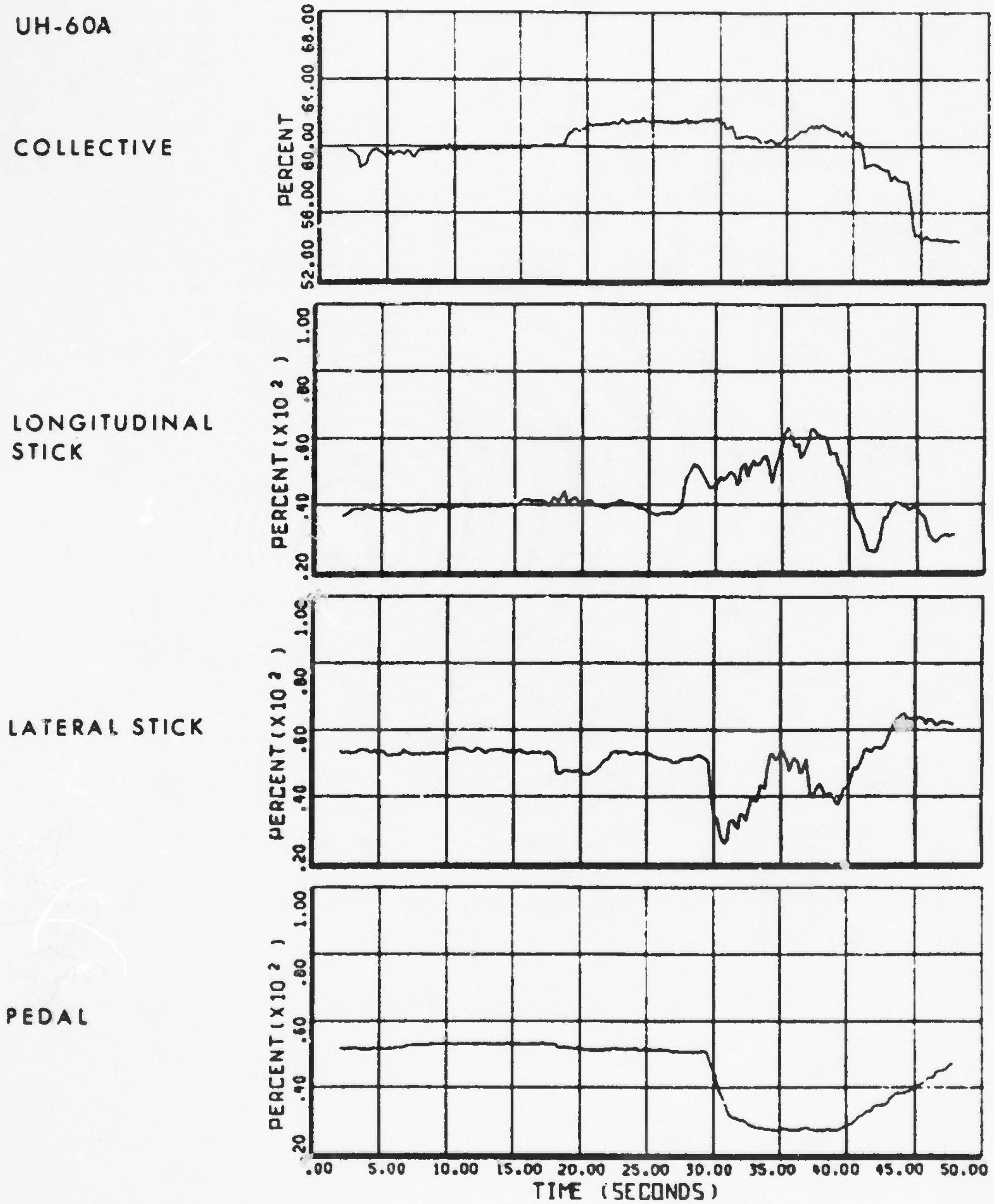
(g)
Figure F-1. Continued.



(h)
Figure F-1. Continued.

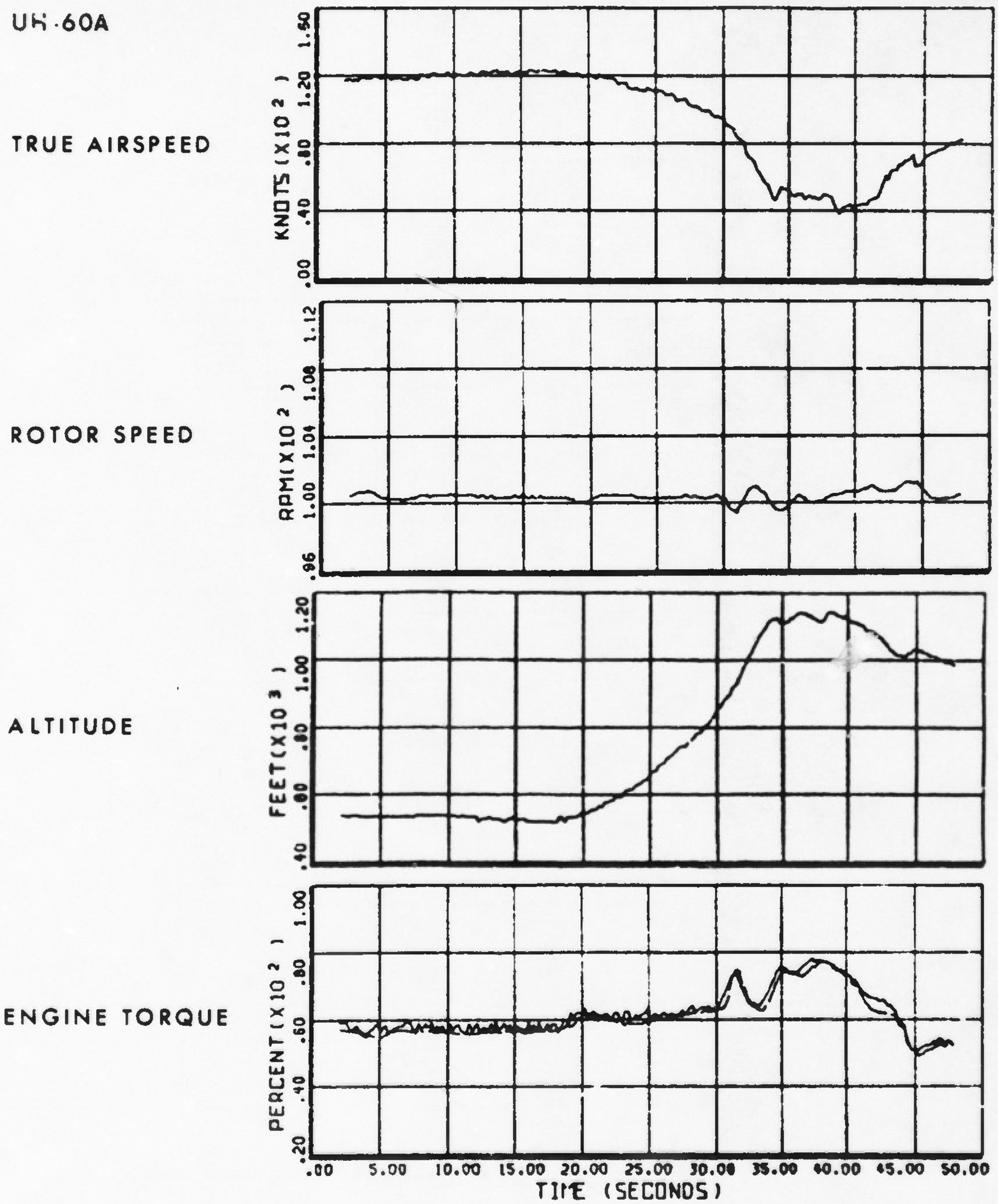


(i)
Figure F-1. Continued.



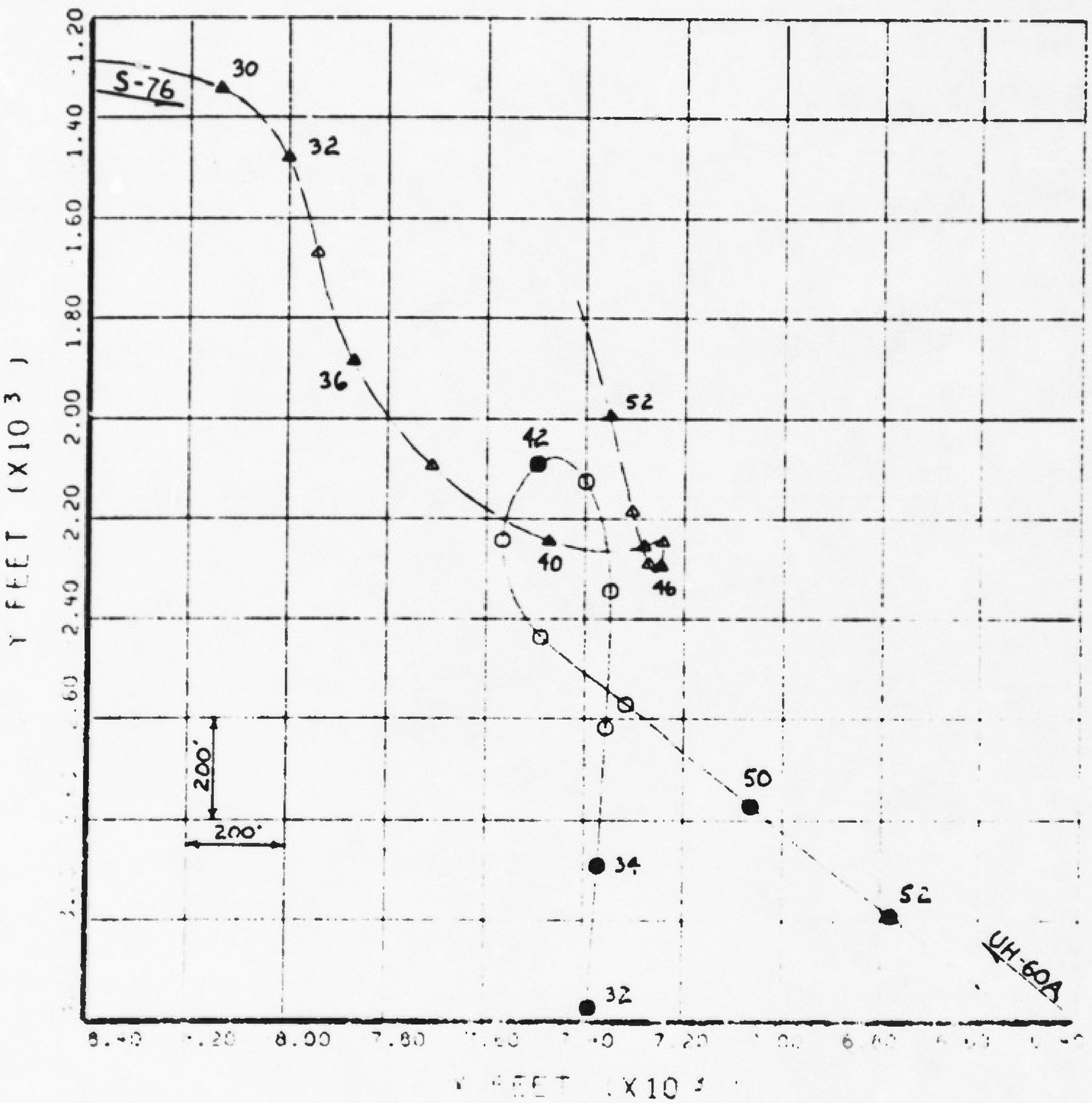
(j)

Figure F-1. Continued.



(k)

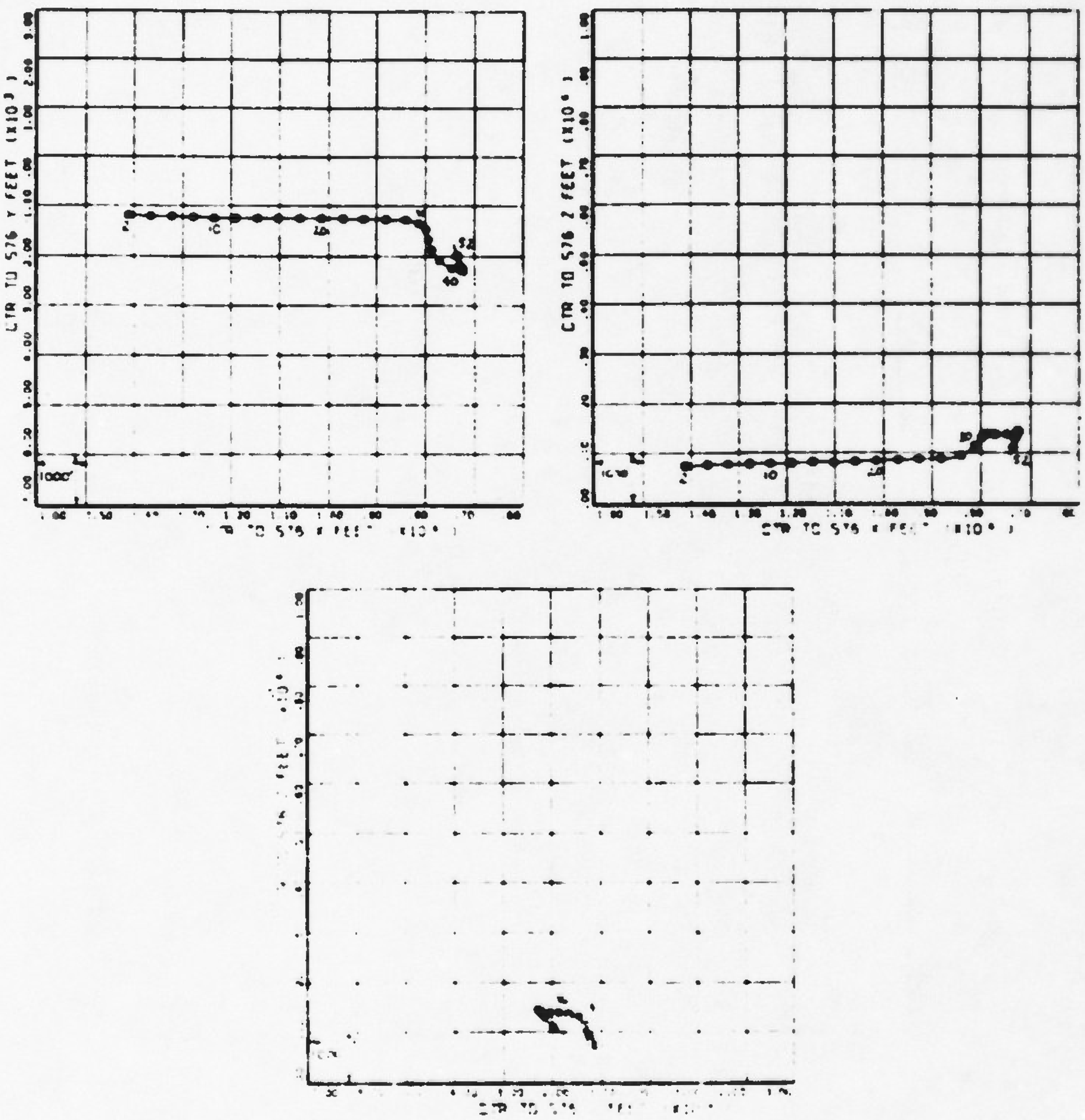
Figure F-1. Continued.



(a)

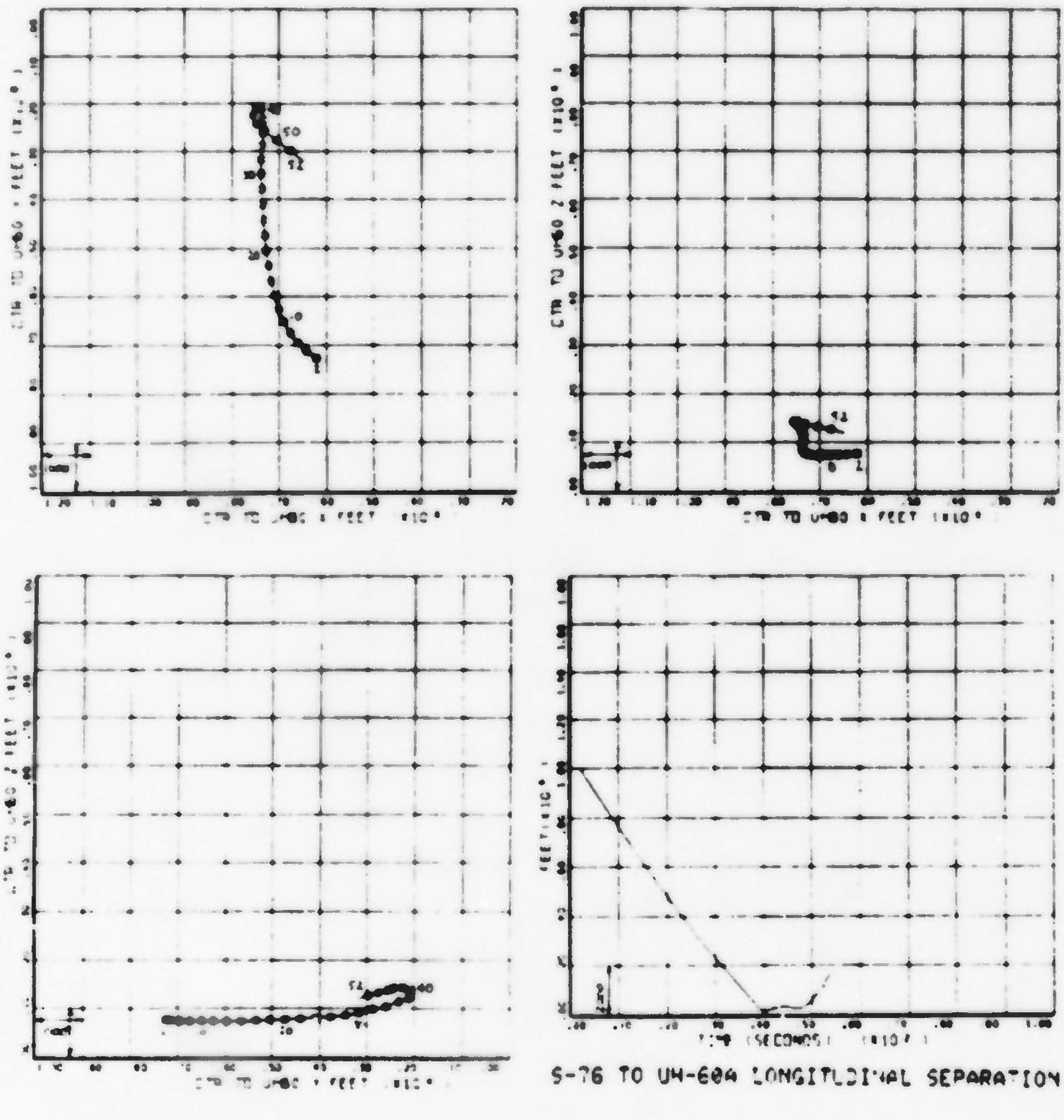
Figure F-2. Free engagement – UH-60A attacks S-76 abeam (level)

S-76
FLIGHT PATH PLOTS

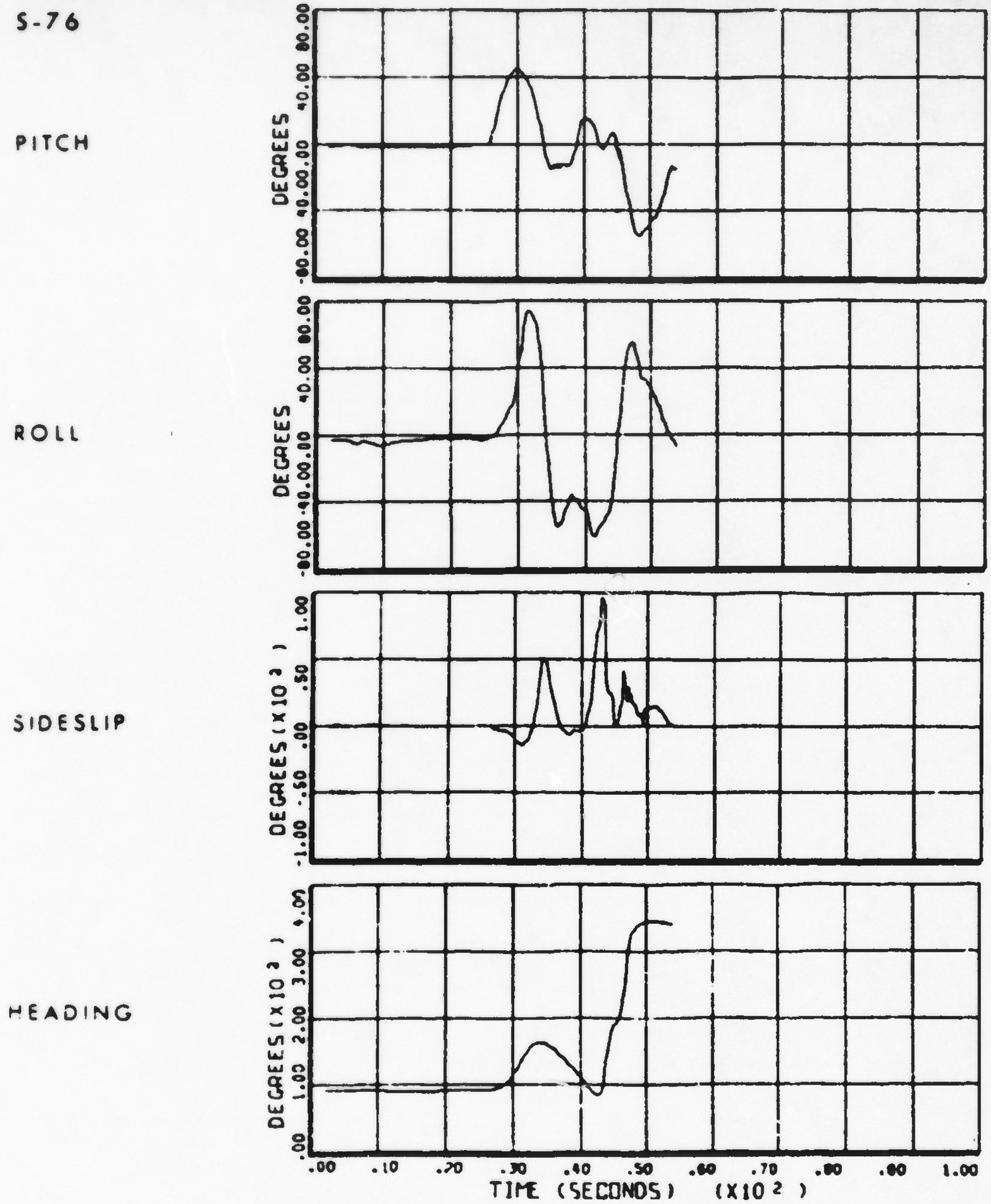


(b)
Figure F-2. Continued.

UH-60A
FLIGHT PATH PLOTS

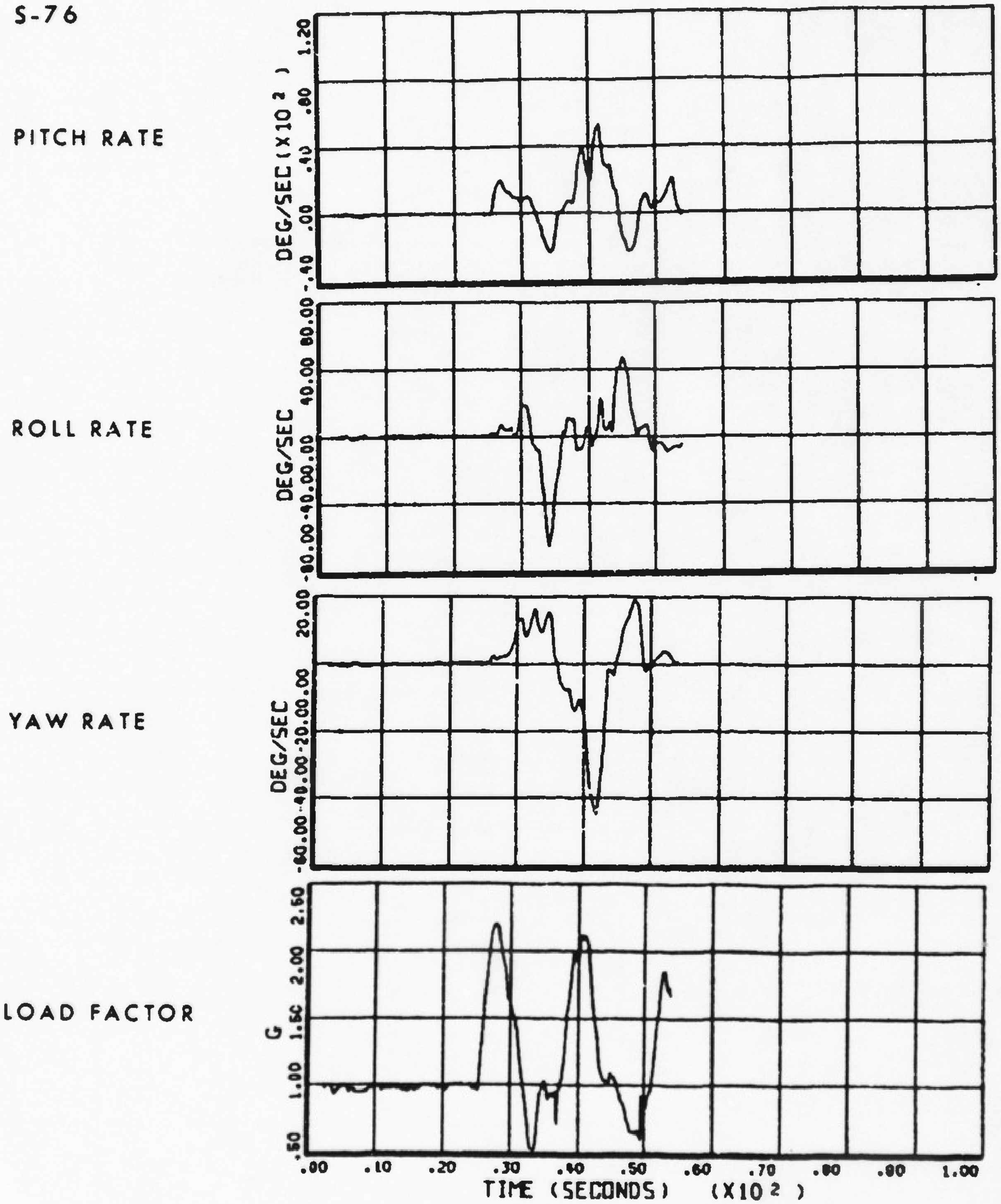


(c)
Figure F-2. Continued.



(d)
Figure F-2. Continued.

S-76



(e)

Figure F-2. Continued.

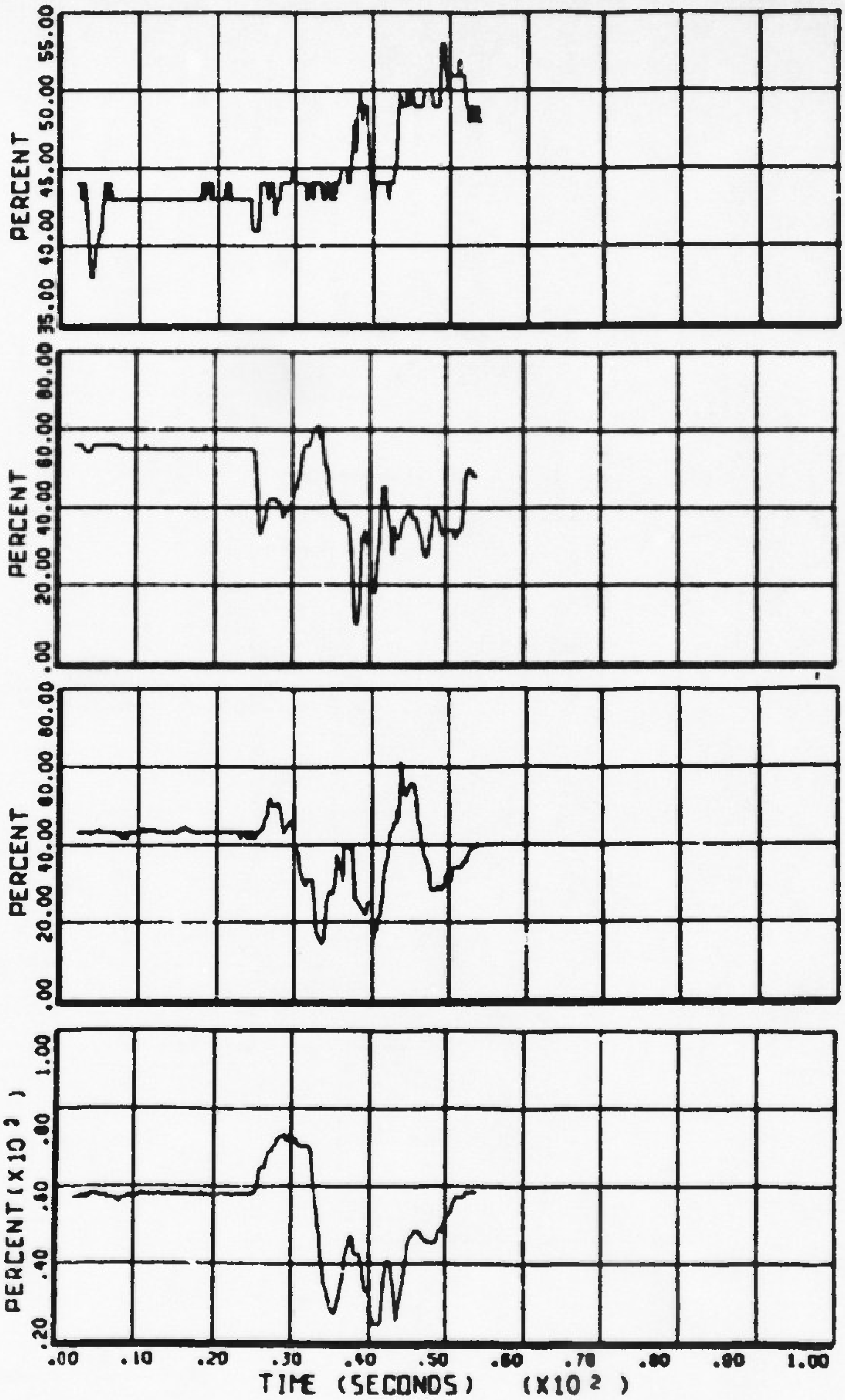
S-76

COLLECTIVE

LONGITUDINAL STICK

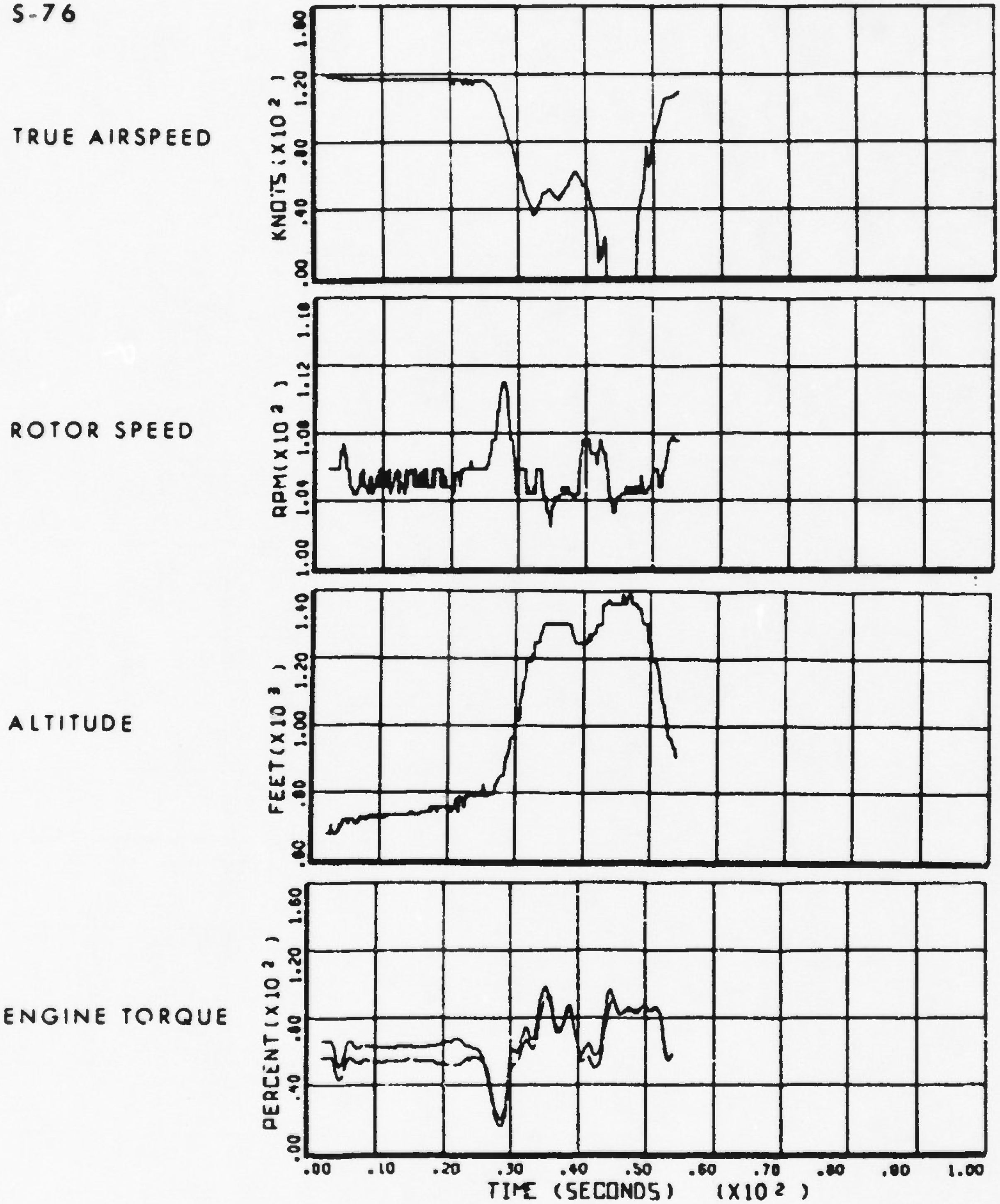
LATERAL STICK

PEDAL



(f)

Figure F-2. Continued.



(g)
Figure F-2. Continued.

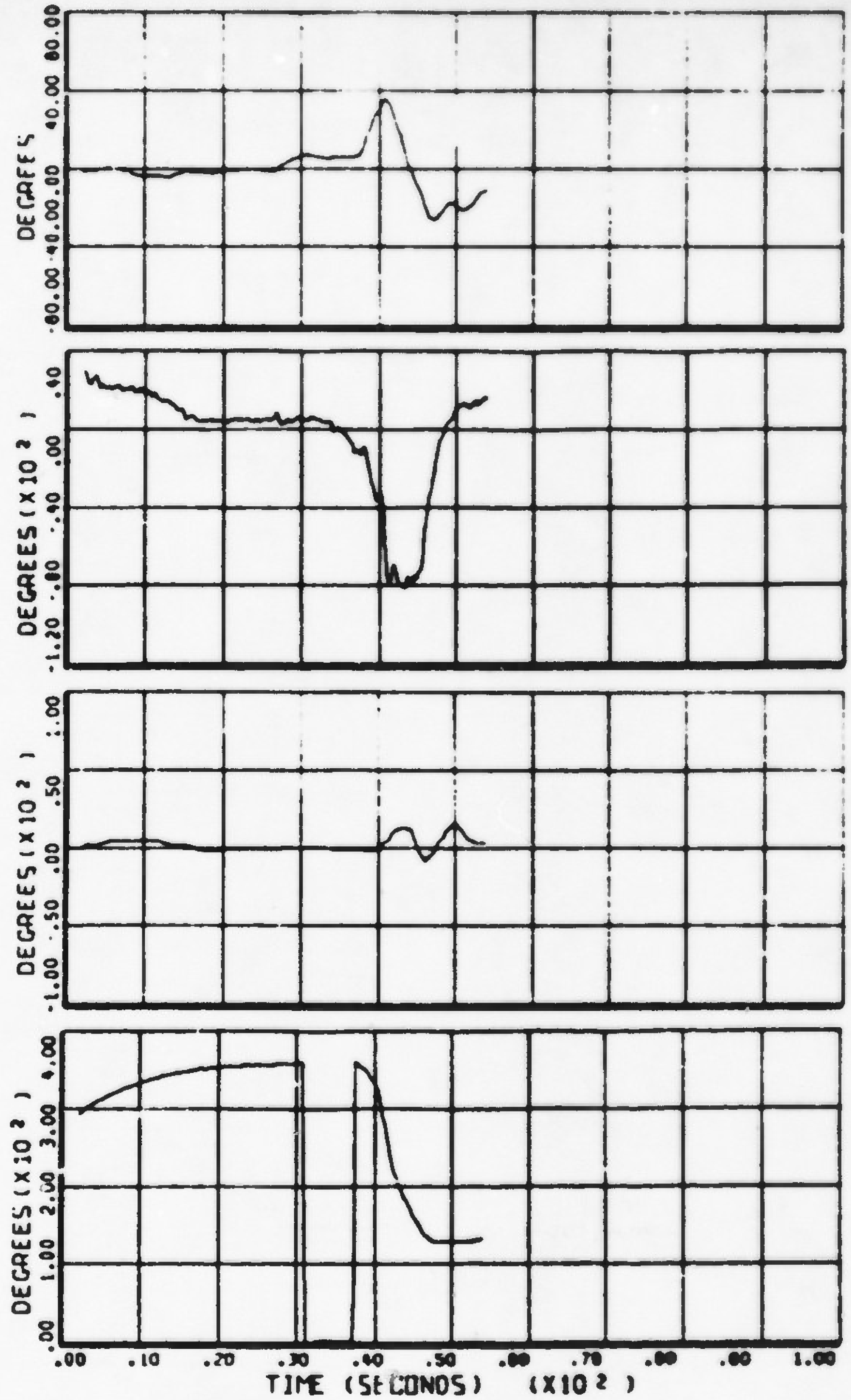
UH-60A

PITCH

ROLL

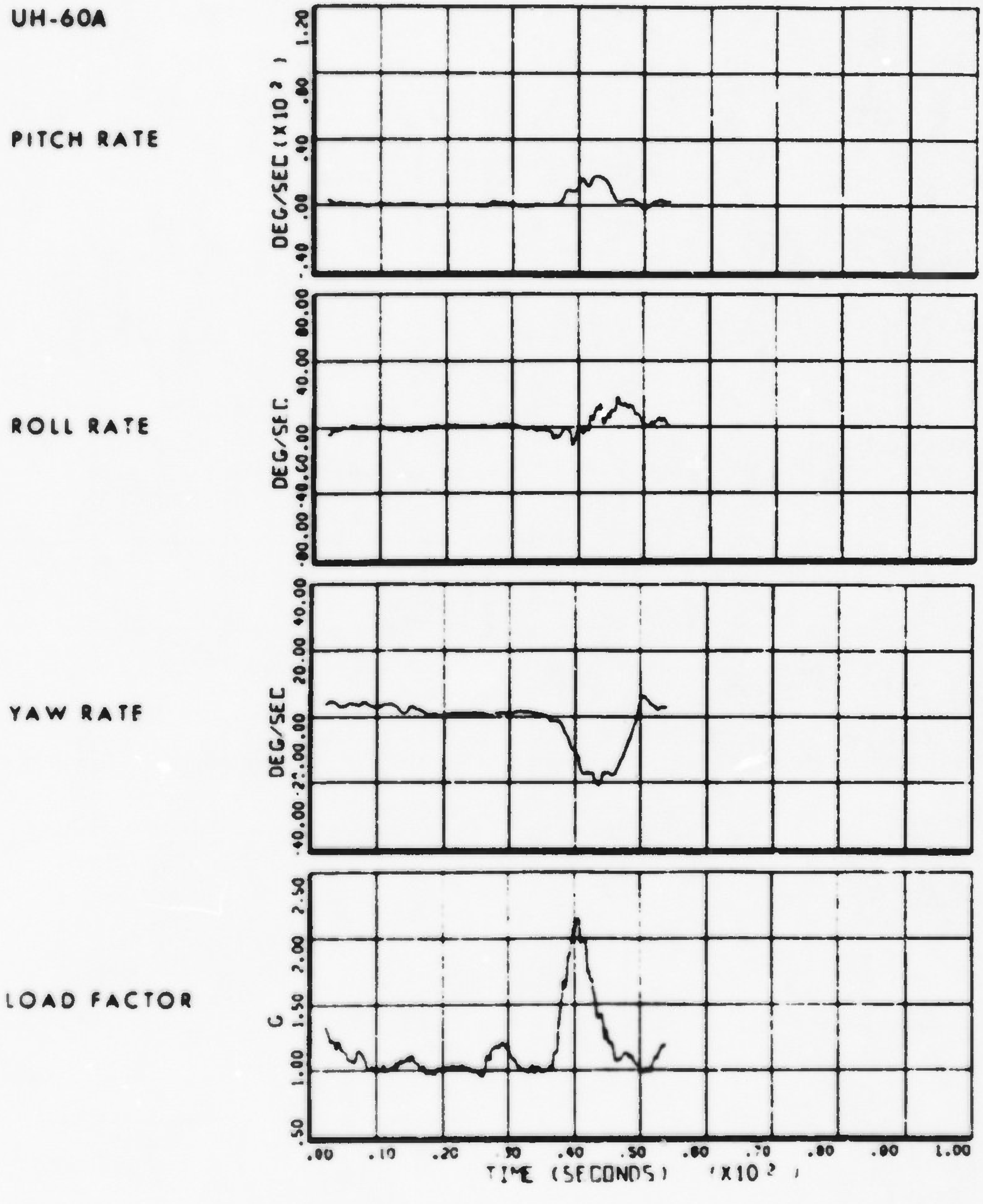
SIDESLIP

HEADING



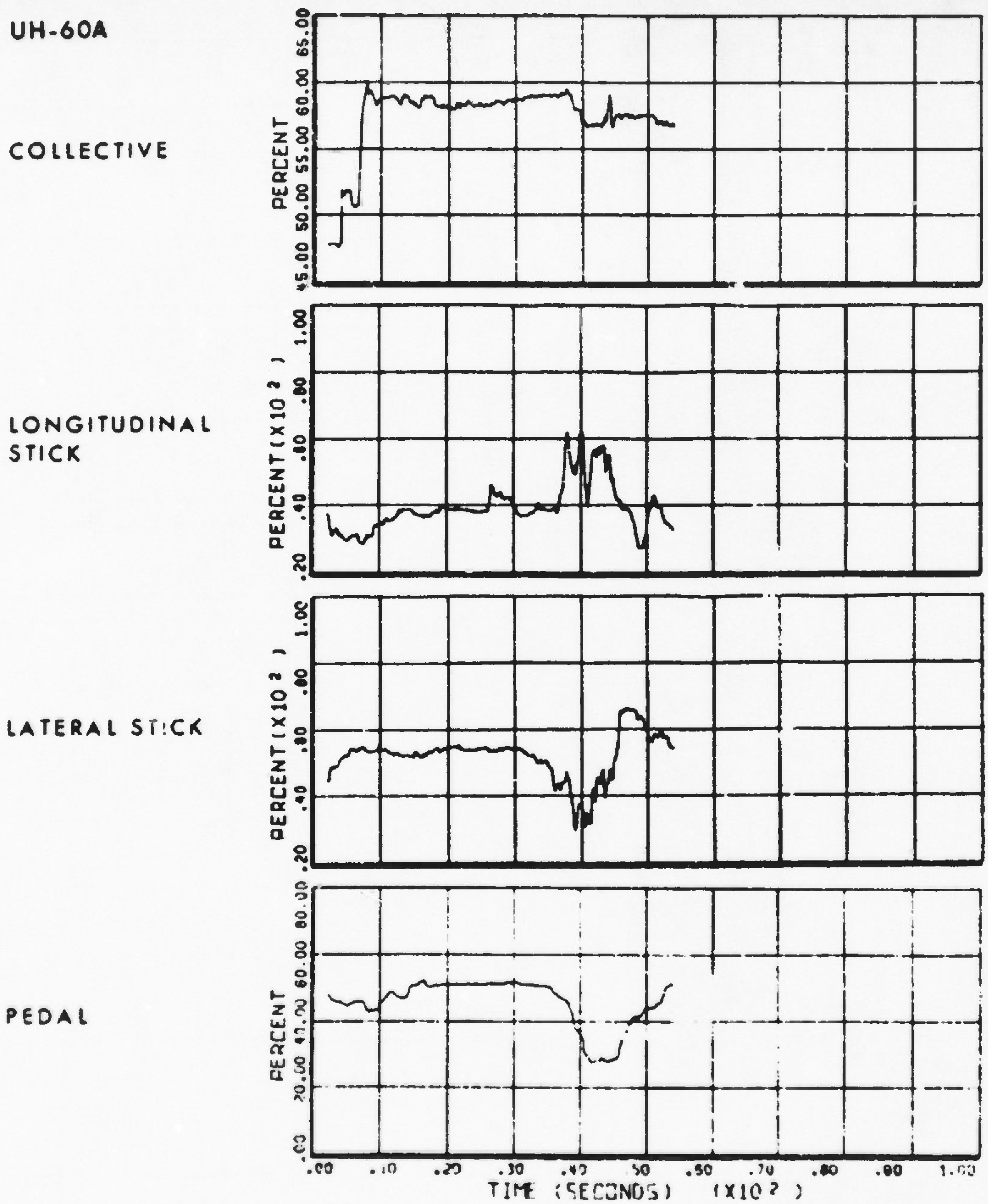
(h)

Figure F-2. Continued.

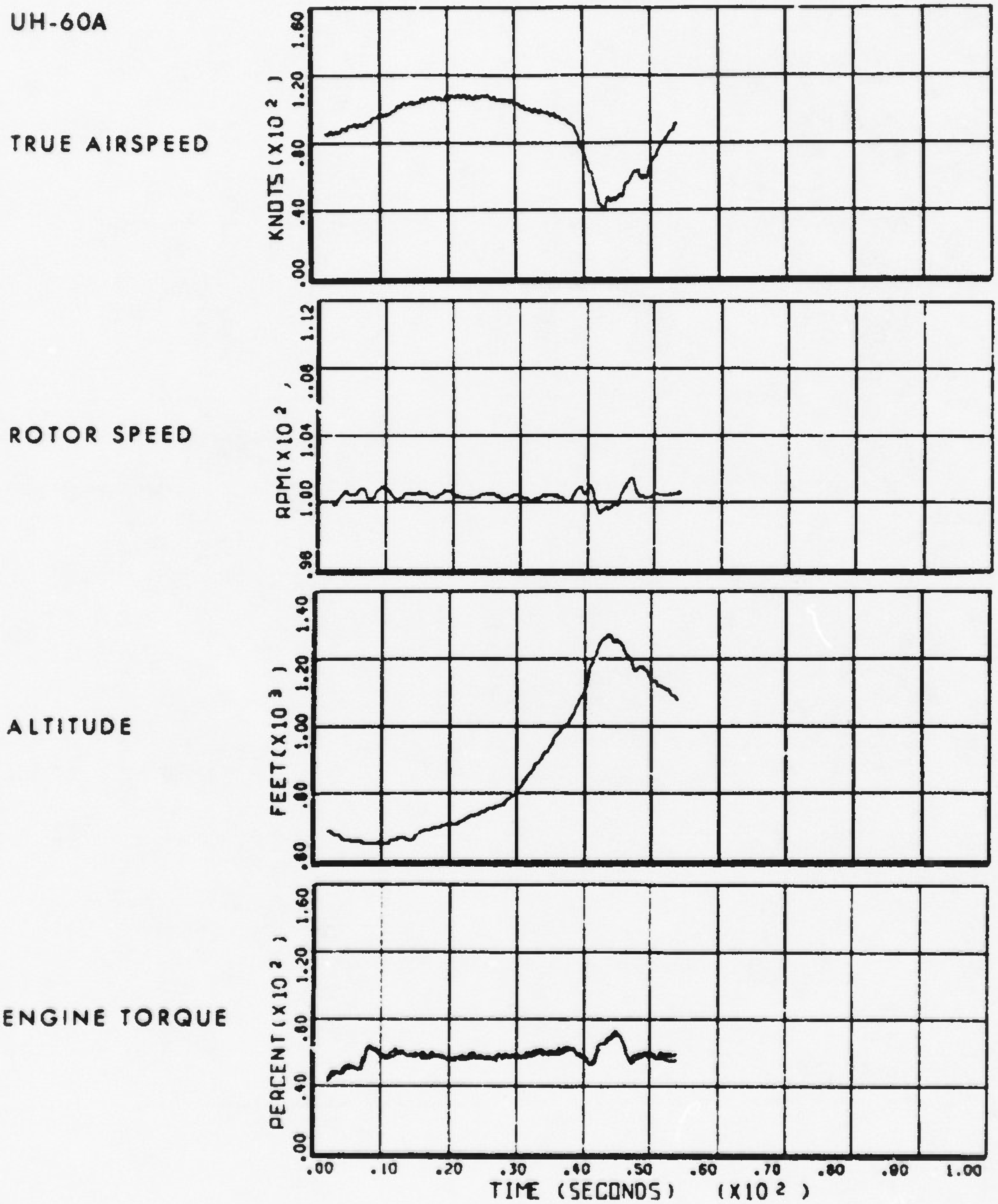


(i)
Figure F-2. Continued.

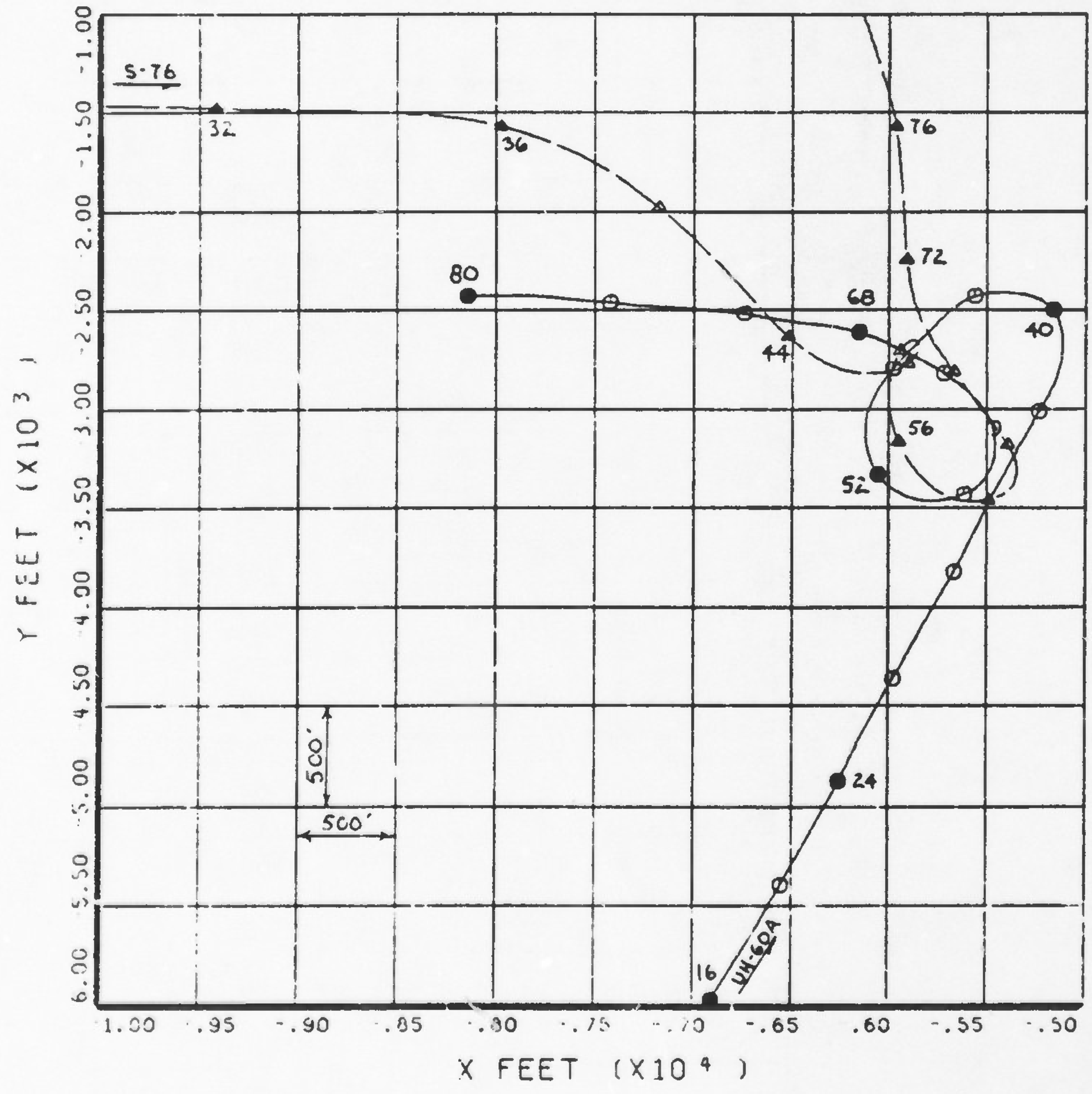
UH-60A



(i)
Figure F-2. Continued.



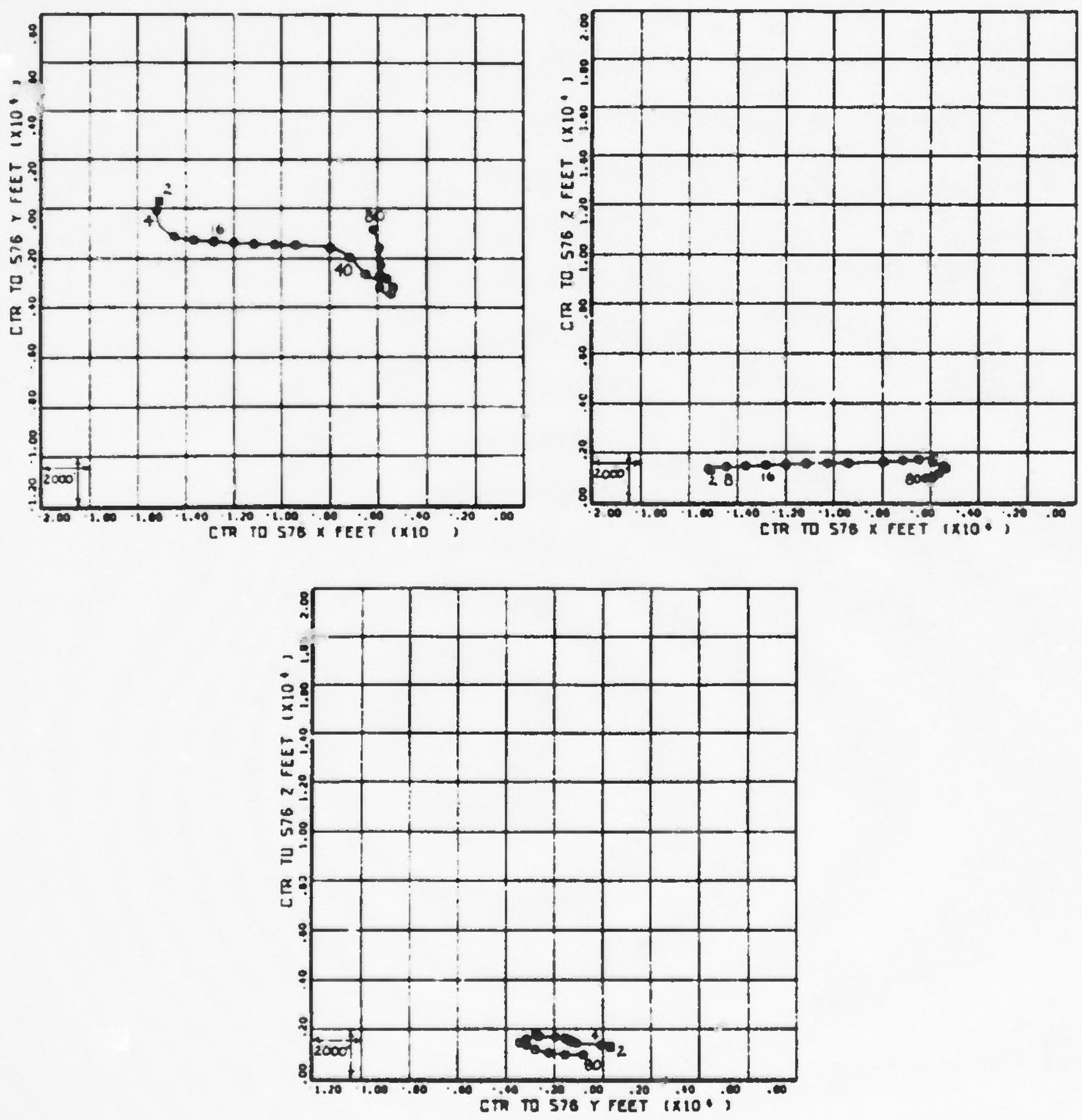
(k)
Figure F-2. Continued.



(a)

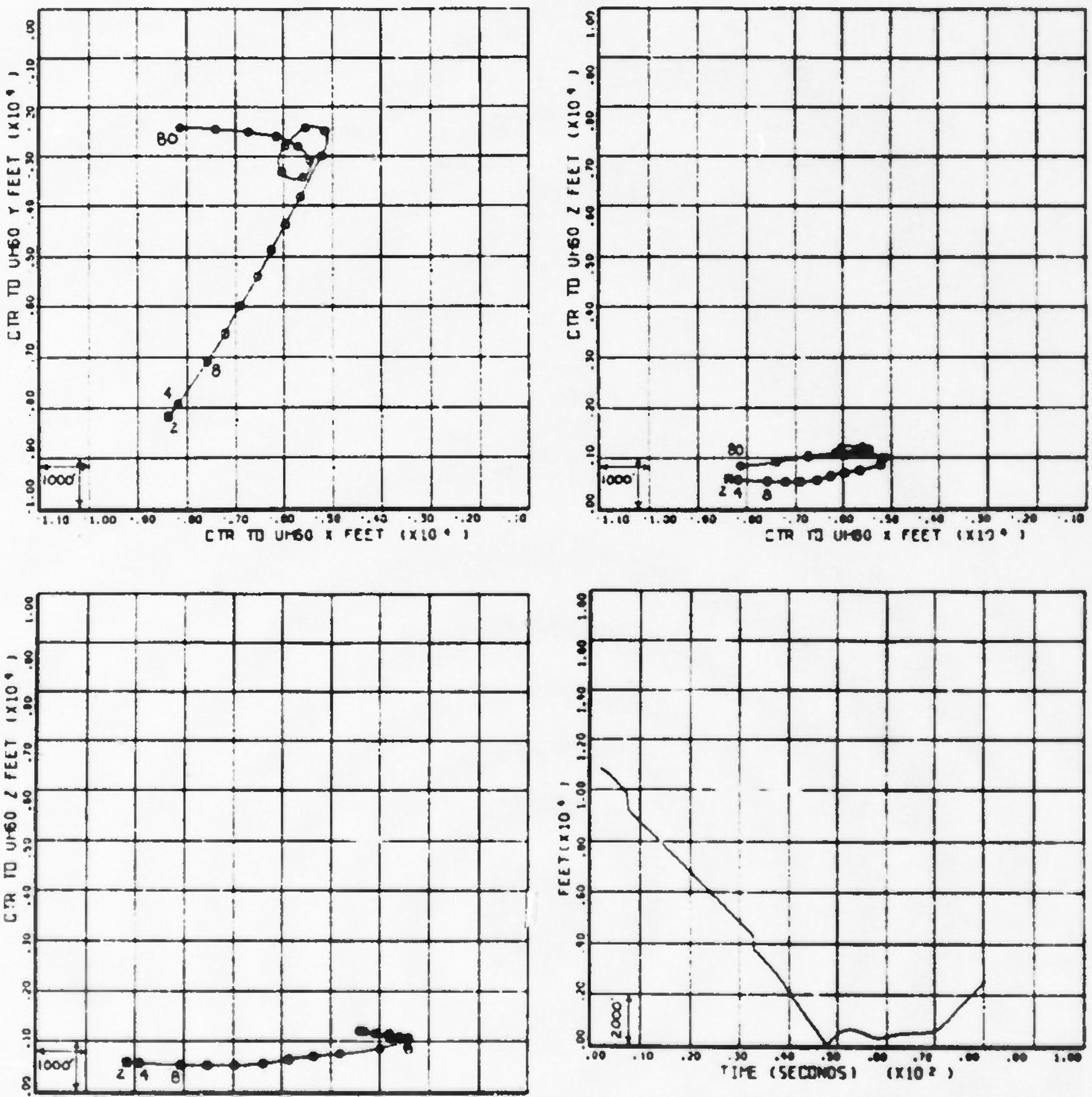
Figure F-3. Free engagement – UH-60A attacks S-76 abeam (UH-60A low).

S-76
FLIGHT PATH PLOTS



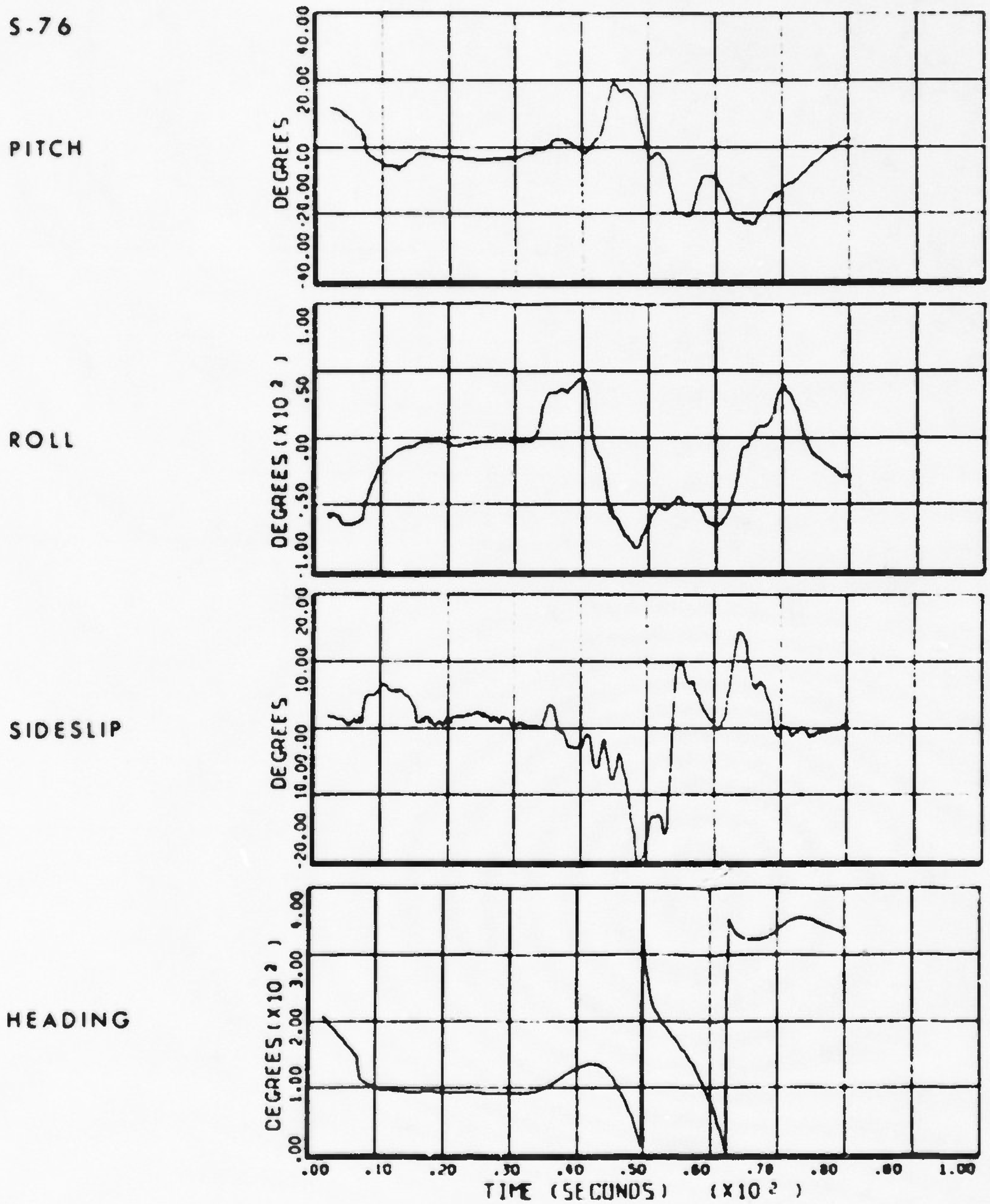
(b)
Figure F-3. Continued.

UH-60A
FLIGHT PATH PLOTS



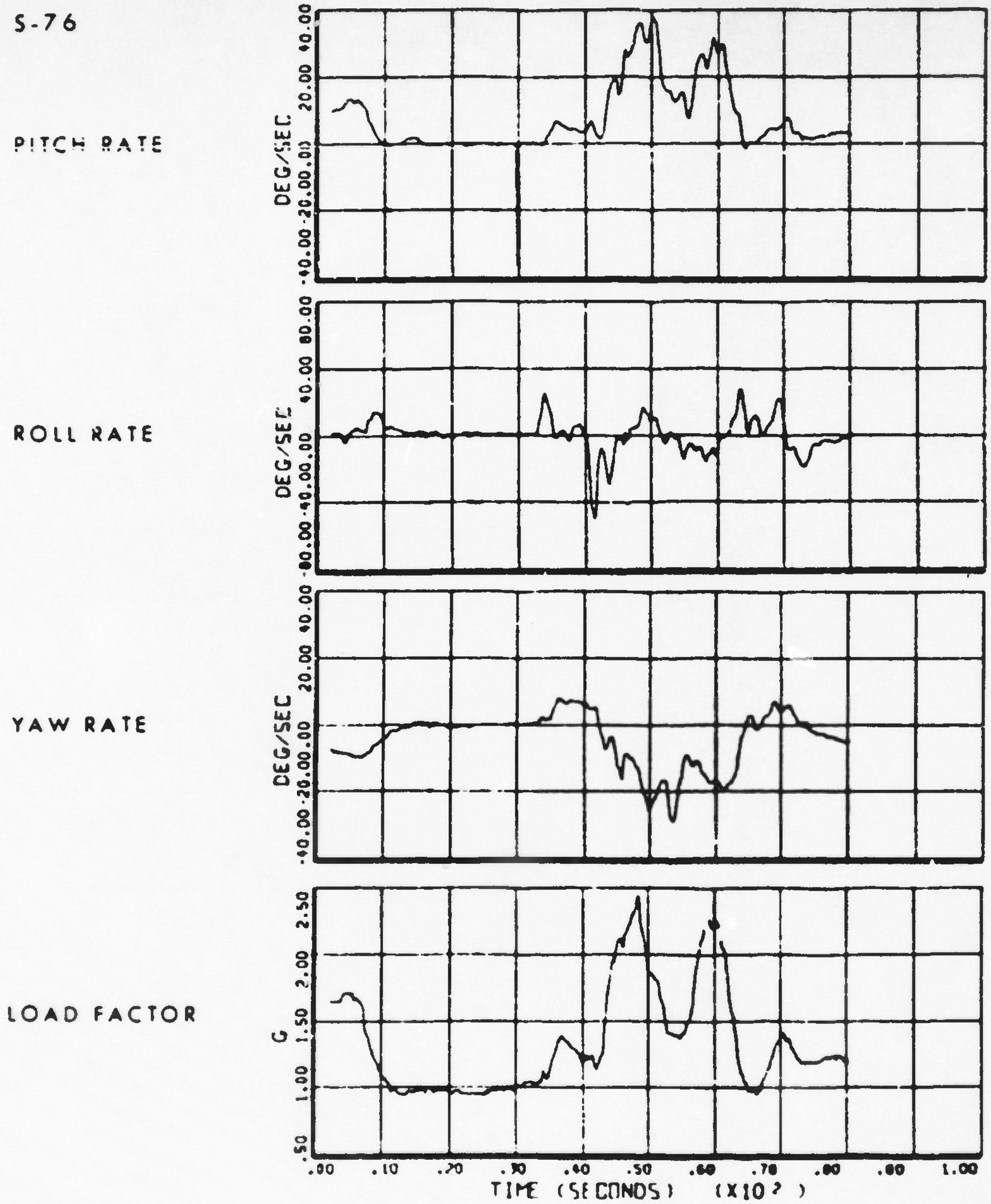
S-76 TO UH-60A LONGITUDINAL SEPARATION

(c)
Figure F-3. Continued.



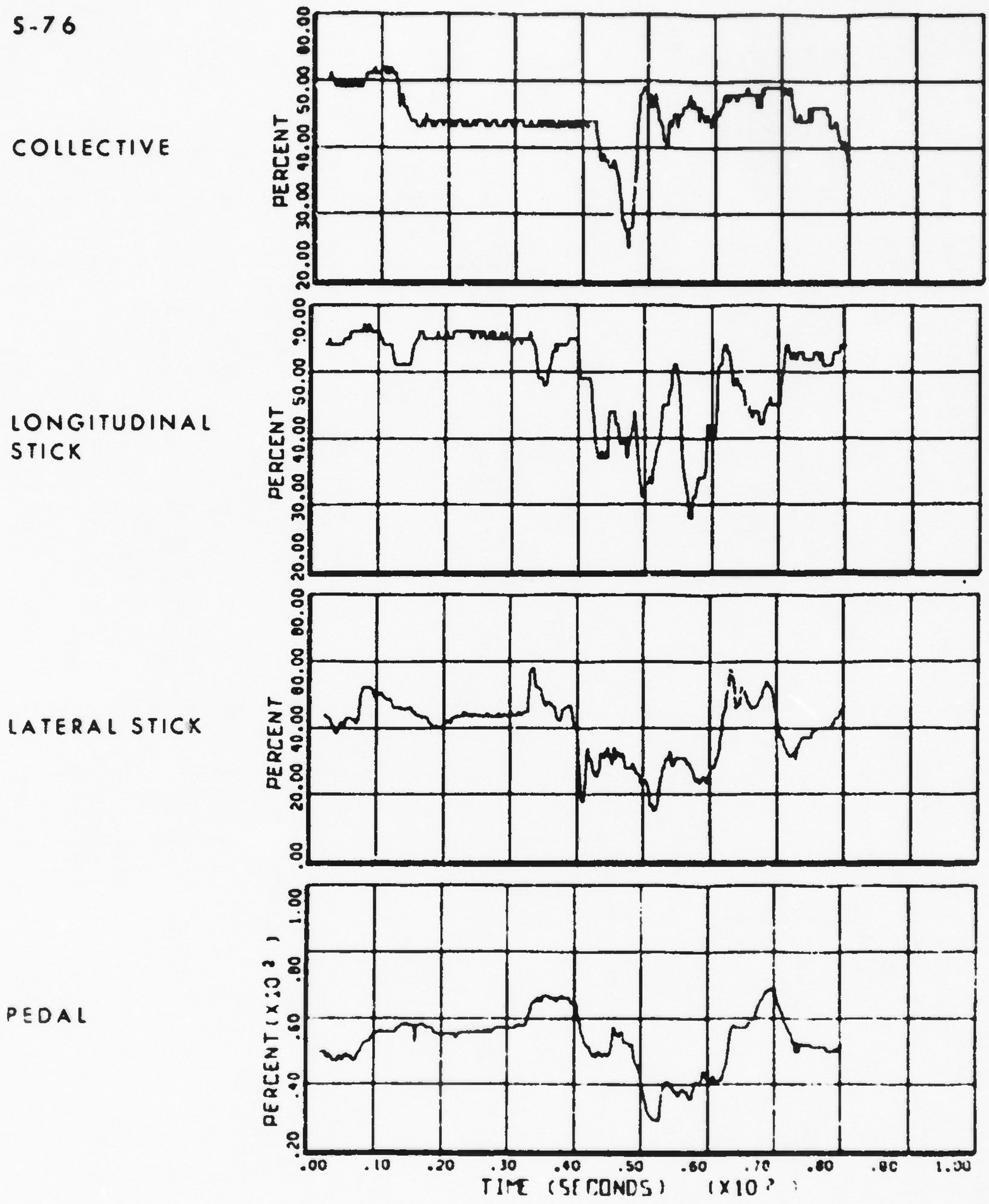
(d)

Figure F-3. Continued.



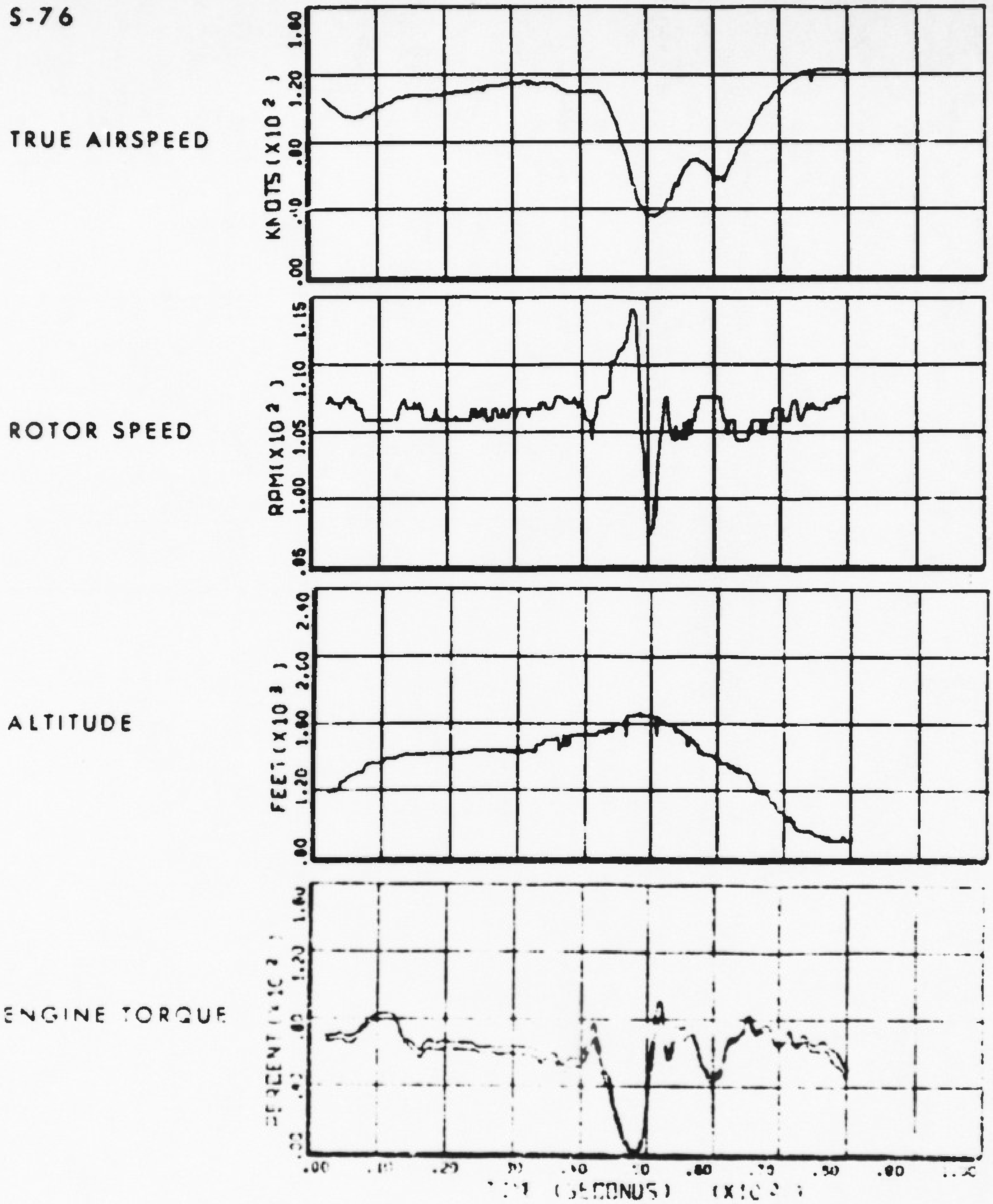
(e)
Figure F-3. Continued.

S-76



(f)

Figure F-3. Continued.



(g)

Figure F-3. Continued

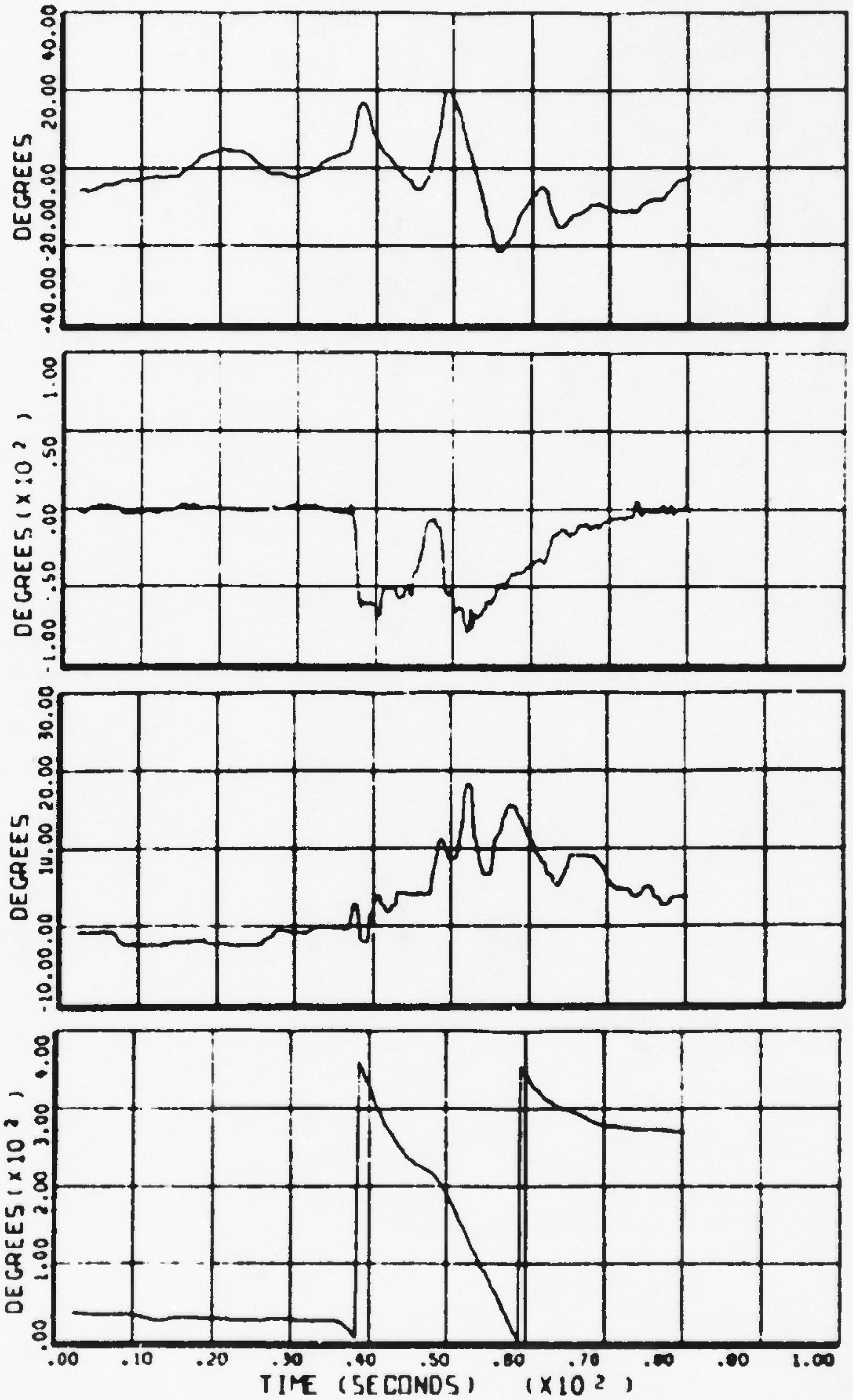
UH-60A

PITCH

ROLL

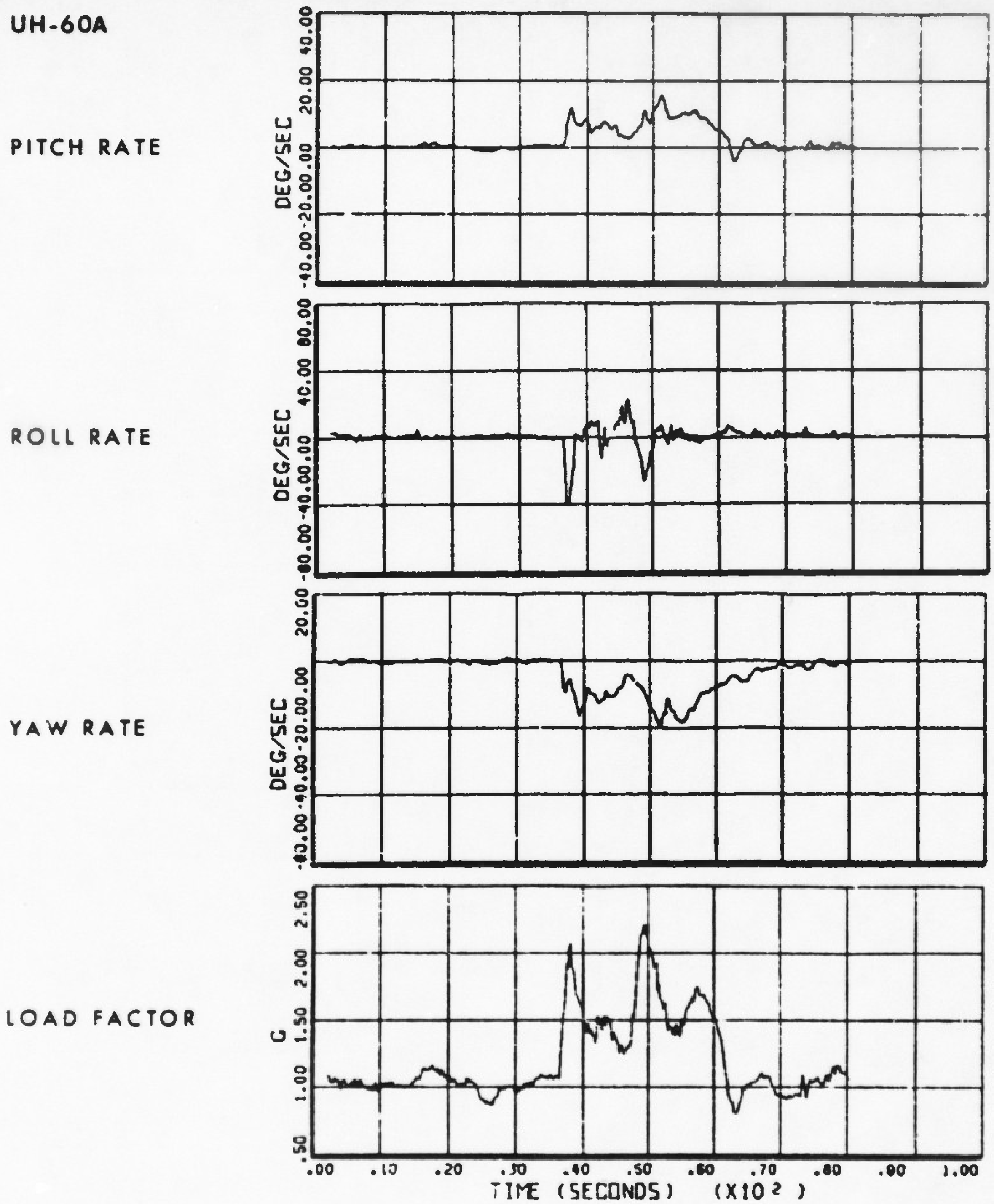
SIDESLIP

HEADING

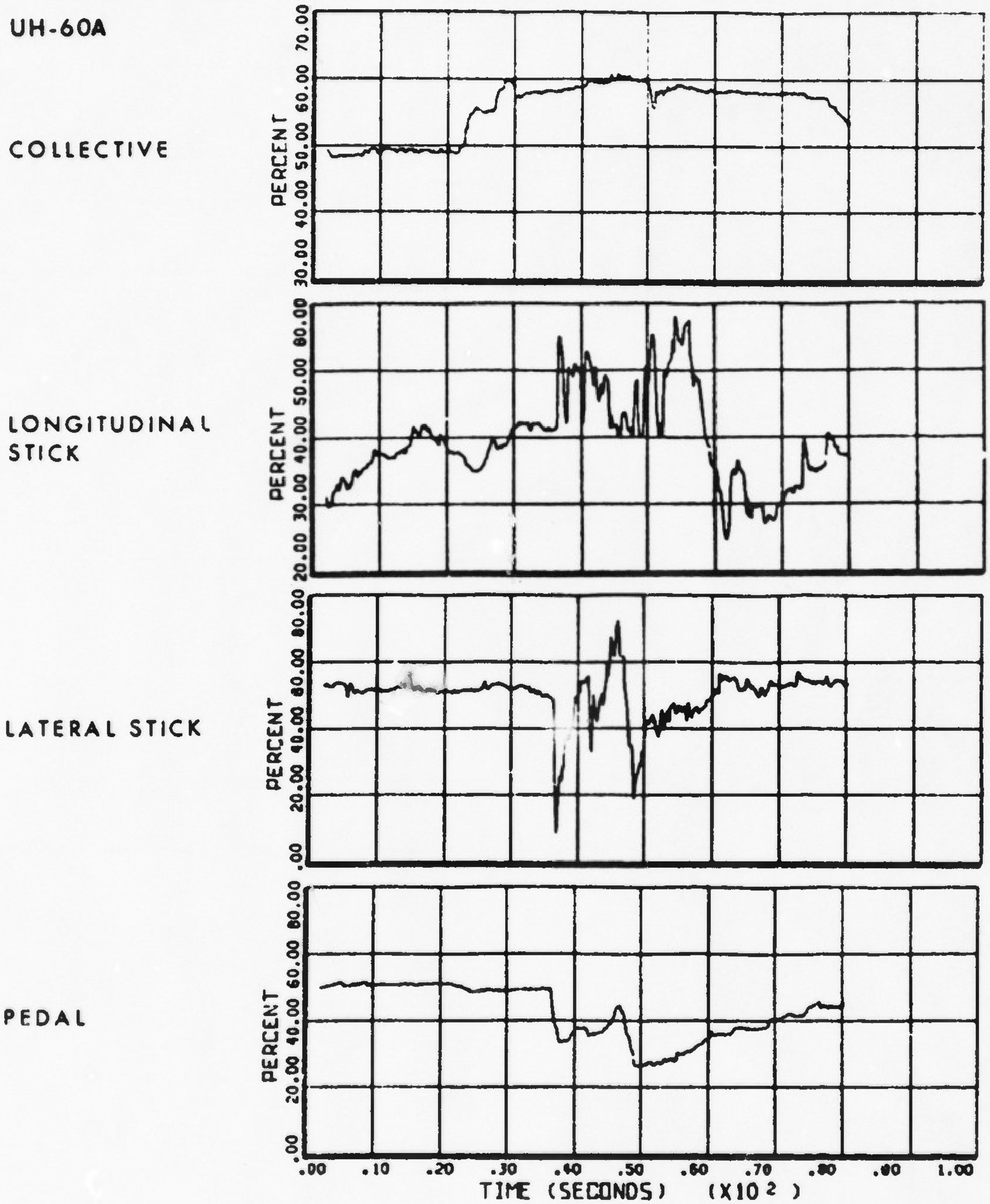


(h)

Figure F-3. Continued.



(i)
Figure F-3. Continued.



(j)
Figure F-3. Continued.

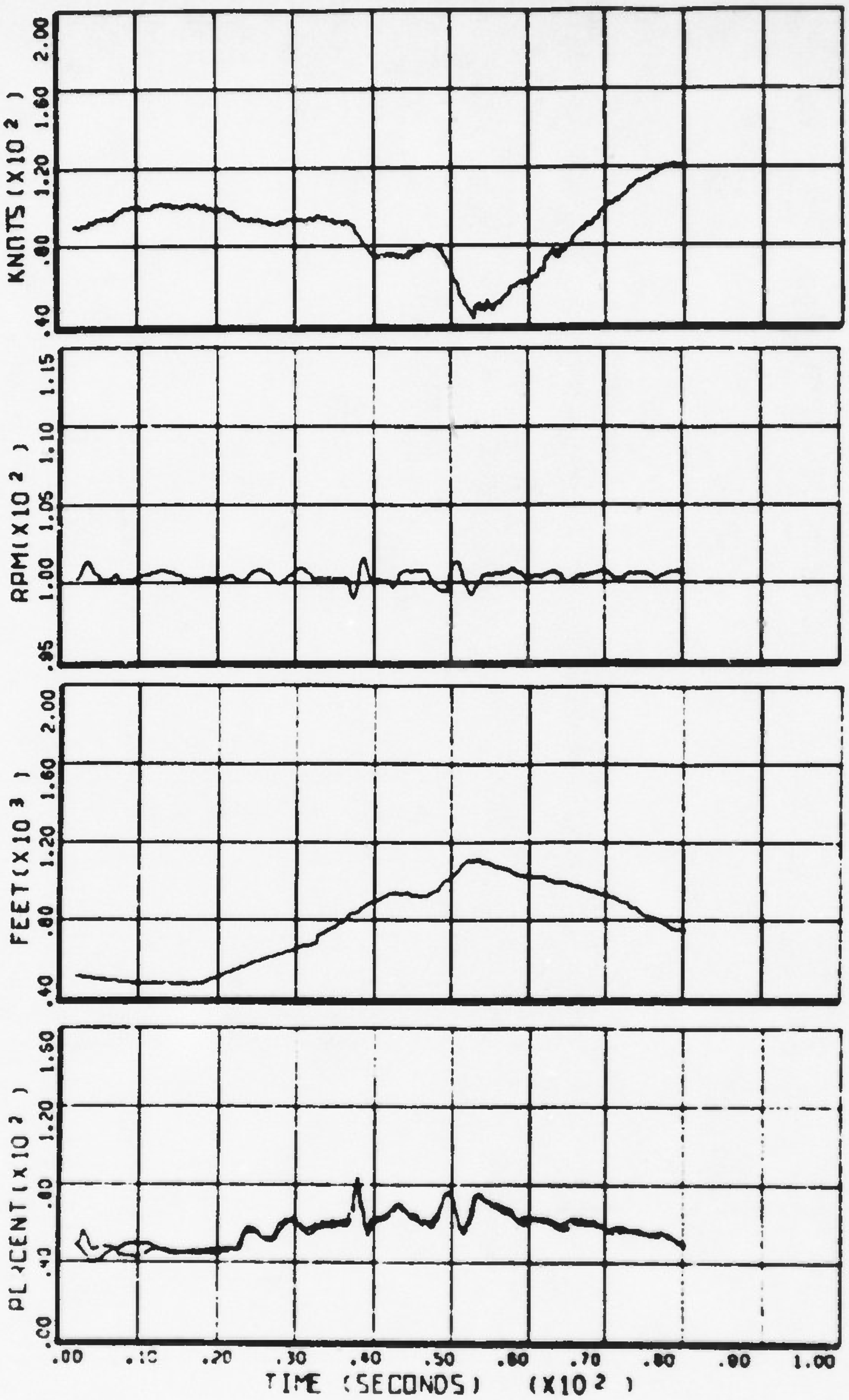
UH-60A

TRUE AIRSPEED

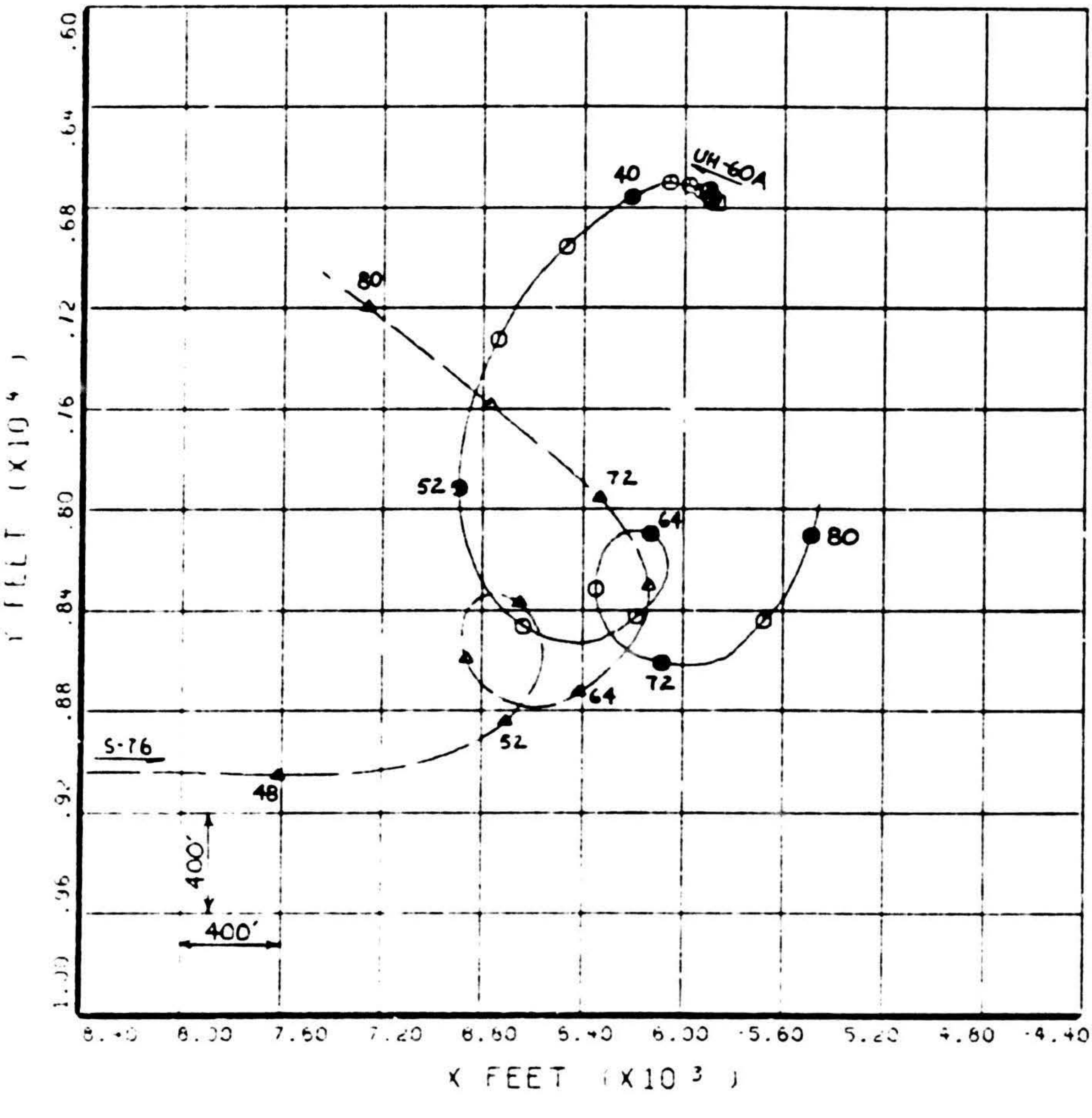
ROTOR SPEED

ALTITUDE

ENGINE TORQUE



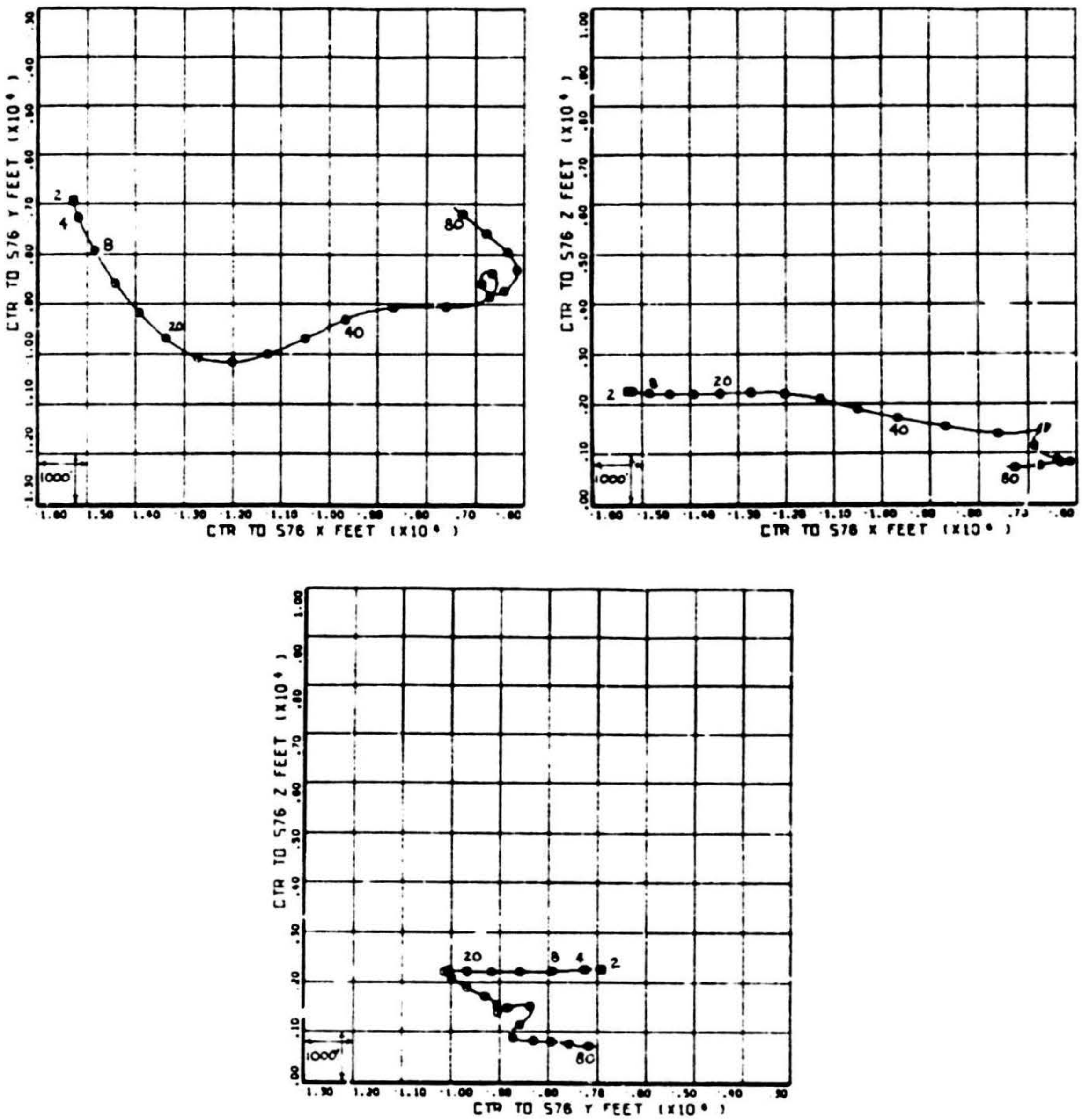
(k)
Figure F-3. Continued.



(a)
Figure F-4. Free engagement – simulated NOE (UH-60A hover).

S-76

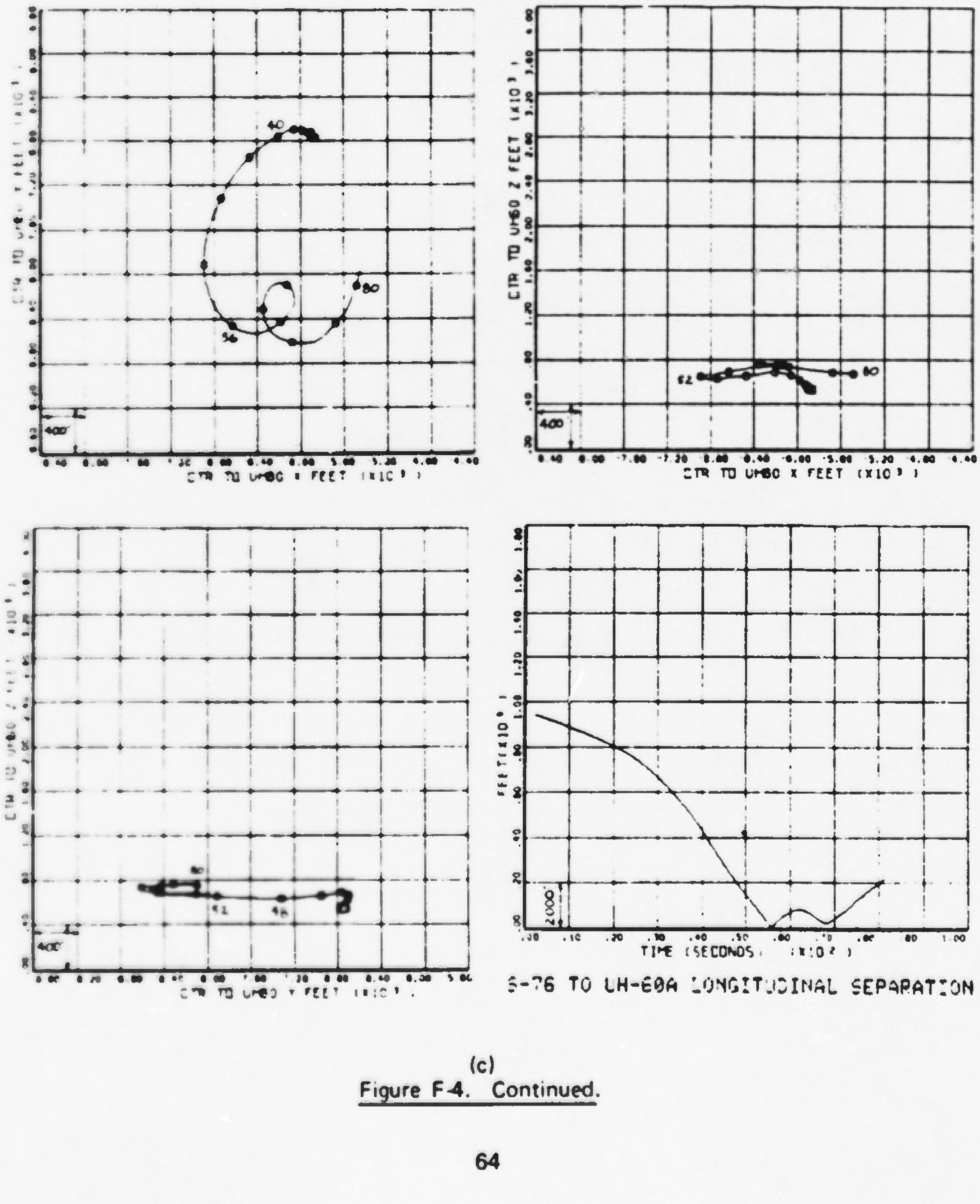
FLIGHT PATH PLOTS



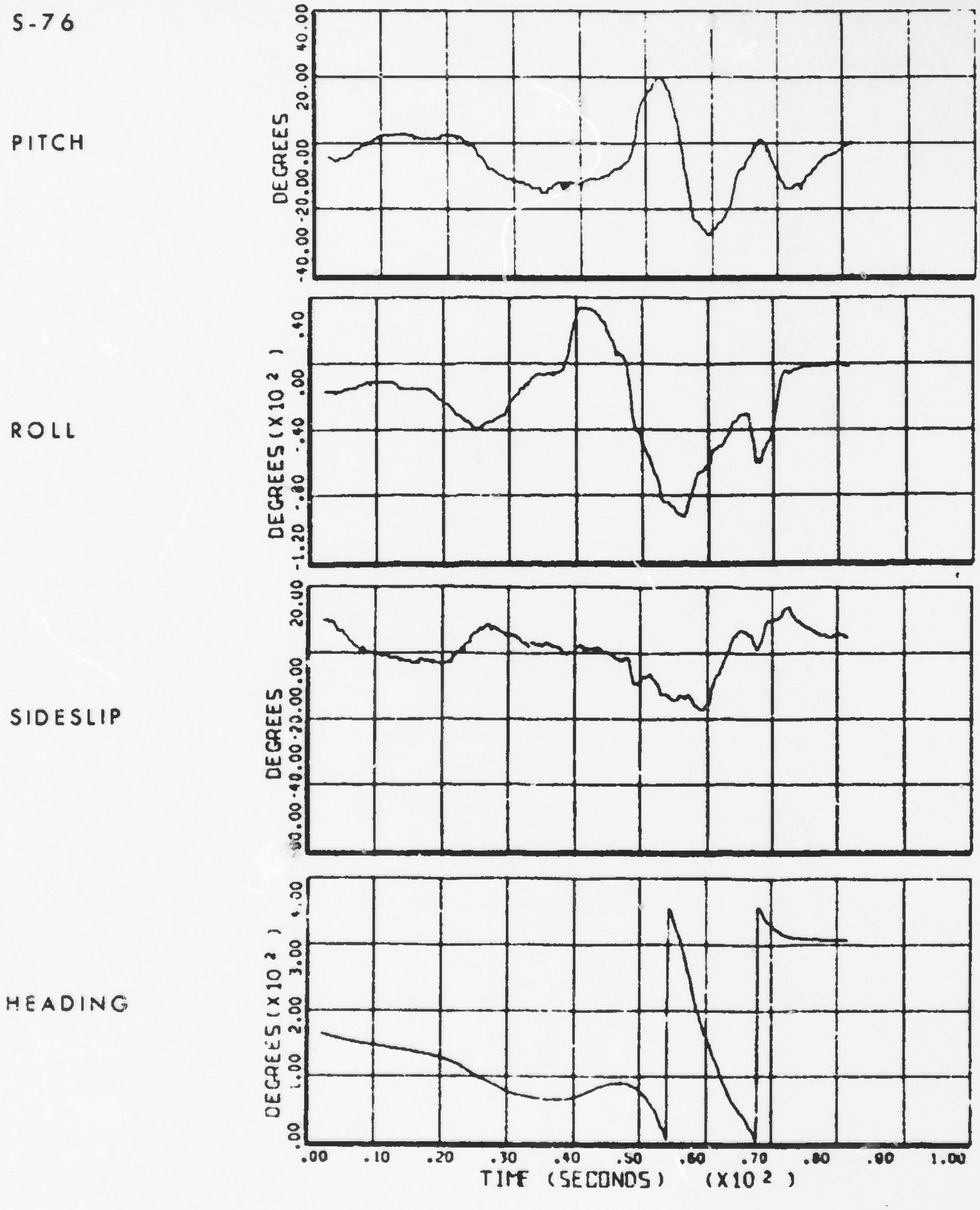
(b)

Figure F-4. Continued.

UH-60A
FLIGHT PATH PLOTS

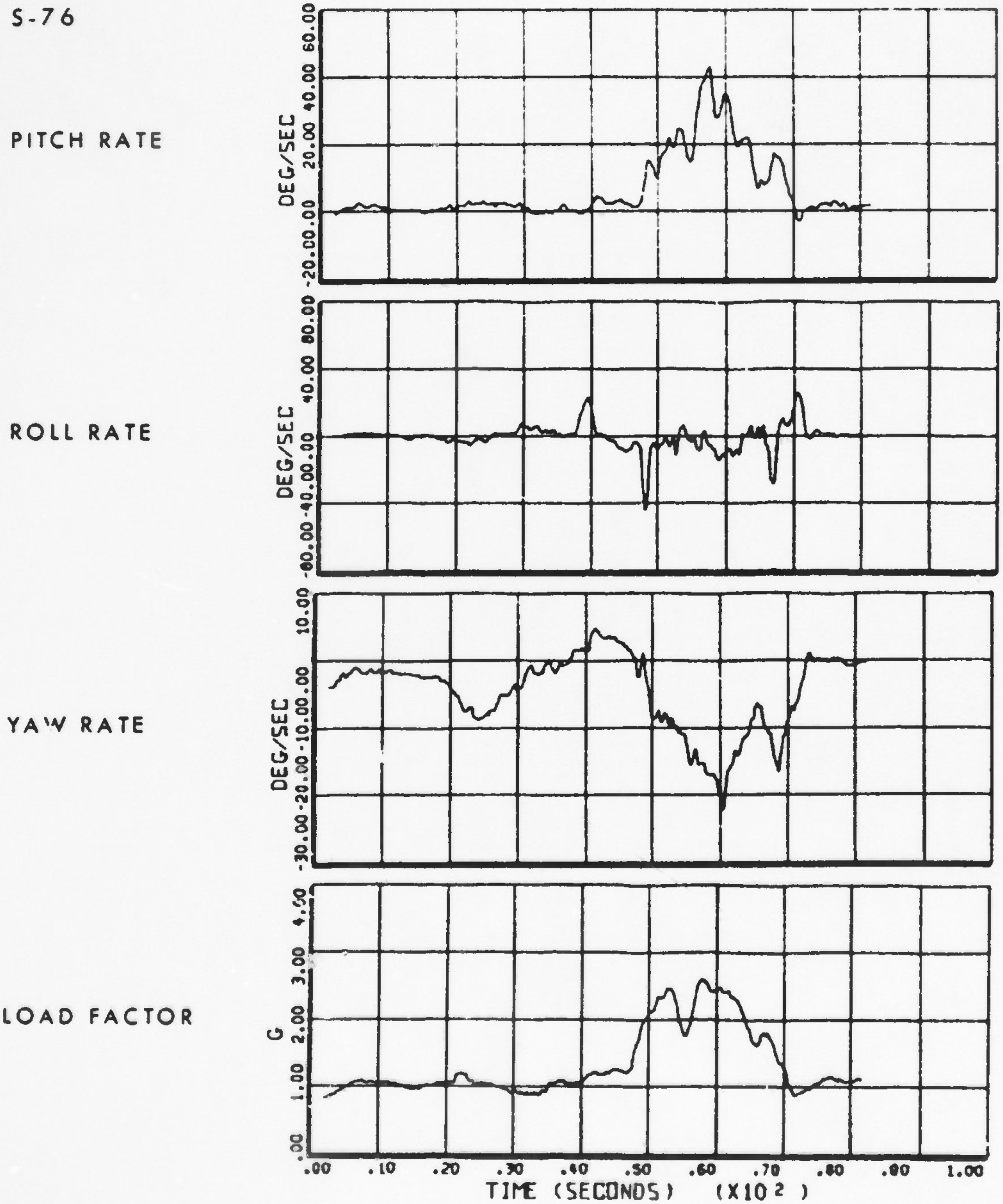


(c)
Figure F-4. Continued.

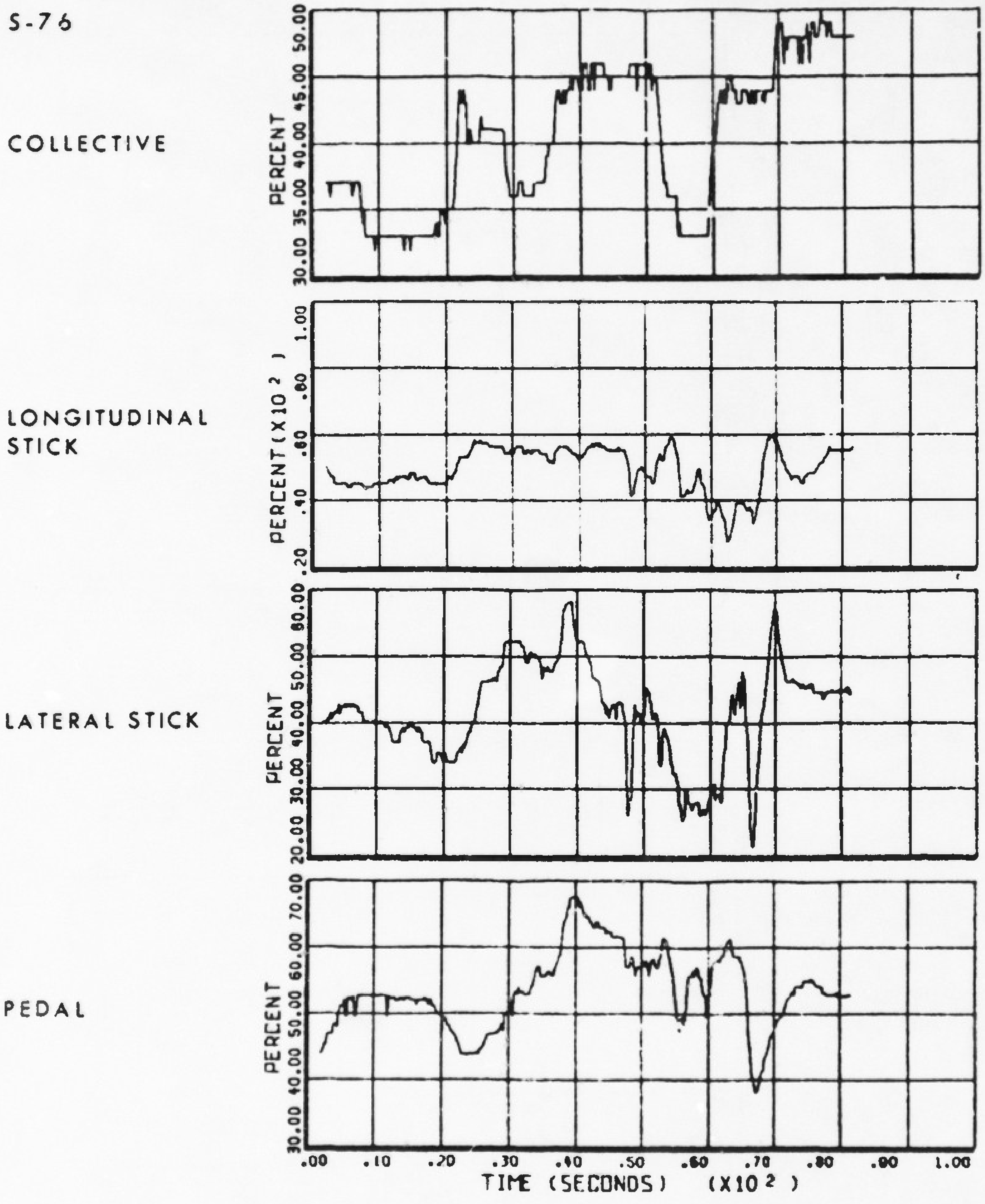


(d)
Figure F-4. Continued.

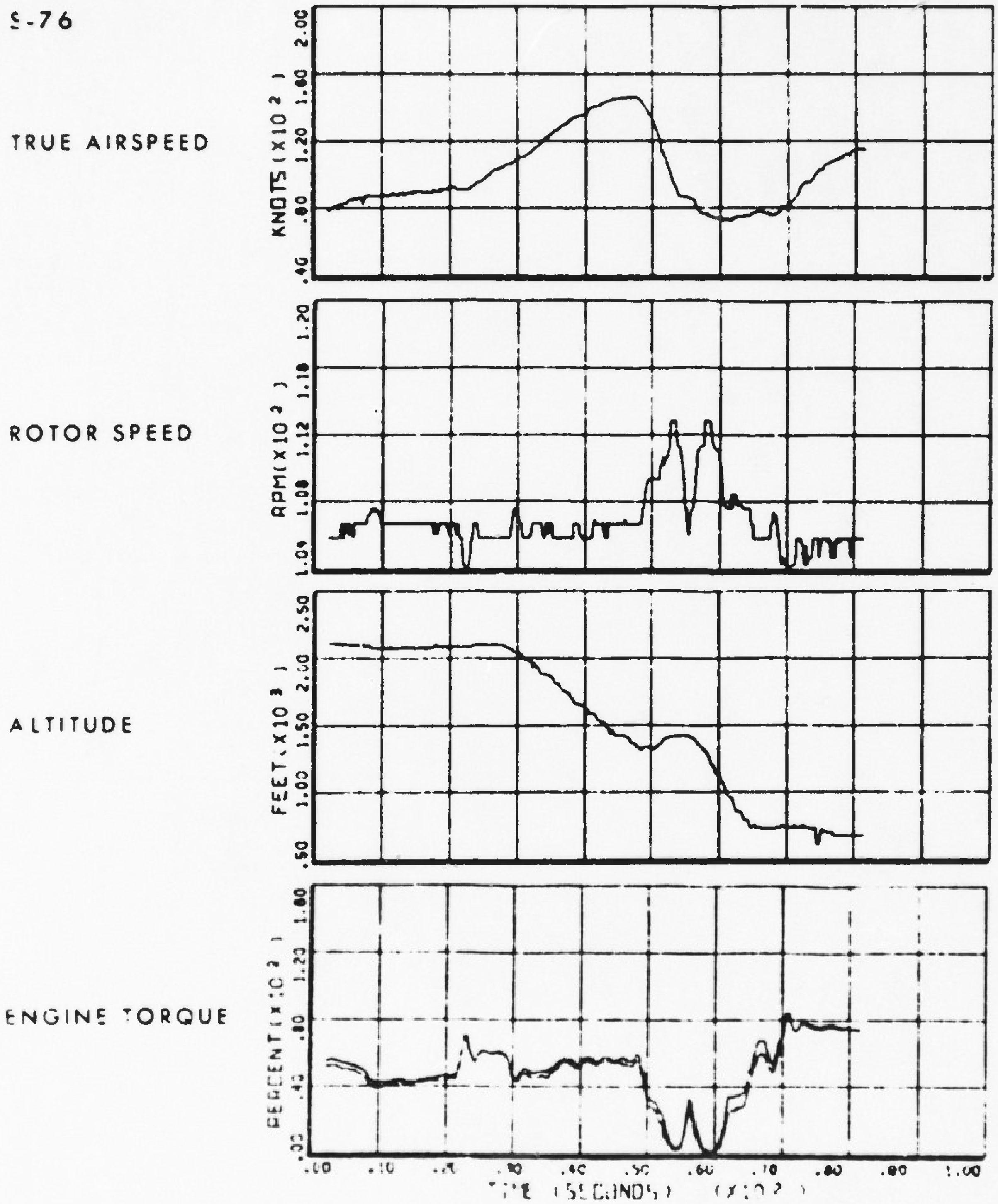
S-76



(e)
Figure F-4. Continued.



(f)
Figure F-4. Continued.



(g)

Figure F-4 Continued

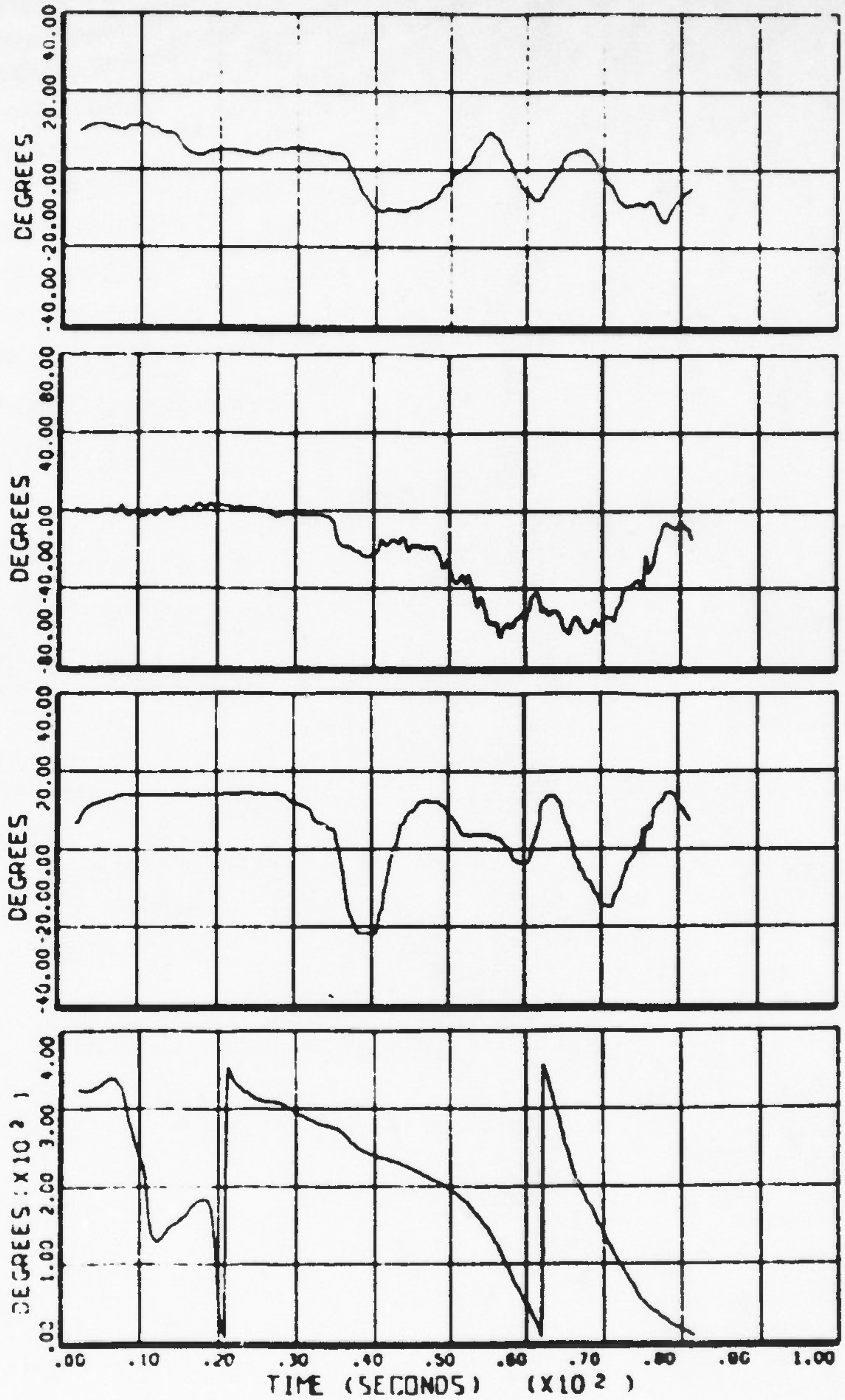
UH-60A

PITCH

ROLL

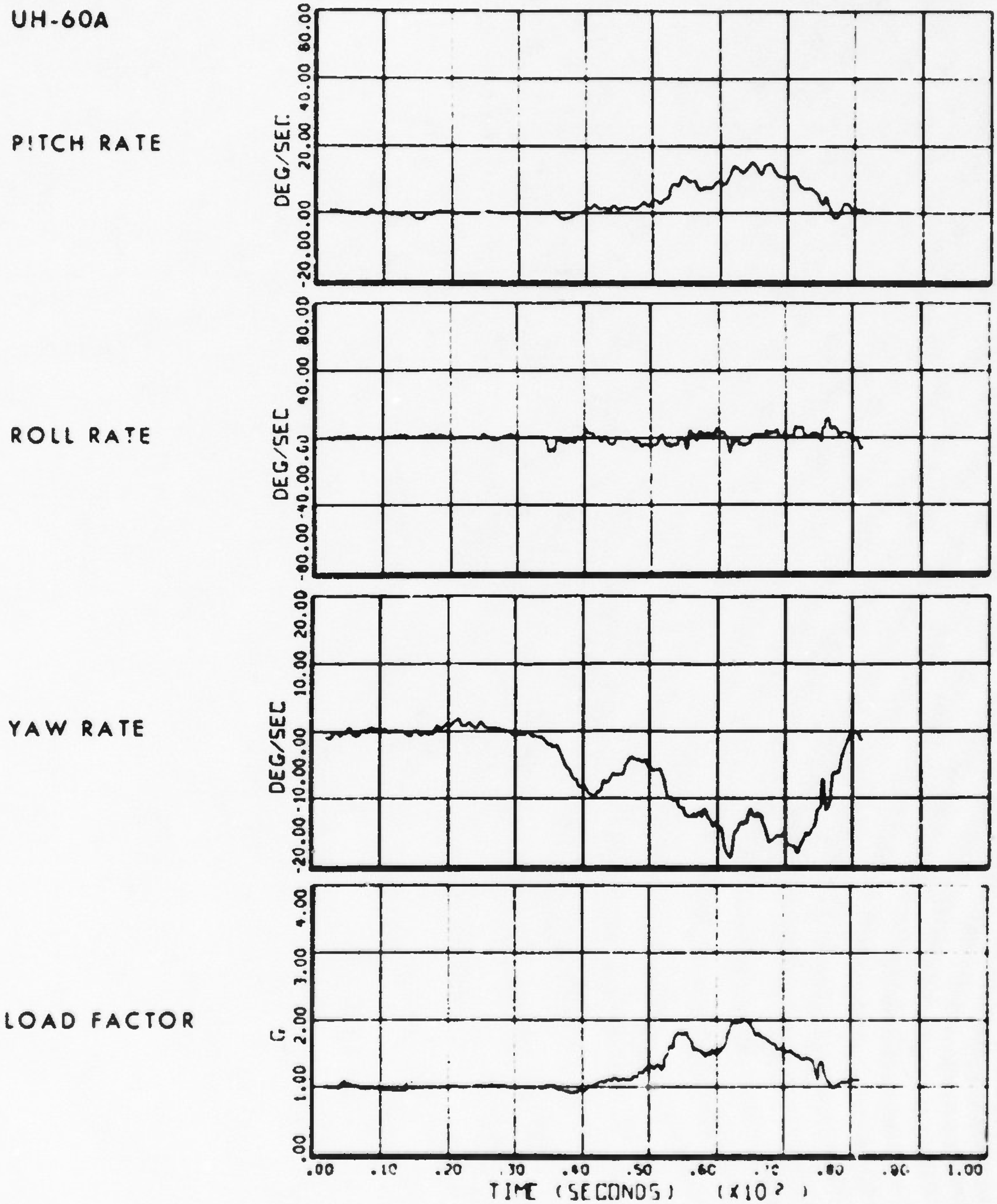
SIDESLIP

HEADING

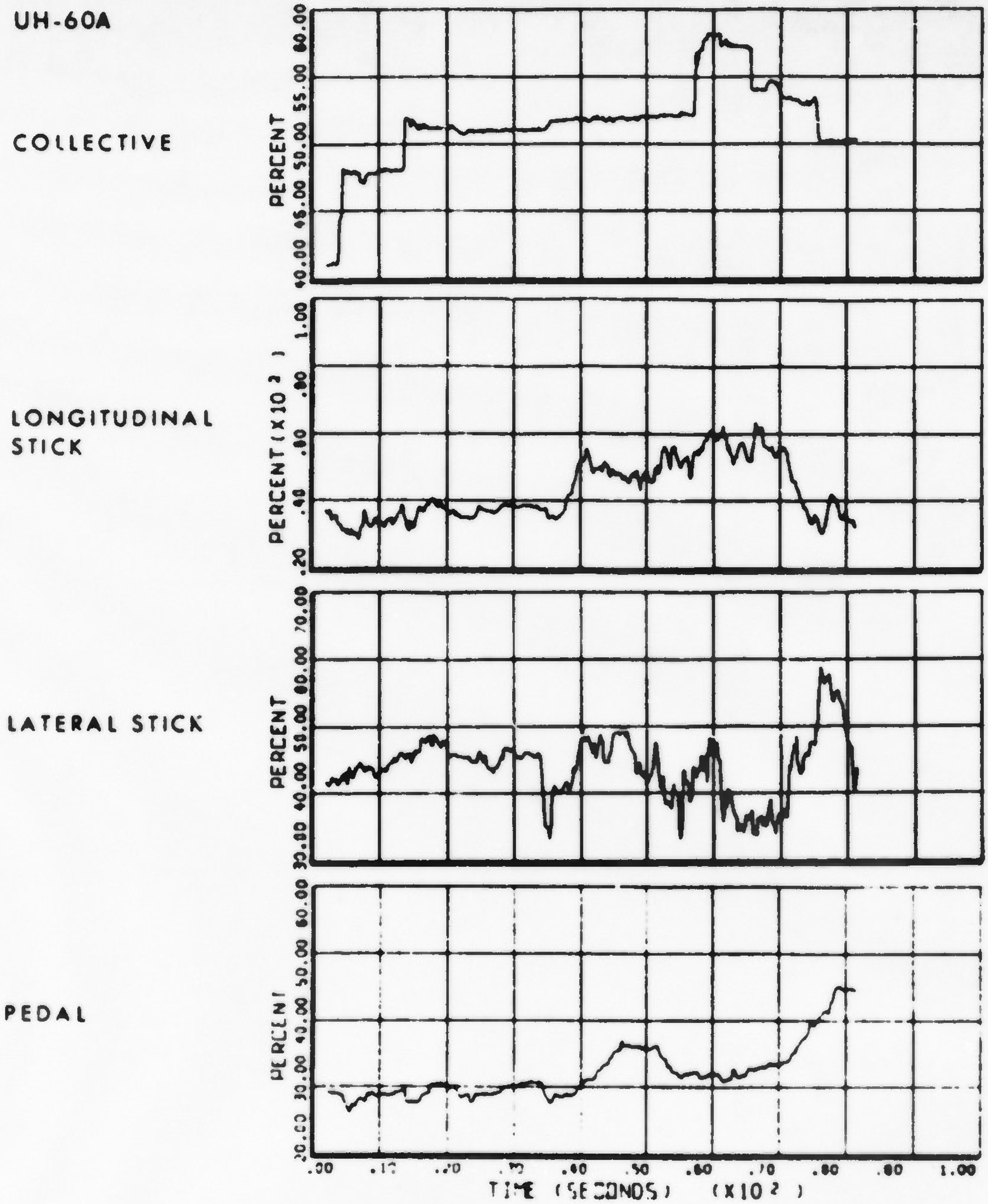


(h)

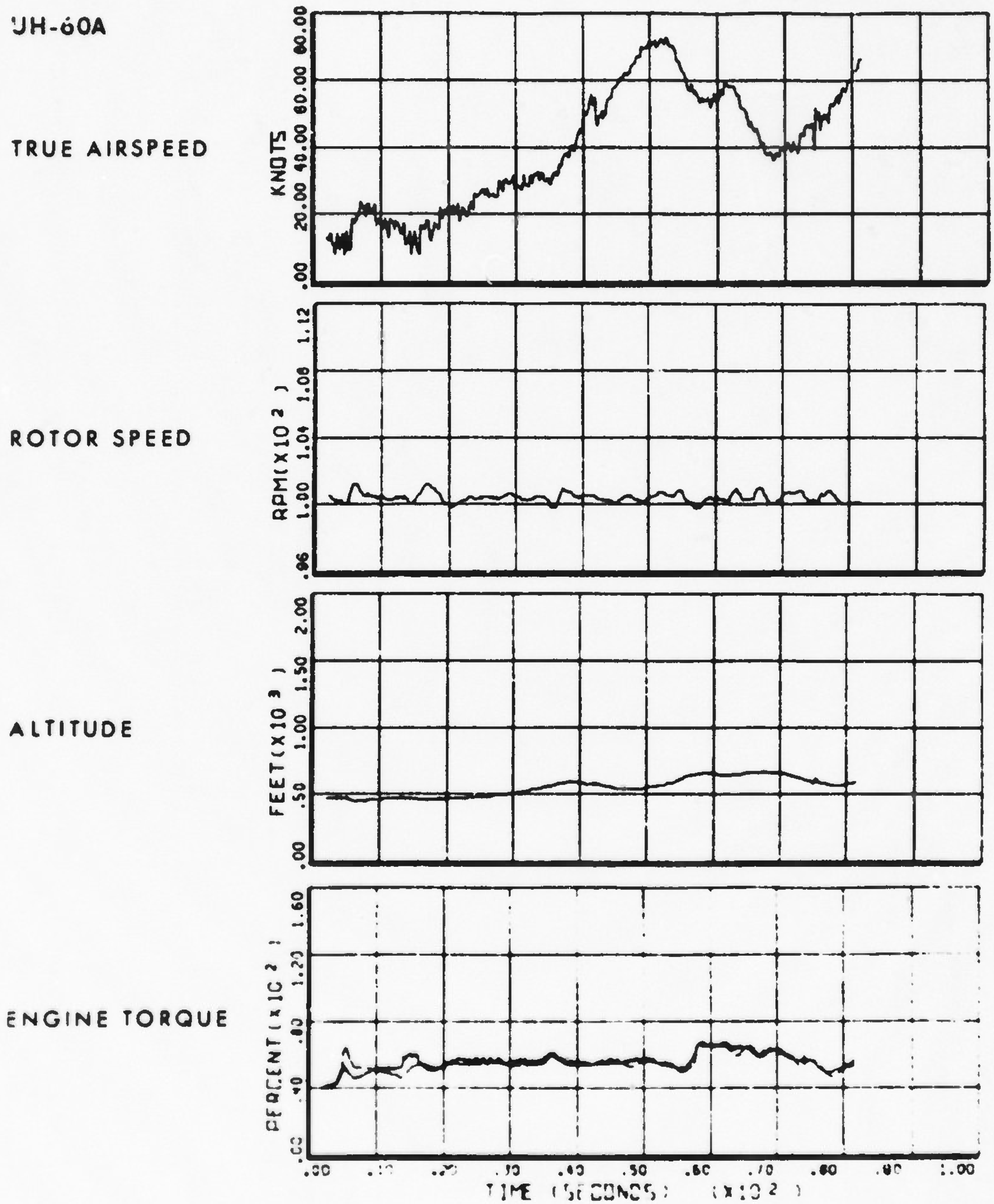
Figure F-4. Continued.



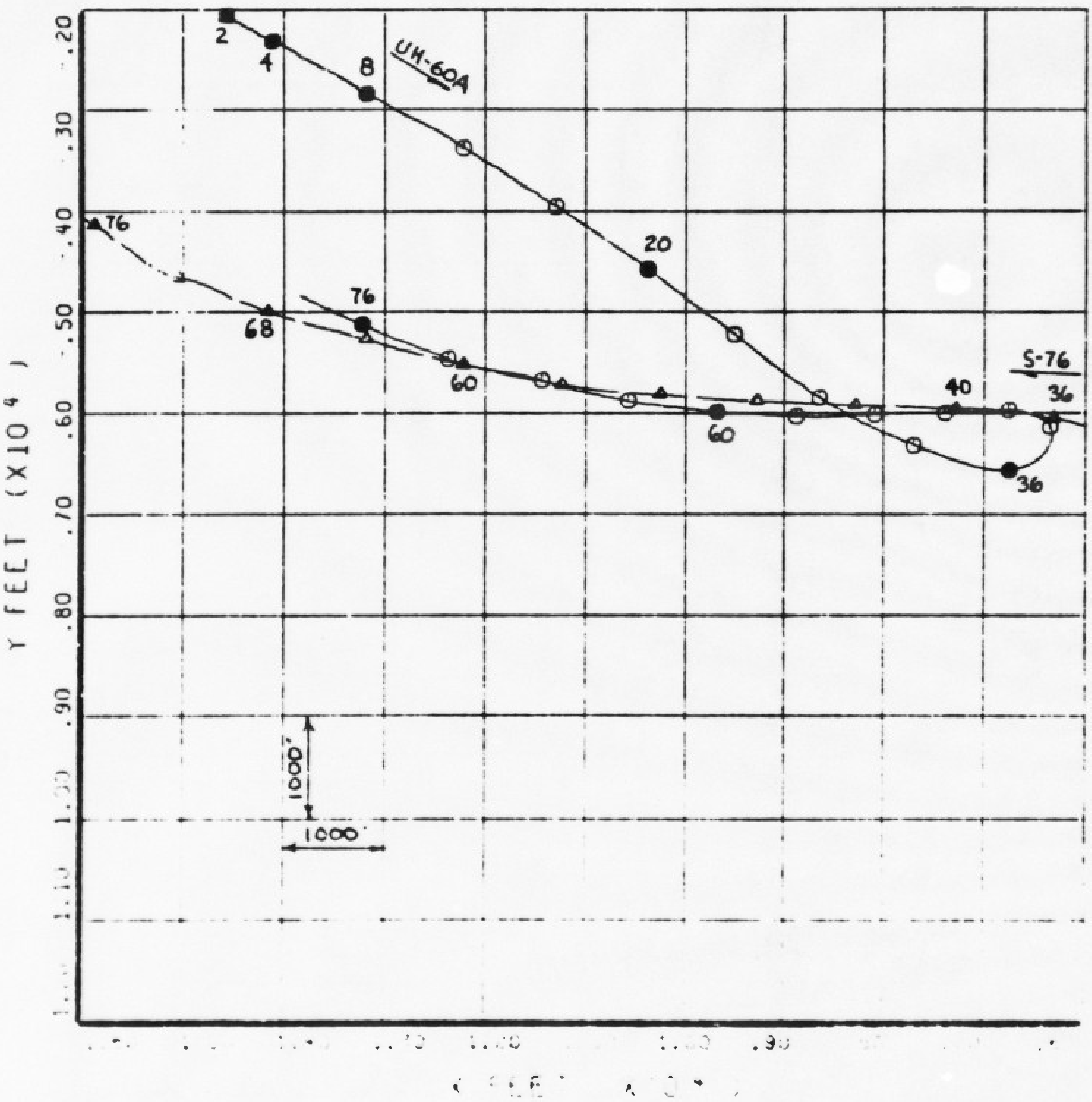
(i)
Figure F-4. Continued.



(j)
Figure F-4. Continued.



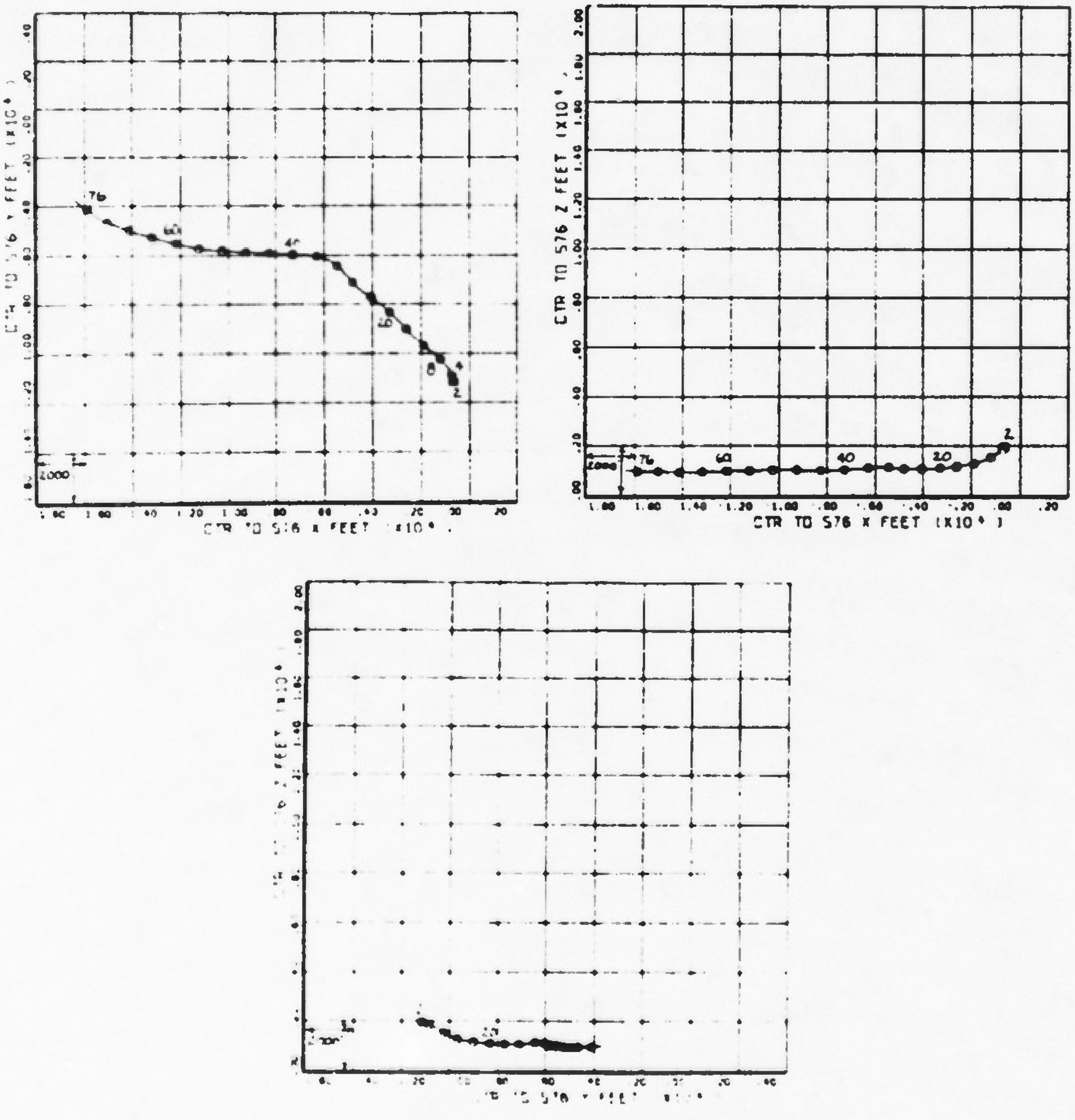
(k)
Figure F 4. Continued.



(a)

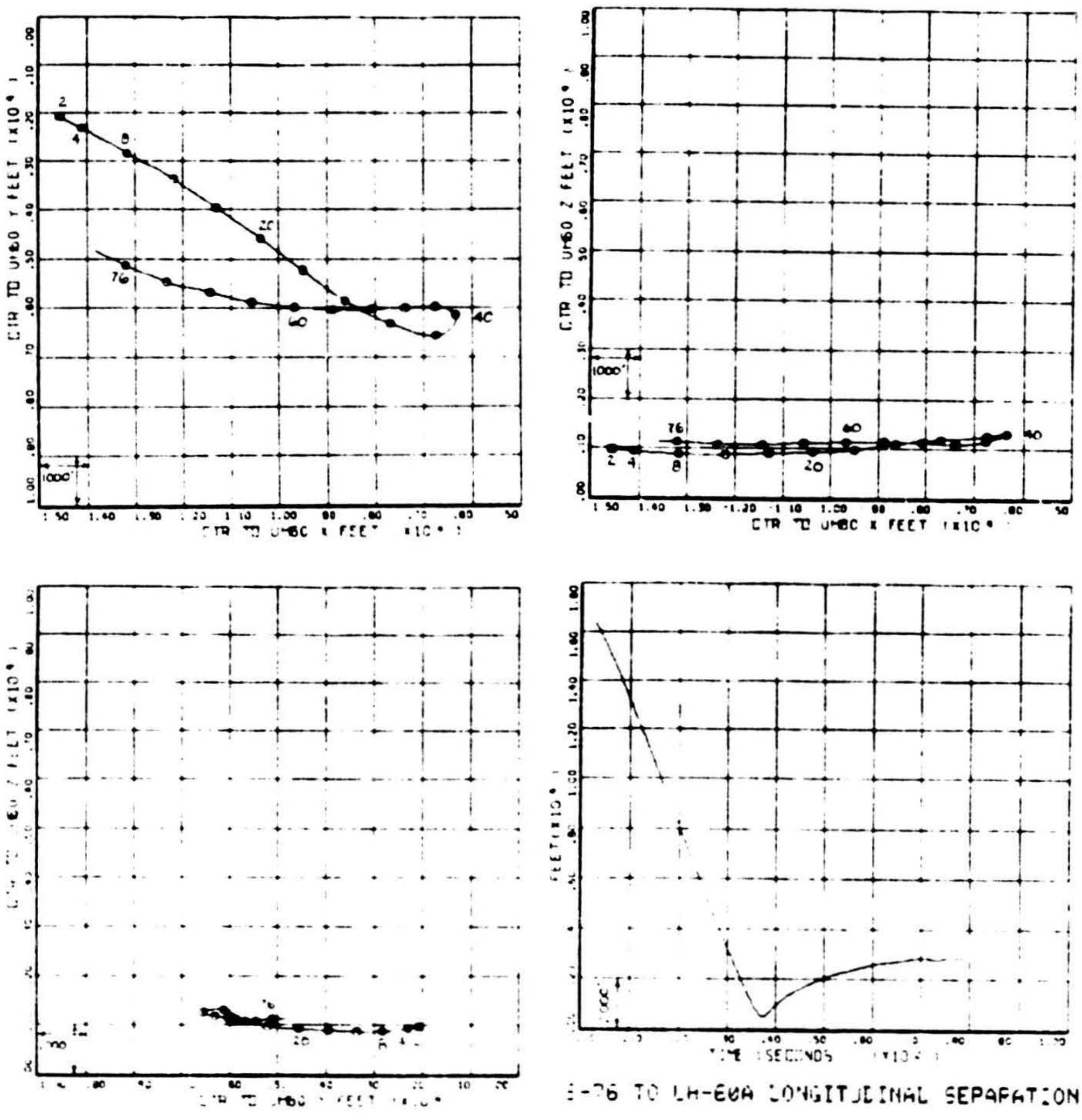
Figure F.5 Free engagement — head to head (V_H)

S-76
FLIGHT PATH PLOTS



(b)
Figure F-5. Continued.

UH-60A
FLIGHT PATH PLOTS



(c)
Figure F-5. Continued.

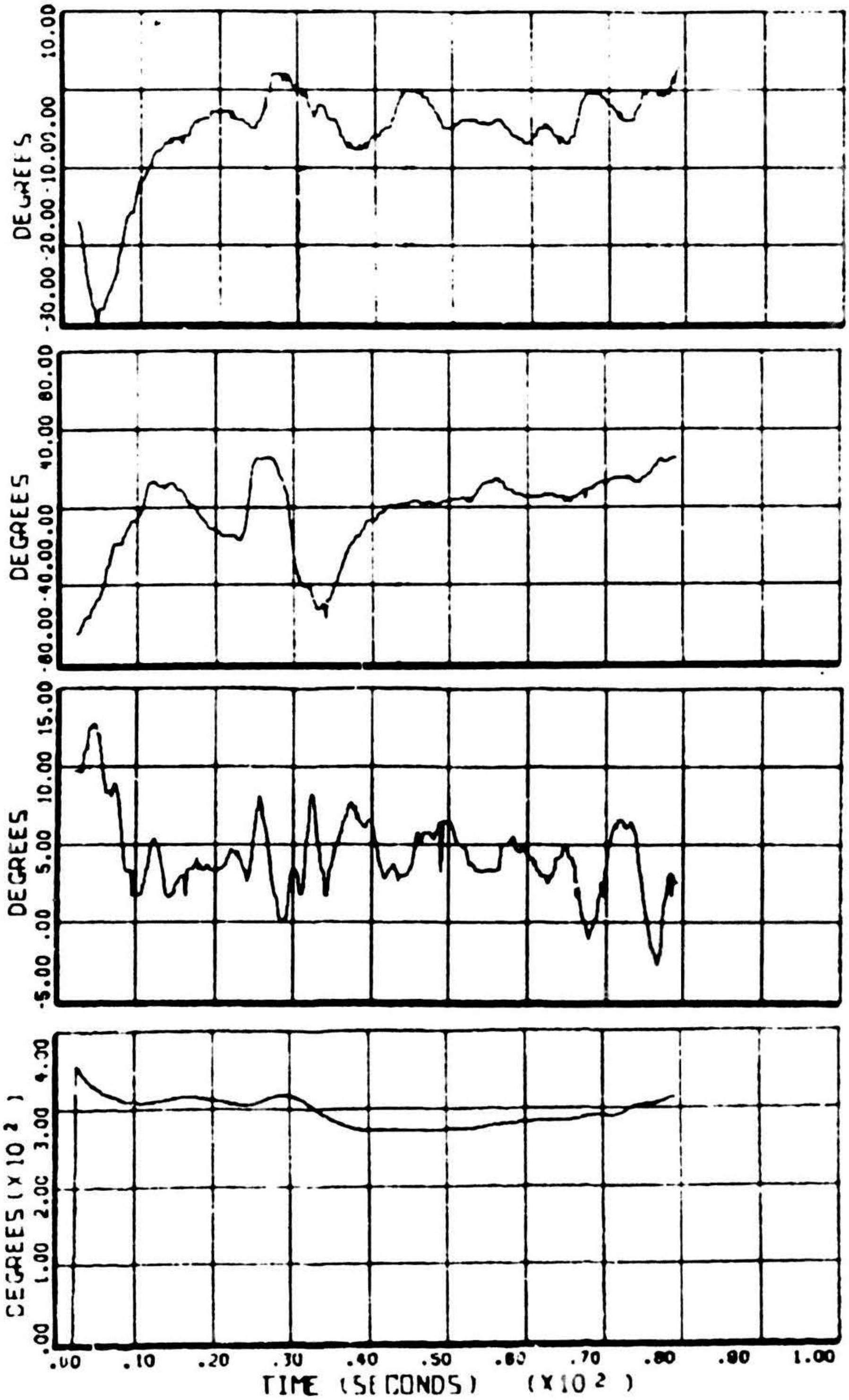
S-76

PITCH

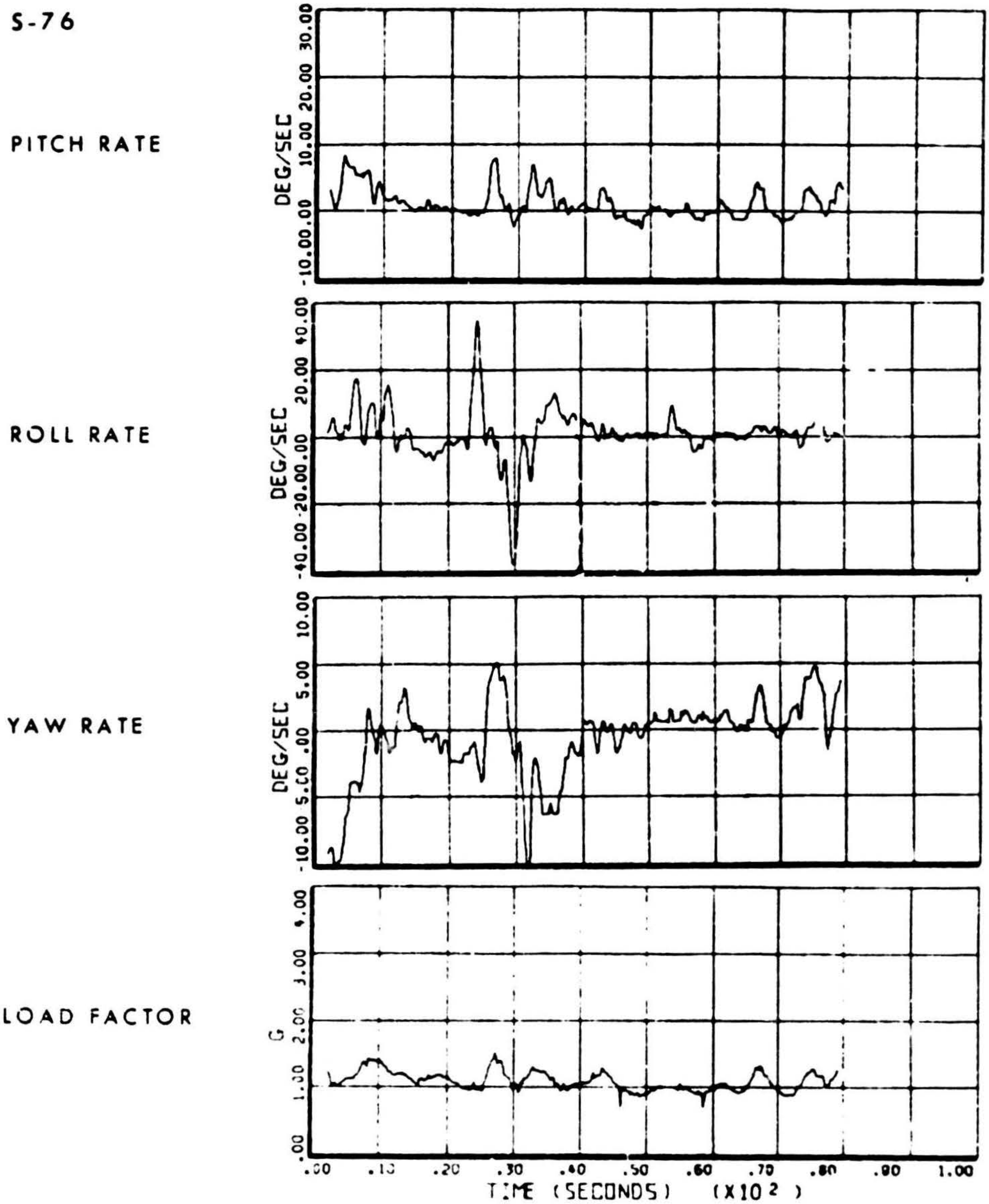
ROLL

SIDESLIP

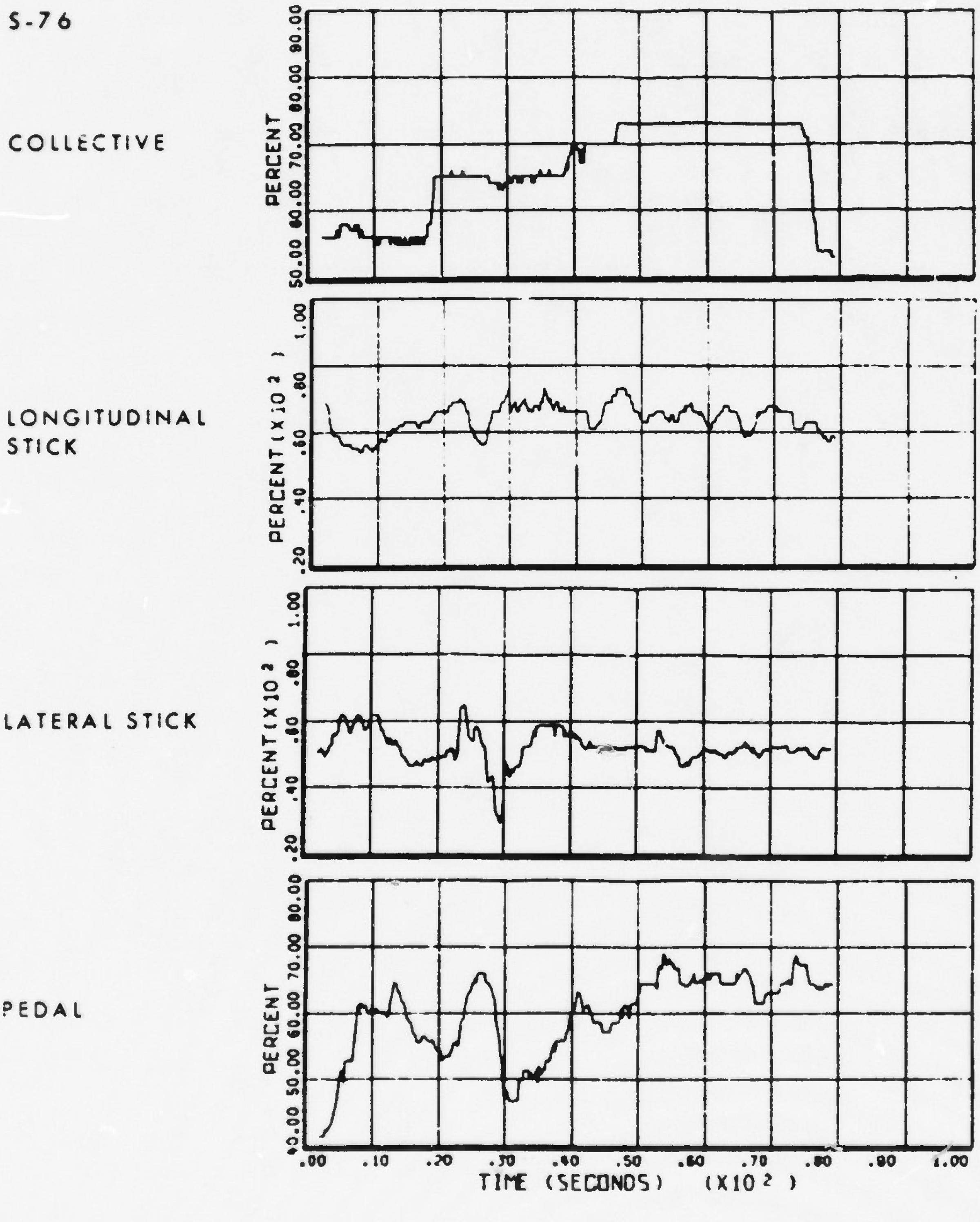
HEADING



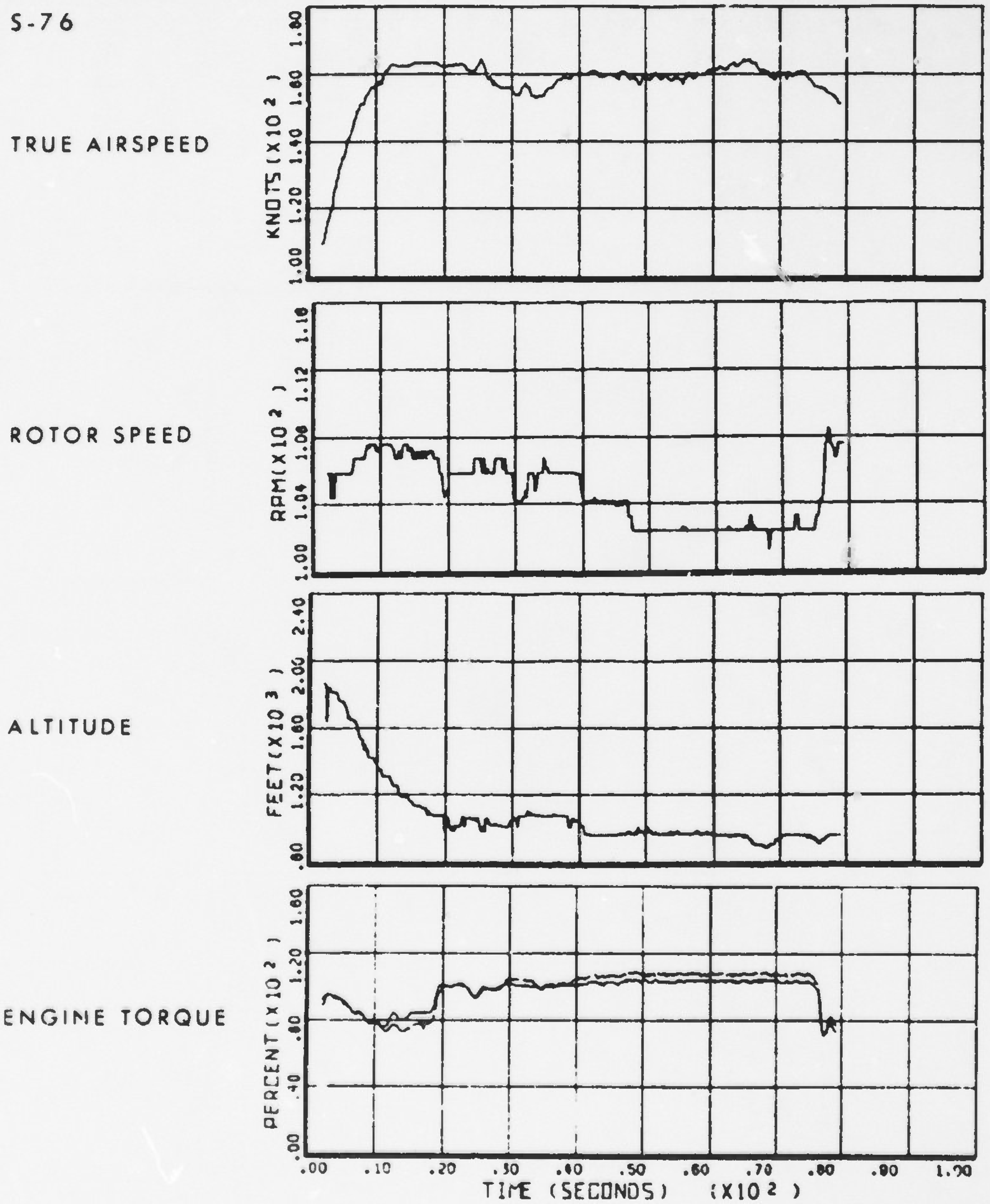
(d)
Figure F 5. Continued



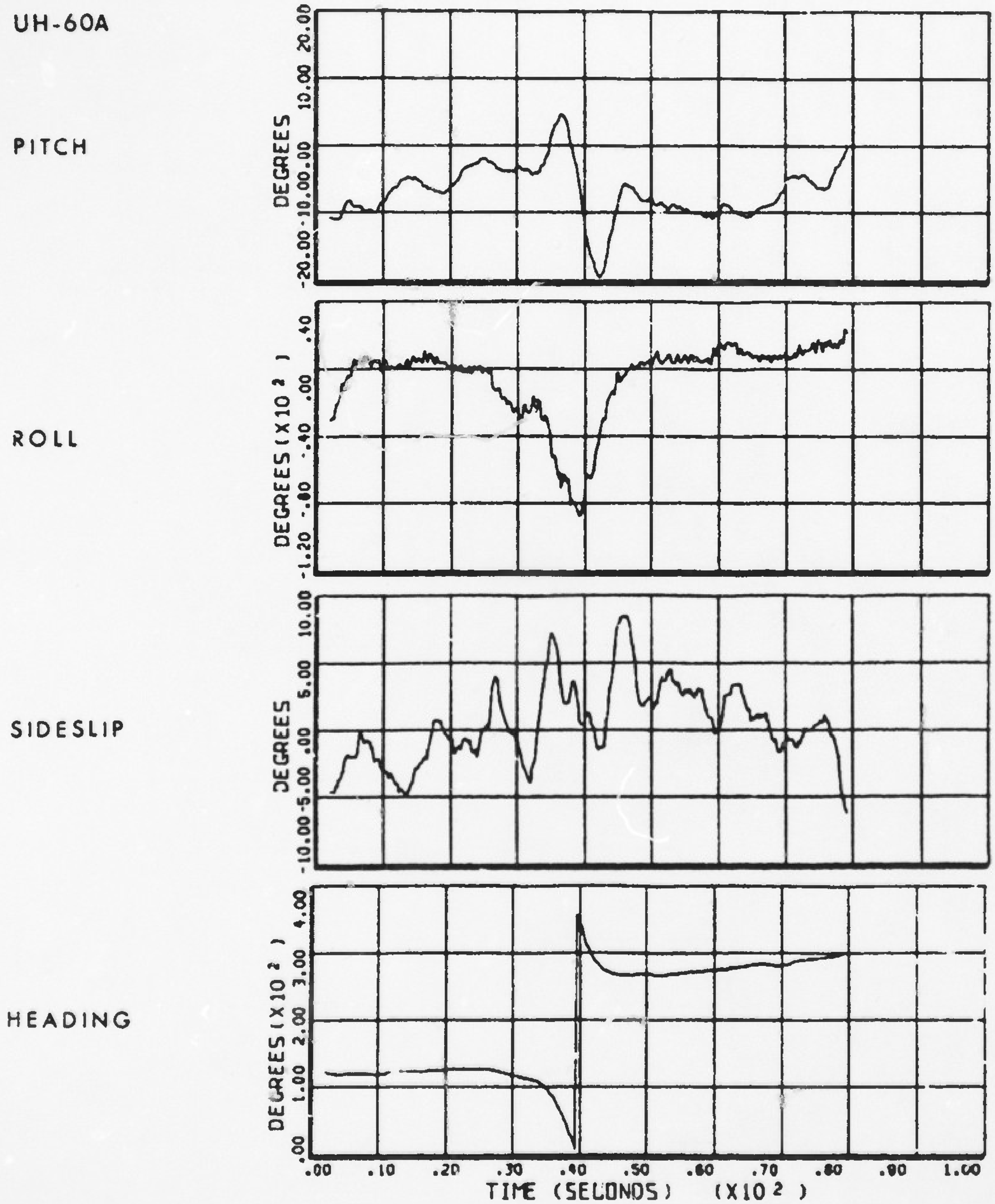
(e)
Figure F-5. Continued.



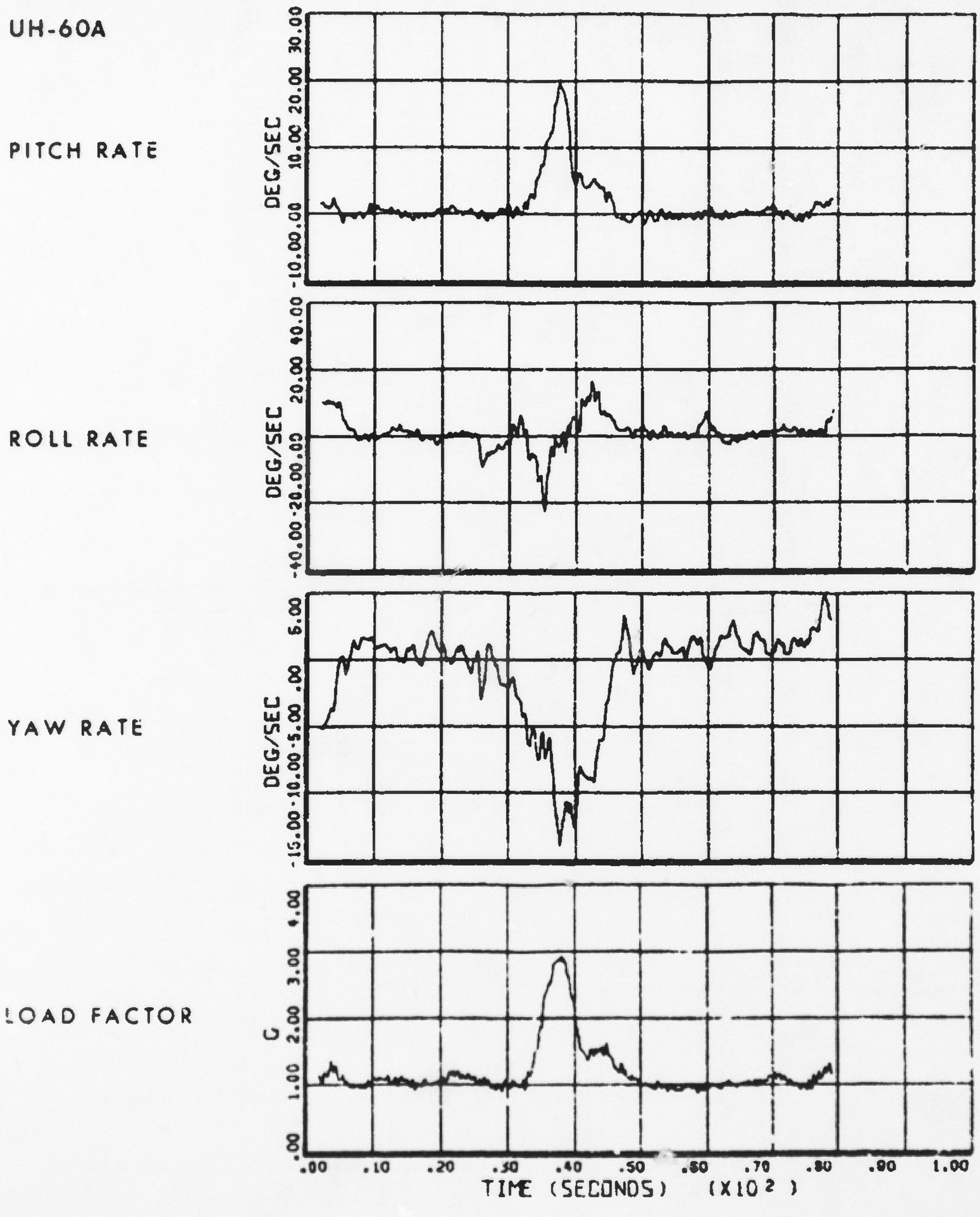
(f)
Figure F-5. Continued.



(g)
Figure F-5. Continued.



(h)
Figure F-5. Continued.



(i)
Figure F-5. Continued.

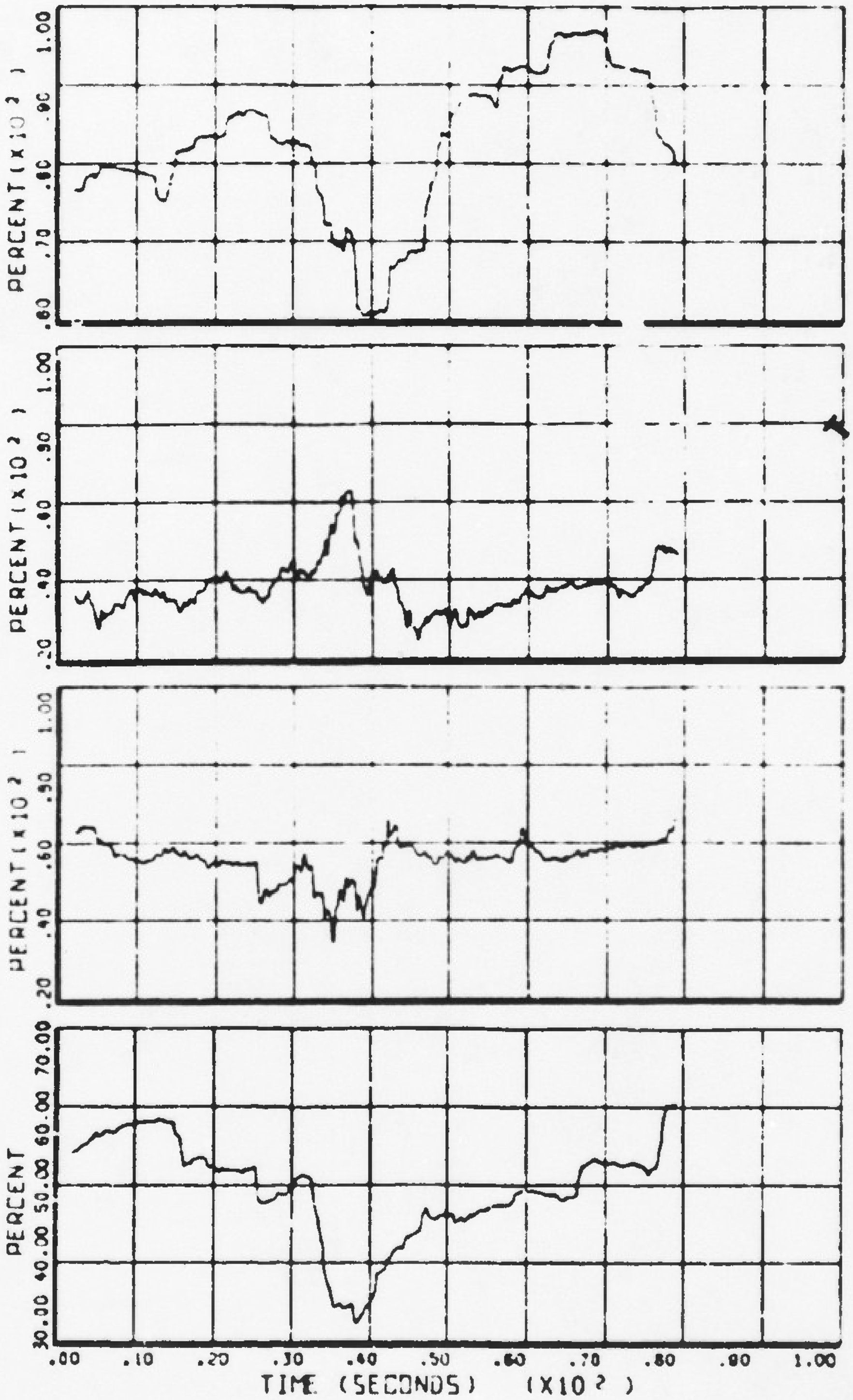
UH-60A

COLLECTIVE

LONGITUDINAL STICK

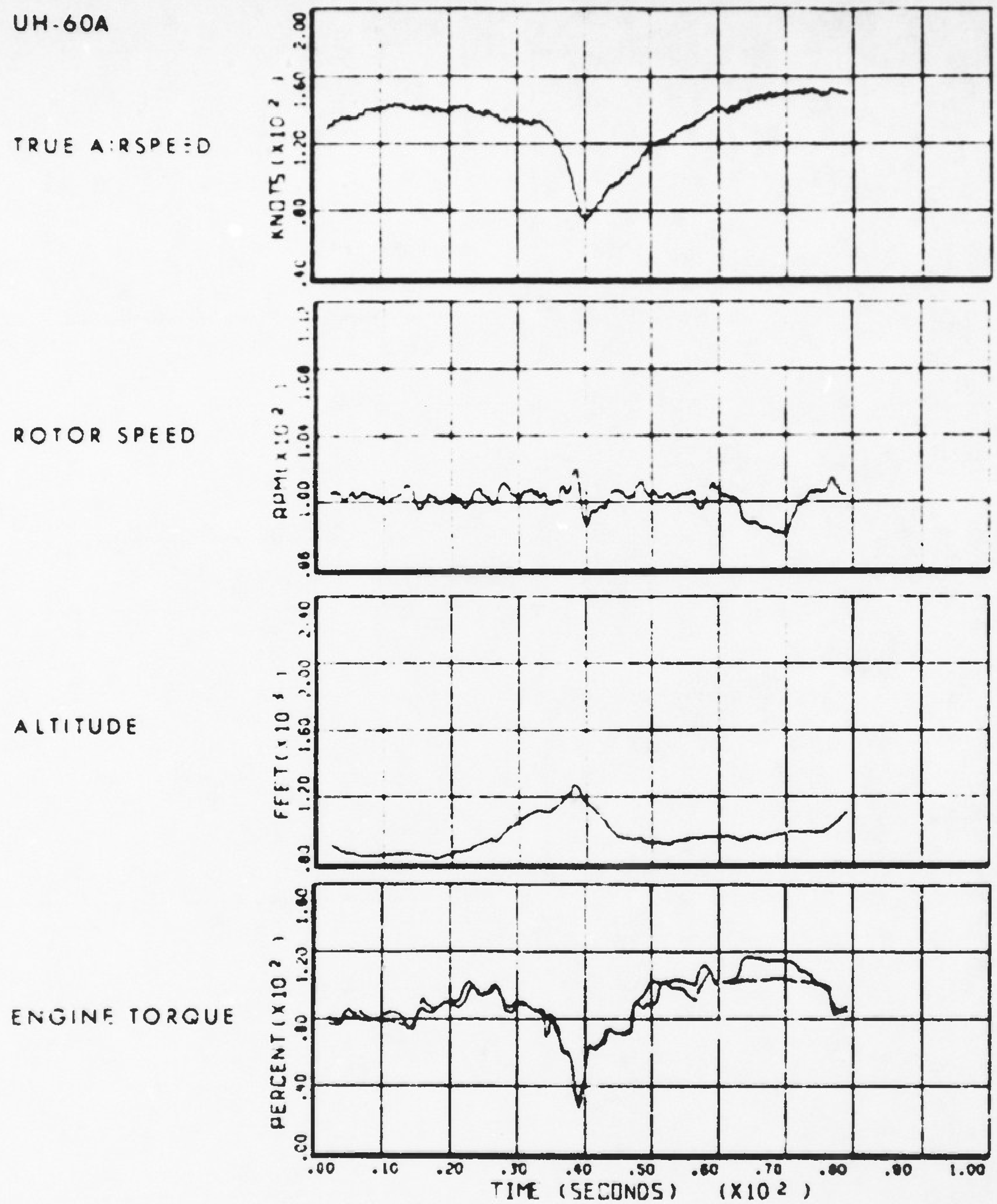
LATERAL STICK

PEDAL



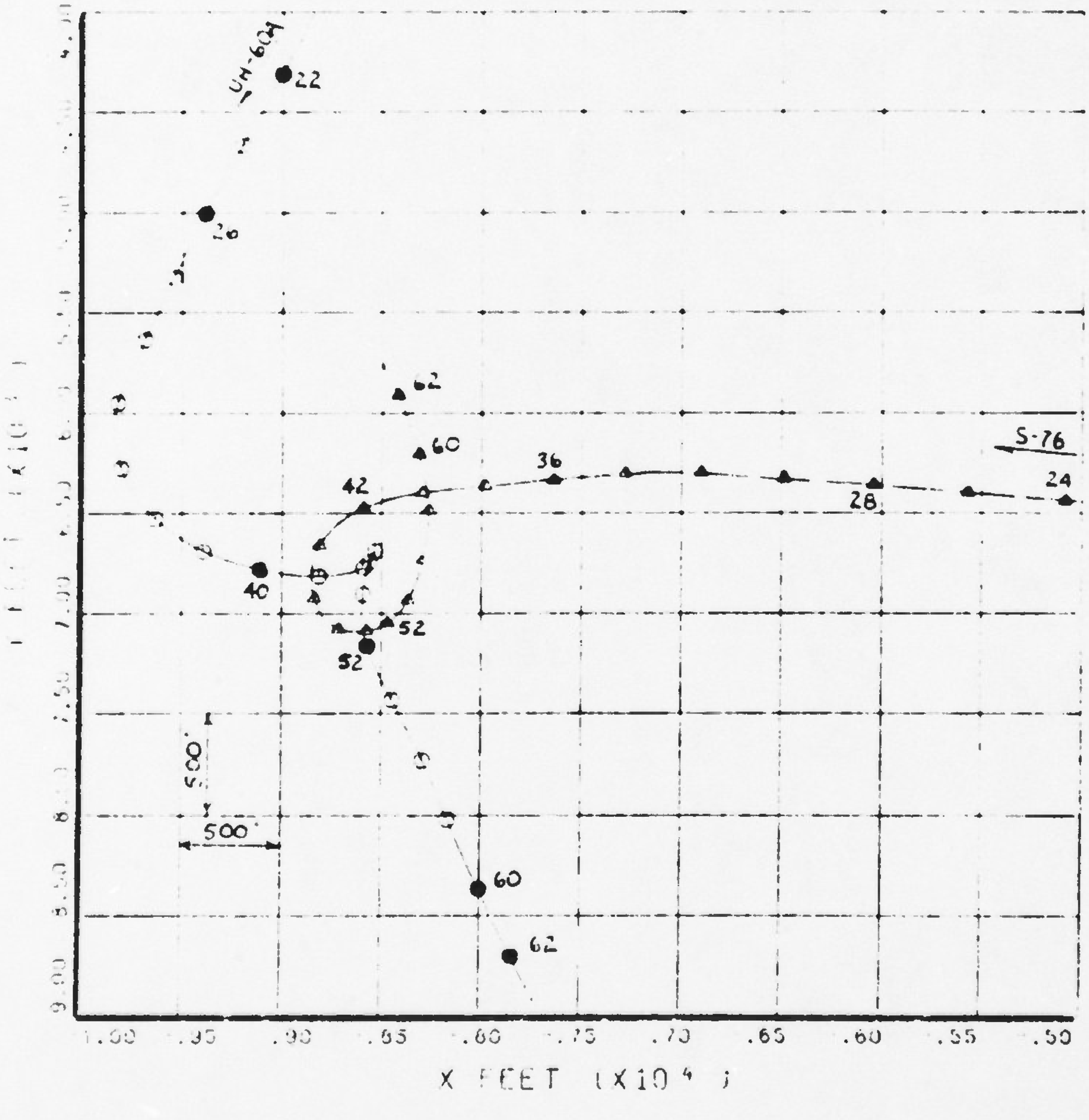
(j)

Figure F.5. Continued.



(k)

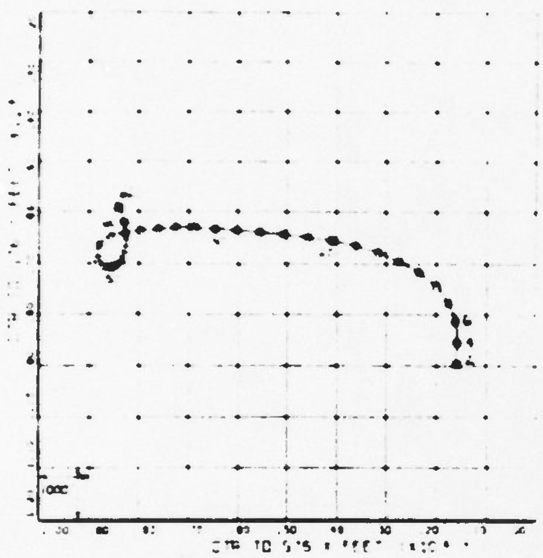
Figure F-5. Continued.

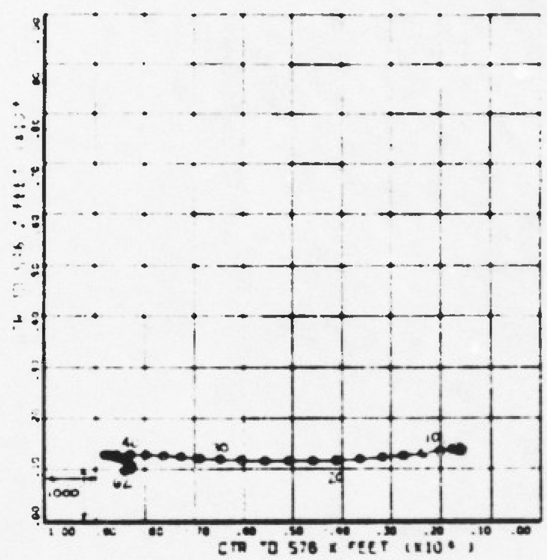


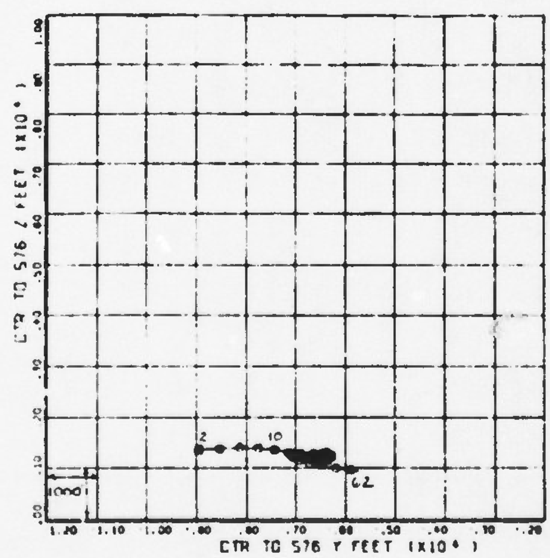
(a)
Figure F-6. Free engagement – S-76 attacks UH-60A abeam (level).

S-76

FLIGHT PATH PLOTS





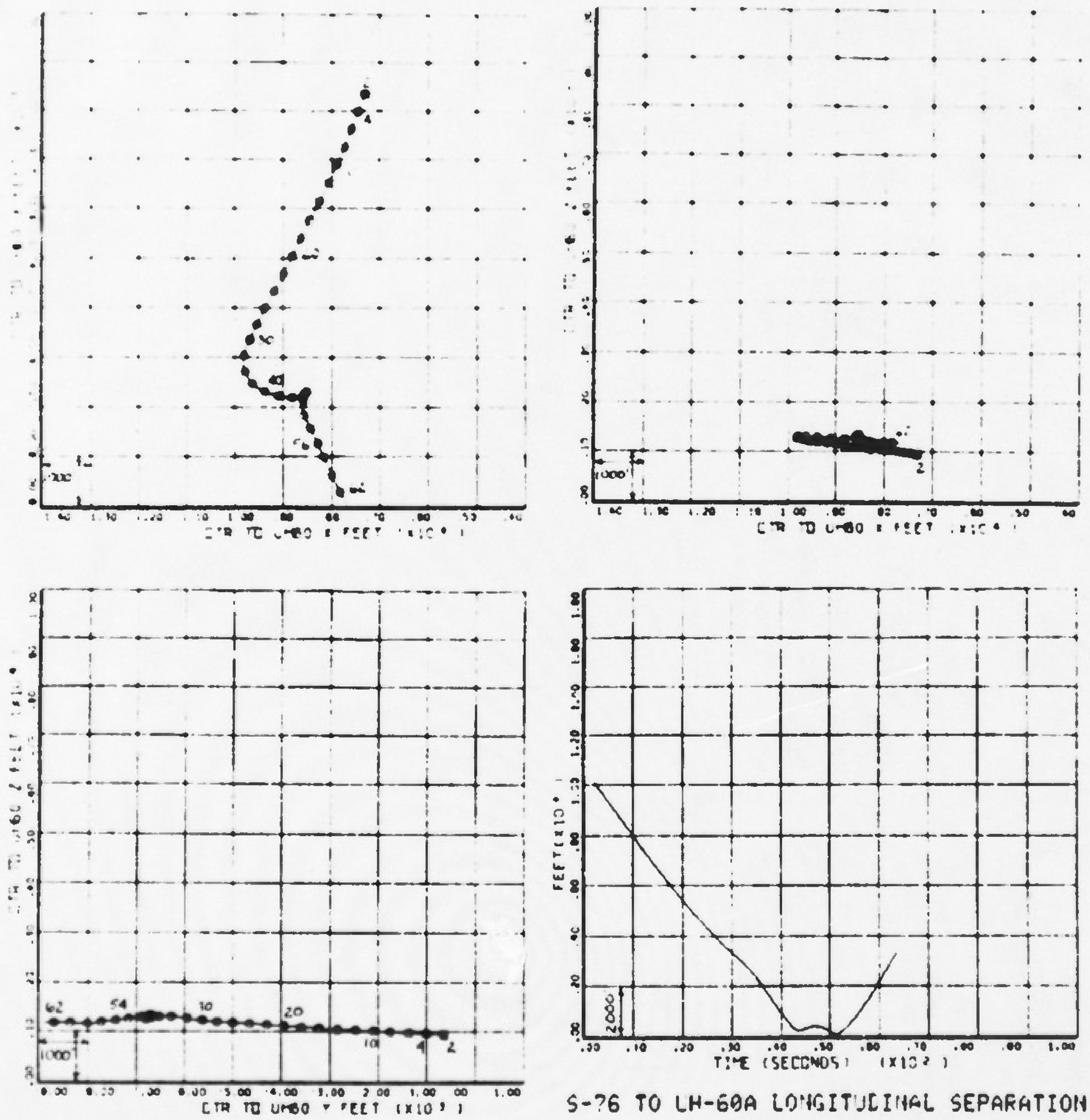


(b)

Figure F-6. Continued.

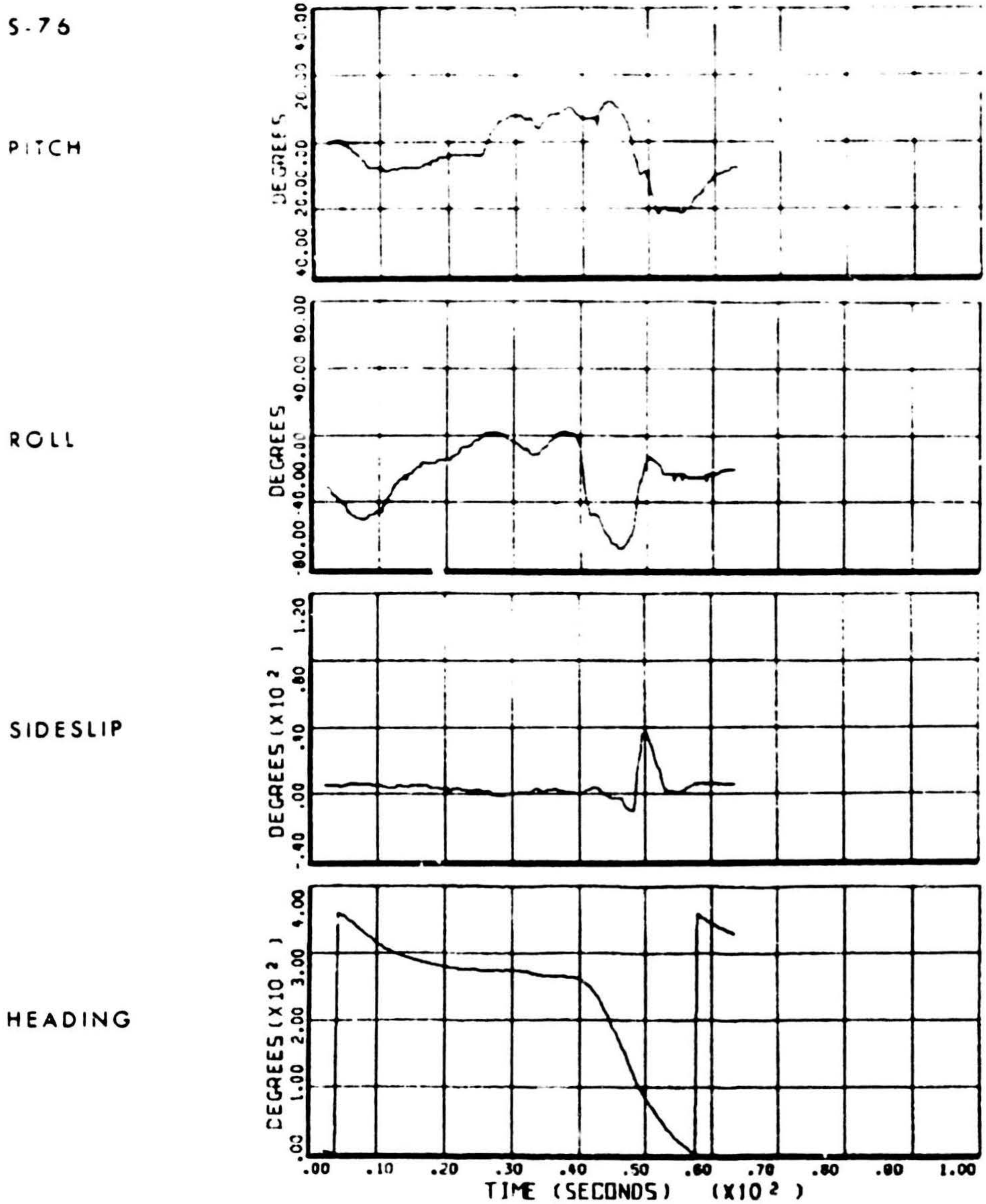
UH-60A

FLIGHT PATH PLOTS

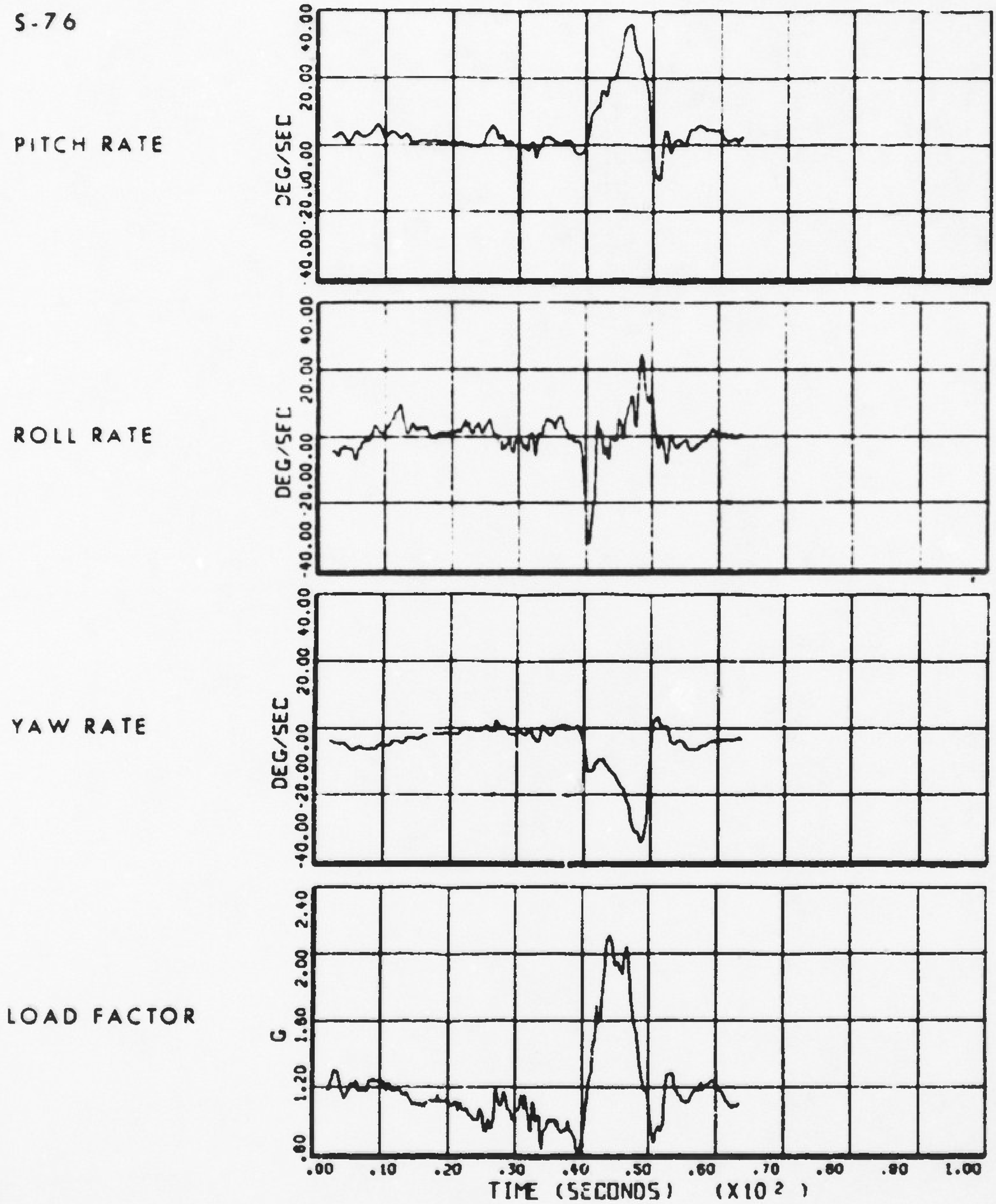


(c)

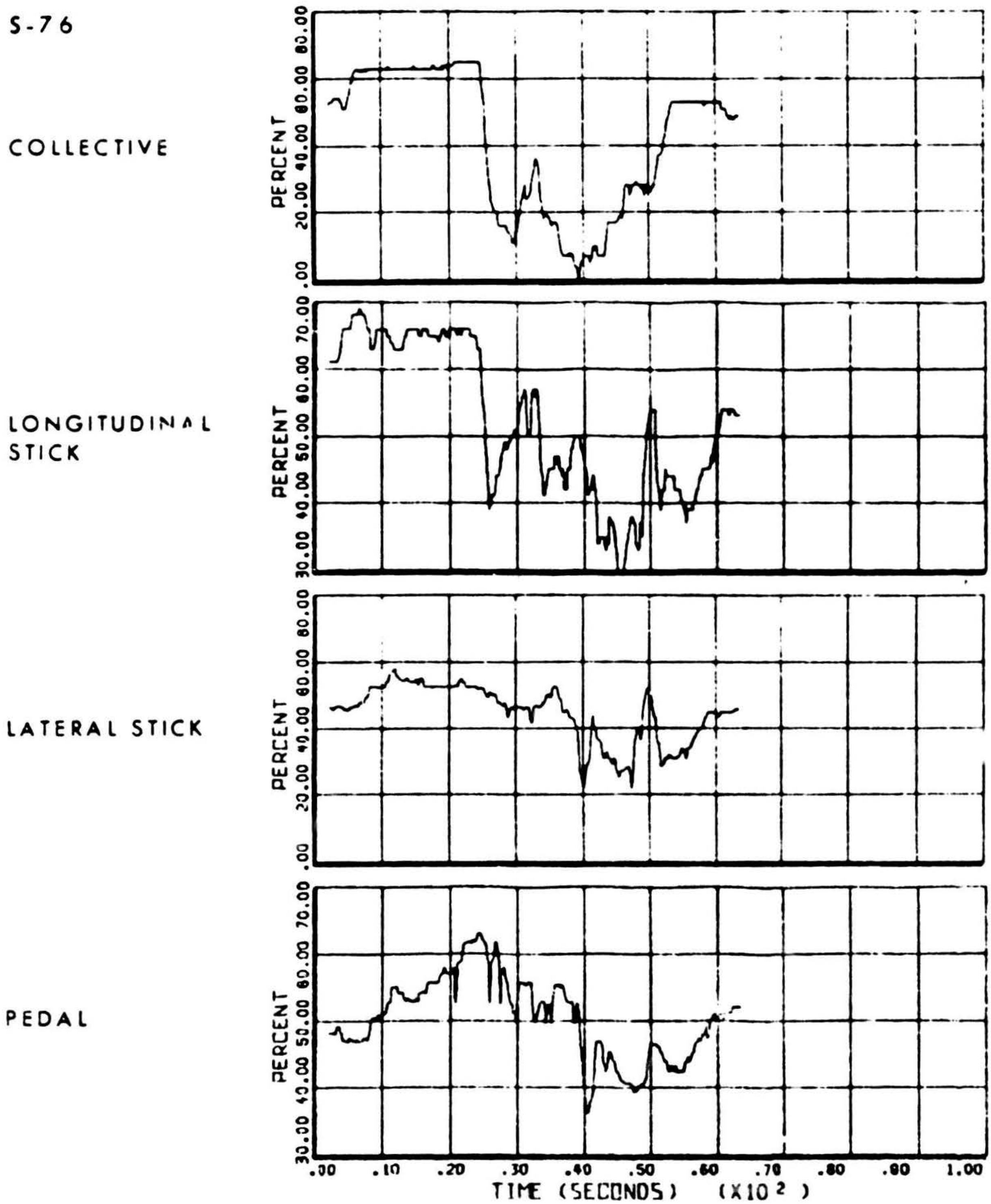
Figure F-6. Continued.



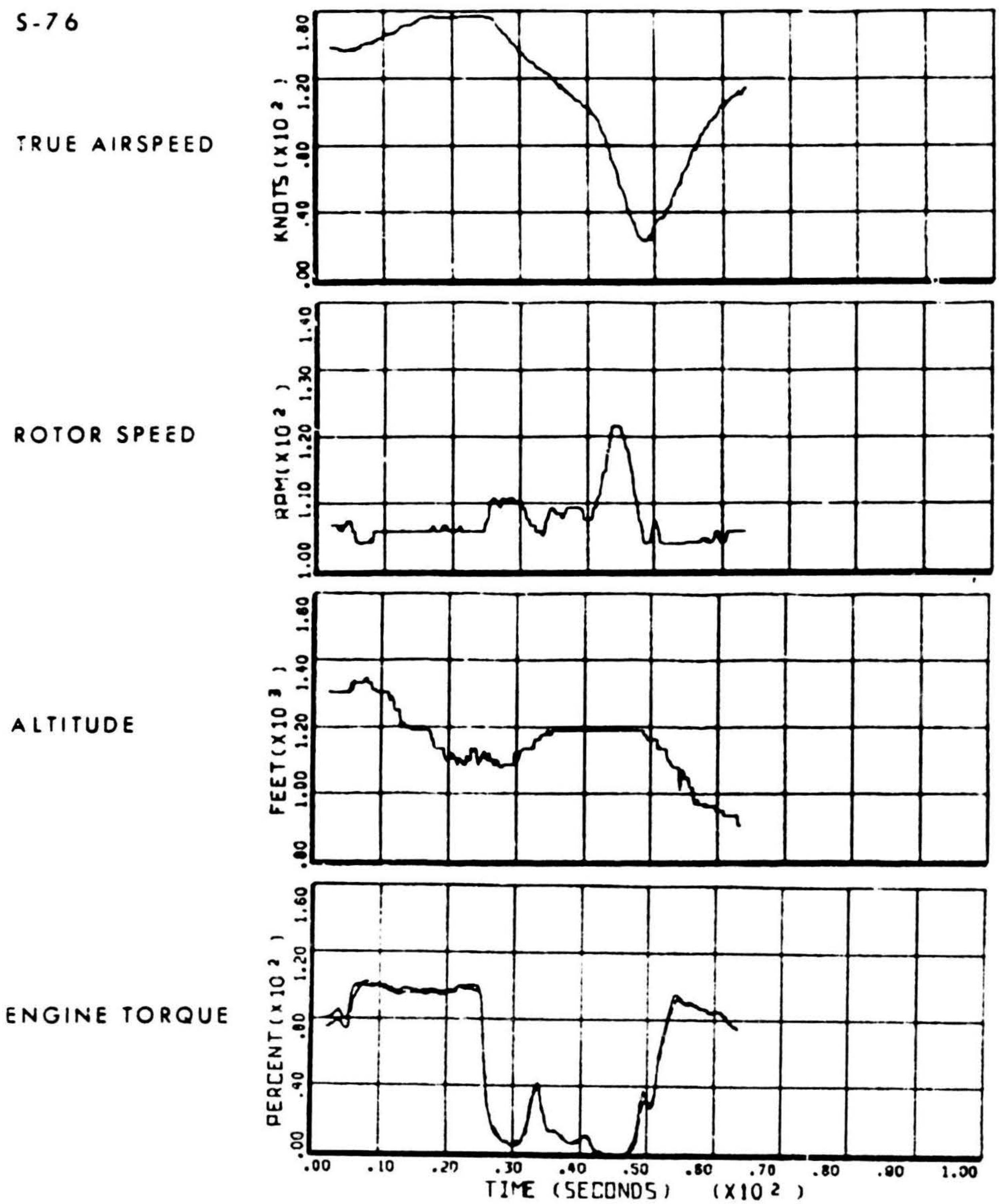
(d)
Figure F-6. Continued.



(e)
Figure F-6. Continued.



(f)
Figure F-6. Continued.



(g)
Figure F-6. Continued.

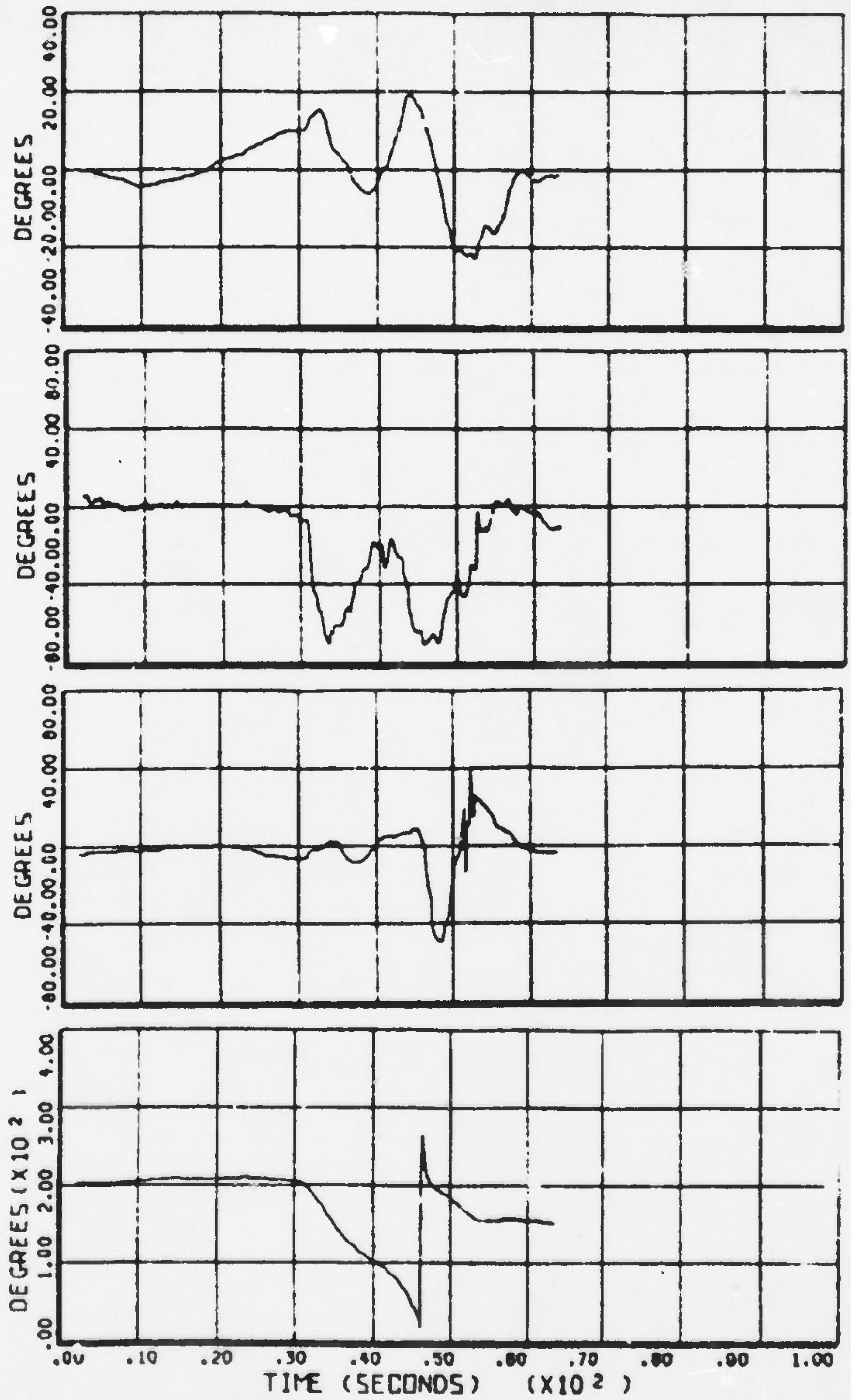
UH-60A

PITCH

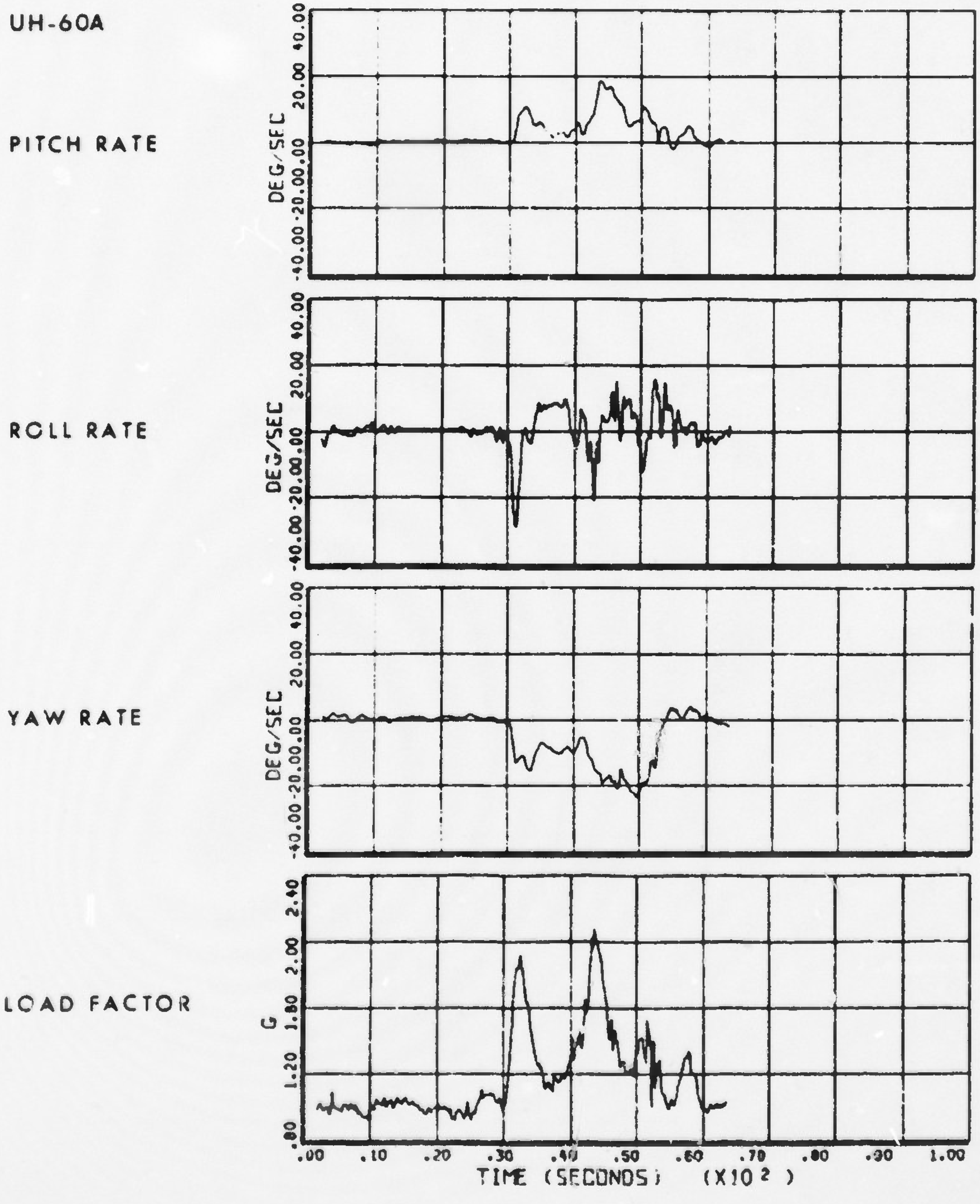
ROLL

SIDESLIP

HEADING

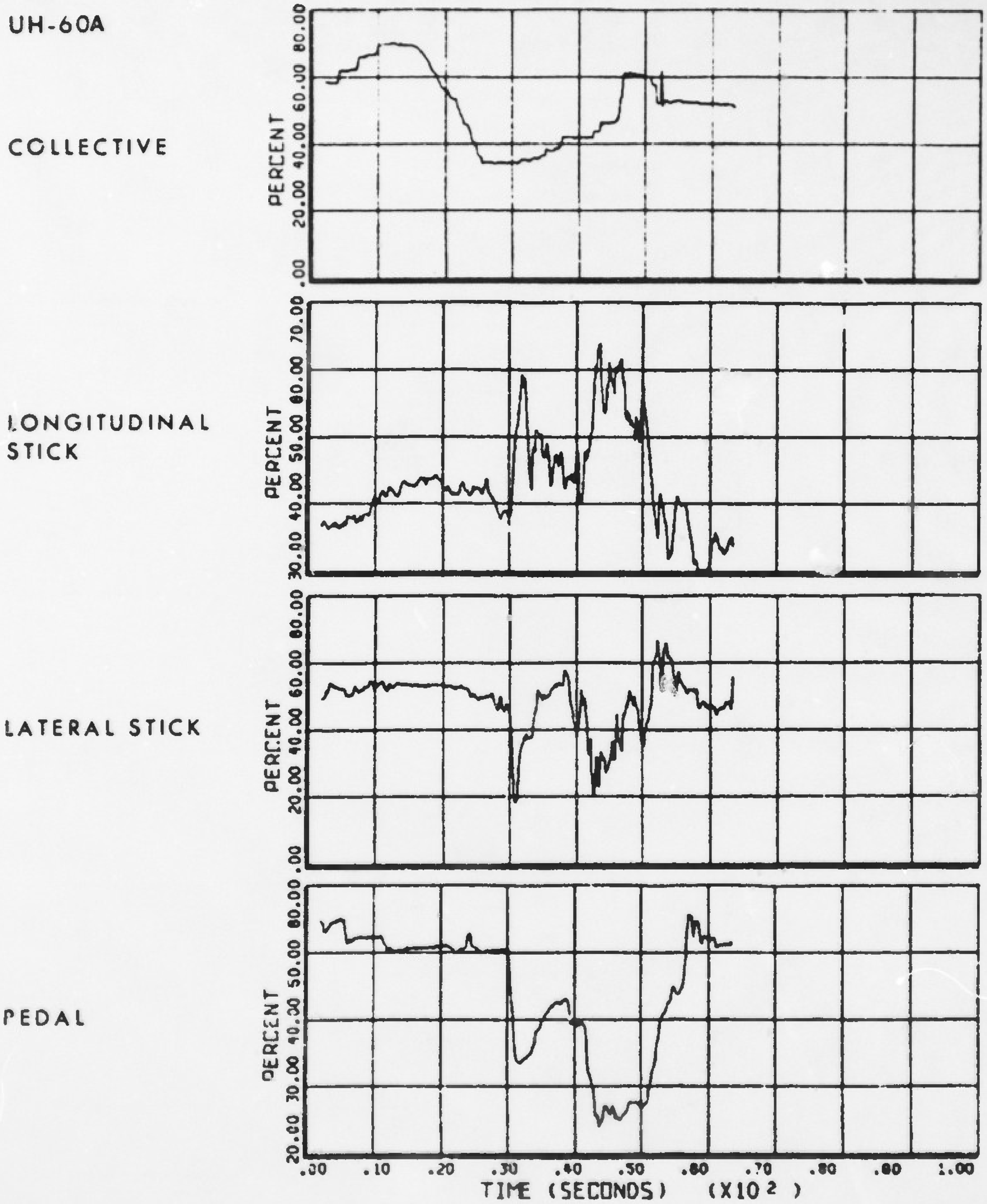


(h)
Figure F-6. Continued.

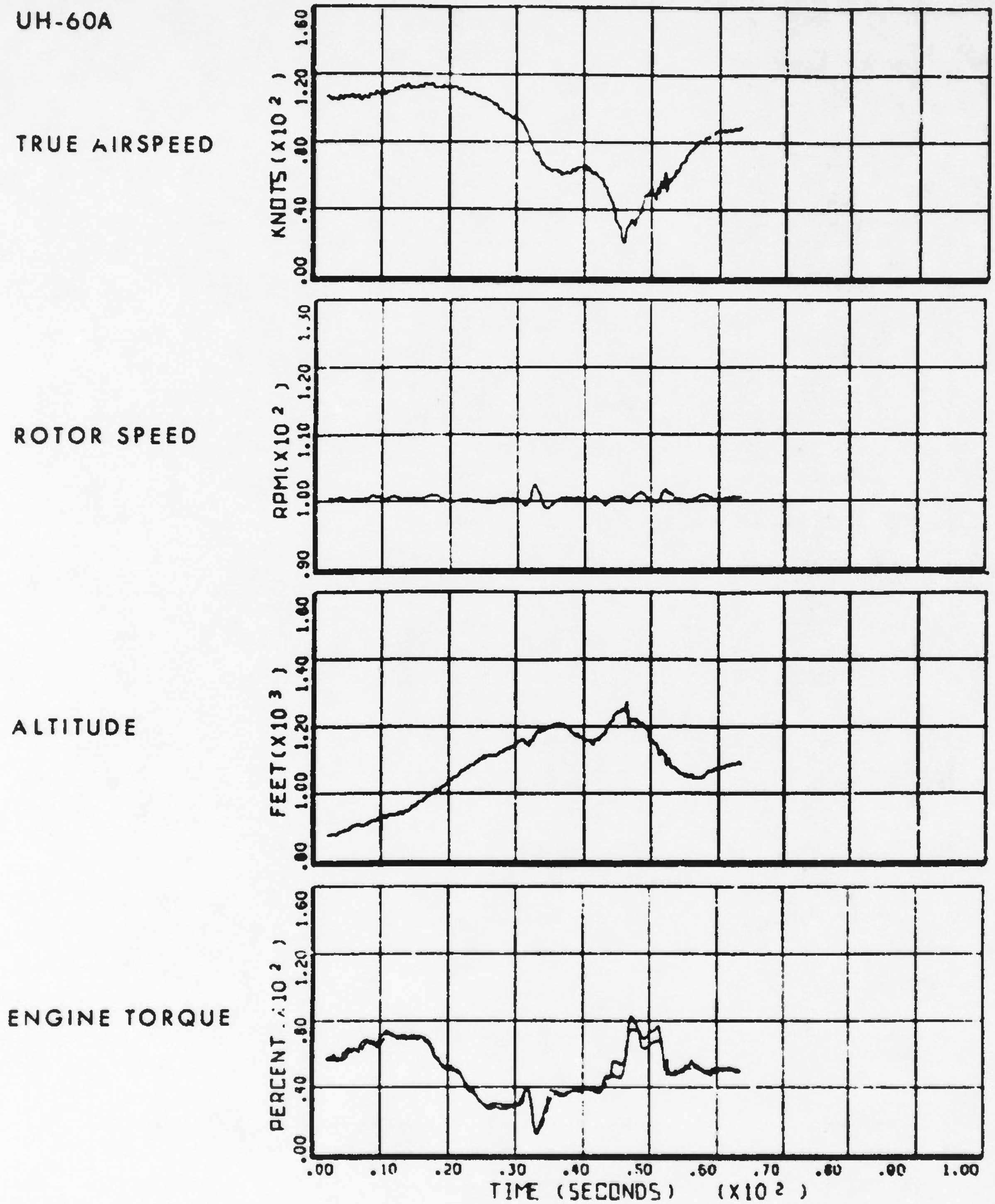


(i)

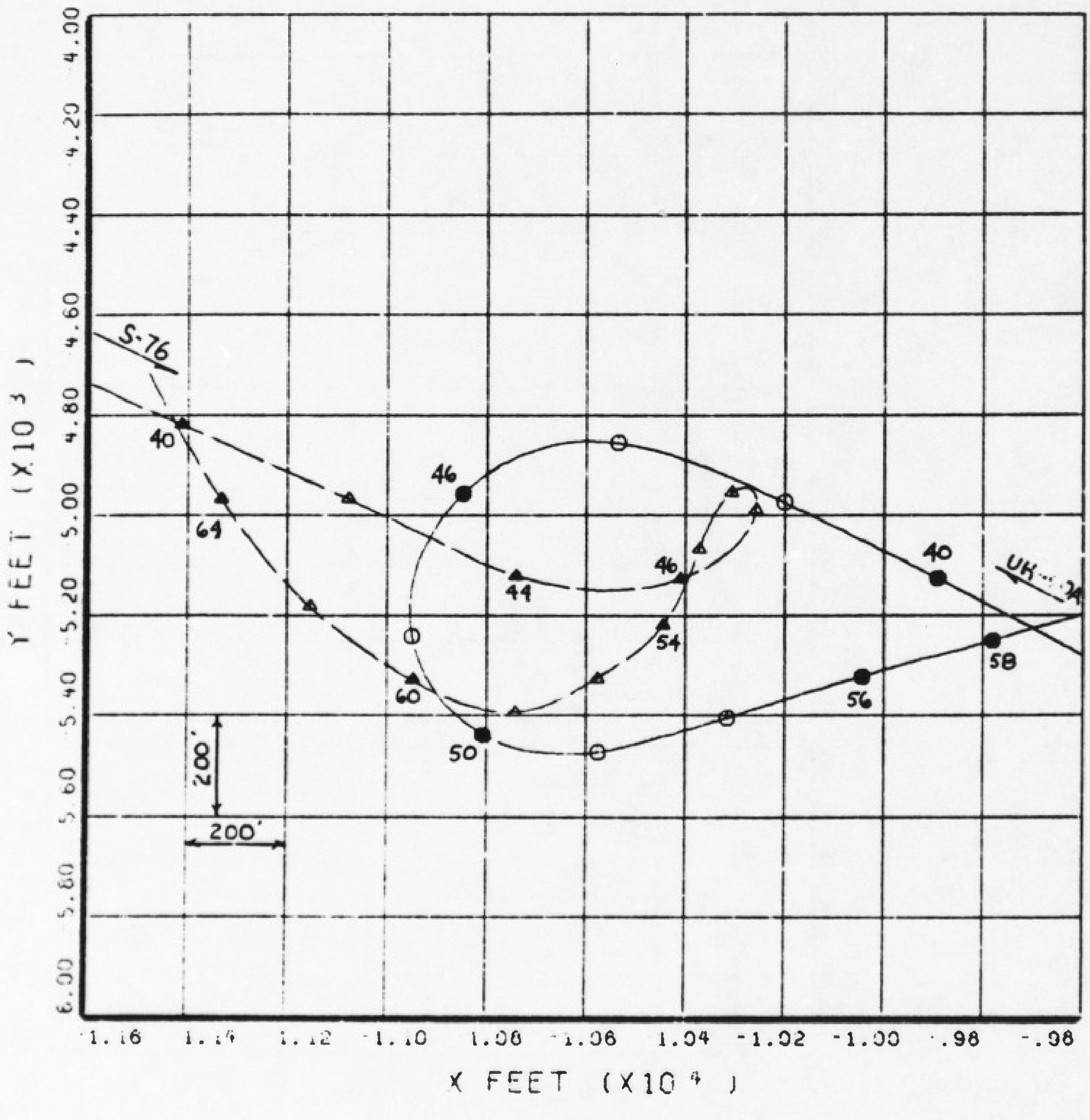
Figure F-6. Continued.



(j)
Figure F-6. Continued.



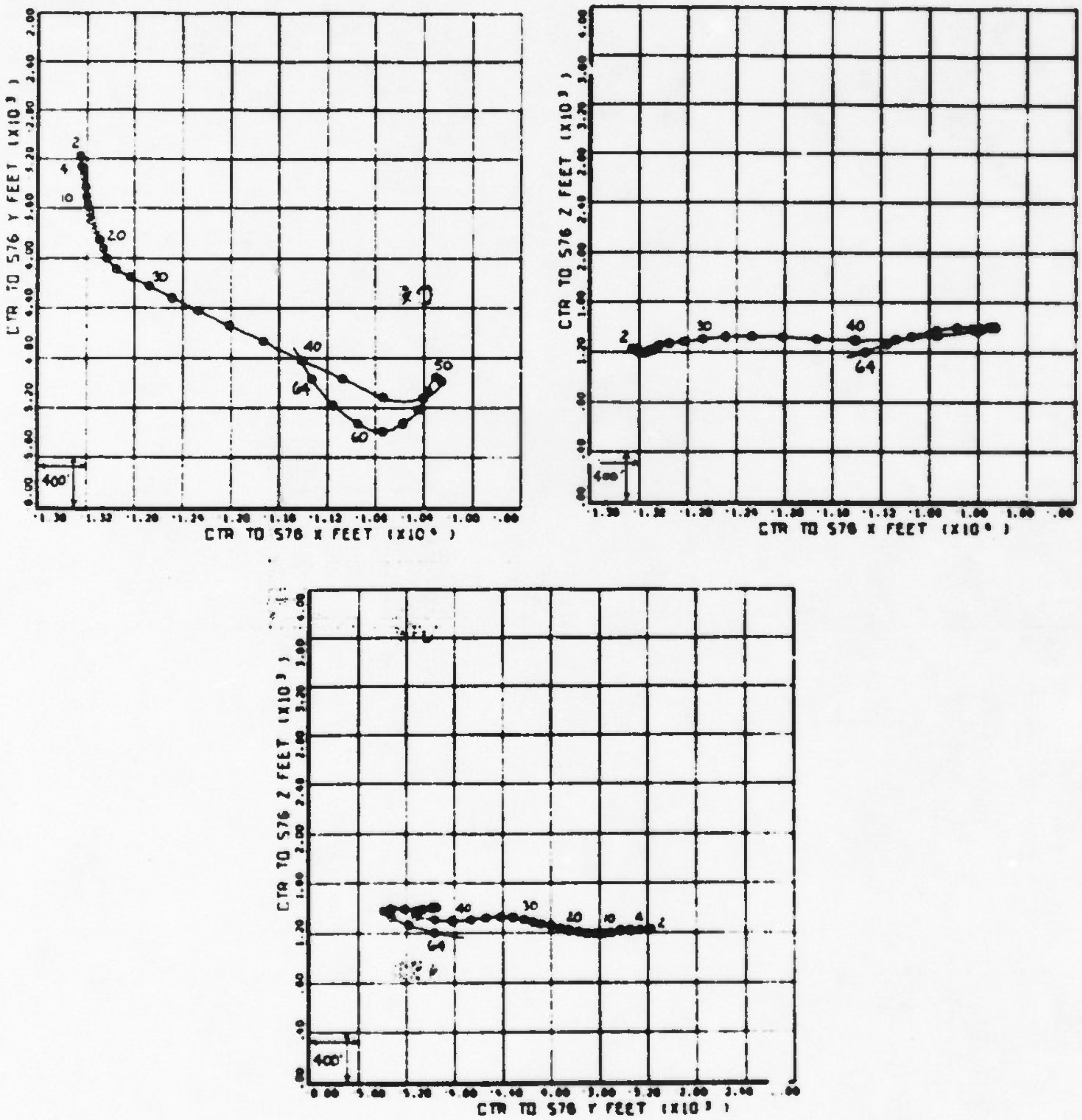
(k)
Figure F-6. Continued.



(a)

Figure F-7. Free engagement – simulated NOE (S-76 hover).

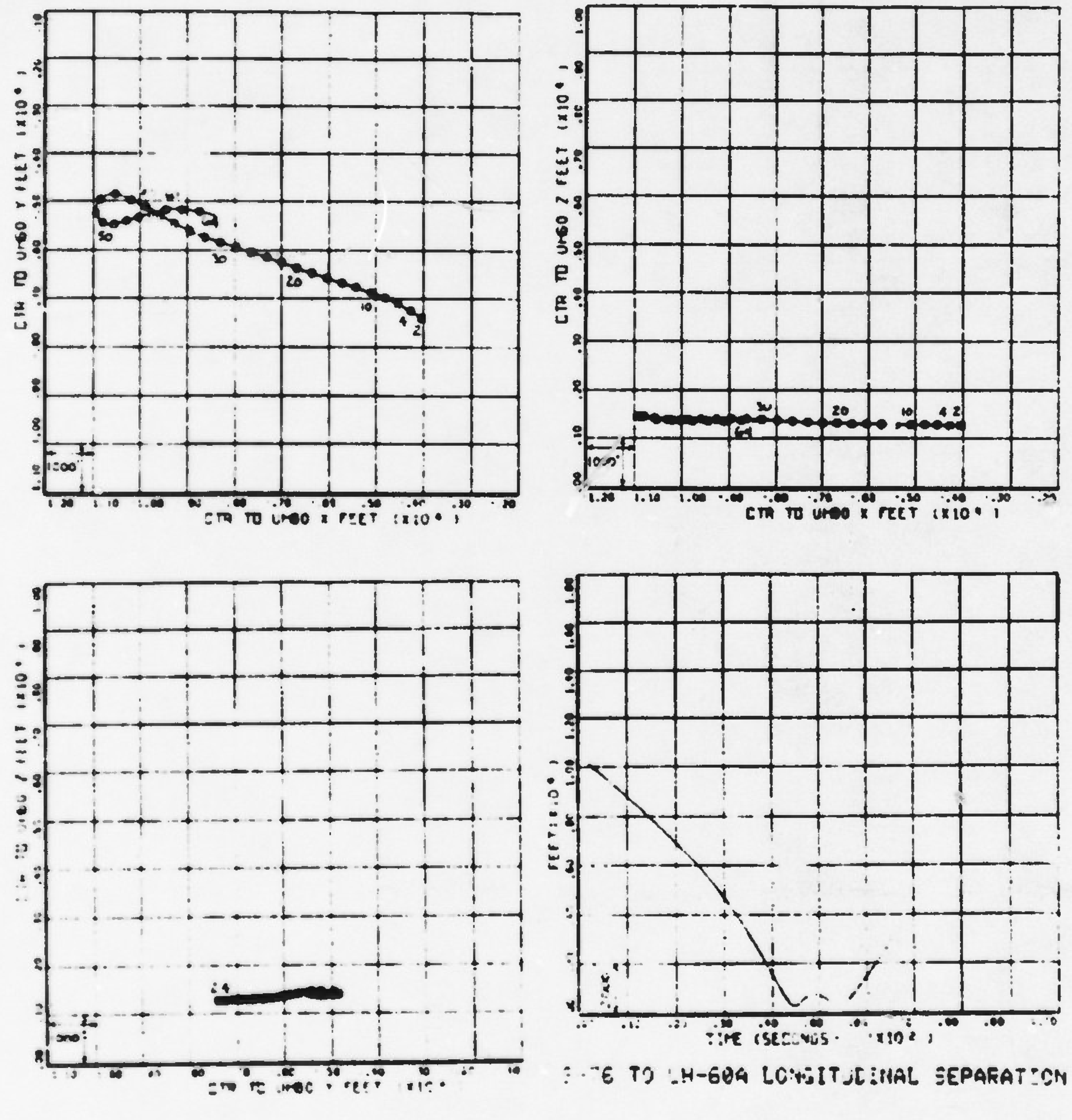
S-76
FLIGHT PATH PLOTS



(b)
Figure F-7. Continued.

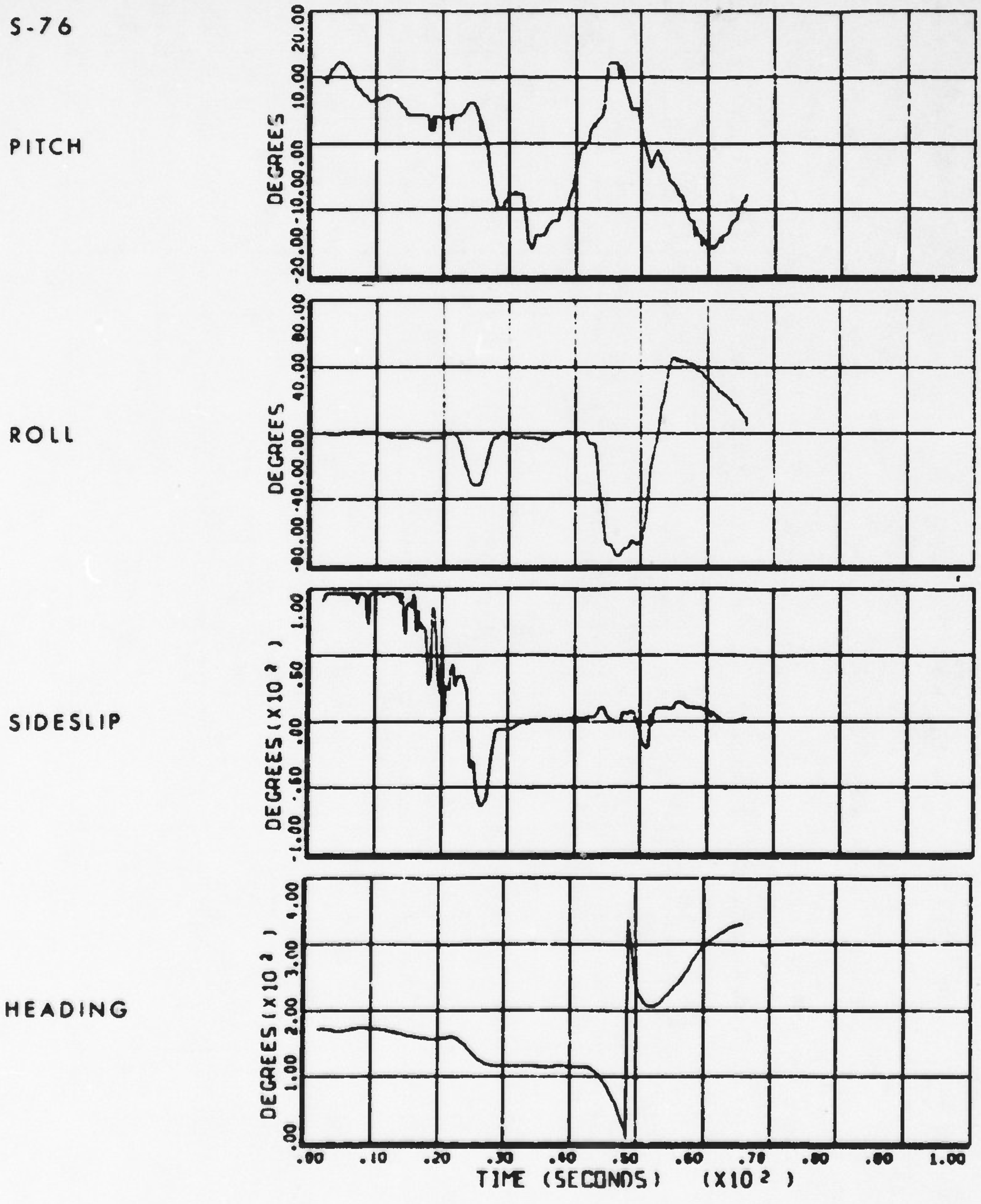
UH-60A

FLIGHT PATH PLOTS

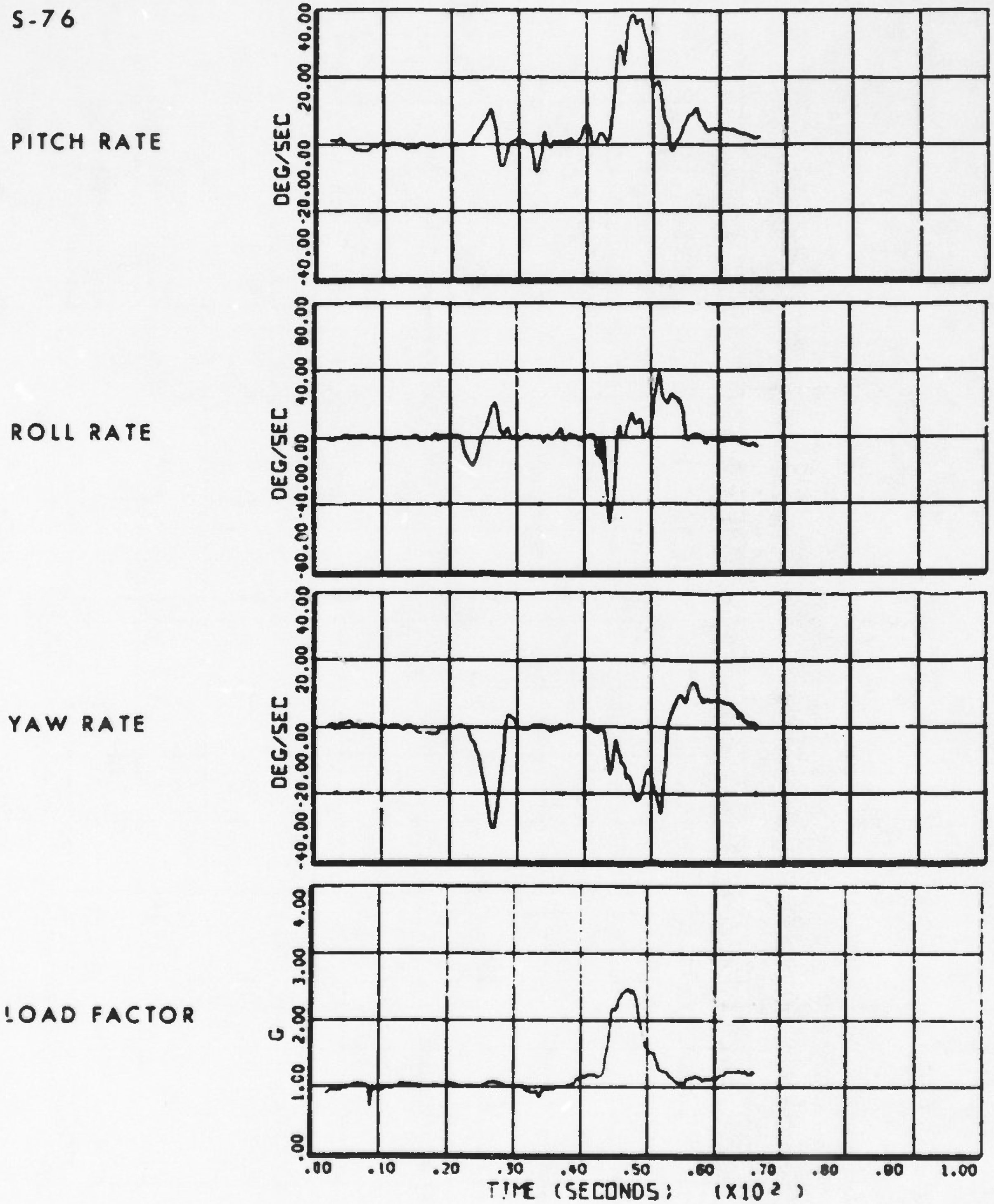


(c)

Figure F-7. Continued.

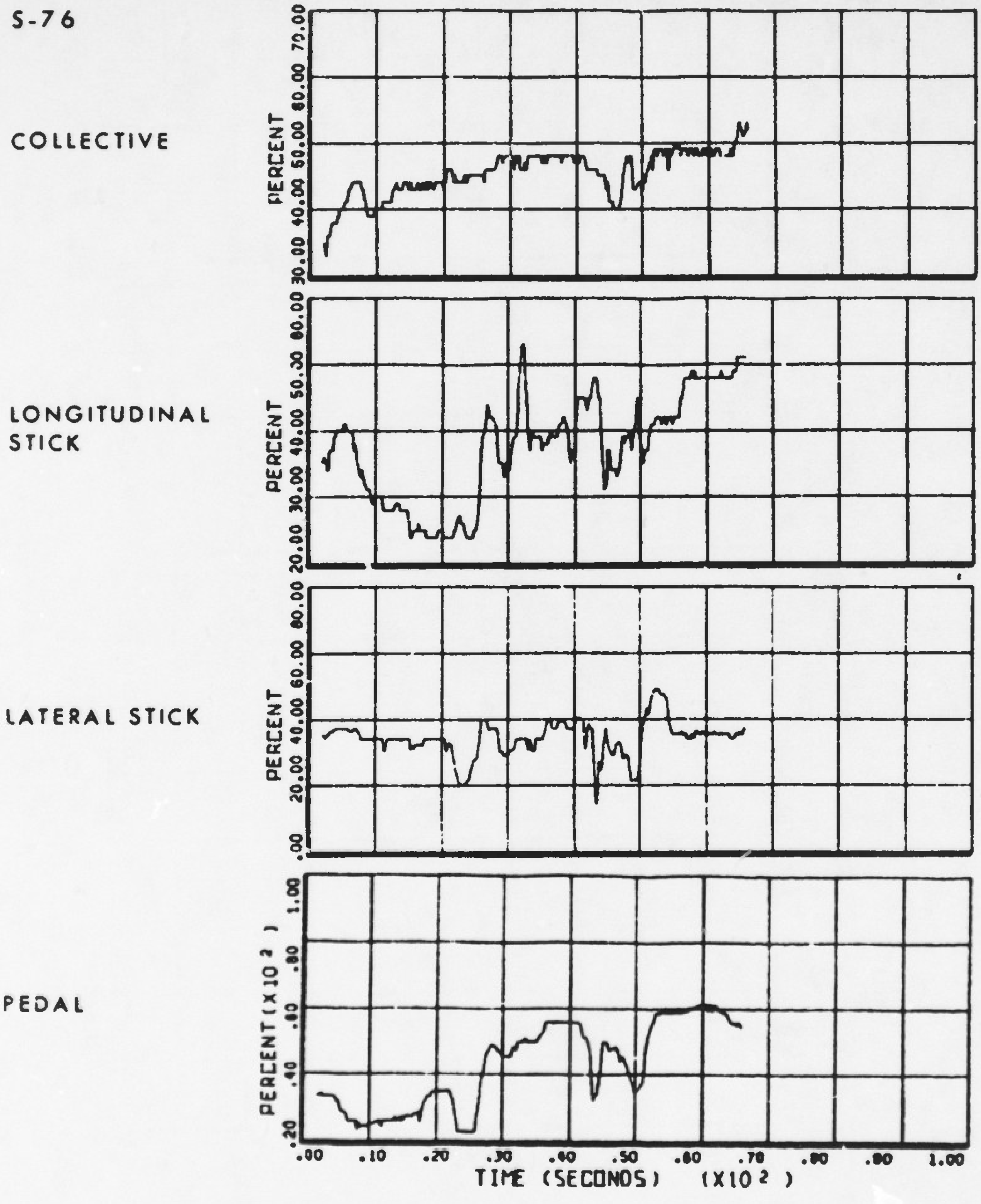


(d)
Figure F-7. Continued.



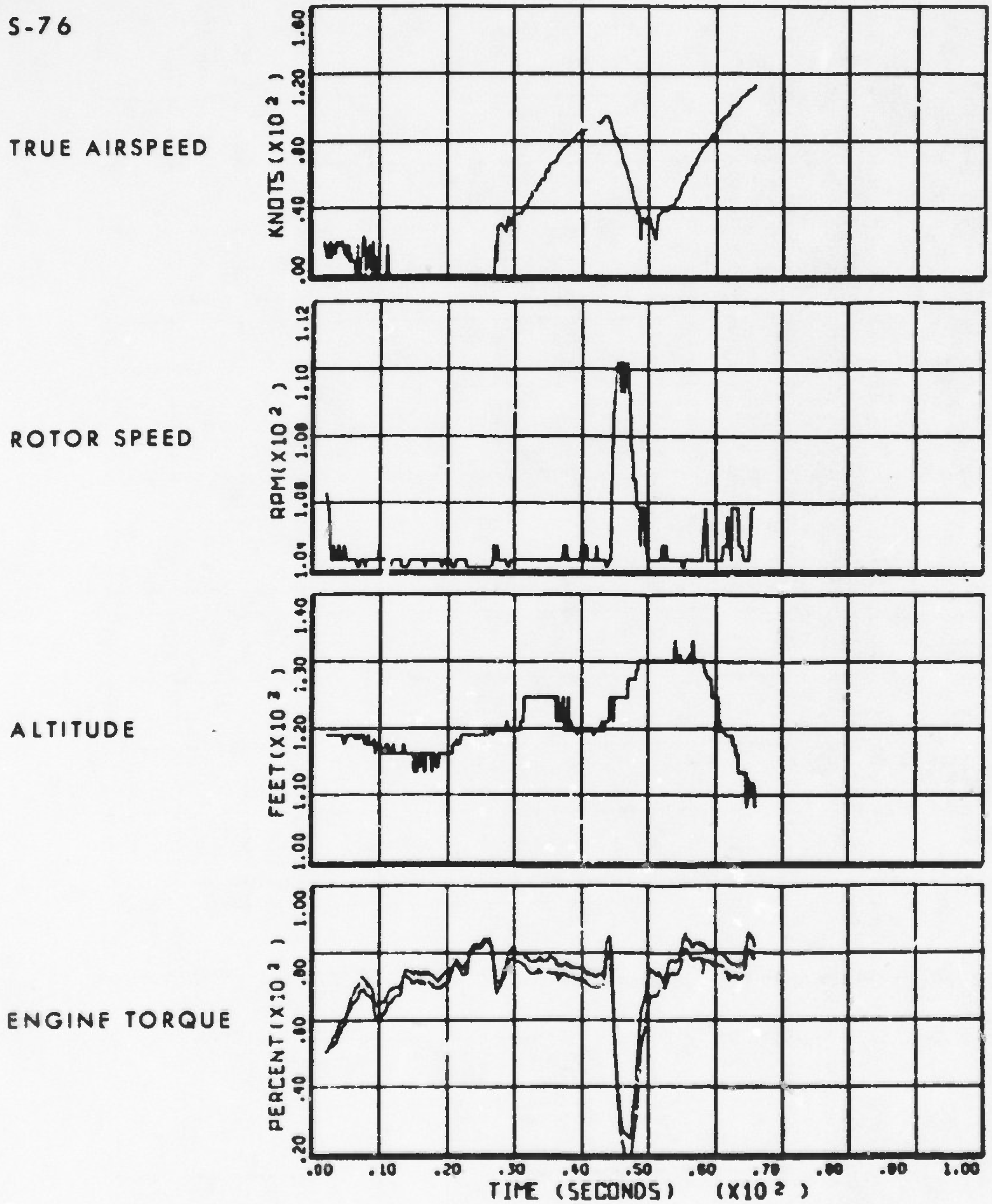
(e)
Figure F-7. Continued.

S-76

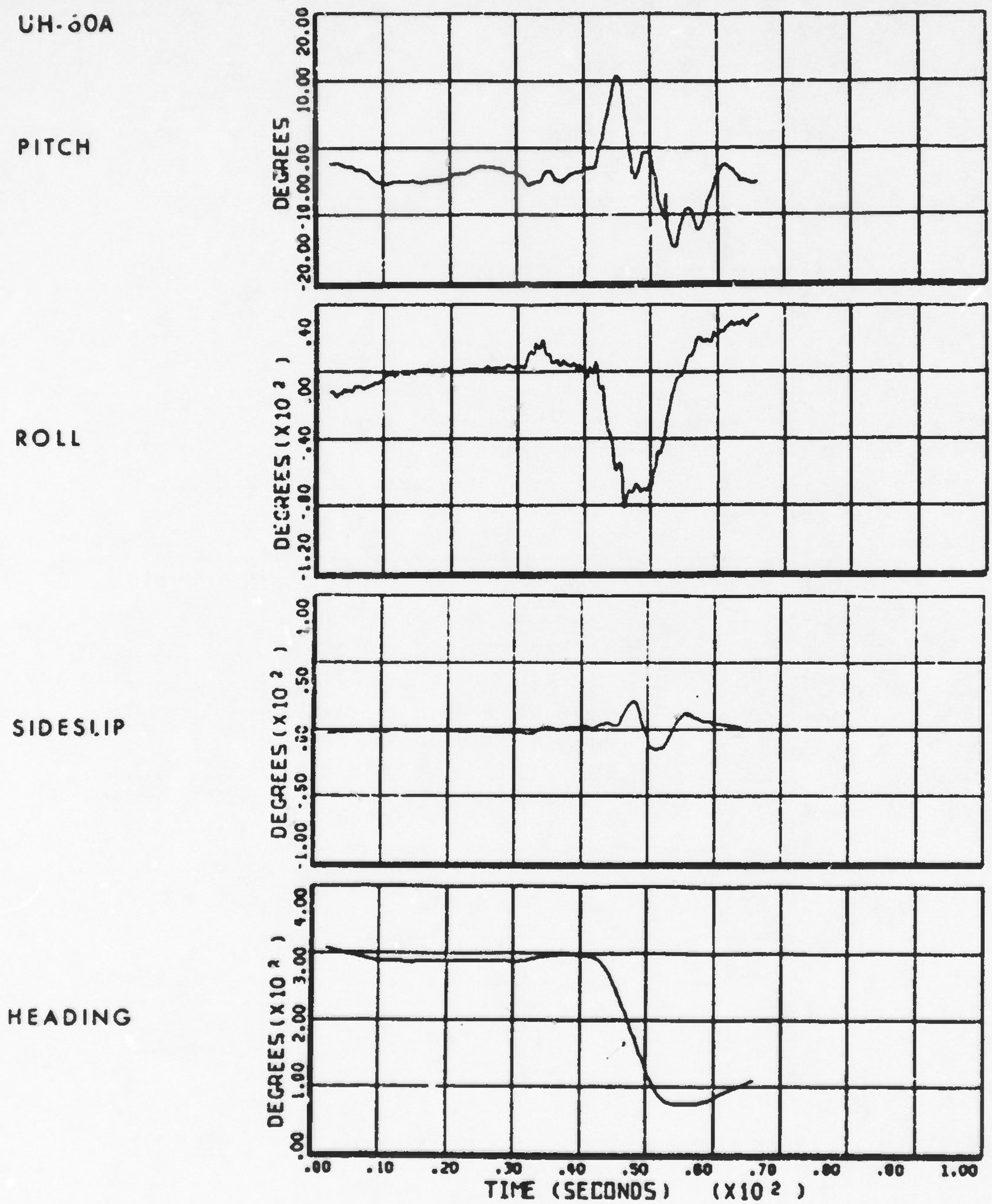


(f)
Figure F-7. Continued.

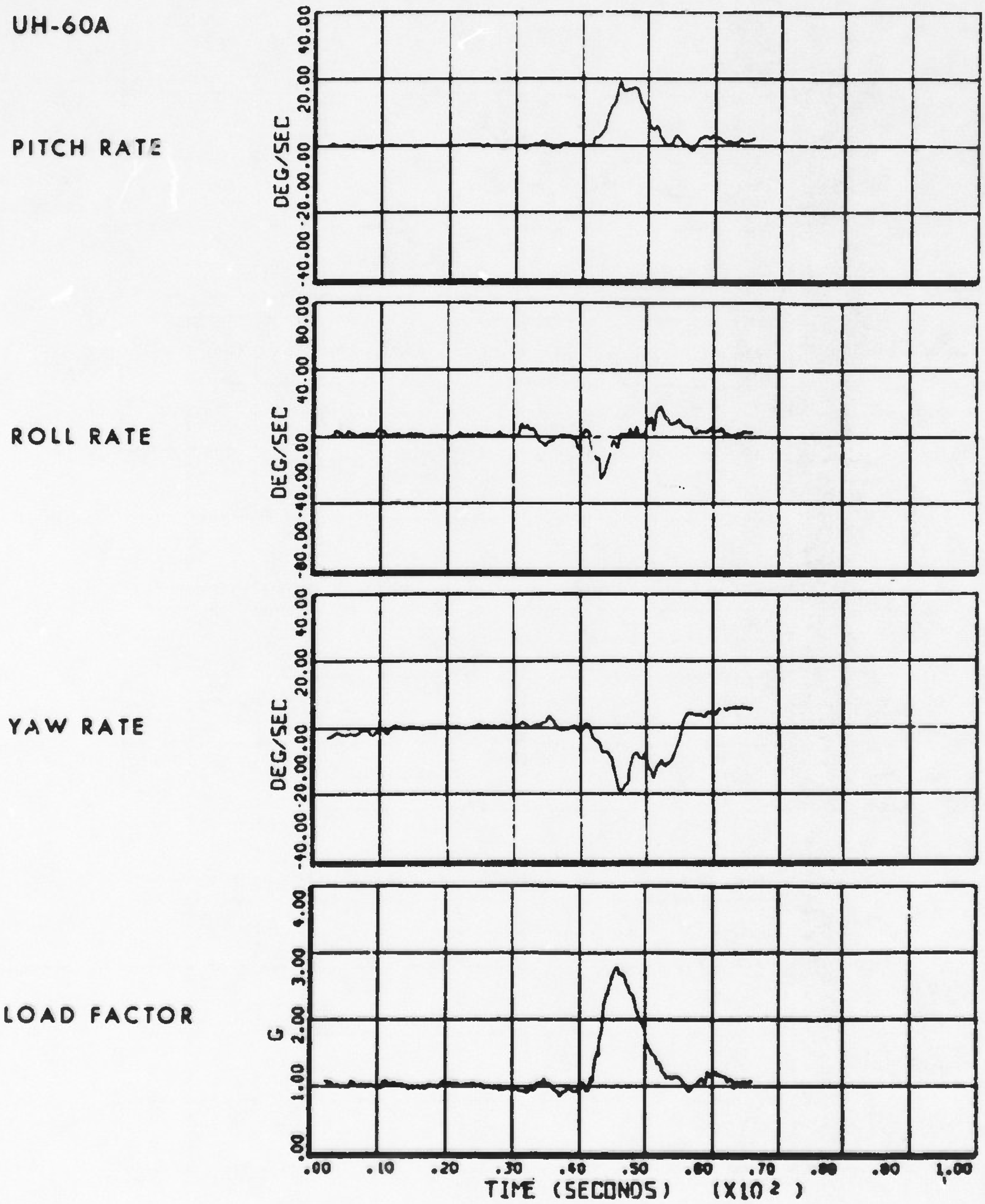
S-76



(g)
Figure F-7. Continued.



(h)
Figure F-7. Continued.



(i)
Figure F-7. Continued.

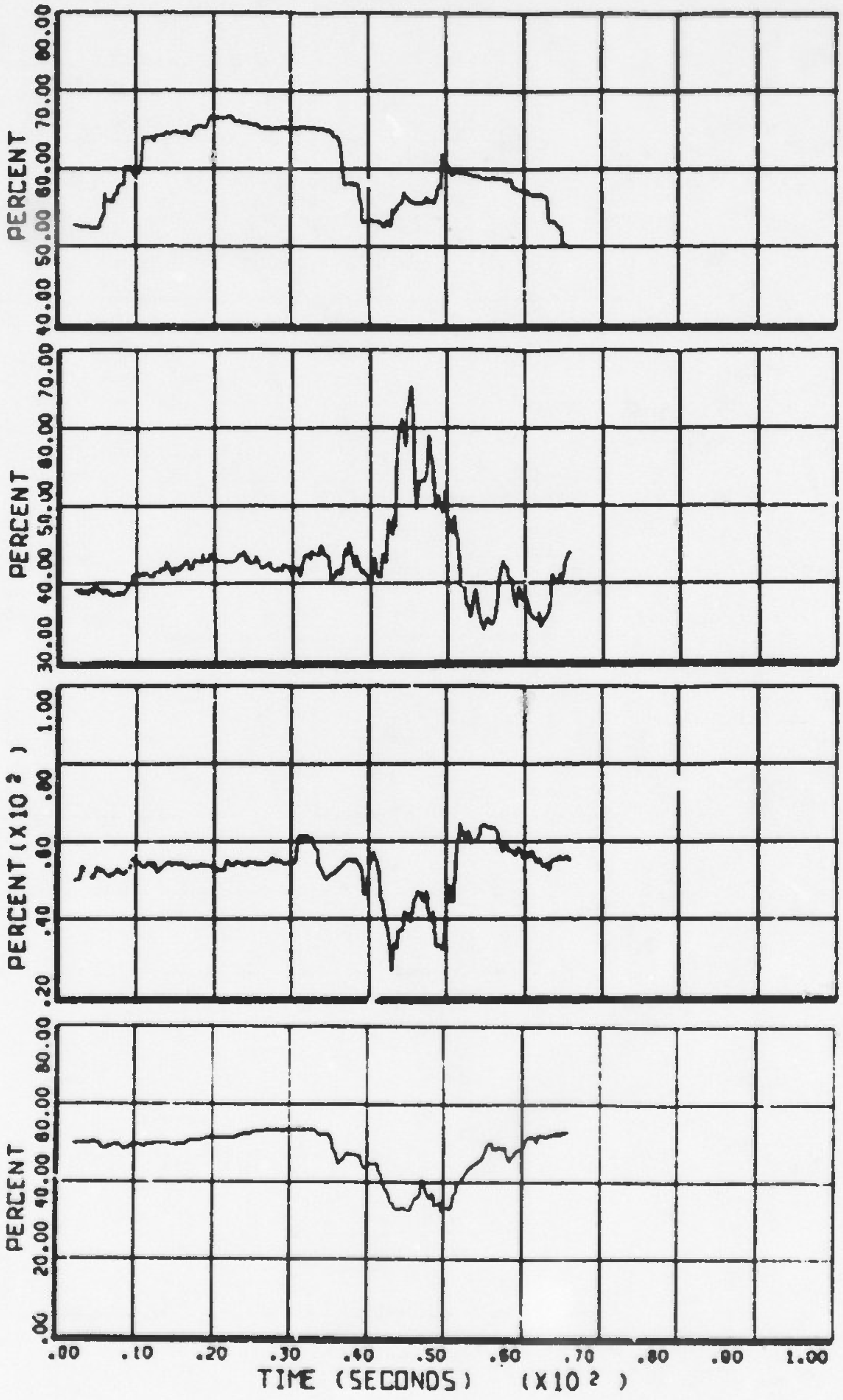
UH-60A

COLLECTIVE

LONGITUDINAL STICK

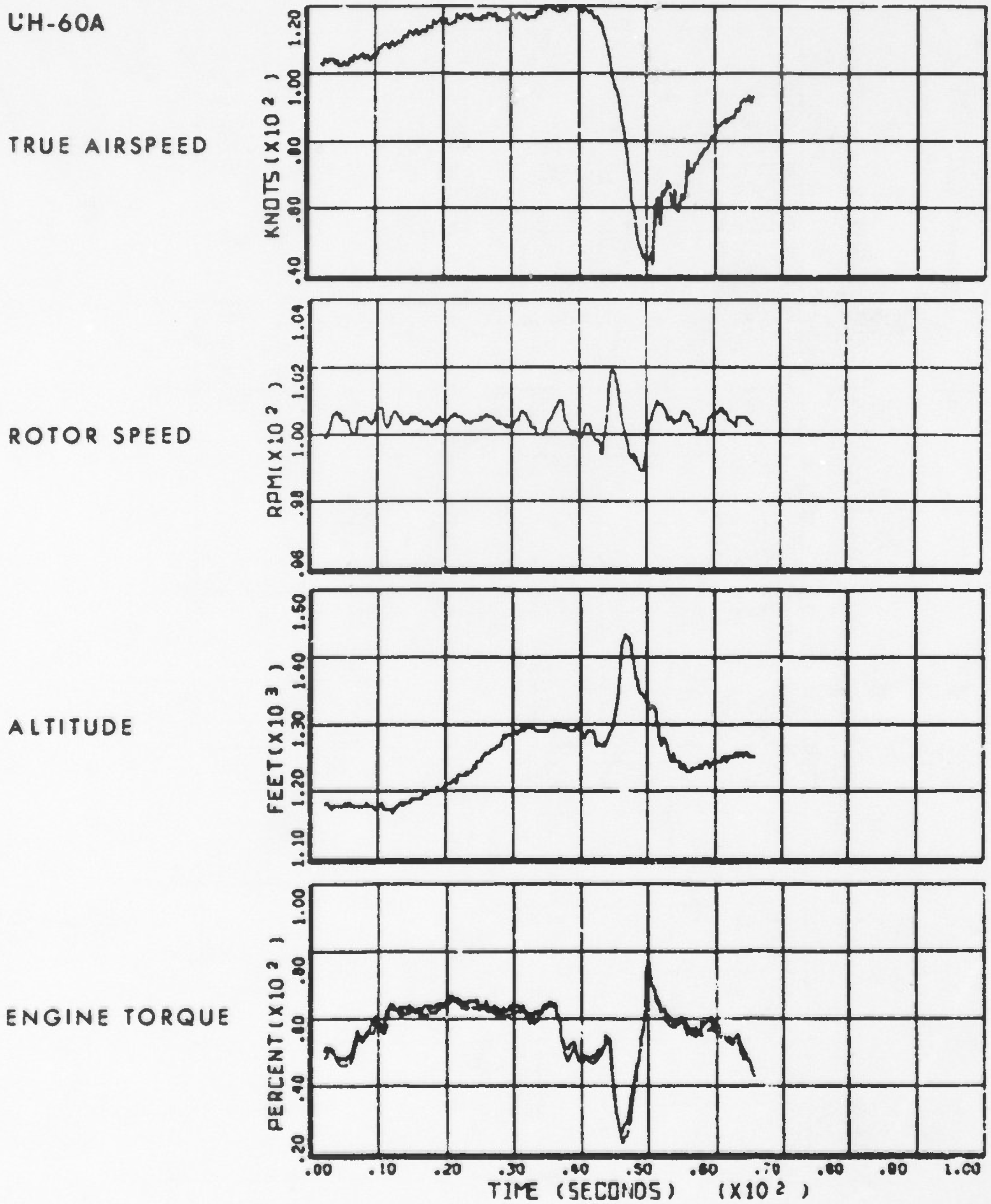
LATERAL STICK

PEDAL

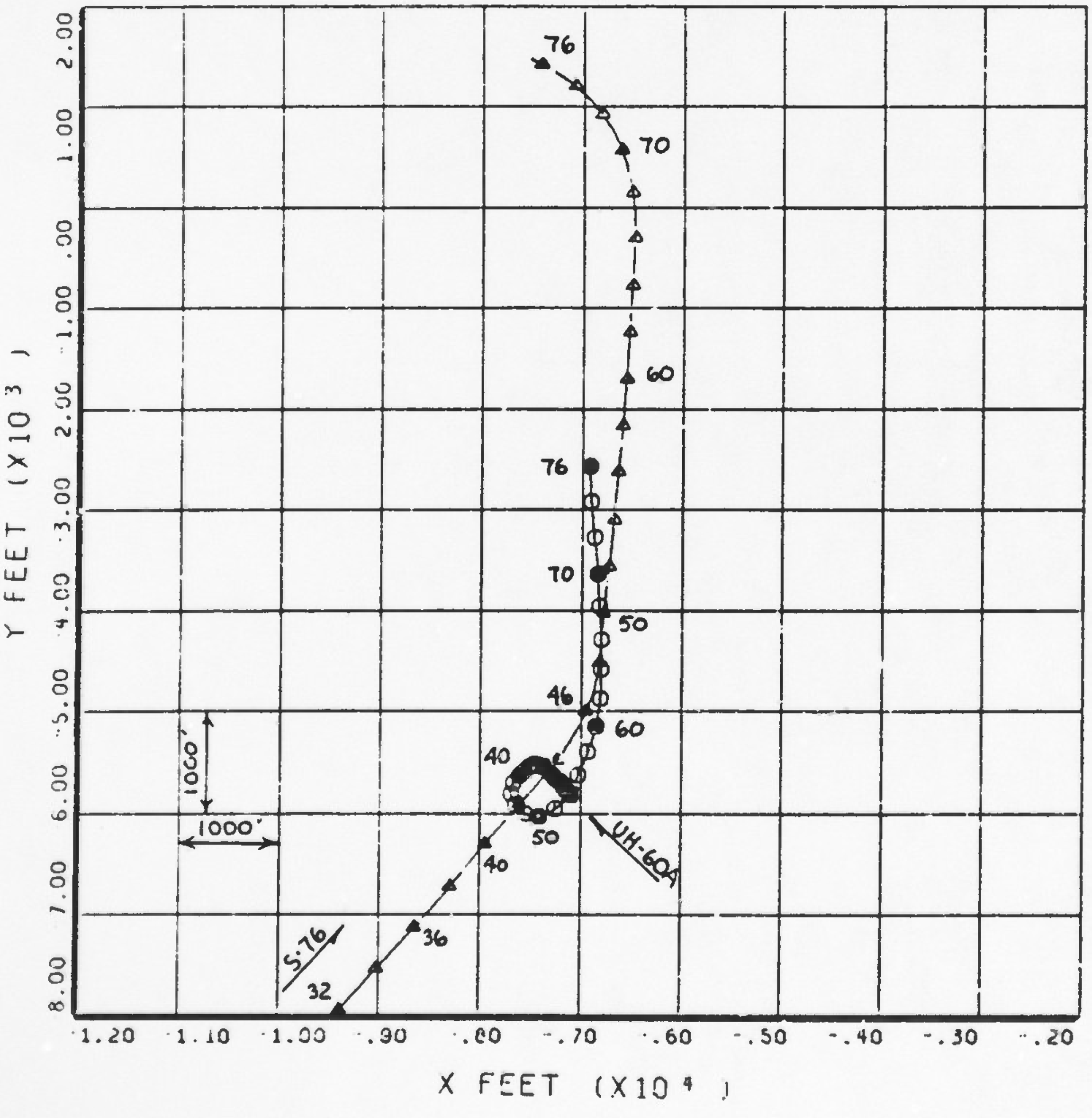


(j)

Figure F-7. Continued.



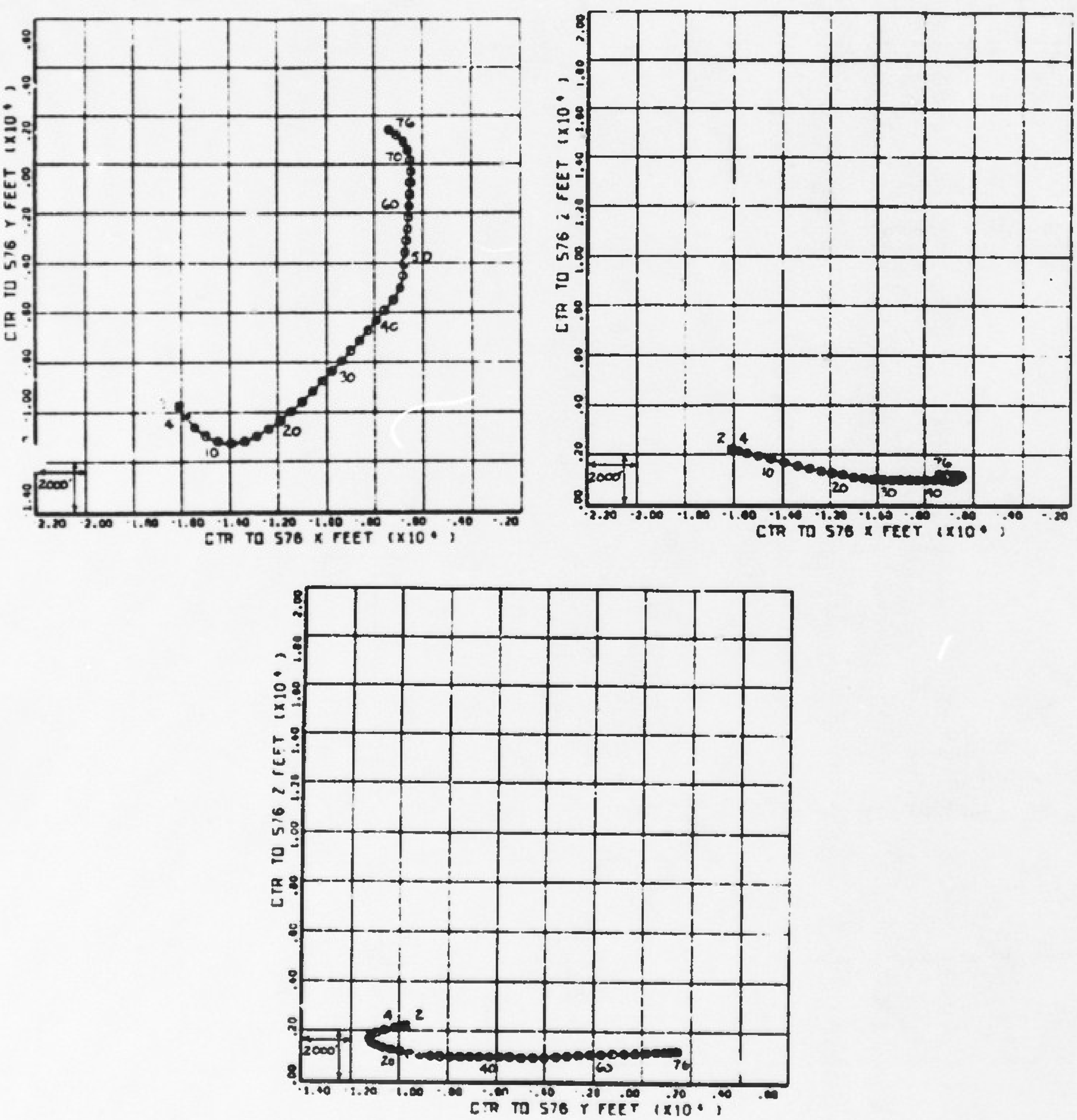
(k)
Figure F-7. Continued.



(a)

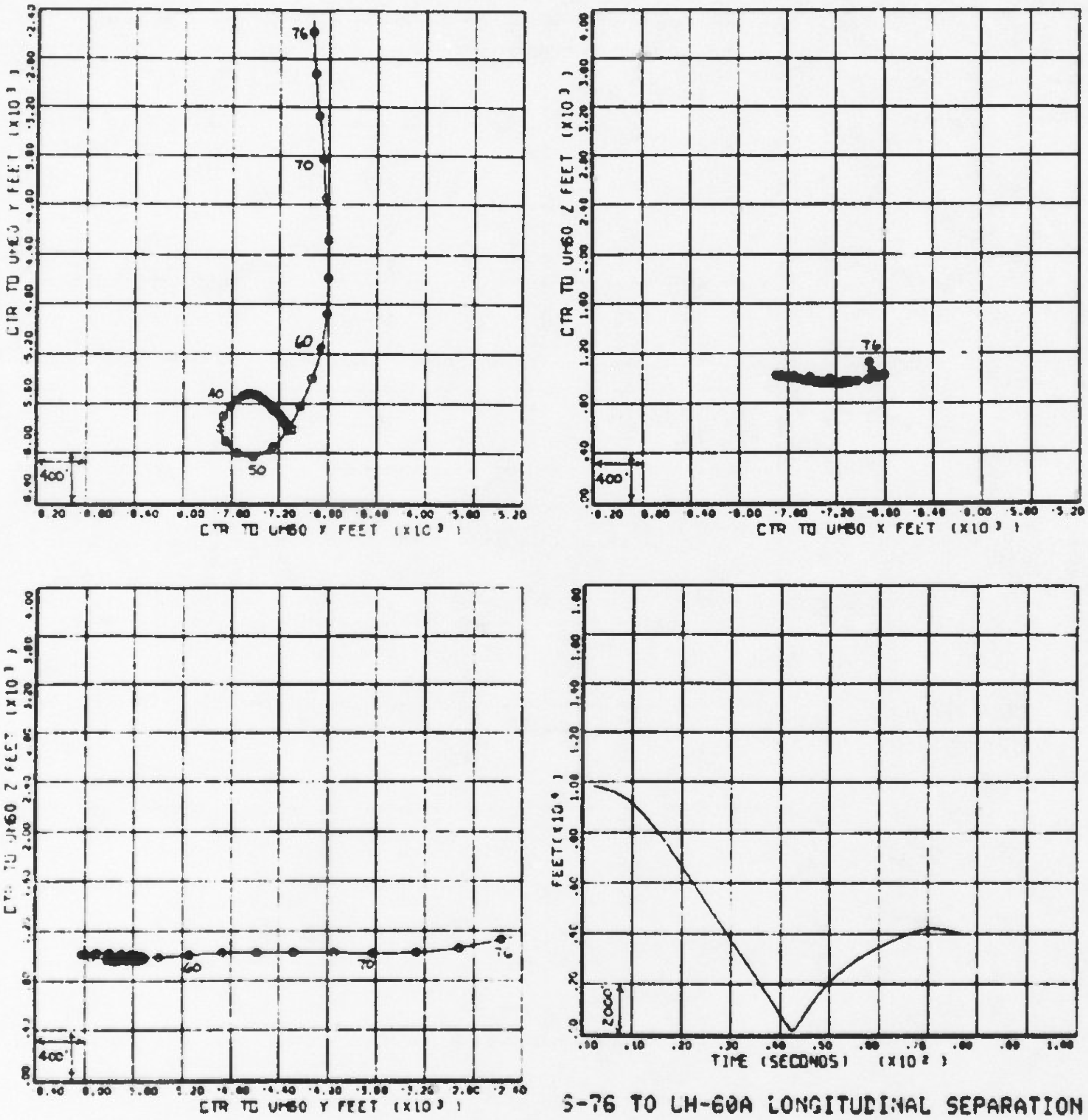
Figure F-8. Free engagement – simulated NOE (UH-60A hover).

S-76
FLIGHT PATH PLOTS



(b)
Figure F-8. Continued.

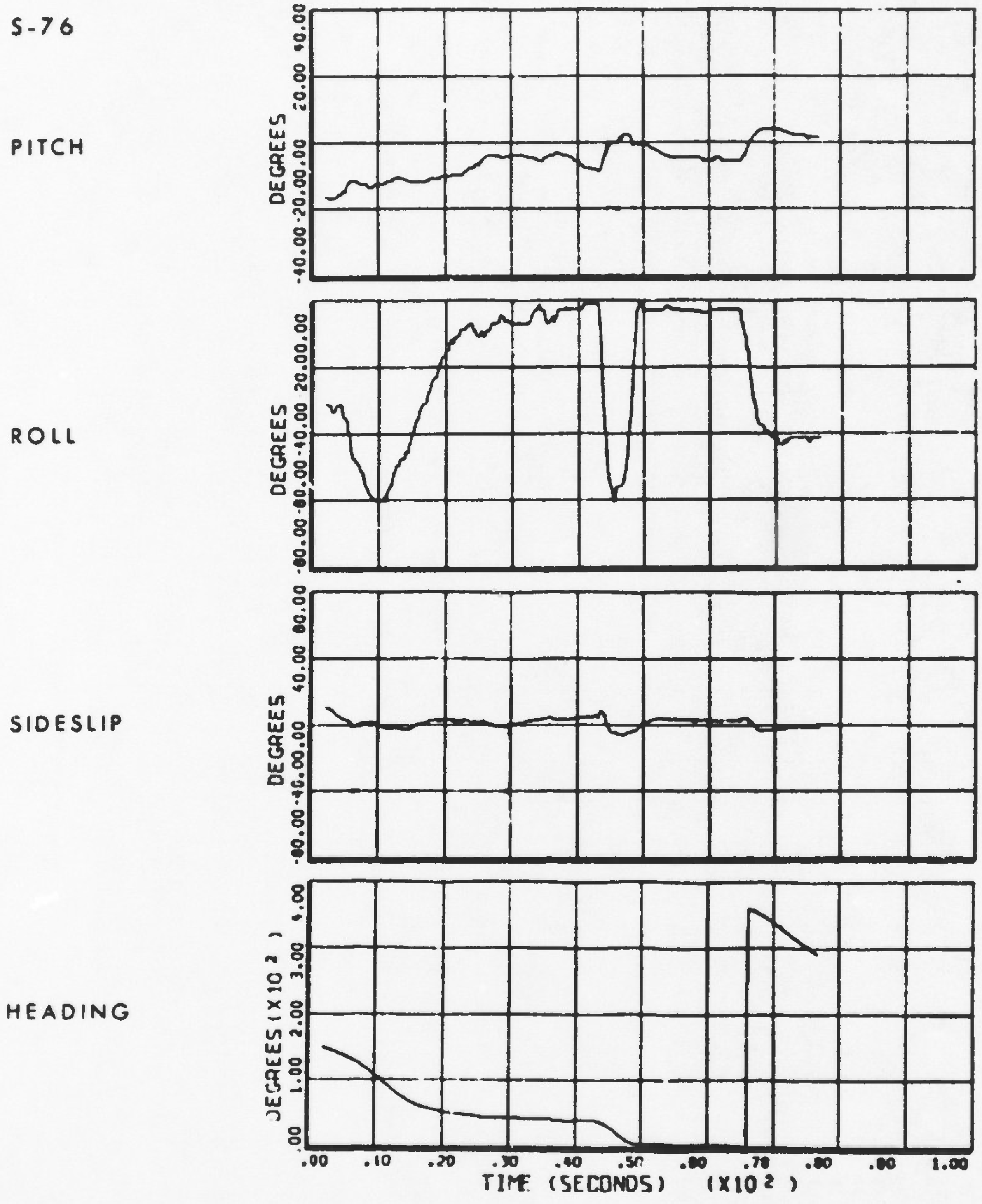
UH-60A
FLIGHT PATH PLOTS



S-76 TO LH-60A LONGITUDINAL SEPARATION

(c)
Figure F-8. Continued.

S-76



(d)
Figure F-8. Continued.

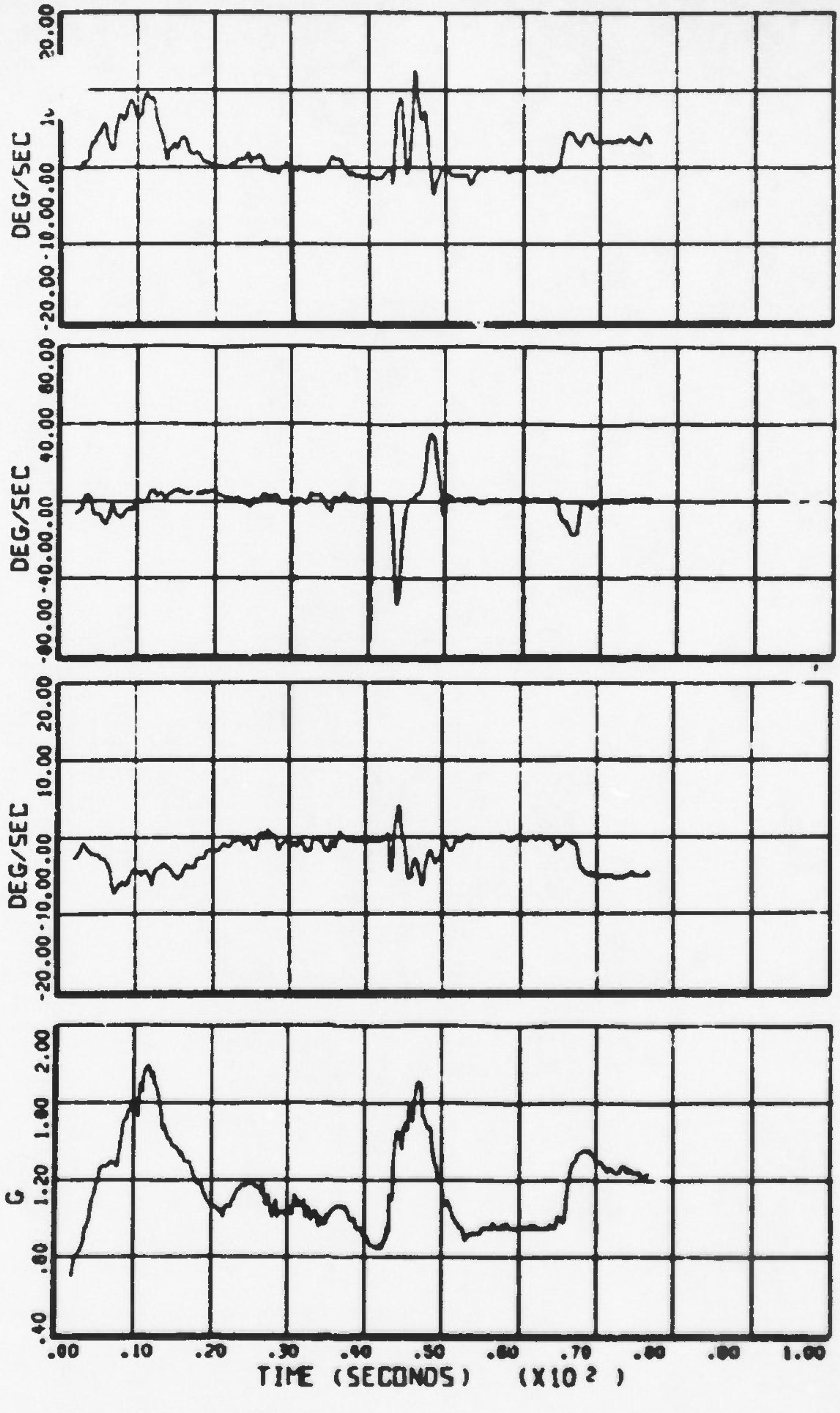
S-76

PITCH RATE

ROLL RATE

YAW RATE

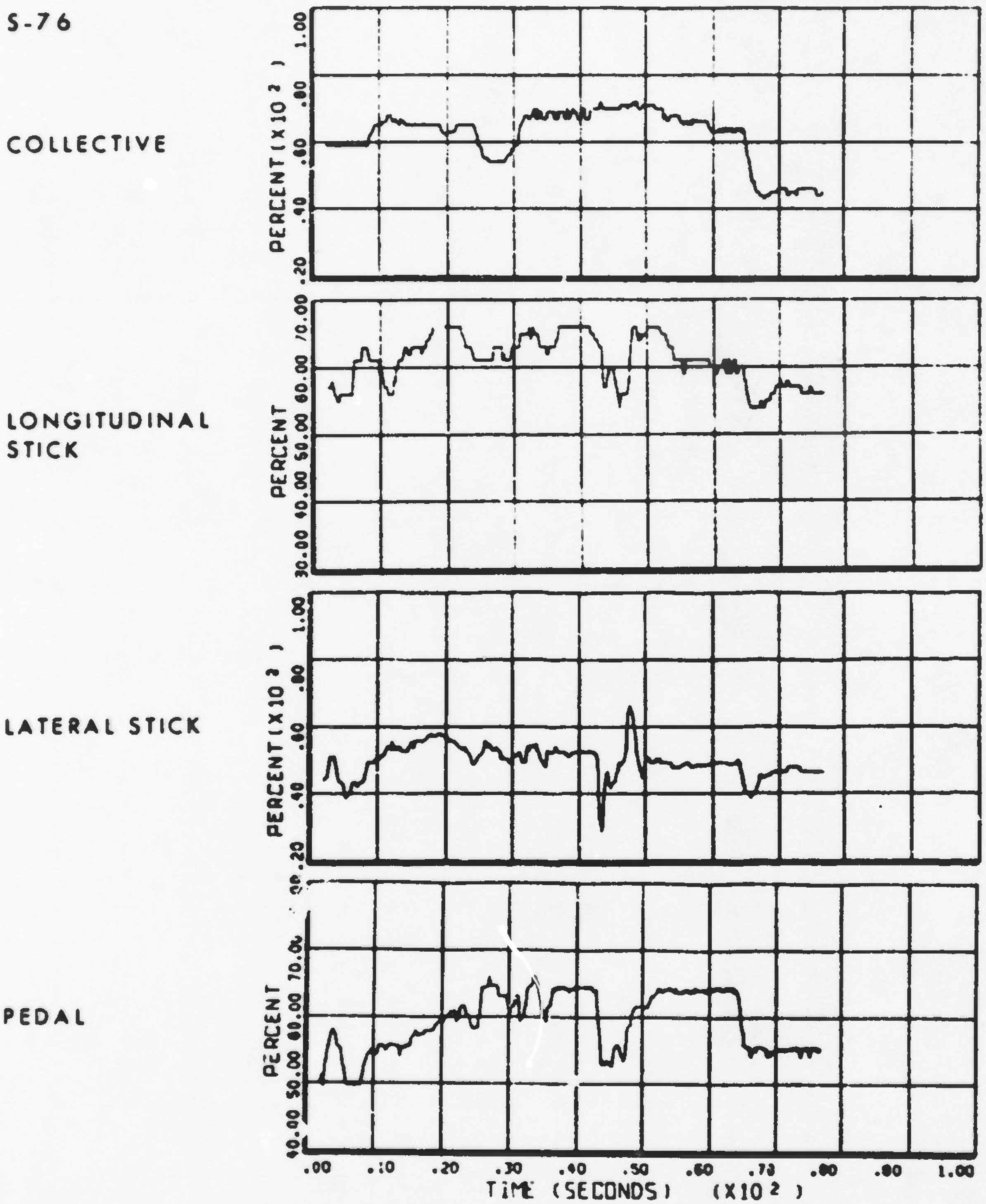
LOAD FACTOR



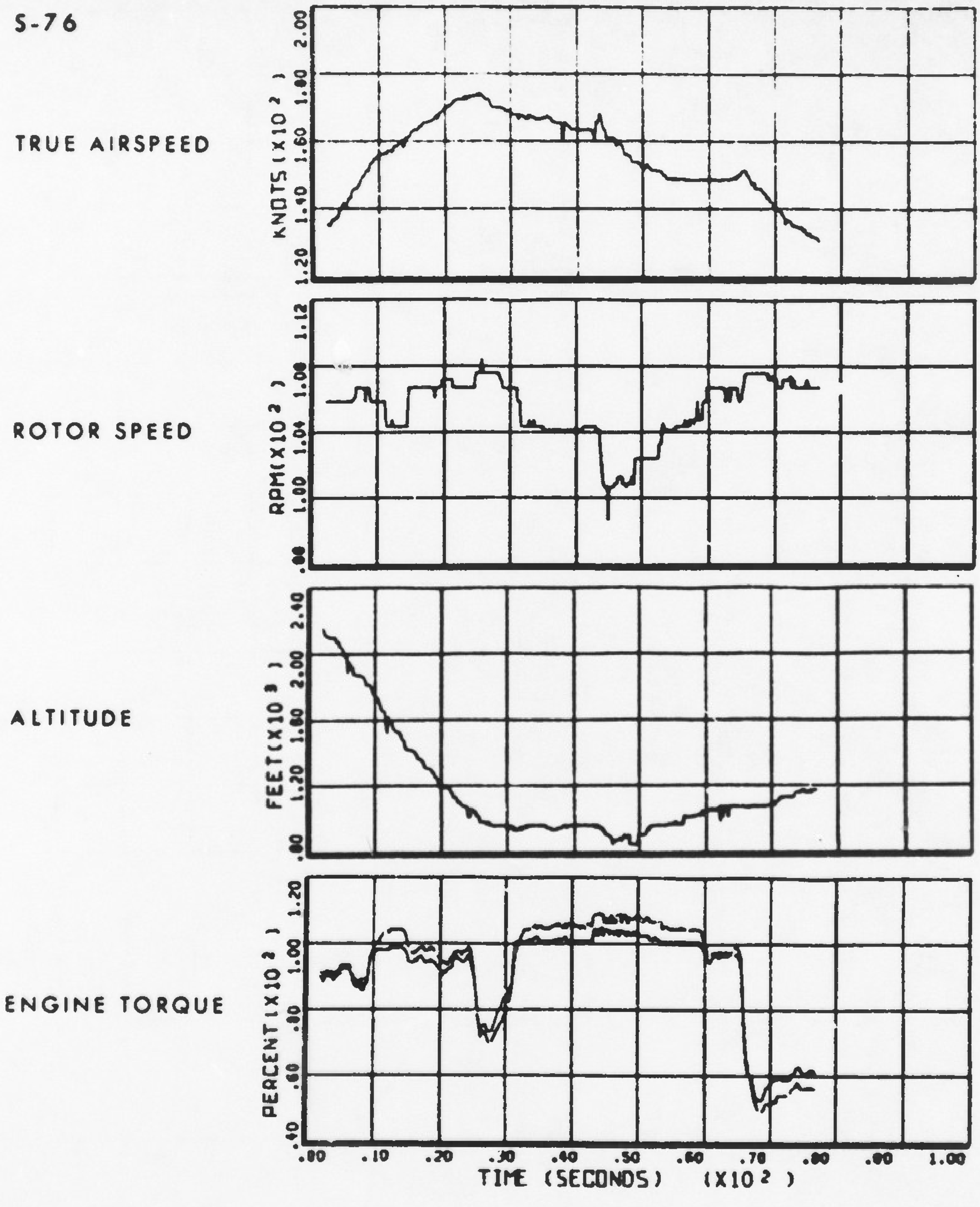
(e)

Figure F-8. Continued.

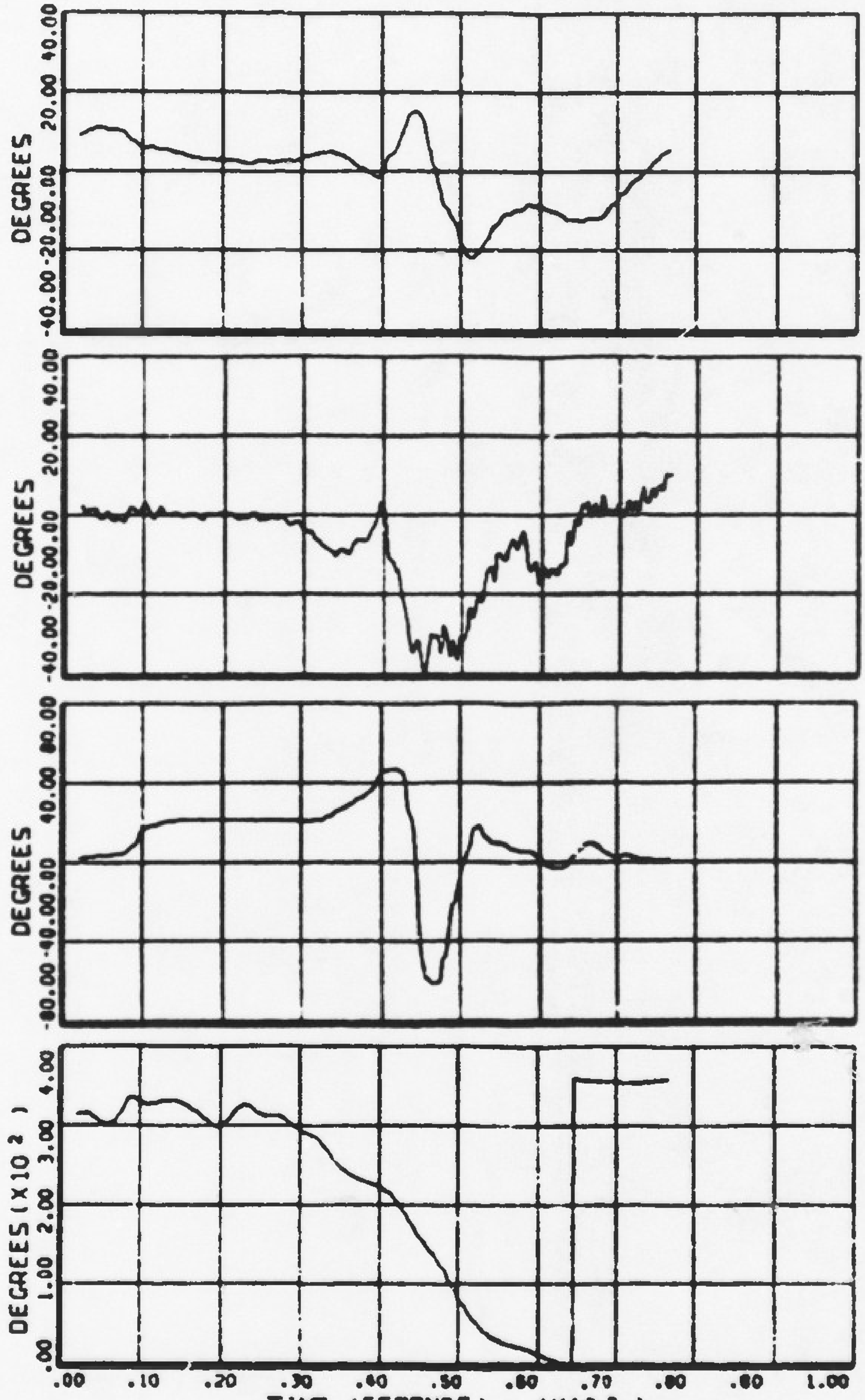
S-76



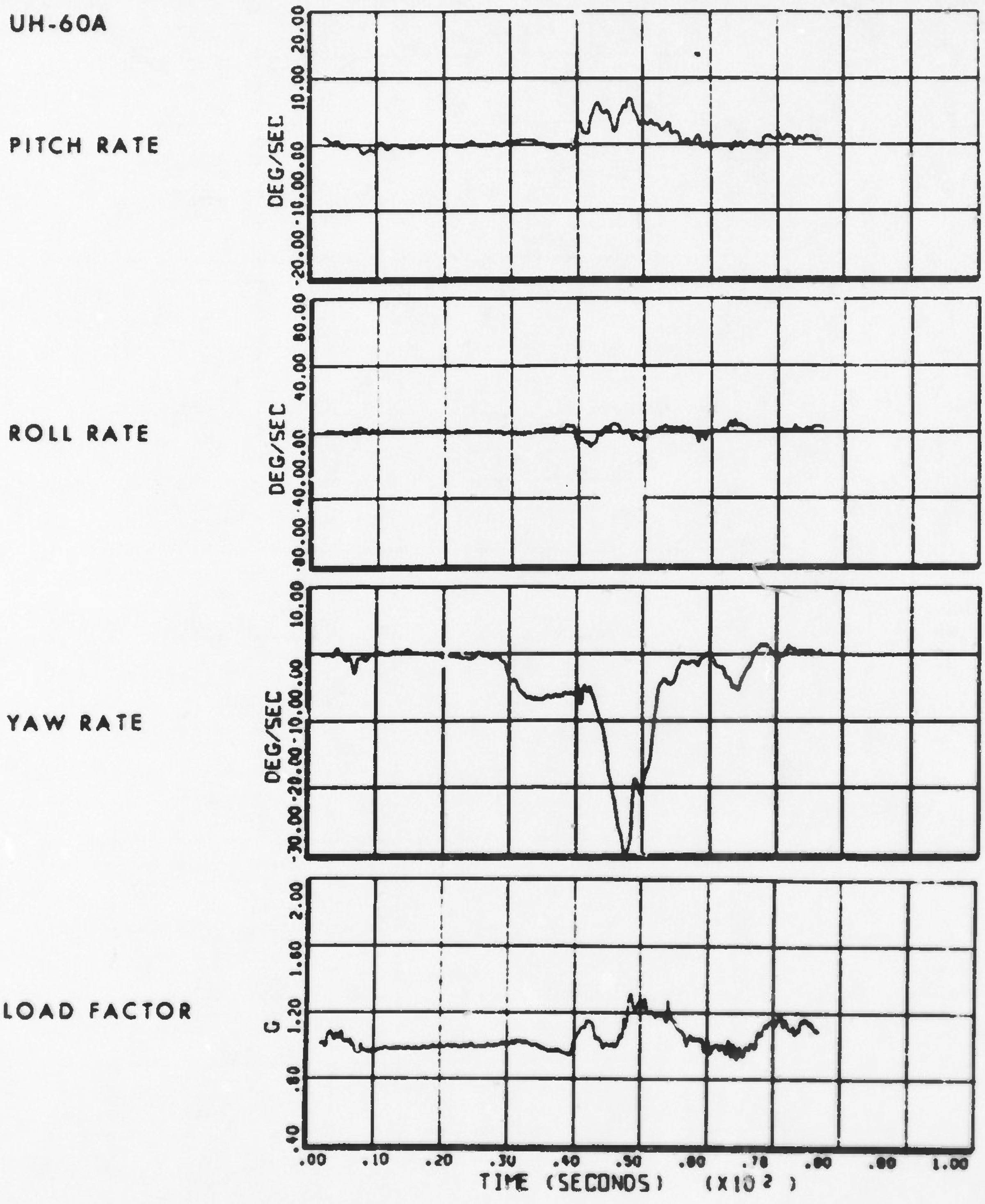
(f)
Figure F-8. Continued.



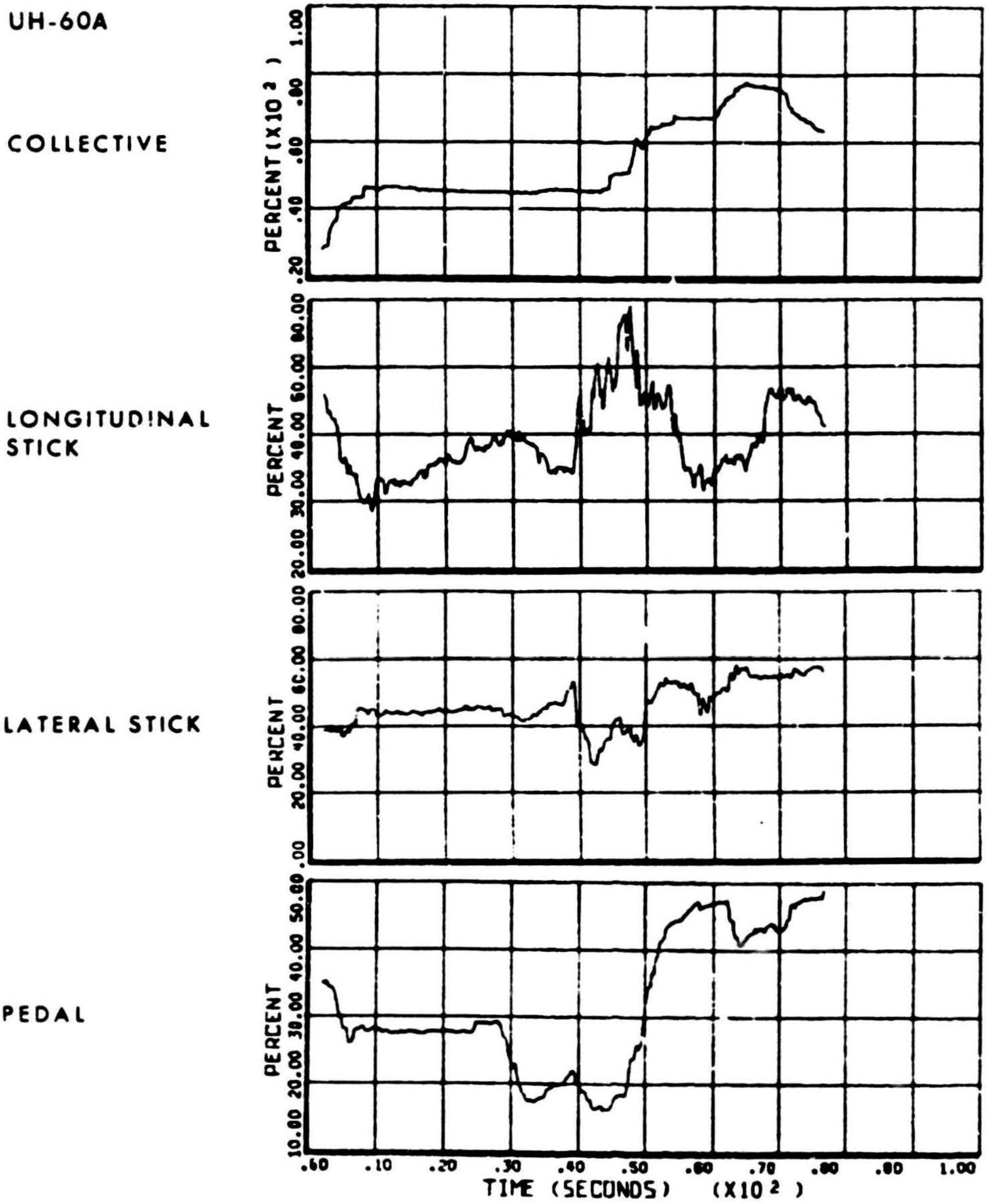
(g)
Figure F-8. Continued.



(h)
Figure F-8. Continued.

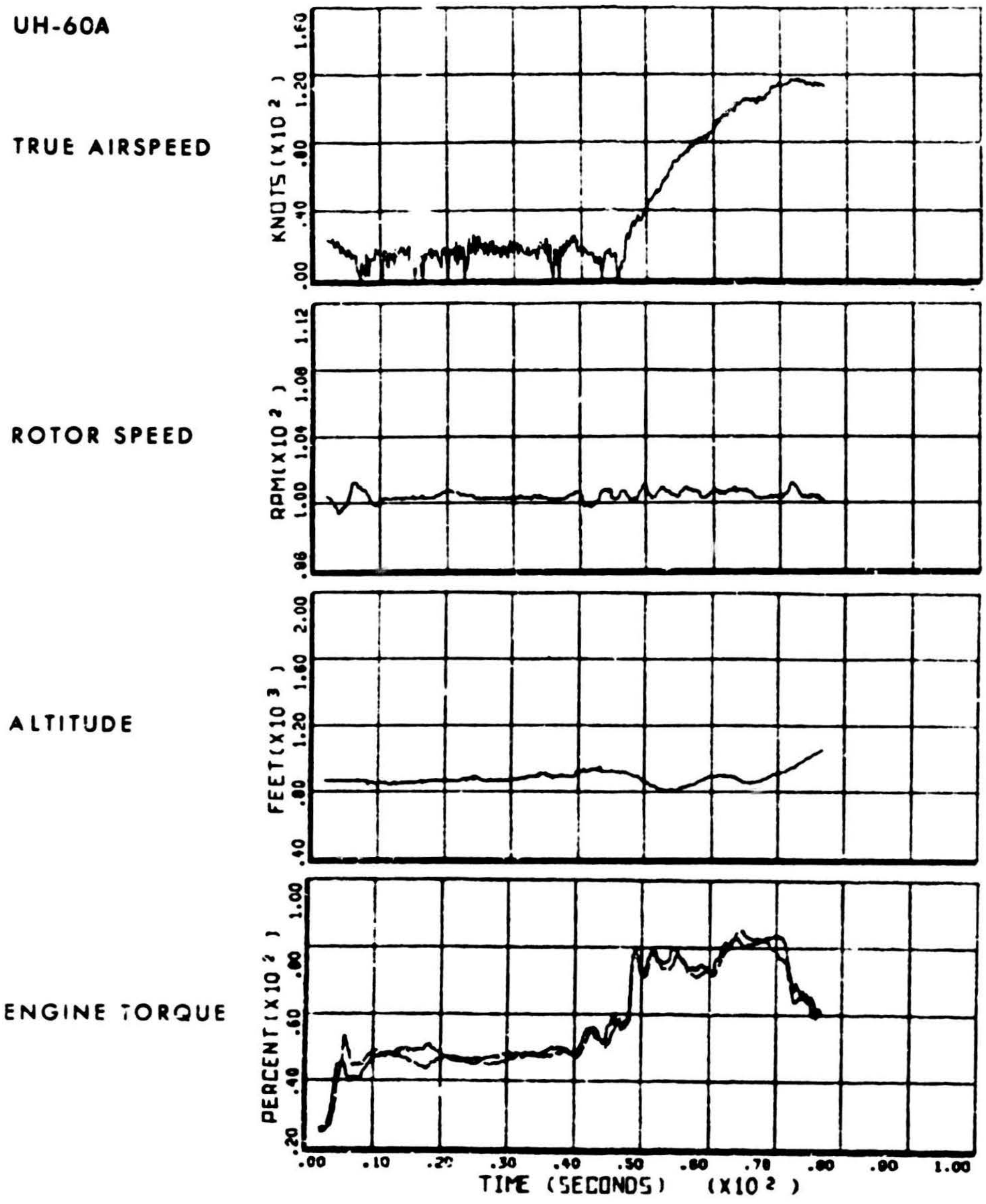


(i)
Figure F-8. Continued.



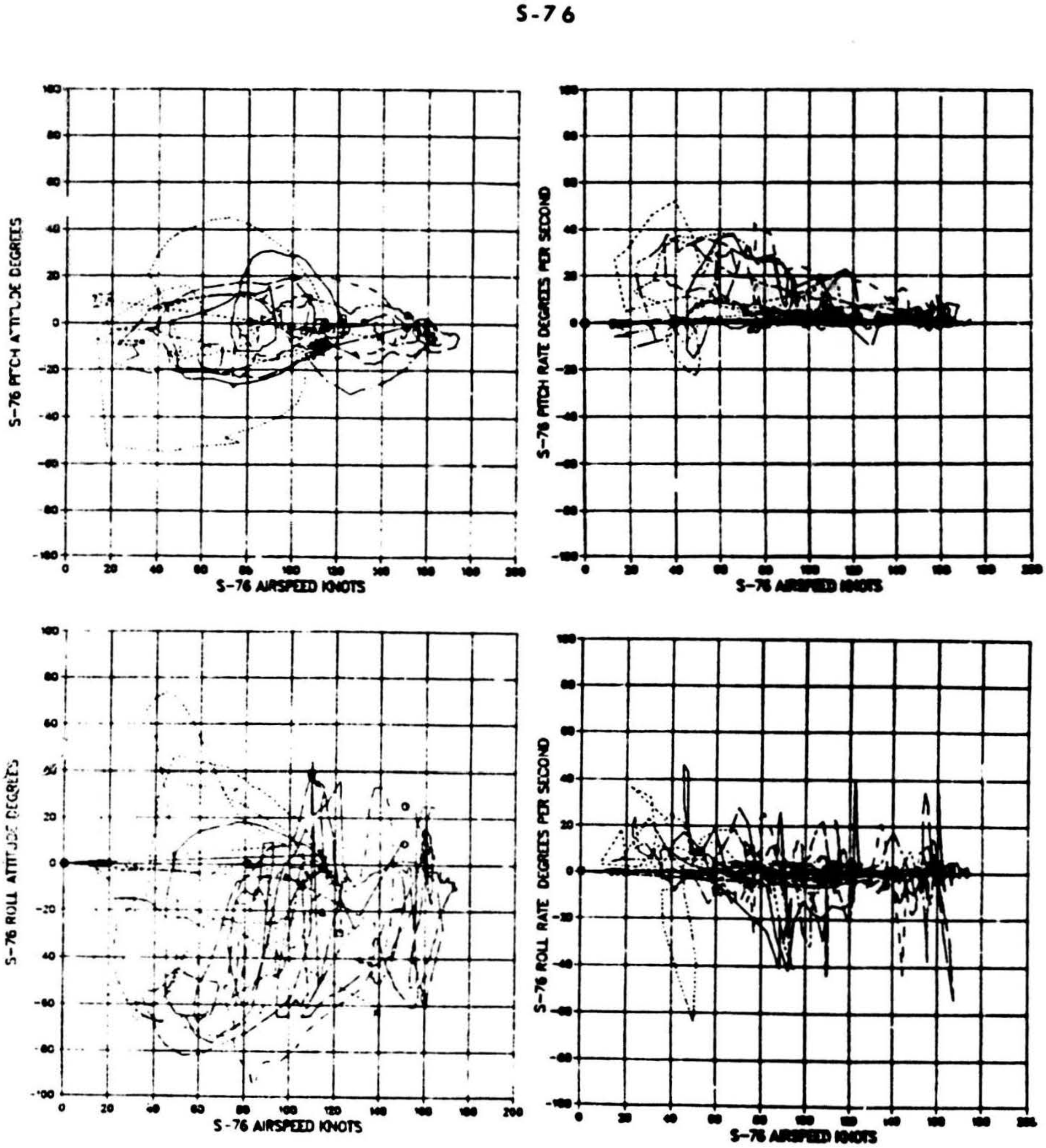
(j)
Figure F-8. Continued.

UH-60A



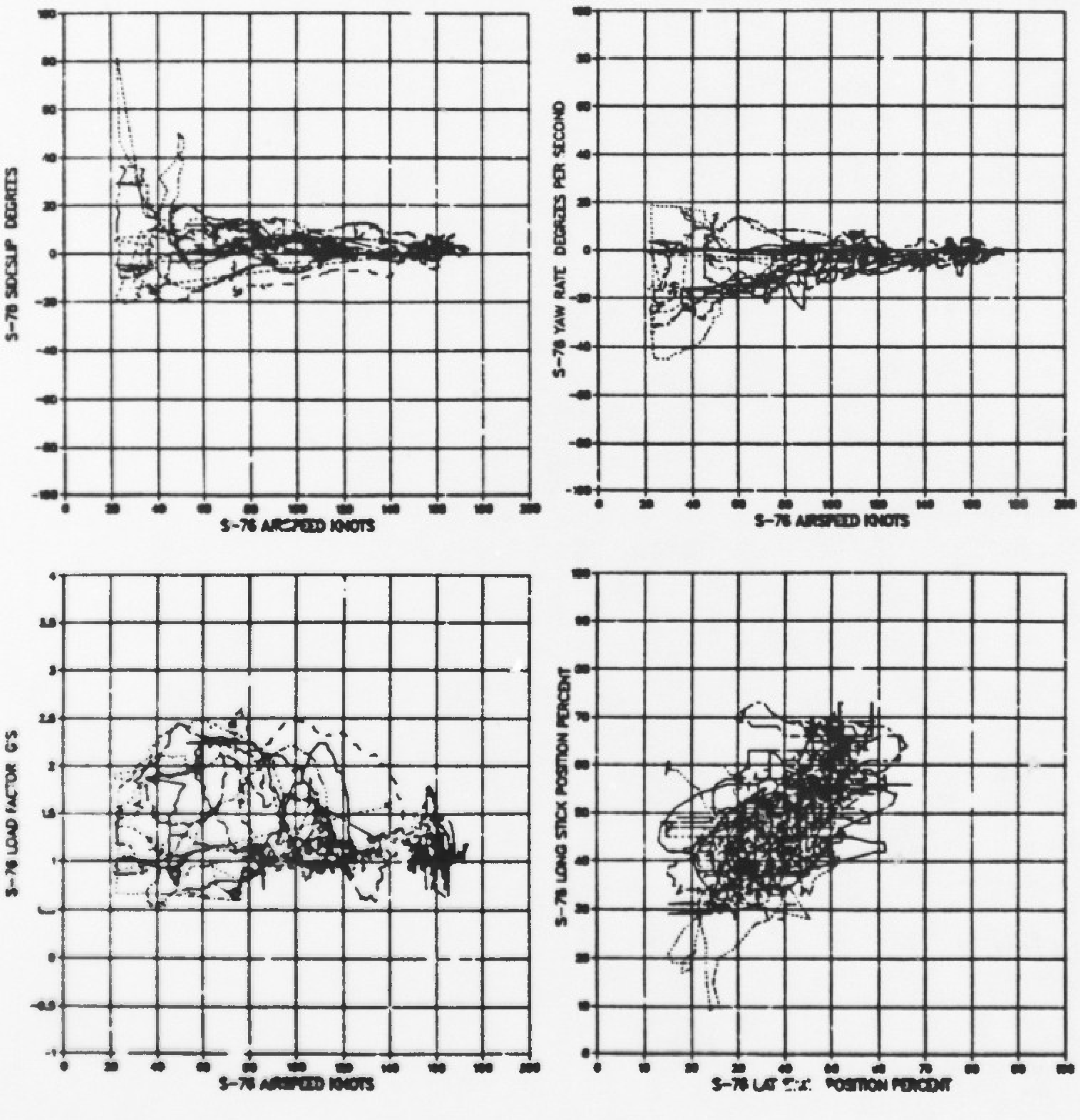
(k)
Figure F-8. Continued.

APPENDIX G
FLIGHT ENVELOPES



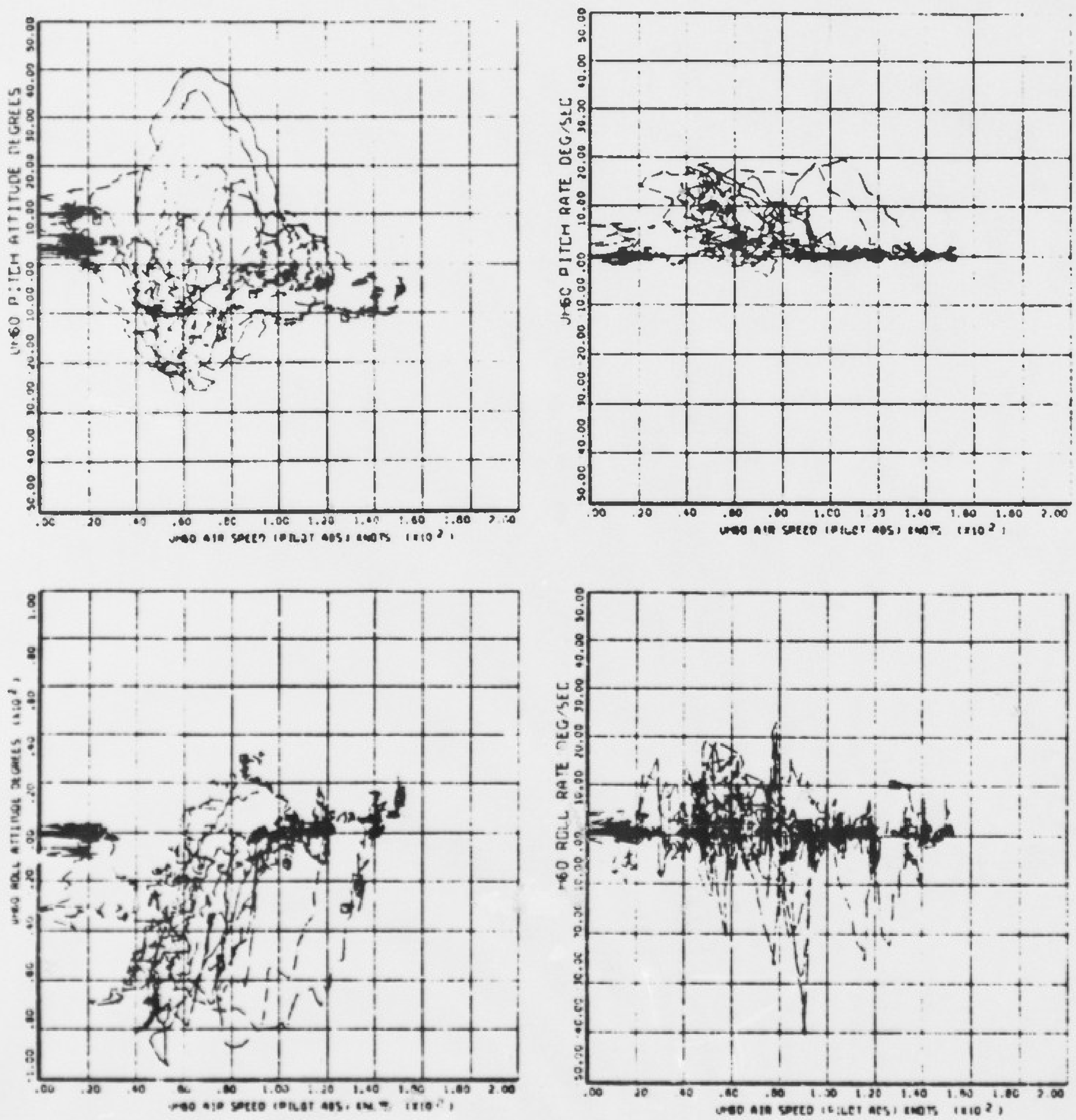
(a)
Figure G-1. S-76 flight envelopes.

S-76



(b)
Figure G-1. Continued.

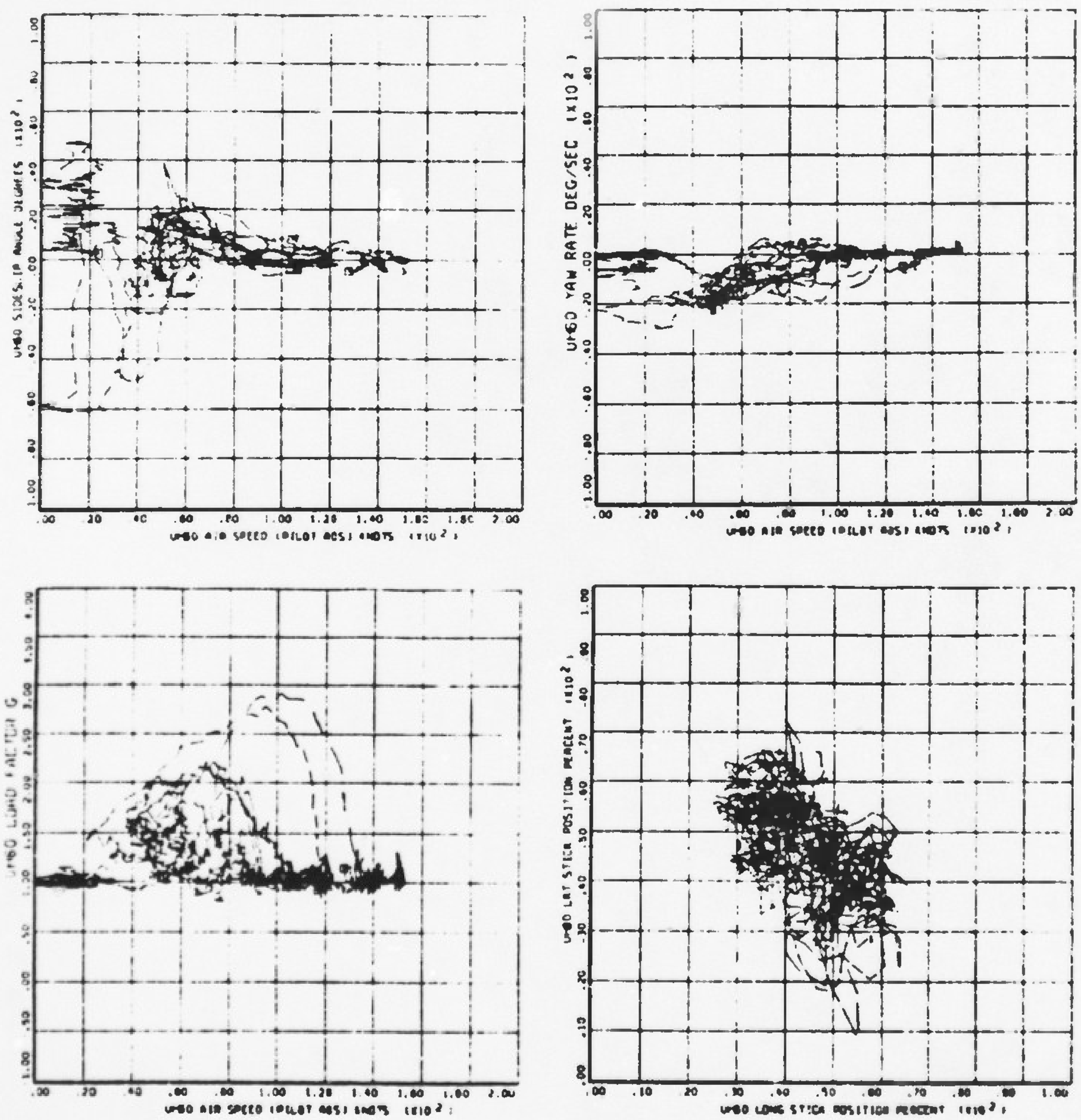
UH-60A



(a)

Figure G-2. UH-60A flight envelopes.

UH-60A



(b)
Figure G-2. Continued.