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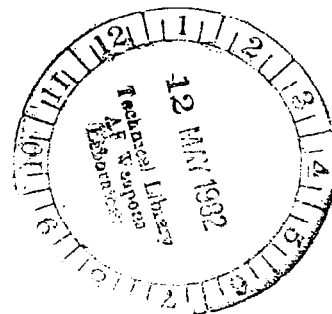
An Electronic Control for an Electrohydraulic Active Control Landing Gear for the F-4 Aircraft

Irving Ross and Ralph Edson

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An Electronic Control for an Electrohydraulic Active Control Landing Gear for the F-4 Aircraft

Irving Ross and Ralph Edson
Hydraulic Research Textron, Inc.
Valencia, California

Prepared for
Langley Research Center
under Contract NAS1-16420



National Aeronautics
and Space Administration

**Scientific and Technical
Information Branch**

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1.0

SUMMARY

The electronic controller described in this report is a modification of the controller which was designed under NASA Contract NAS1-14459 and fully documented in Reference 1.

As in the original design, the controller continuously compares the kinetic energy of the aircraft with the work potential of the gear until the work potential exceeds the kinetic energy. The wing/gear interface force present at this condition becomes the command force to a servo loop which maintains the wing/gear interface force at this level by providing a signal to an electrohydraulic servovalve to port flow into or out of the landing gear.

Analytical results indicate that the controller provides significant reductions in forces sustained by the aircraft during vertical drops and radical reductions in forces during rollout over repaired bomb craters.

2.0

INTRODUCTION

Hydraulic Research Textron (HRT) was retained under NASA Contract NAS1-16420 to design a controller for an active control landing gear (ACLG) to be used on the F-4 aircraft. The design was a modification of the controller originally designed for a 2948 kg. (6,500 lb) aircraft and described in detail in Reference 1.

The design was to be based on a digital computer simulation using a linear model of the aircraft and landing gear. However, it became apparent early in the program that the linear model was not adequate by itself to predict performance under certain phases of landing where nonlinear relationships prevail. Therefore extensive use was made of the HRT nonlinear model as well as the linear model to achieve the final design. The parameters of the aircraft/landing gear system were supplied by NASA.

The problem was similar to that encountered in the original design. However, the aircraft is heavier and the stroke of the strut is greater so that new scaling requirements are imposed. These are discussed in Appendix A.

3.0 DYNAMIC ANALYSIS OF F-4 ACTIVE CONTROL LANDING GEAR

3.1 PREFACE

This section presents the dynamic analyses that were performed for the development of an electrohydraulic active control system for the F-4 landing gear. The main objective of these analyses was to develop a loop compensation network for the active control landing gear concept applied to the F-4 aircraft and to evaluate the performance of the active control gear with respect to the passive (conventional) F-4 landing gear. Section 3.2 contains a list of symbols and section 3.3 describes the analytical tools used in these studies, which are the linear and nonlinear vertical drop dynamic simulation models of the landing gear, without aircraft equations of motion included. Section 3.4 presents the correlation between the linear and nonlinear simulations. Section 3.5 presents the development of the loop compensation network. Section 3.6 presents analytical results for specific landing impact cases and cases of rollout over "repaired bomb craters", using the nonlinear vertical drop model, for both the passive gear and the active control gear.

3.2 SYMBOLS

A_o area of orifice in shock strut orifice plate, see Figure 3-1.

A_p landing gear metering pin area, see Figure 3-2.

A_1 shock strut hydraulic area (piston area), 0.01024 m^2
(15.87 in^2)

A_2 shock strut pneumatic area (cylinder area), 0.01494 m^2
(23.16 in^2)

A_3 annular area in shock strut between piston and cylinder walls, 0.00761 m^2 (1.179 in^2)

ATIRE constant in tire deflection force equation, 1.20

C_d discharge coefficient for active control servovalve orifice, 0.62

C_{do} discharge coefficient for shock strut orifice, 0.60

C_o orifice coefficient for shock strut orifice

$$= C_{do} A_o \sqrt{2g_c / \rho}, \text{ m}^4 \text{ sec}^{-1} \cdot \text{N}^{1/2} (\text{in}^3 / \text{sec} / \text{psi}^{1/2})$$

CP Linearized orifice coefficient for active control servovalve

$$= - \frac{\partial Q_{sv}}{\partial P_1} 3.16 \times 10^{-11} m^5 \cdot N^{-1} \cdot sec^{-1} (0.01334 \text{ in}^3 / \text{sec} / \text{psi})$$

CP_o linearized orifice coefficient for shock strut orifice

$$= \frac{\partial Q_o}{\partial P_1} = C_o / (2\sqrt{P_1 - P_2}), 1.901 \times 10^{-9} m^5 \cdot N^{-1} \cdot sec^{-1} (0.8 \text{ in}^3 / \text{sec} / \text{psi})$$

CQ linearized orifice coefficient for active control servovalve:

$$= \frac{\partial Q_{sv}}{\partial X_{sv}} = C_{sv} \sqrt{(P_S + P_R) / 2}, 8.61 m^2 / \text{sec} (13,340 \text{ in}^3 / \text{sec} / \text{in})$$

C_{sv} orifice coefficient for active control servovalve:

$$= C_d W_{sv} \sqrt{2g_c / \rho}, 0.00268 m^3 \cdot sec^{-1} \cdot N^{-1/2} (344.4 \text{ in}^3 / (\text{in lbf}^{1/2}))$$

f coulomb friction between shock strut piston and cylinder, 222.N (50.lbf)

F_a vertical force exerted on shock strut by the runway surface, N (lbf)

F_{li} impact phase limit force, N (lbf)

F_{lim} limit force, N (lbf)

F_s shock strut force, N (lbf)

F_{wg} wing-gear interface force, N (lbf)

g acceleration due to gravity, 9.81m/sec² (386.in/sec²)

g_c gravitational acceleration constant

$$1 \text{ kg} \cdot \text{m} \cdot \text{N}^{-1} \cdot \text{sec}^{-2} (12 \text{ slug} \cdot \text{in} \cdot \text{lbf}^{-1} \cdot \text{sec}^{-2})$$

i₁ input signal to electronic compensation networks, A

i₂ output signal from electronic compensation networks, or input signal to active control servovalve, (±0.040 A maximum)

K_a amplifier gain in active control loop, 0.000020 A/V

K_f position feedback gain in strut position control loop, 563 V/m (14.29V/in)
 K_{FDGE} fraction of total strut stroke assumed available when computing impact phase force, 1.0
 K_{SV} position gain of servovalve in active control loop, 0.0635 m/A (2.50 in/A)
 K_{TIRE} constant in tire deflection force equation 1727.1 kN/m (9862 lbf/in)
 K_x gain in strut position control loop, 1.0 m/m (1.0 in/in)
 L total lift force, N (lbf)
 M mass of airplane per gear, 8345 kg (18398 lbm)
 M_c mass of upper portion of landing gear (cylinder plus orifice plate attachment, kg (slugs)
 M_L mass of lower portion of landing gear (piston plus tire), 204. kg (13.99 slugs = 1.166 lbf . sec²/in = 450. lbm)
 M_U upper mass, 8143. kg (558. slugs = 46.5 lbf. sec²/in = 17948. lbm)
 PE_t potential energy stored in tire due to compression, N . m (ft . lbf)
 P_S hydraulic supply pressure, 2.07×10^7 N/m² (3000 . psi)
 P_R hydraulic return pressure, 0.0 N/m² (0.0 psi)
 P_1 hydraulic pressure in shock strut piston, N/m² (psi)
 P_2 pneumatic pressure in shock strut cylinder, N/m² (psi)
 P_3 pressure in volume between walls of shock strut piston and cylinder, N/m² (psi)
 Q_o flow rate through shock strut orifice from piston to cylinder, m³/sec (in³/sec)

Q_{SV} flow rate from active control servovalve to shock strut piston, linear model, m^3/sec (in^3/sec)

Q_{SV1} flow rate through active control servovalve from supply pressure to the shock strut piston, m^3/sec (in^3/sec)

Q_{SV2} flowrate through active control servovalve from shock strut piston to return pressure, m^3/sec (in^3/sec)

R_S the slope of the limit force with respect to time during transition phase, 444800. N/sec (100000. lbf/sec)

s LaPlace operator, sec^{-1}

t time, sec

V velocity, m/sec (in/sec)

V_S sink rate, m/sec (in/sec)

V_1 hydraulic volume in shock strut piston and lines up to the active control servovalve, $0.00497 m^3$ ($303.in^3$)

V_2 pneumatic volume, $0.00742 m^3$ ($453. in^3$) for fully extended strut

V_3 volume between shock strut piston and cylinder, $0.0 m^3$ ($0.0 in^3$) for fully extended strut

W_{SV} window width of orifices on third stage spool of active control servovalve, $0.0884 m$ ($3.48 in$)

X_a displacement of lower mass of shock strut or axle, m (in)

X_c commanded position of shock strut, $0.216 m$ ($8.50 in$)

X_g ground level displacement, m (in)

X_S shock strut stroke, m(in) $X_S = 0$ fully extended, $X_S = 0.403 m$ ($15.88 in$) fully compressed

x_{wg} displacement of wing gear interface, m (in)

β bulk modulus of hydraulic fluid, $6.89 \times 10^8 N/m^2$ ($1 \times 10^5 psi$)

ν ratio of specific heat of gas at constant pressure to that at constant volume, 1.06

ρ	mass density of hydraulic fluid, 838 kg/m ³ (0.000941 slugs/in ³ = 0.0303 lbm/in ³)
τ_f	time constant in strut position feedback loop, 0.10 sec
τ_1	time constant in compensation, 0.001621 sec
τ_2	time constant in compensation, 0.0001621 sec
τ_3	time constant in compensation, 6.464 x 10 ⁻⁴ sec
τ_4	time constant in compensation, 6.464 x 10 ⁻⁵ sec
ω_c	corner frequency in active control servovalve transfer function, 1263 sec ⁻¹
ω_{sv}	natural frequency in active control servovalve transfer function, 655.5 sec ⁻¹
ω_1	natural frequency of notch network, 565 sec ⁻¹
ζ_{sv}	damping coefficient in active control servovalve transfer function, 0.436
ζ_1	damping coefficient in denominator of notch network, 5.1
ζ_2	damping coefficient in numerator of notch network, 0.1

Subscripts:

i	initial conditions before impact
im	impact phase
L	lower mass
max	maximum value
min	minimum value
r	rollout phase
s	shock strut relative motion of lower mass (piston) with respect to the upper mass (cylinder)
sv	servovalve
tr	transition phase
U	upper mass

Miscellaneous:

$d()$ indicates the differential of a variable

$\Delta()$ indicates difference or change in a variable

$(.)$, $(..)$, $(...)$ dots indicate differentiation with respect to time

3.3 DYNAMIC SIMULATION MATH MODELS

The main analytical tools used in these studies are the linear (s-domain) and nonlinear (time domain) vertical drop dynamic simulation models of the landing gear. These models simulate motion in the vertical axis only. Aircraft equations of motion are not included, and aircraft mass (per gear) is simulated as a lumped mass resting on top of the landing gear.

3.3.1 Linear Model

The linear model simulated the dynamics of the active control landing gear system in the frequency domain for small perturbations about the condition where the airplane mass (per gear) is resting on top of the gear with the gear always in contact with the ground and with the lower cylinder hydraulic pressure at a value halfway between the hydraulic supply and return pressures. The input disturbance variable is command limit force. Airplane lift and ground level are assumed constant. The linear model is a valuable tool since it allows rapid evaluation of system modifications or the effect of variation in system parameters in the areas of system stability and frequency response. A detailed description of the linear model, including equations, is presented in Reference 1, and will not be repeated here. The values of the constants used in the simulations for this study are given in Section 3.2 of this report.

3.3.2. Nonlinear Model

The nonlinear model is developed from the time-dependent algebraic and differential equations of the system. The response of the system to input disturbances is obtained by integrating the differential equations with respect to time. Controller laws (including switching logic) and all other identifiable nonlinear attributes of the system of significance are simulated. Thus, the nonlinear model represents a more accurate simulation of the actual physical case than the linear model. This however, comes at the expense of considerably longer computational times. The nonlinear model accepts input variations in airplane lift, ground level, and command limit force (for vertical drop impact transients, however, the controller automatically sets the command limit force subsequent to initiation of active control). A detailed description of the nonlinear model, including equations, is presented in Reference 1. The nonlinear model used herein is identical to that described in Reference 1 except the values of the system constants are different and the linear spring tire force assumption was modified to a nonlinear spring, according to the relationship:

$$F_a = \begin{cases} KTIRE(XA - XG)^{ATIRE} & \text{for } XA > XG \\ 0 & \text{for } XA < XG \end{cases}$$

where KTIRE and ATIRE are constants. This equation replaces the expression for F_a in Equation 4 of Reference 1.

The values of the constants used in the linear and nonlinear simulations for this study are given in Section 3.2.

The important variables are shown in Figure 3-1.

3.4 CORRELATION OF LINEAR AND NONLINEAR MODELS

Since both the linear and nonlinear models were utilized in the development of the loop compensation, the first task was to correlate the linear model with the more precise nonlinear model to ensure that it would give at least reasonably credible results. Figures 3-3, 3-4, and 3-5 show frequency response results obtained from the linear and nonlinear models, without compensation. The loop is opened at the point of wing/gear force feedback, and the strut position feedback loop is not included. The input is command limit force and the output is the wing/gear force response. The nonlinear runs were made with zero lift and for command amplitudes of ± 890 N (± 200 pounds), and the amplitude and phase angle at each frequency were computed from a Fourier analysis of the resultant input and output waveforms. The linear model results were obtained using a linearized orifice coefficient for the shock strut orifice (CP_o) of $0.8 \text{ in}^3/\text{sec}/\text{psi}$. This value seemed to give the best overall correlation between the linear and nonlinear models. Note that the agreement is reasonably good out to a frequency of about 150 Hertz. At higher frequencies, the nonlinear model shows considerably more phase lead and less amplitude response than the linear model. Figures 3-6 and 3-7 show open loop Nyquist diagrams for these same results, for the linear and nonlinear models, respectively. Again, reasonably good correlation is indicated.

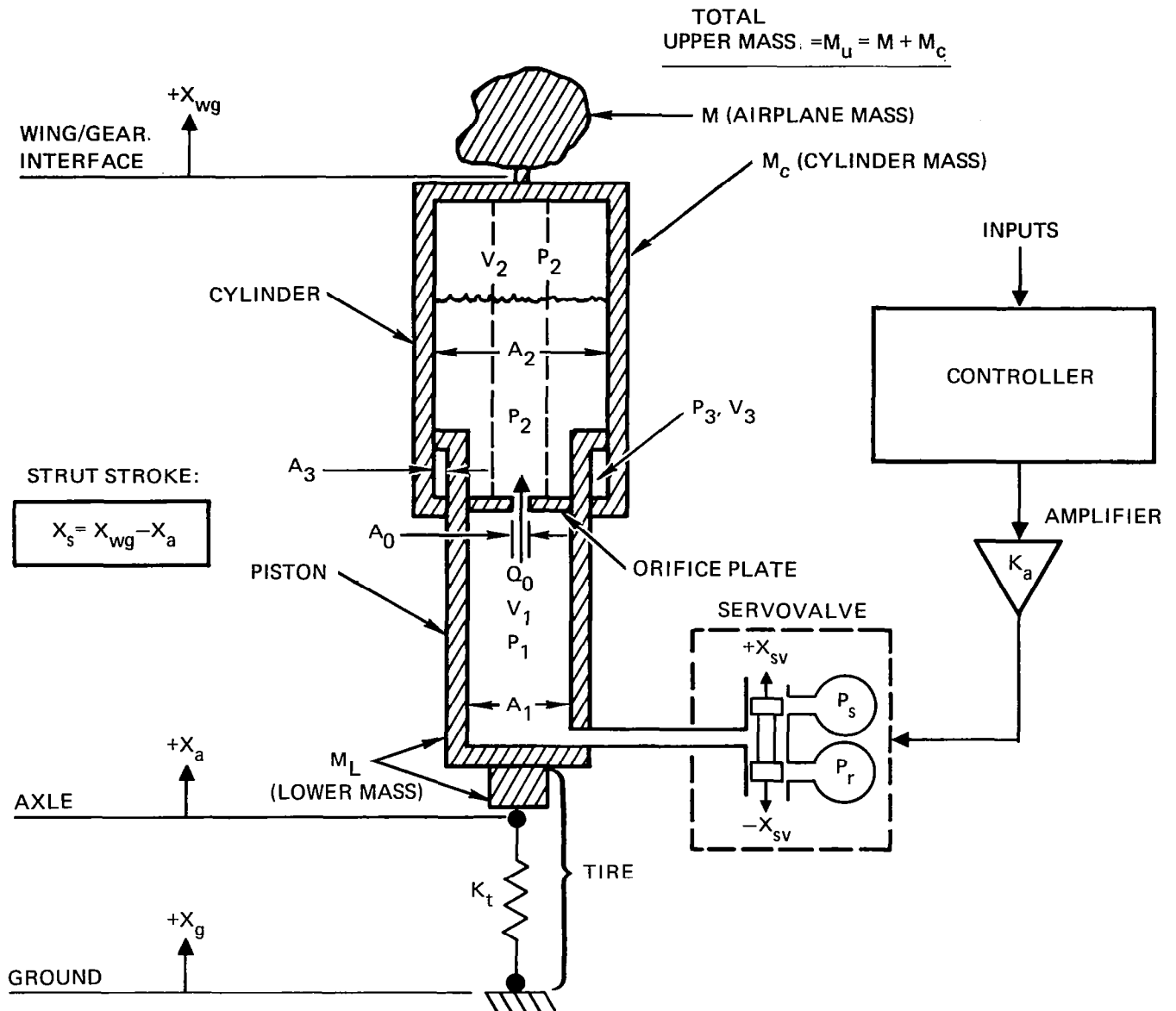


FIGURE 3-1 ILLUSTRATION OF VARIABLES USED IN NONLINEAR SIMULATION OF SIMPLIFIED VERTICAL DROP CASE

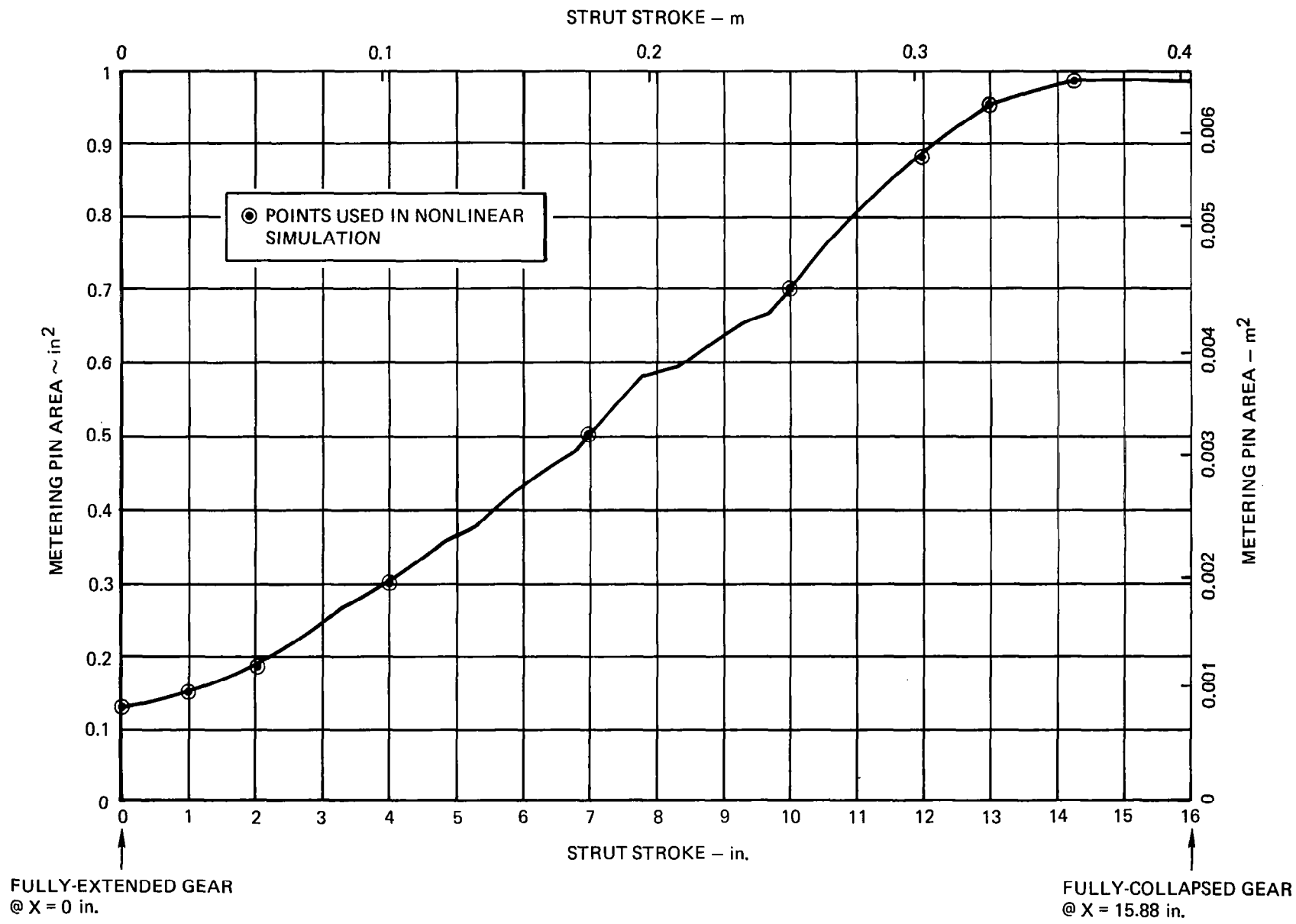


FIGURE 3-2. F-4 LANDING GEAR METERING PIN AREA VERSUS STRUT STROKE

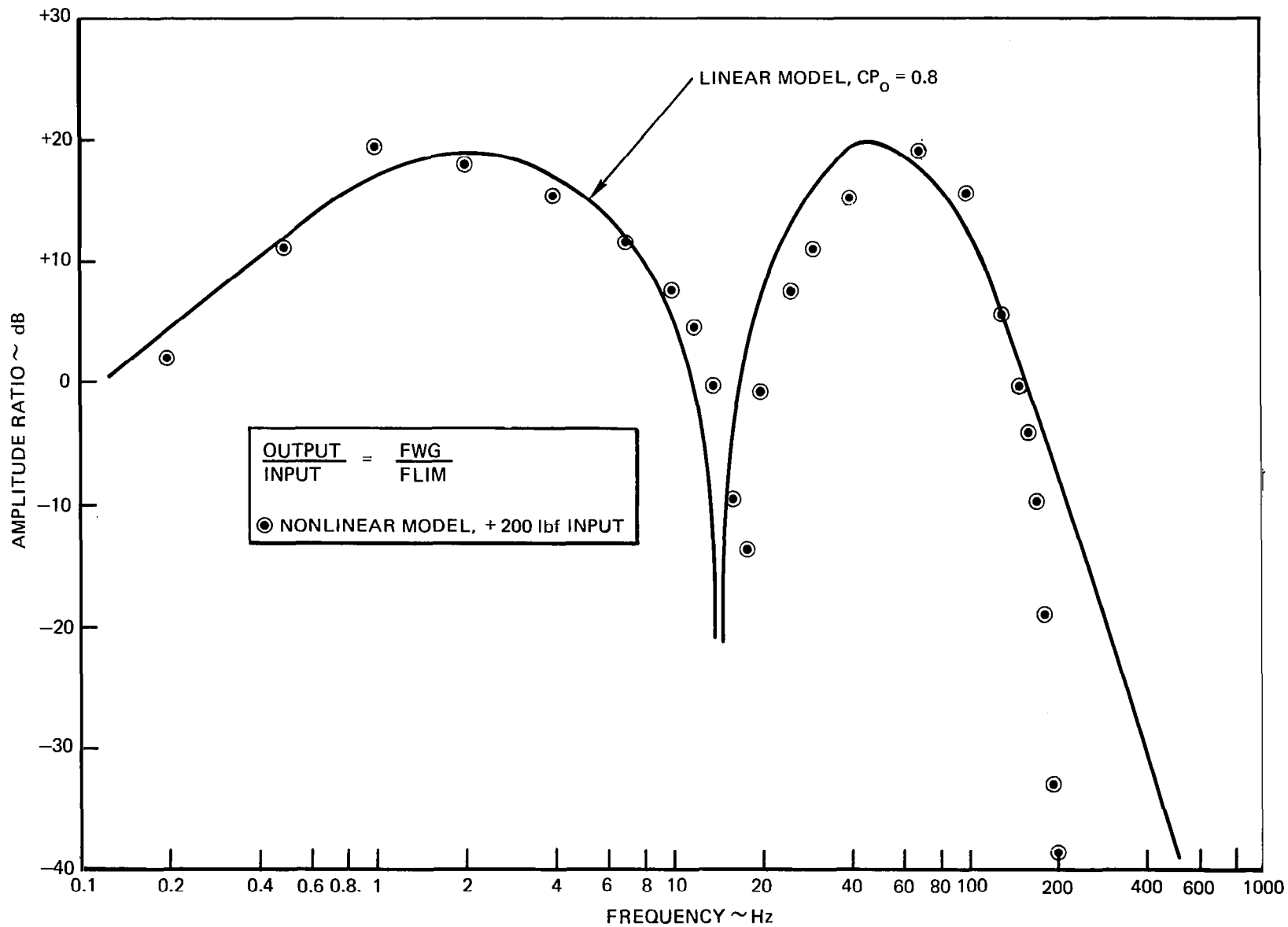


FIGURE 3-3 OPEN-LOOP, NO COMPENSATION
FREQUENCY RESPONSE

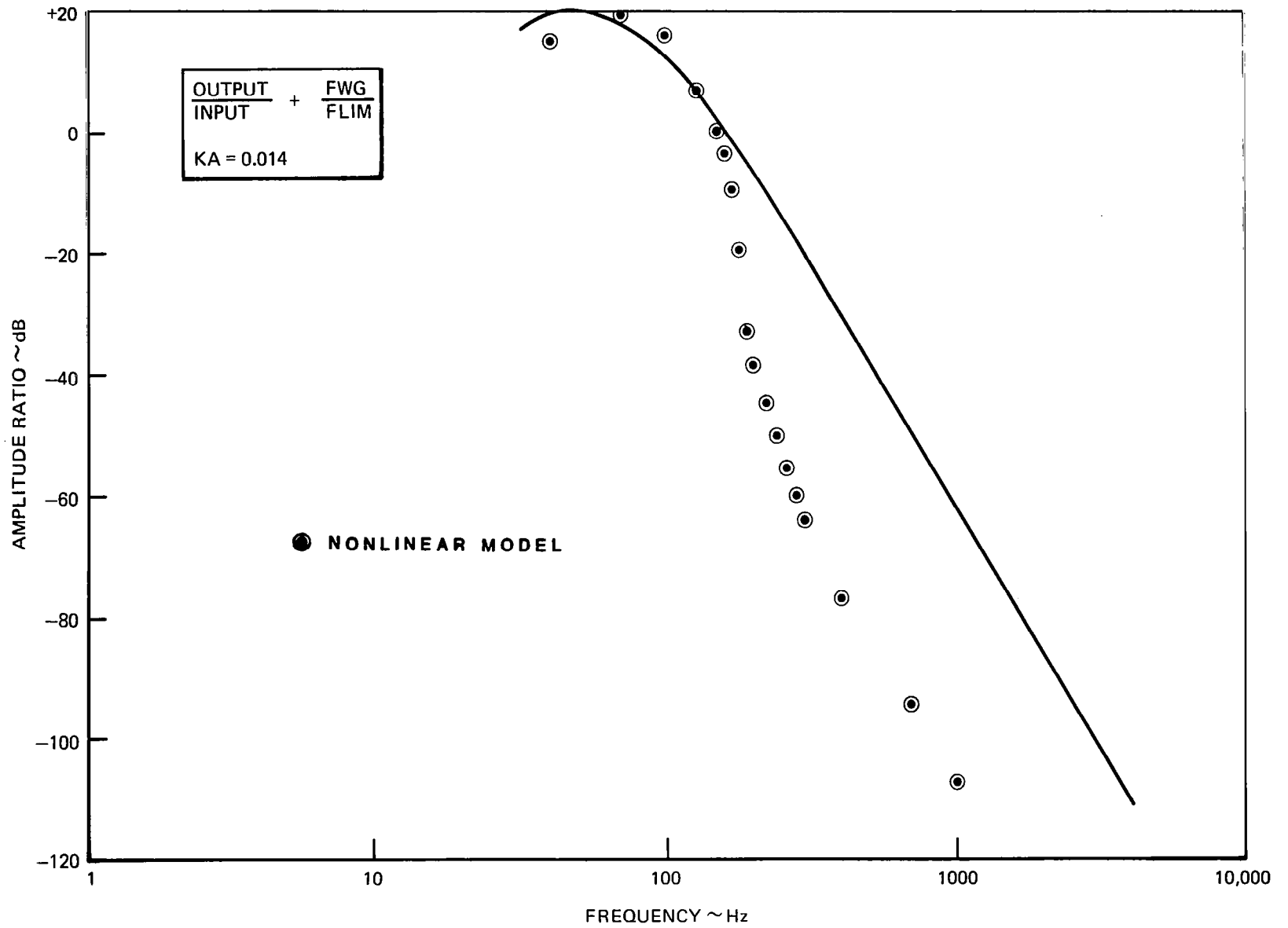


FIGURE 3-4. F-4 GEAR, OPEN-LOOP, NO COMPENSATION FREQUENCY RESPONSE

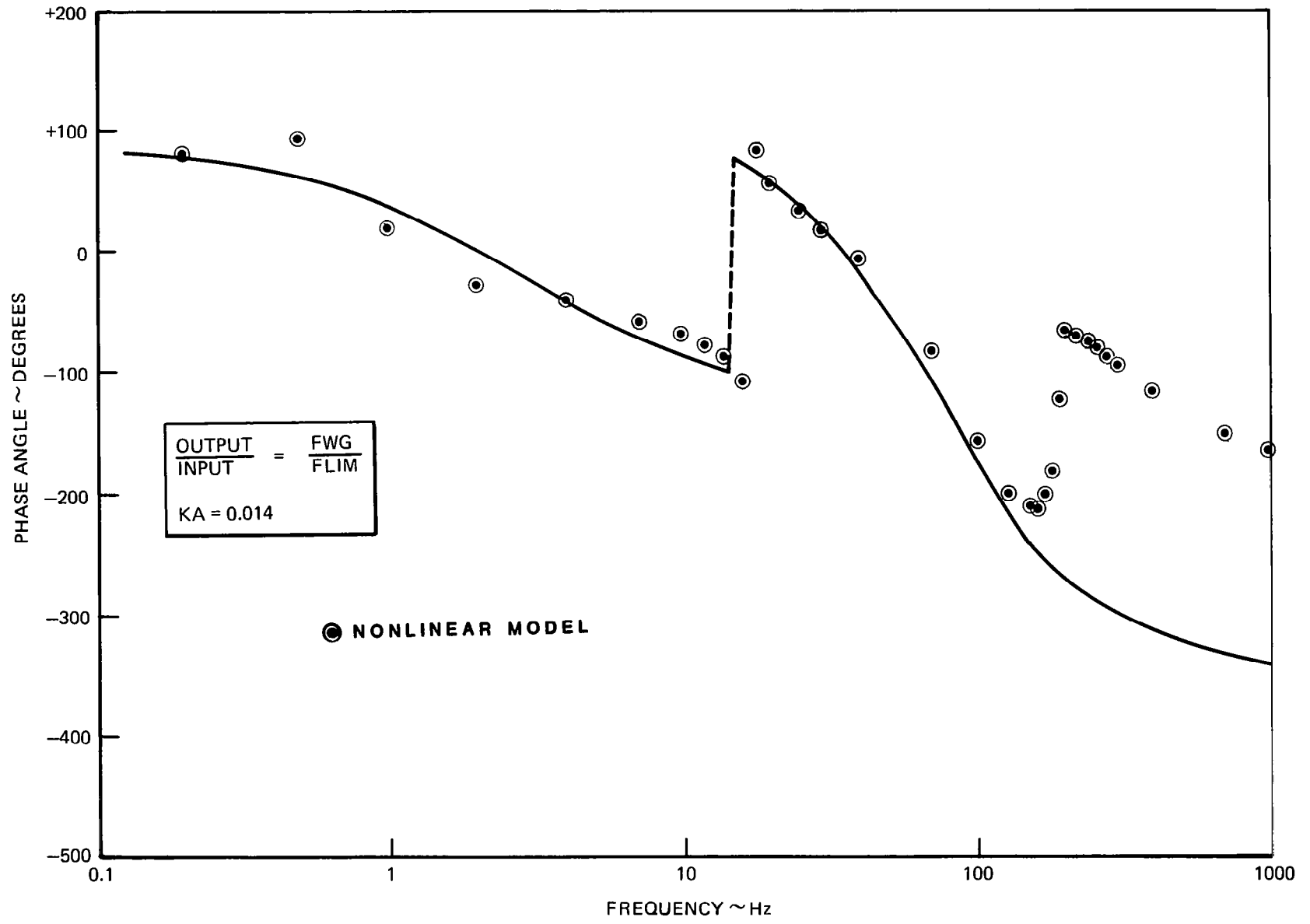


FIGURE 3-5. F-4 GEAR, OPEN-LOOP, NO COMPENSATION FREQUENCY RESPONSE

3.5 LOOP COMPENSATION

The open-loop Nyquist diagrams of the uncompensated system presented in the previous section (Figures 3-6 and 3-7) indicate that the system is unstable around 100 Hertz. Thus, compensation is deemed necessary. The compensation that was developed for this system is implemented in the forward path of the control loop, and has the following transfer function.

$$T(S) = \left[\frac{\frac{S^2}{565.2} + \frac{2(.100)}{565.}S+1}{\frac{S^2}{565.2} + \frac{2(5.10)}{565}S+1} \right] \left[\frac{\frac{S}{617.} + 1}{\frac{S}{6170.} + 1} \right] \left[\frac{\frac{S}{1547.} + 1}{\frac{S}{15470.} + 1} \right] \quad (3-1)$$

It consists of a notch filter at 90 Hertz and two first-order 20 dB lead/lag networks. The frequency response of the compensation is shown in Figures 3-8 and 3-9 and the Nyquist plot including compensation is shown in Figure 3-10.

To understand the effect of each part of the compensation network on system dynamics, open-loop Nyquist diagrams obtained from the linear model are presented with successive portions of the compensation network incorporated. Figure 3-11 shows the uncompensated Nyquist diagram (this is the same as the results in Figure 3-6 except that the amplifier gain has been adjusted). Figure 3-12 shows the effect of including the compensation notch only. The system is now stable, but rather low damped at a frequency around 60 Hertz. The first lead/lag network was included to add phase lead in this frequency range. The Nyquist diagram with the notch and this lead/lag incorporated is shown in Figure 3-13. The second lead/lag was included to add phase lead in the 190 Hertz range. The open-loop Nyquist diagram with the entire compensation network included is presented in Figure 3-14.

The effect of each part of the compensation network on system dynamics was also evaluated using the nonlinear model on a typical vertical drop case. The conditions of the case are as follows:

1. The sink rate prior to impact is 1.83 m/sec (72 ins/sec)
2. The lift is equal to airplane weight at initial impact, then linearly reduced to 10 percent of the airplane weight over the next 1 second, then held constant at 10 percent thereafter.
3. The ground level is held constant.

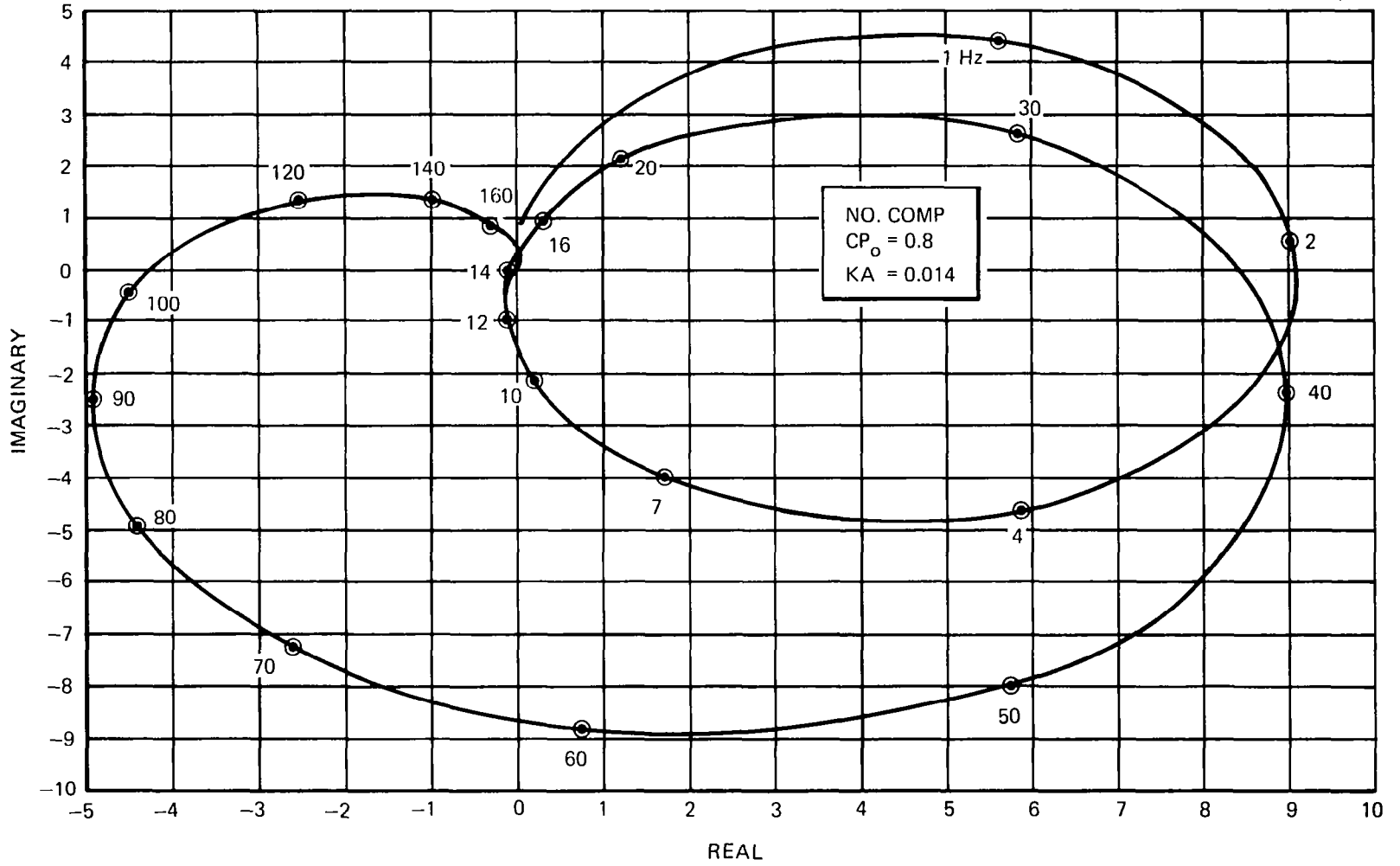


FIGURE 3-6. OPEN-LOOP LINEAR MODEL WITHOUT COMPENSATION

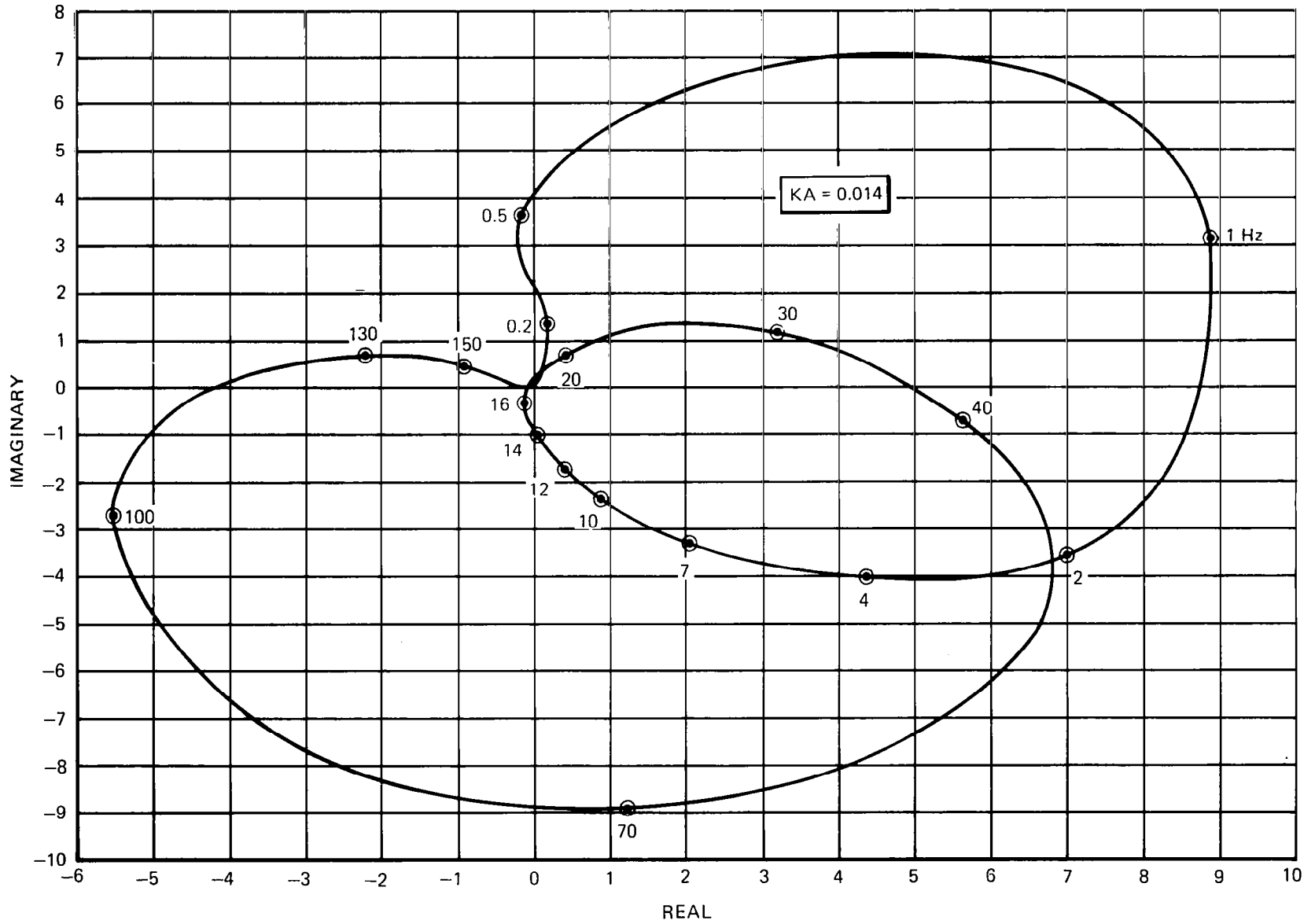


FIGURE 3-7. OPEN-LOOP NONLINEAR MODEL, 889.6N (± 200 LBF) INPUT

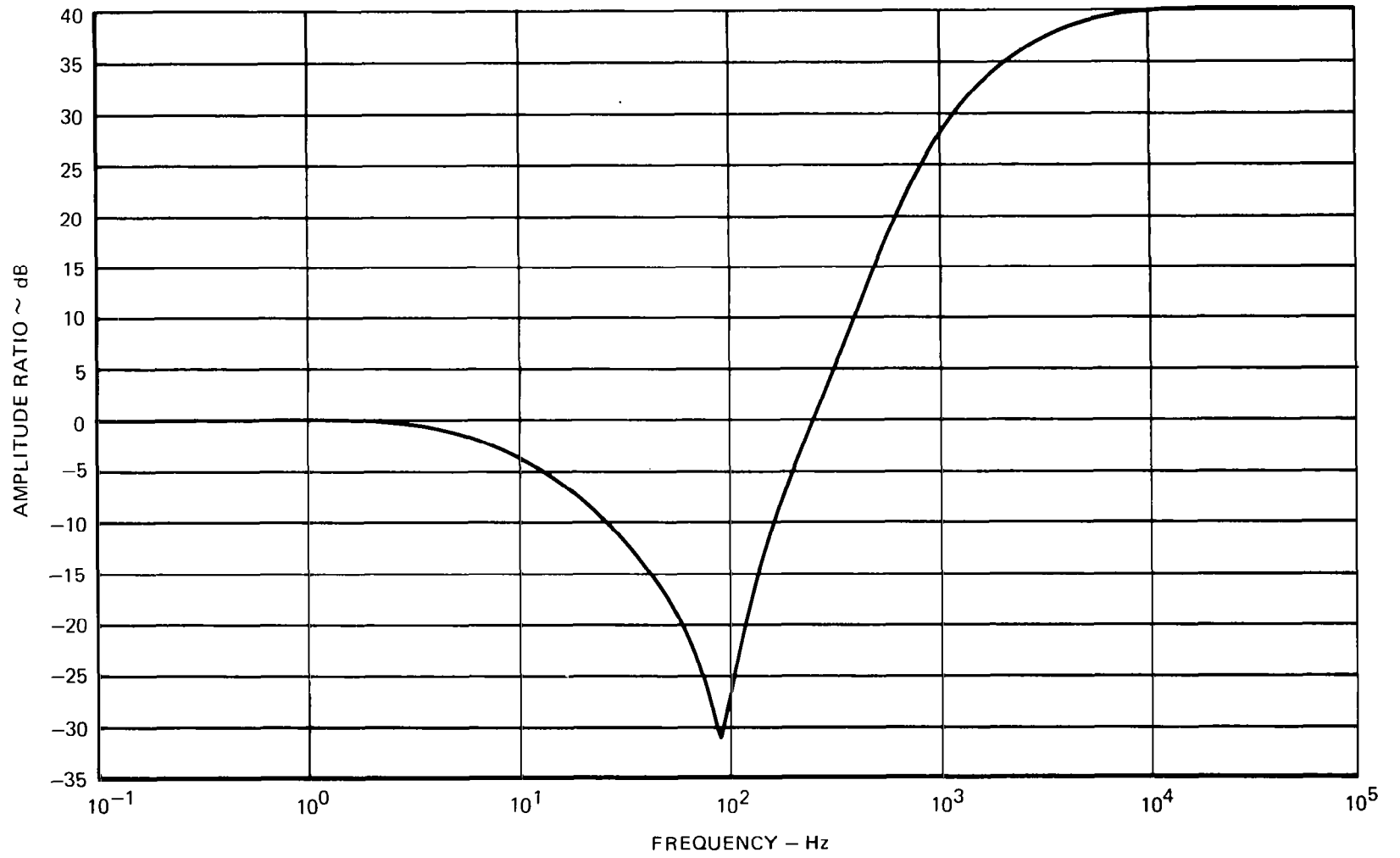


FIGURE 3-8 COMPENSATION

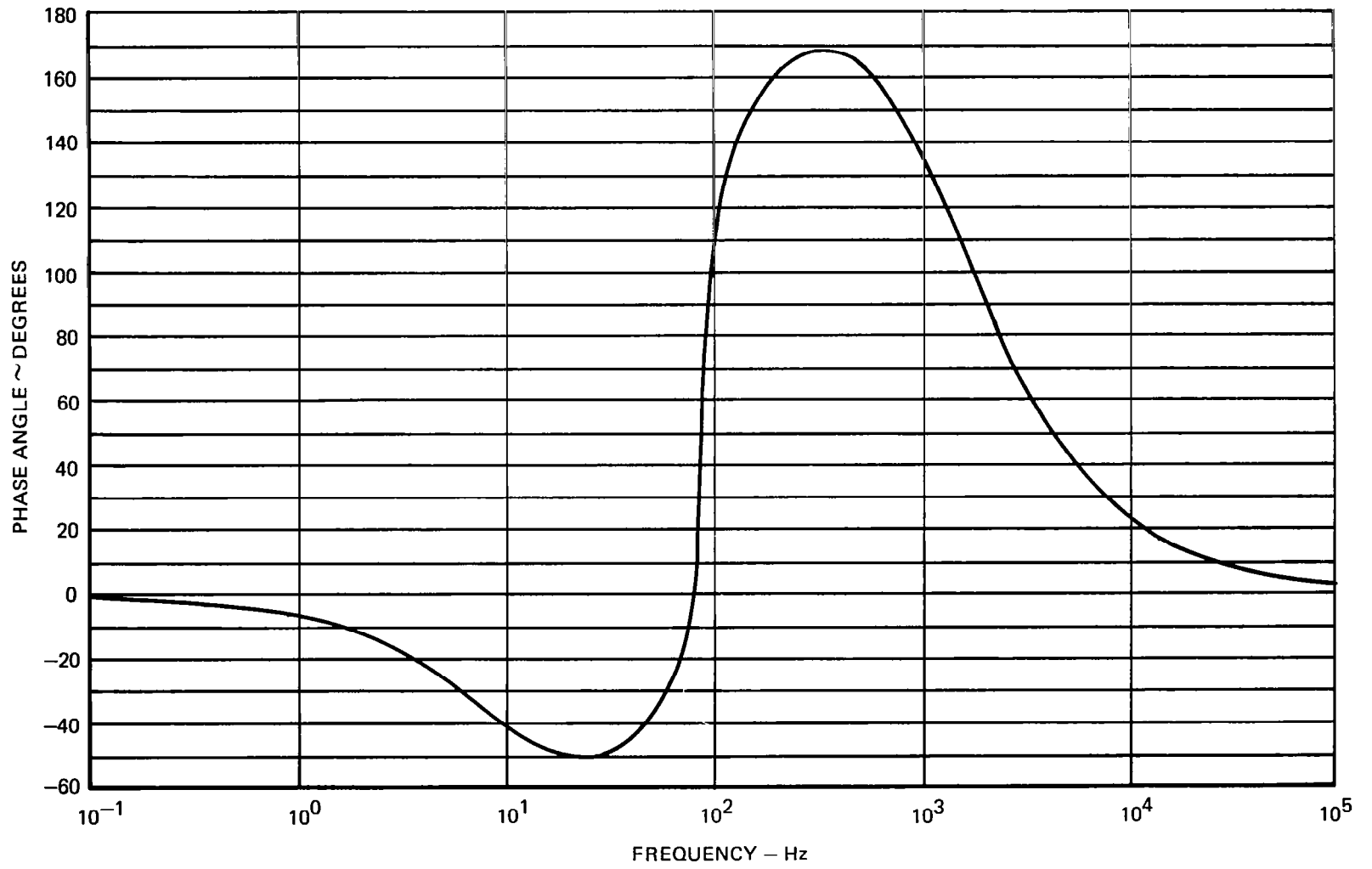


FIGURE 3-9 COMPENSATION

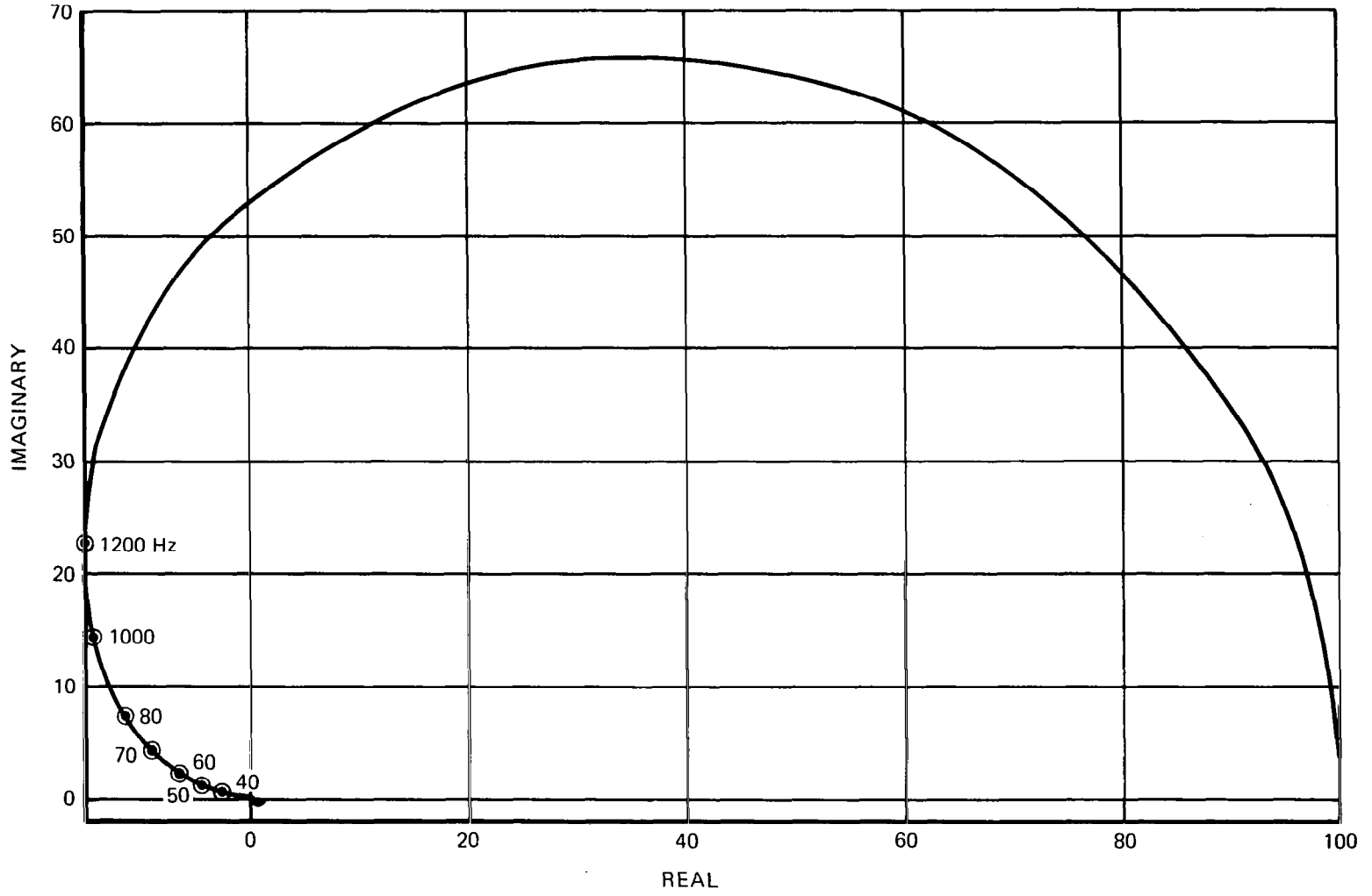


FIGURE 3-10 NYQUIST PLOT—COMPENSATION

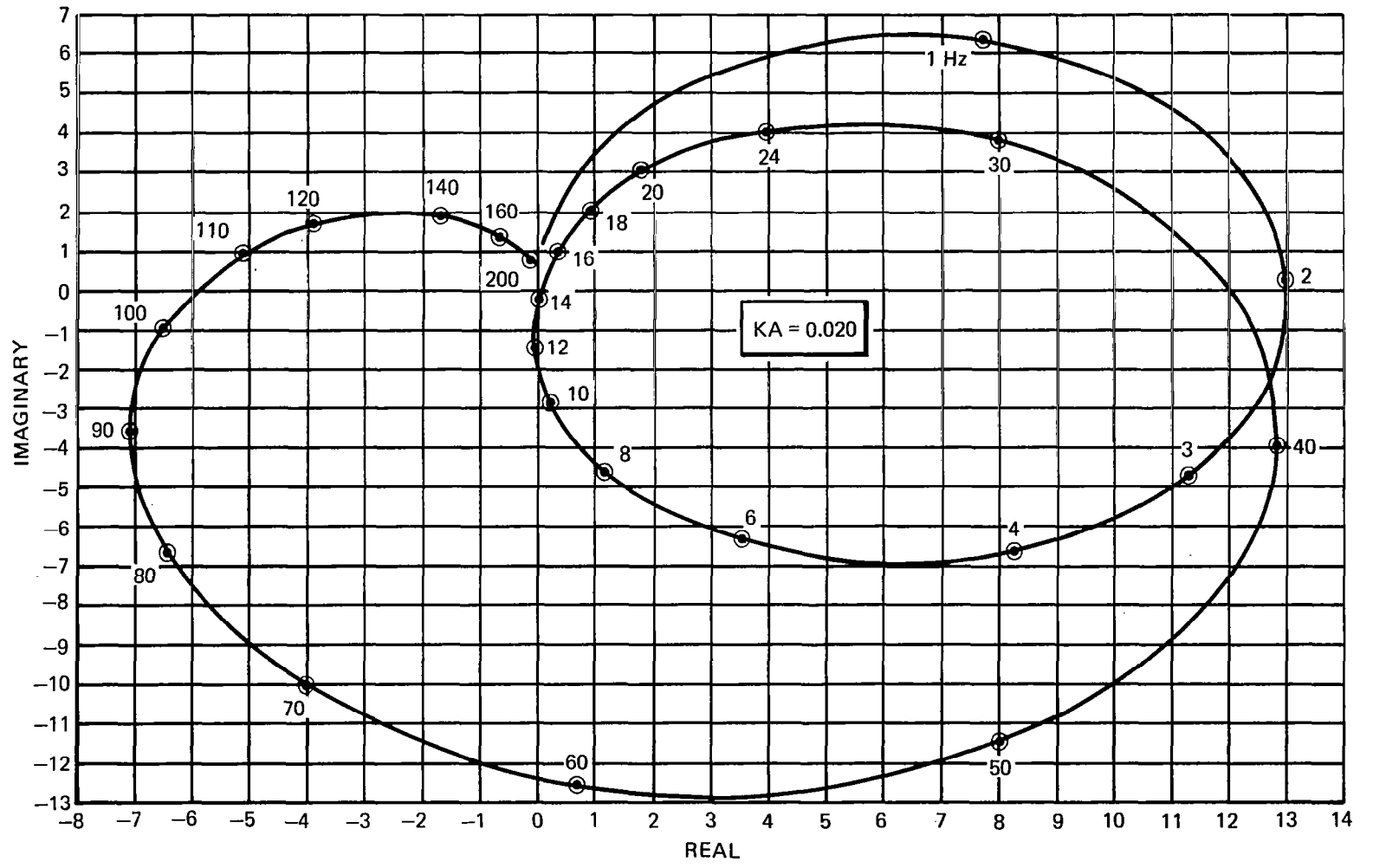


FIGURE 3-11 NO COMPENSATION

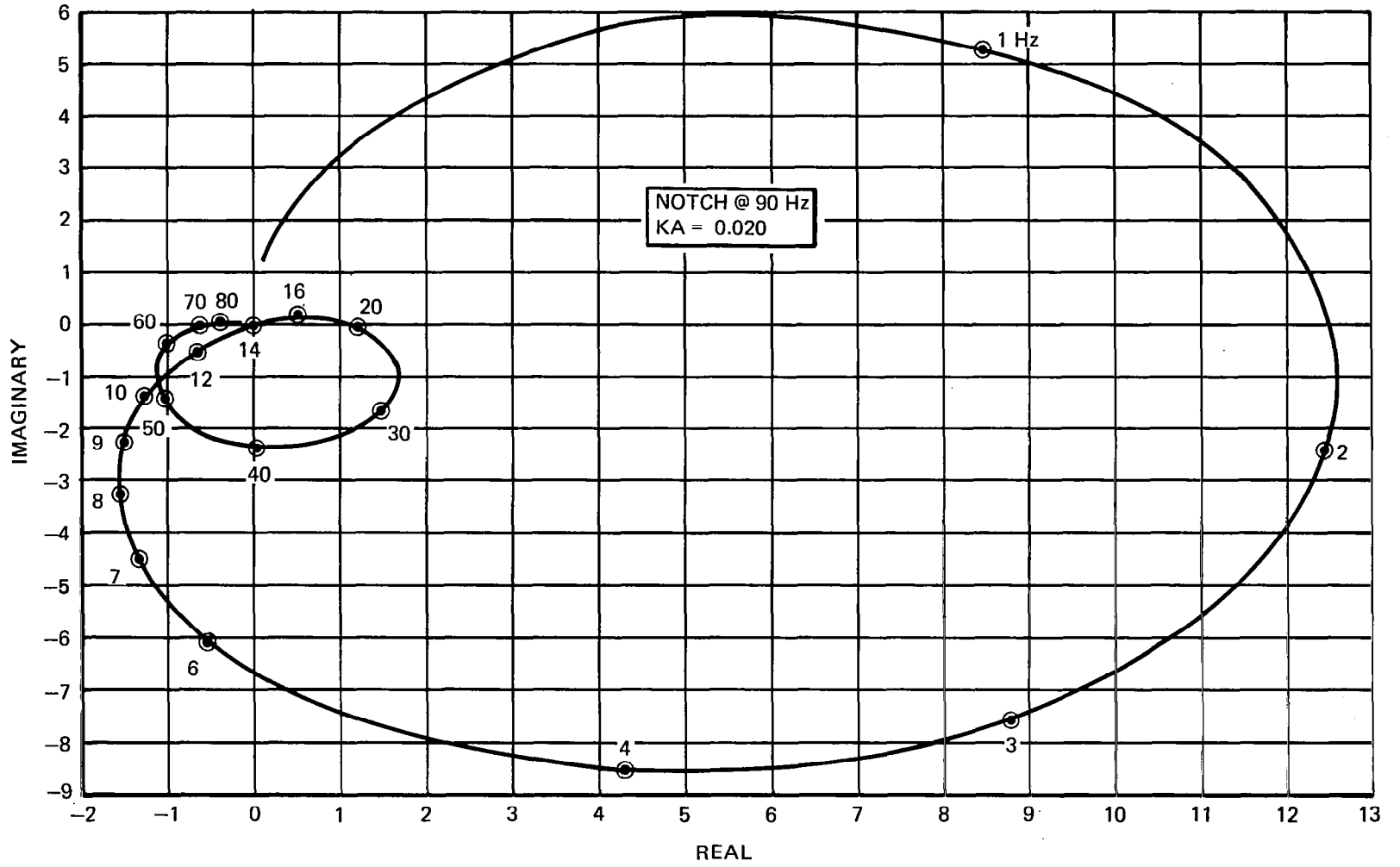


FIGURE 3-12. 90 Hz NOTCH

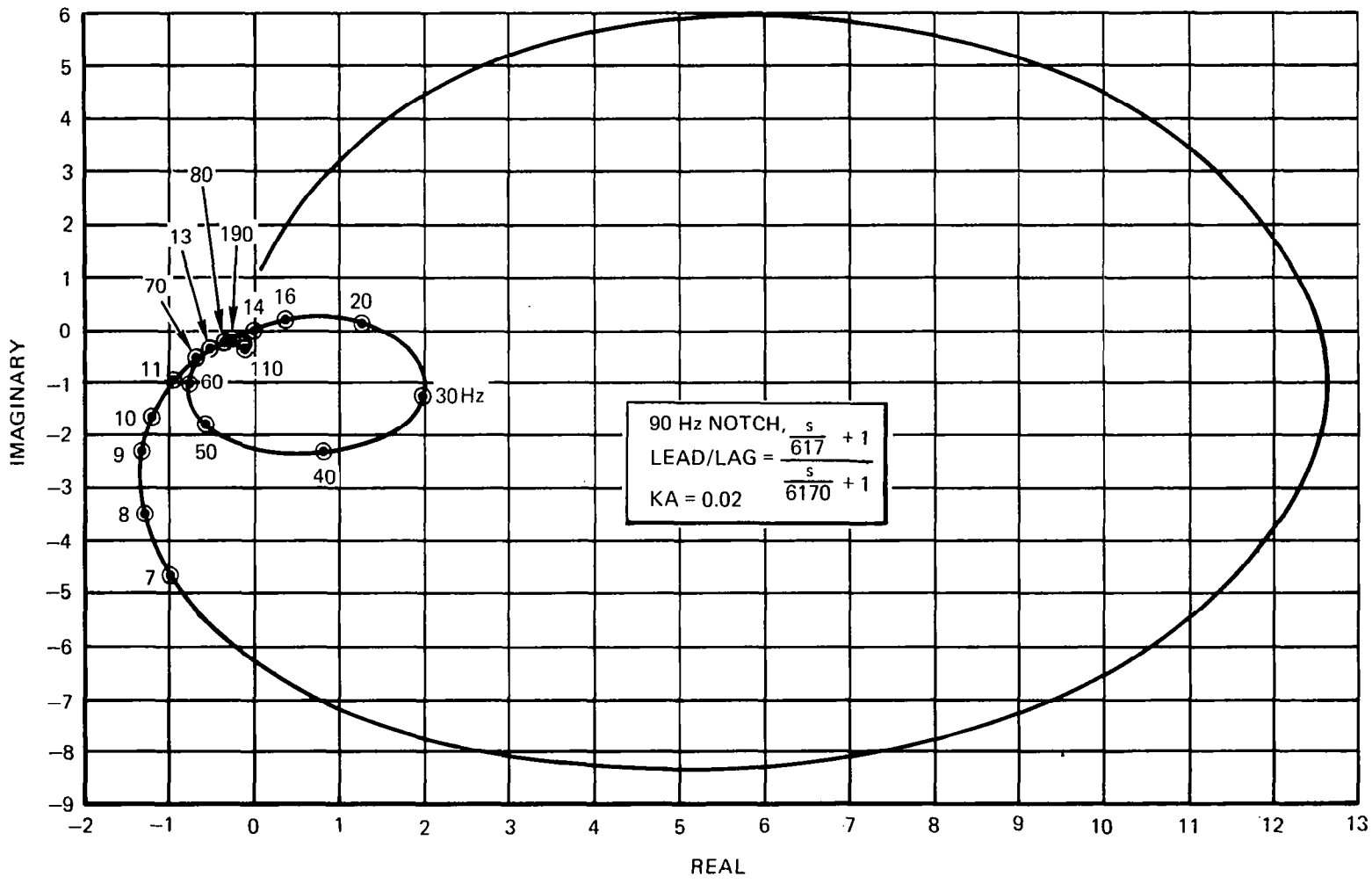


FIGURE 3-13. 90 Hz NOTCH AND LEAD/LAG

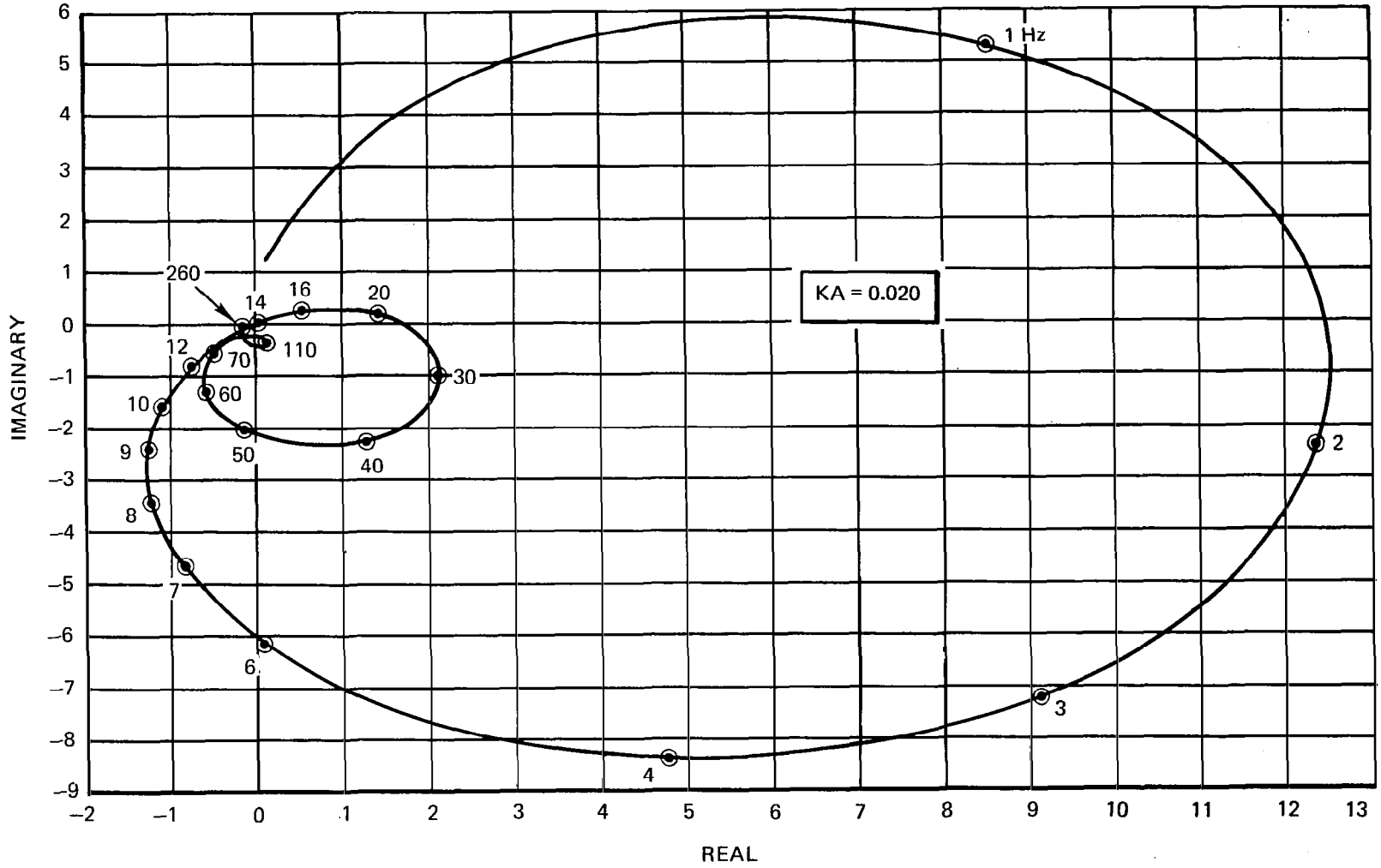


FIGURE 3-14 TOTALLY COMPENSATED LOOP

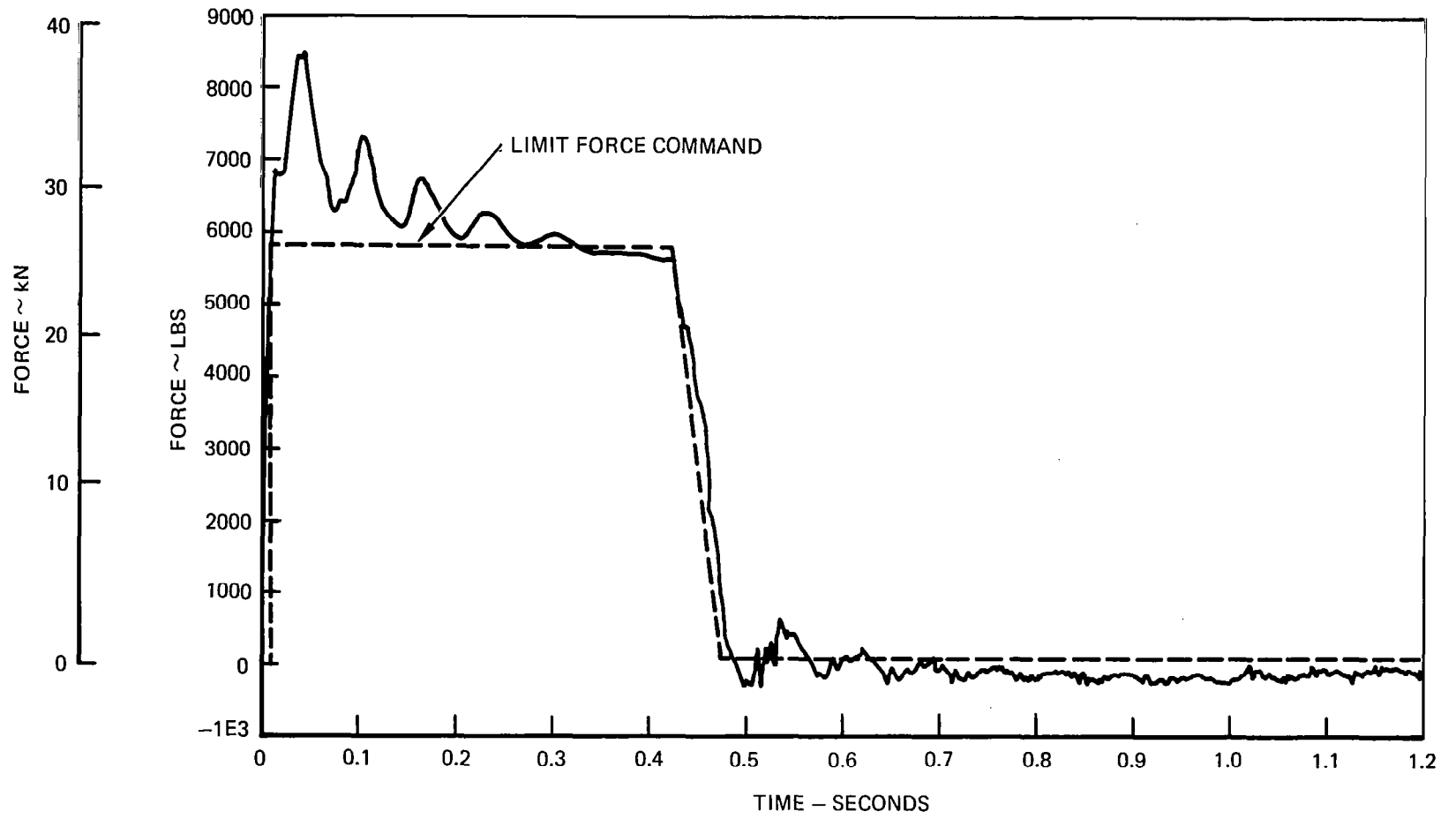


FIGURE 3-15 CASE 2 COMP: NOTCH AT 90 Hz

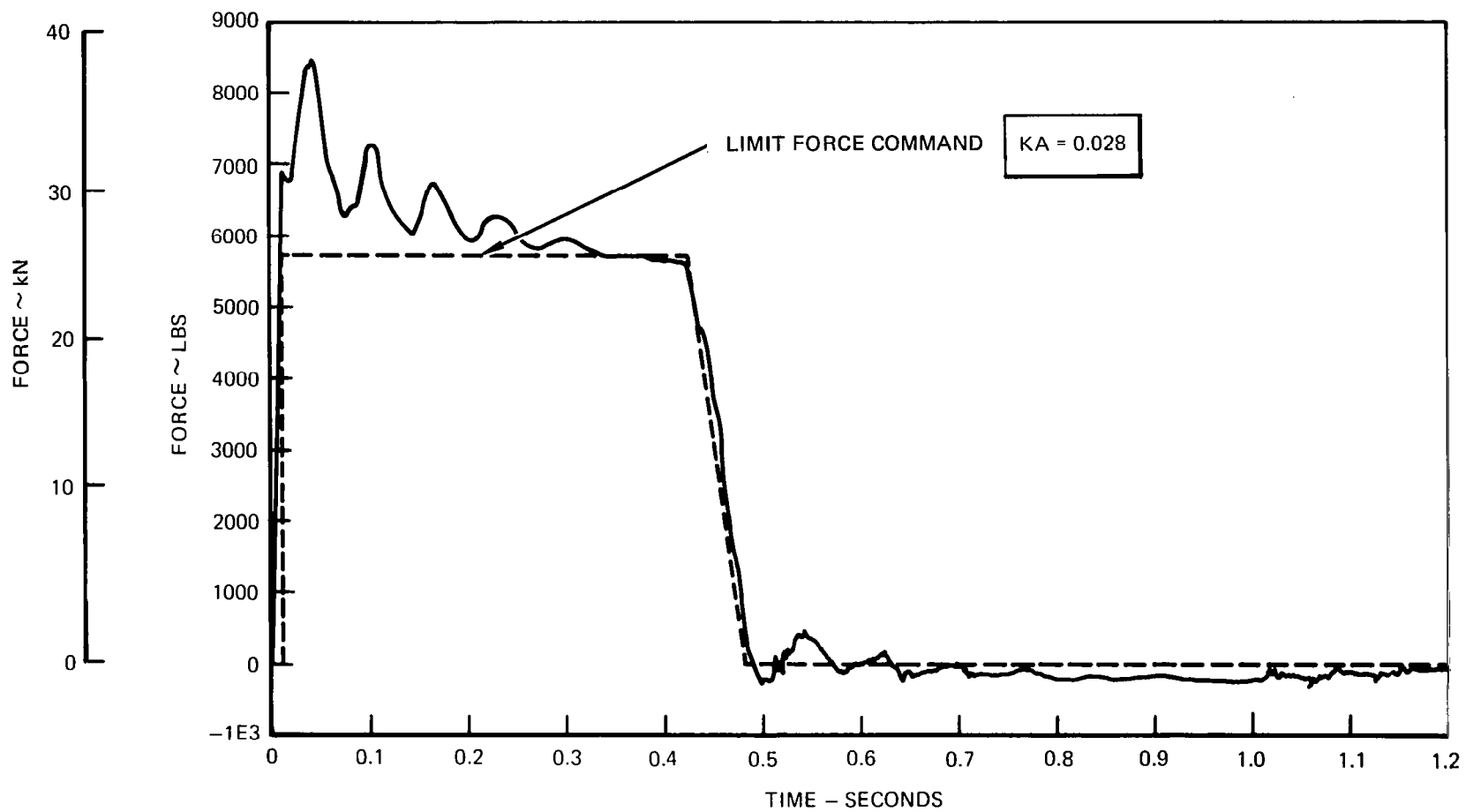


FIGURE 3-16 COMPENSATION - NOTCH @ 90 Hz
+ LEAD/LAG @ 617, 6170 RAD/SEC

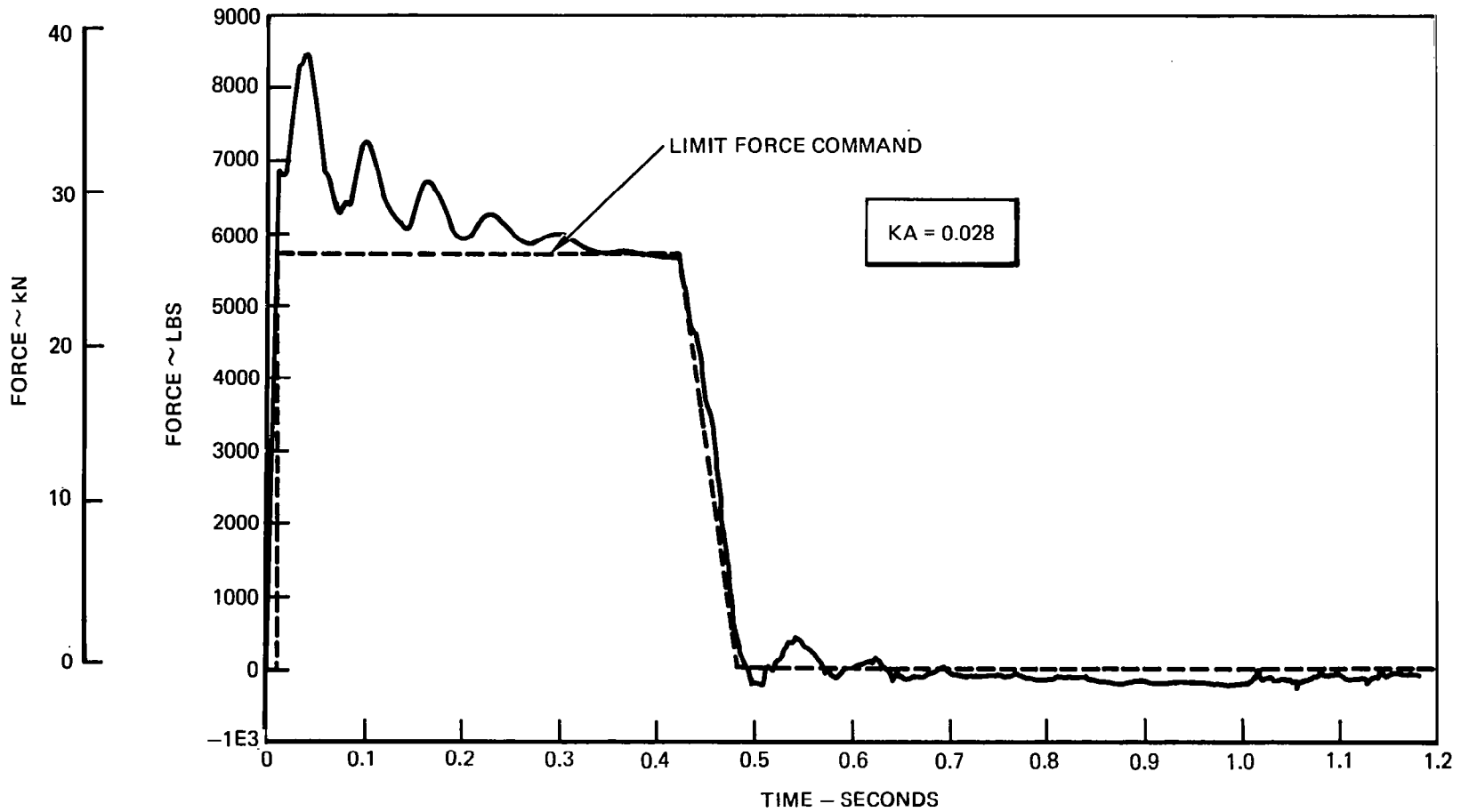


FIGURE 3-17 TOTALLY COMPENSATED LOOP

The resultant force transients are shown in Figures 3-15, 3-16, and 3-17 for the notch compensation only, the notch plus the first lead/lag compensation only, and the entire compensation network, respectively. The results show that the notch stabilizes the system, and the lead/lag networks effectively reduce the oscillatory behavior of the system at the higher frequencies. It should be noted that the amplifier gain was set at 0.028 milliamperes per volt for each of these runs, which is higher than the final design value of 0.020.

Note from Figures 3-15 through 3-17 that the system exhibits a low damped oscillatory behavior at about 15 Hertz. This behavior is also exhibited in the Nyquist diagrams already presented. The linear model Nyquist diagram results predict a somewhat lower frequency of oscillation than the nonlinear results, however, (compare Figures 3-6 and 3-7) an attempt was made to increase the damping of these oscillations by adding some phase lead in that frequency range using another 20 dB lead/lag network. Although the resultant linear model Nyquist diagram looked promising, the nonlinear vertical drop results showed marginal improvement in the low-frequency oscillatory behavior. The resultant compensation also possessed significantly greater high-frequency amplification, an undesirable result. The approach was thus taken to employ the compensation network described previously (Equation 3-1), and improve the low frequency oscillations by reducing the loop gain as much as possible without significantly degrading the performance of the active control concept. It was found that the amplifier gain of 0.028 milliamperes/volt used in Figures 3-15 through 3-17 could be reduced to 0.020 mA/V without significantly affecting the ability of the active control gear to reduce the wing/gear forces, for all the cases run herein.

The block diagram of the system is shown in Figure 3-18.

3.6 VERTICAL DROP ANALYTICAL RESULTS

The nonlinear model was used to simulate various vertical drop landings and rollouts over repaired bomb craters using active control on the F-4 landing gear. In all cases the passive gear was also simulated in order to evaluate the effectiveness of active control in reducing the loads transmitted through the wing/gear interface. The compensation developed in Section 3.5 (Equation 3-1) was employed in all active control cases, and the amplifier gain used was 0.020 mA/V.

3.6.1 Vertical Drop, Case I

The conditions for vertical drop case number 1 are as follows:

1. The sink rate prior to impact is 1.83 m/sec (72 in/sec).
2. The lift equals airplane weight (per gear) at all times.
3. The ground level remains constant.

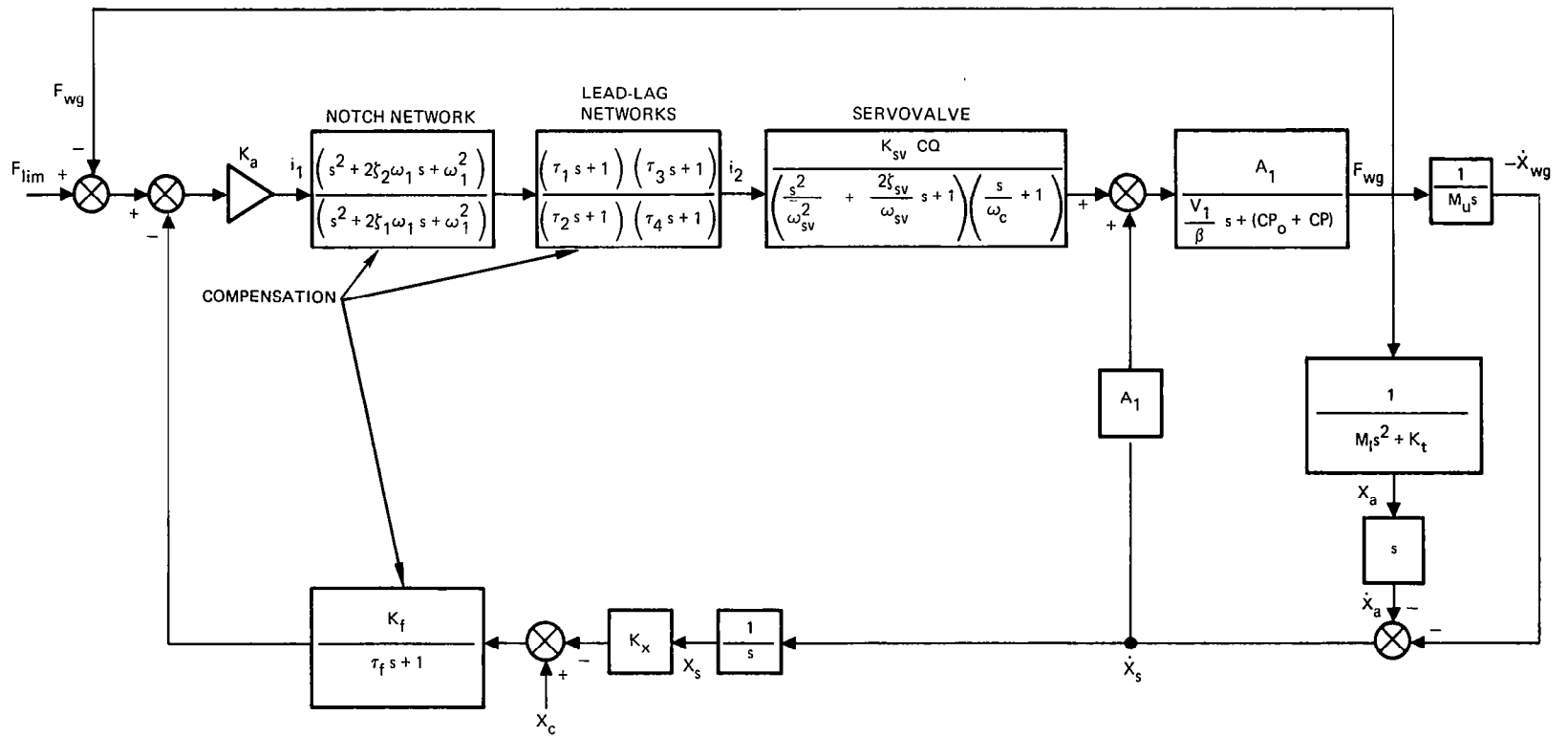


FIGURE 3-18 BLOCK DIAGRAM OF LINEAR MATH MODEL

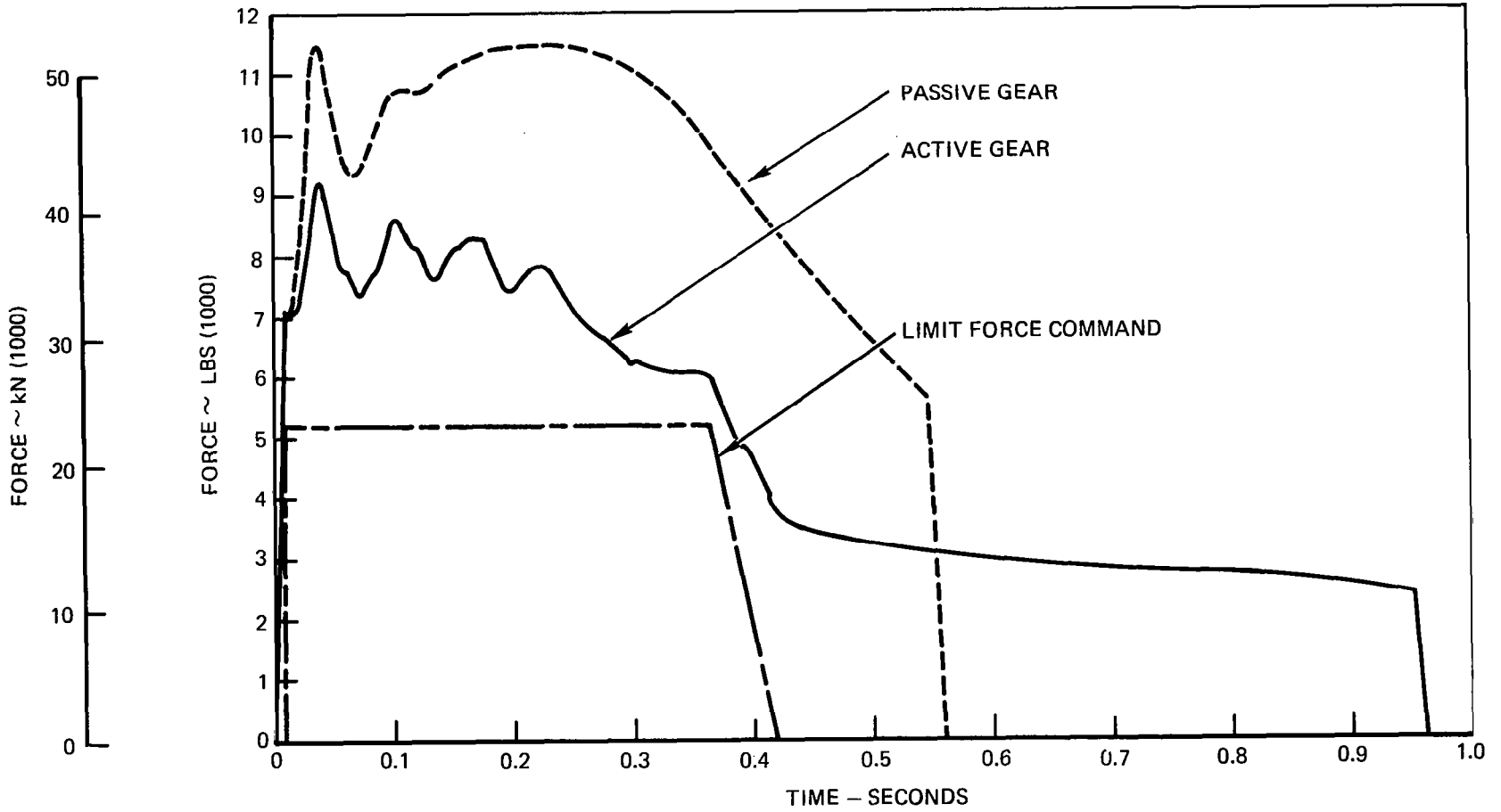


FIGURE 3-19 CASE 1

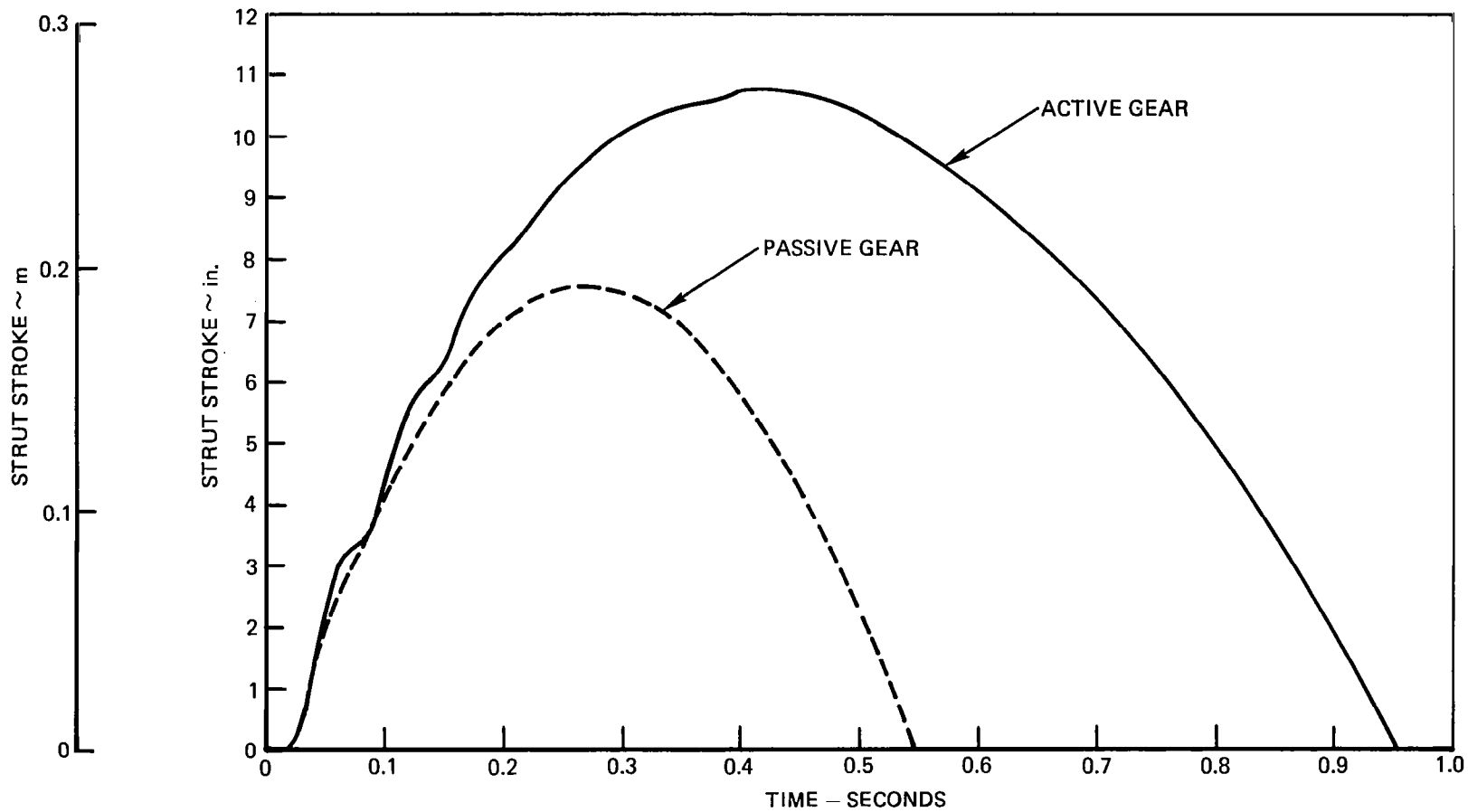


FIGURE 3-20 CASE 1.

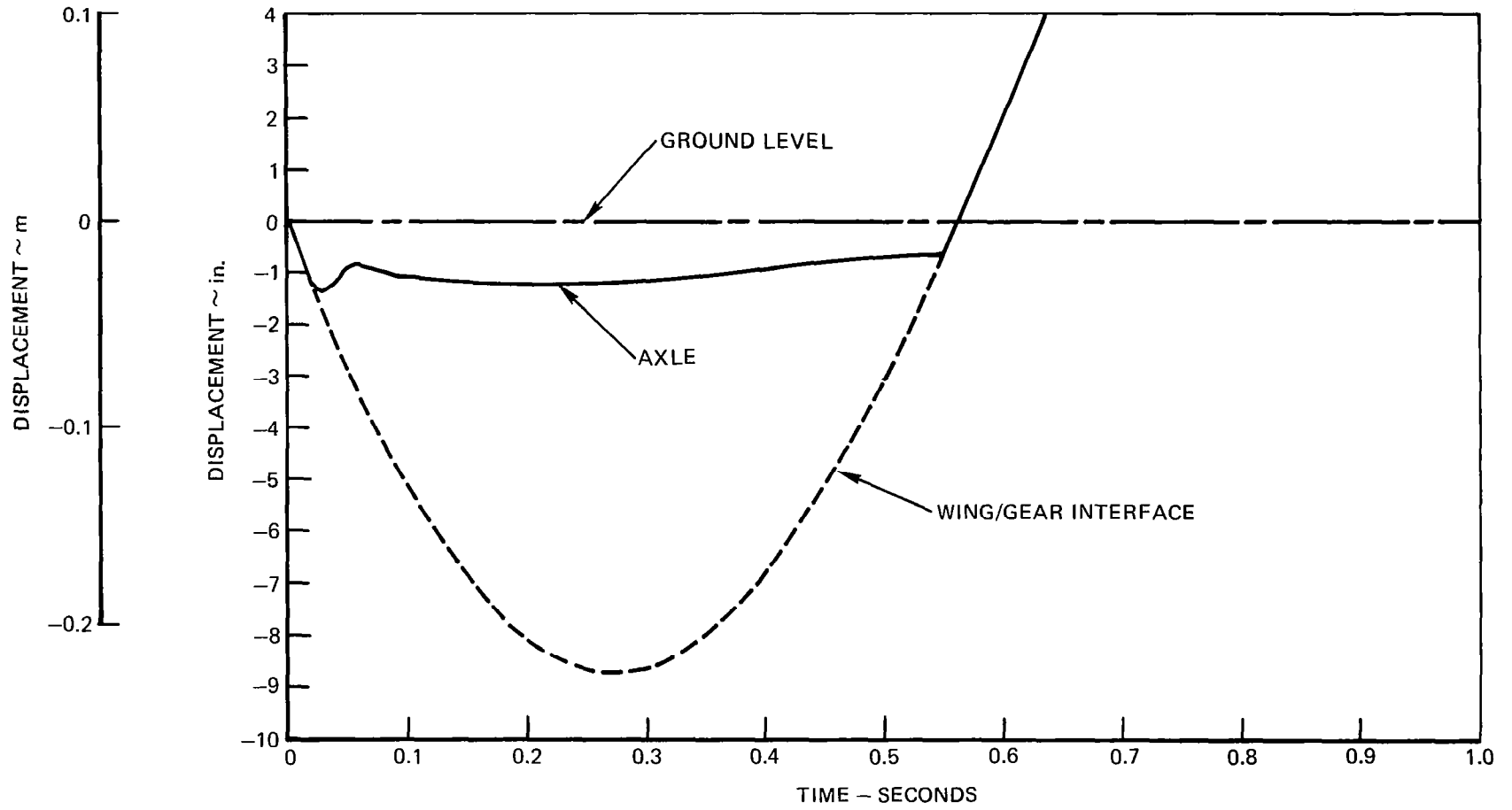


FIGURE 3-21 CASE 1 PASSIVE GEAR

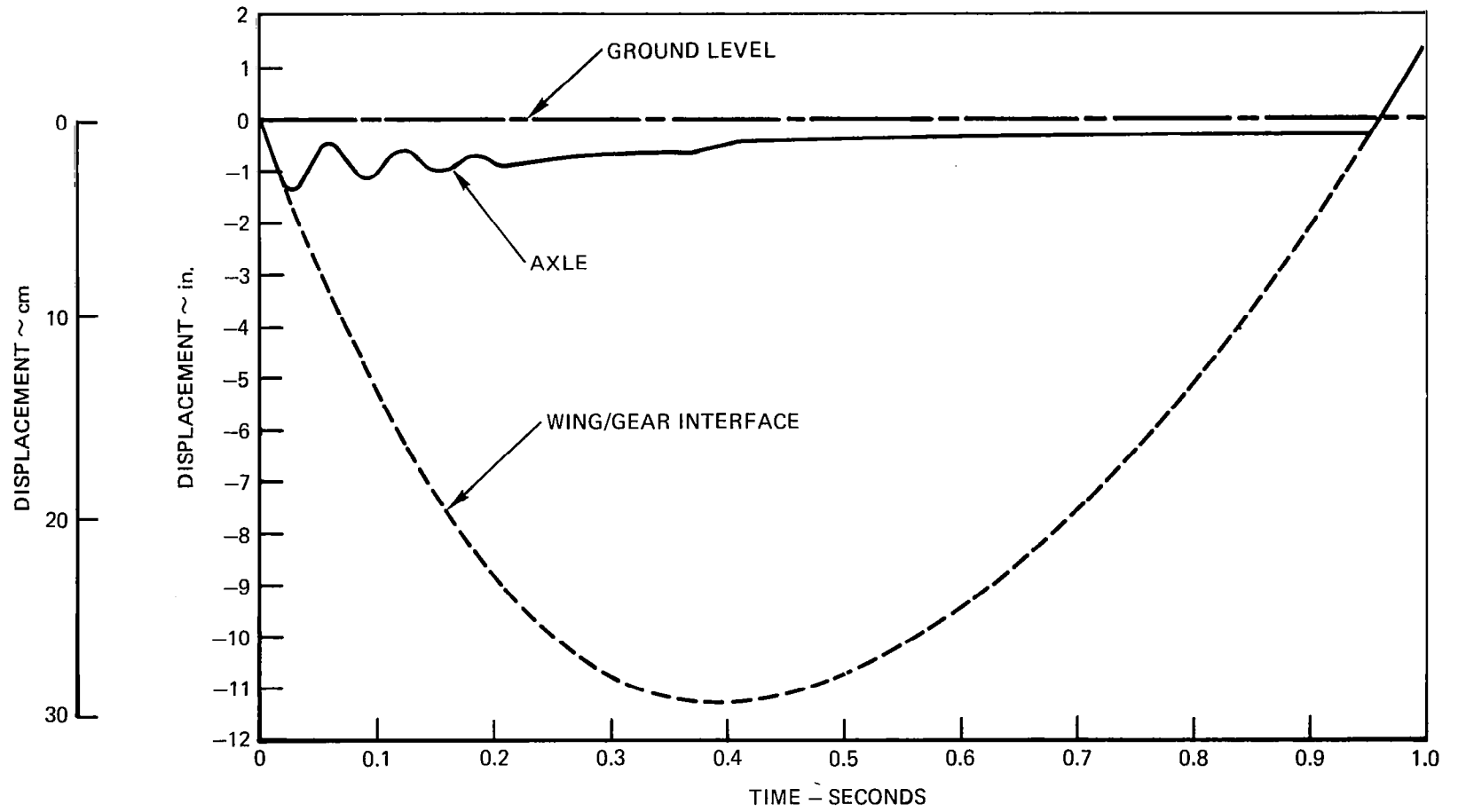


FIGURE 3-22. CASE 1 ACTIVE GEAR

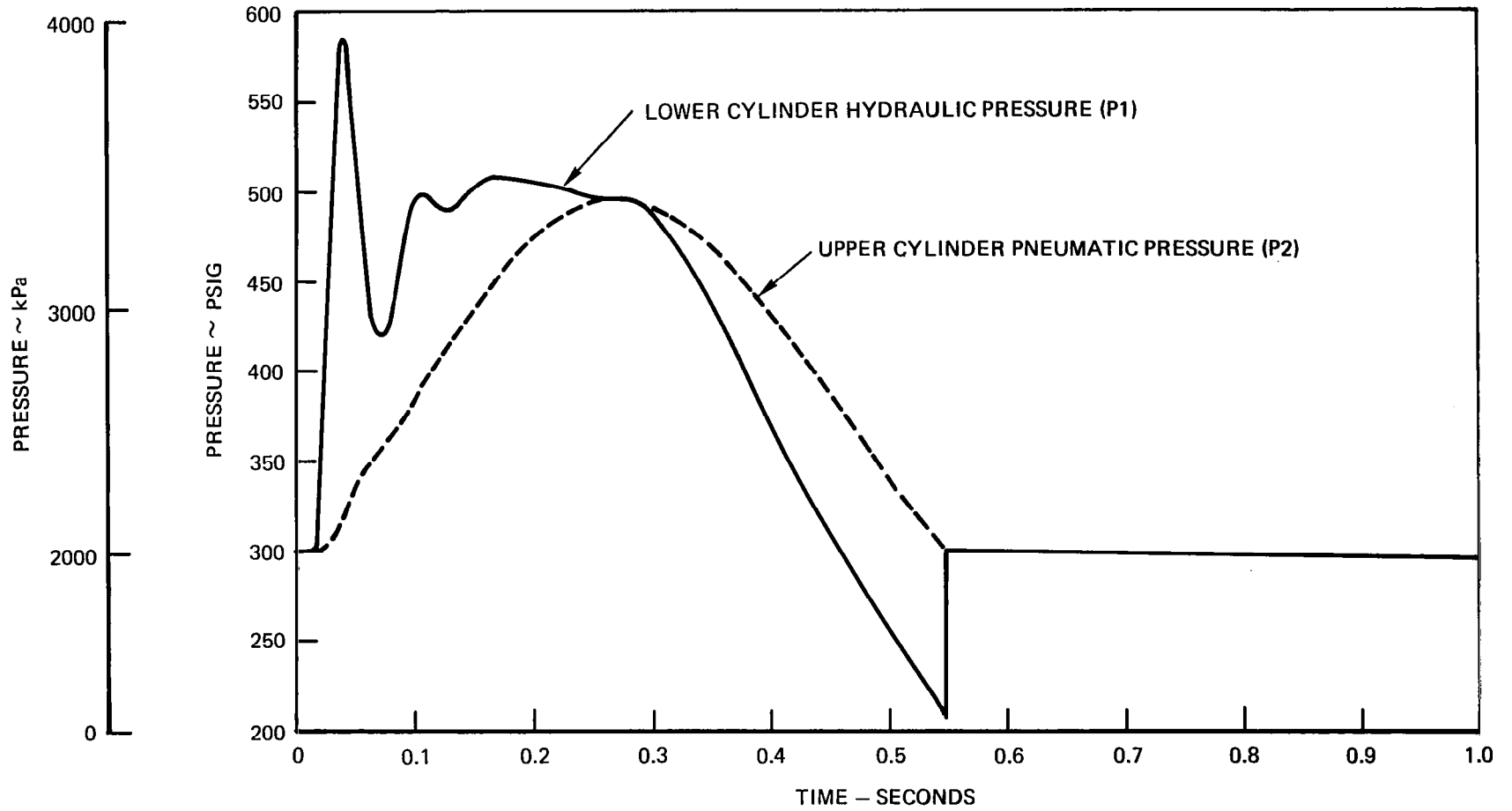


FIGURE 3-23 CASE 1 PASSIVE GEAR

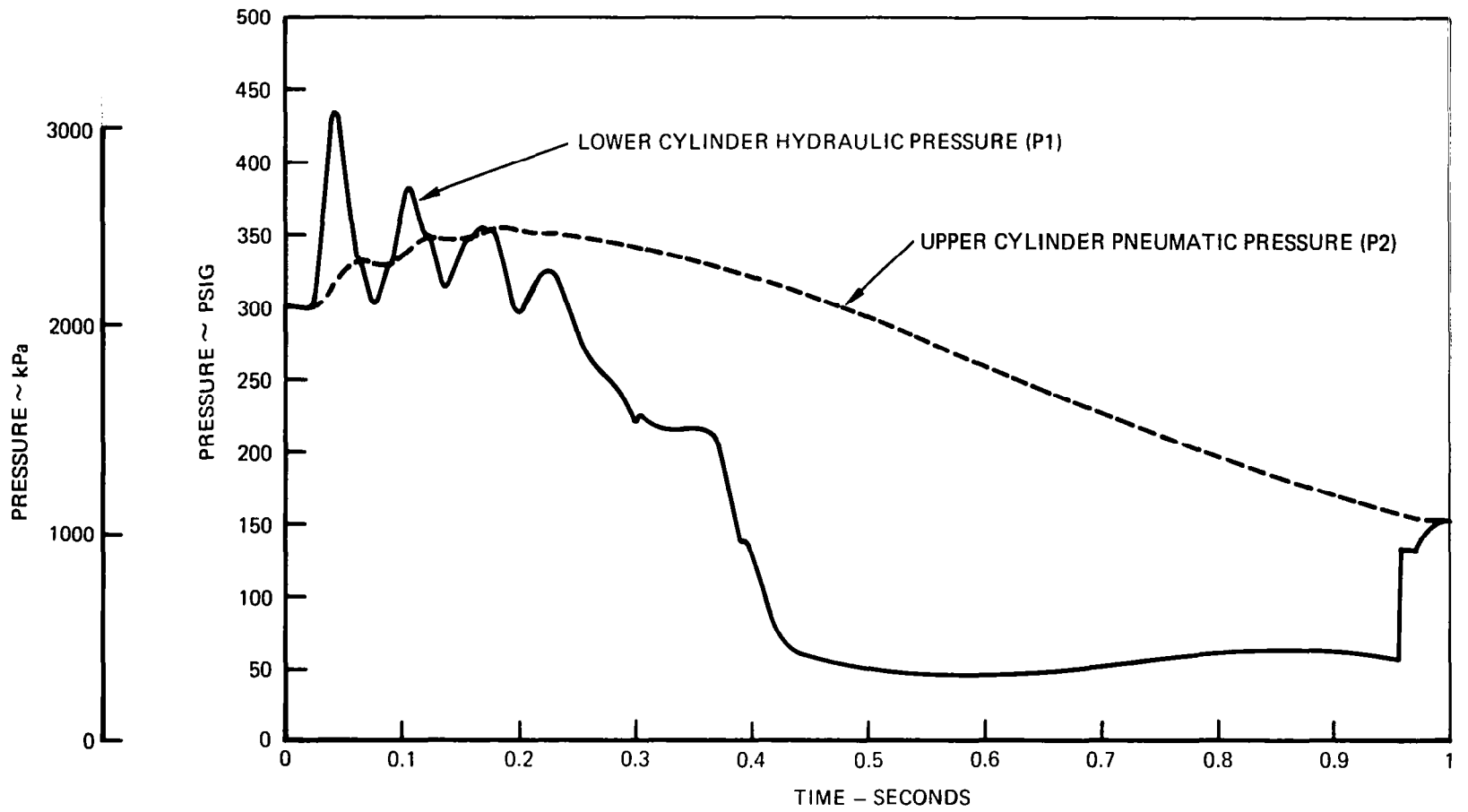


FIGURE 3-24 CASE 1 ACTIVE GEAR

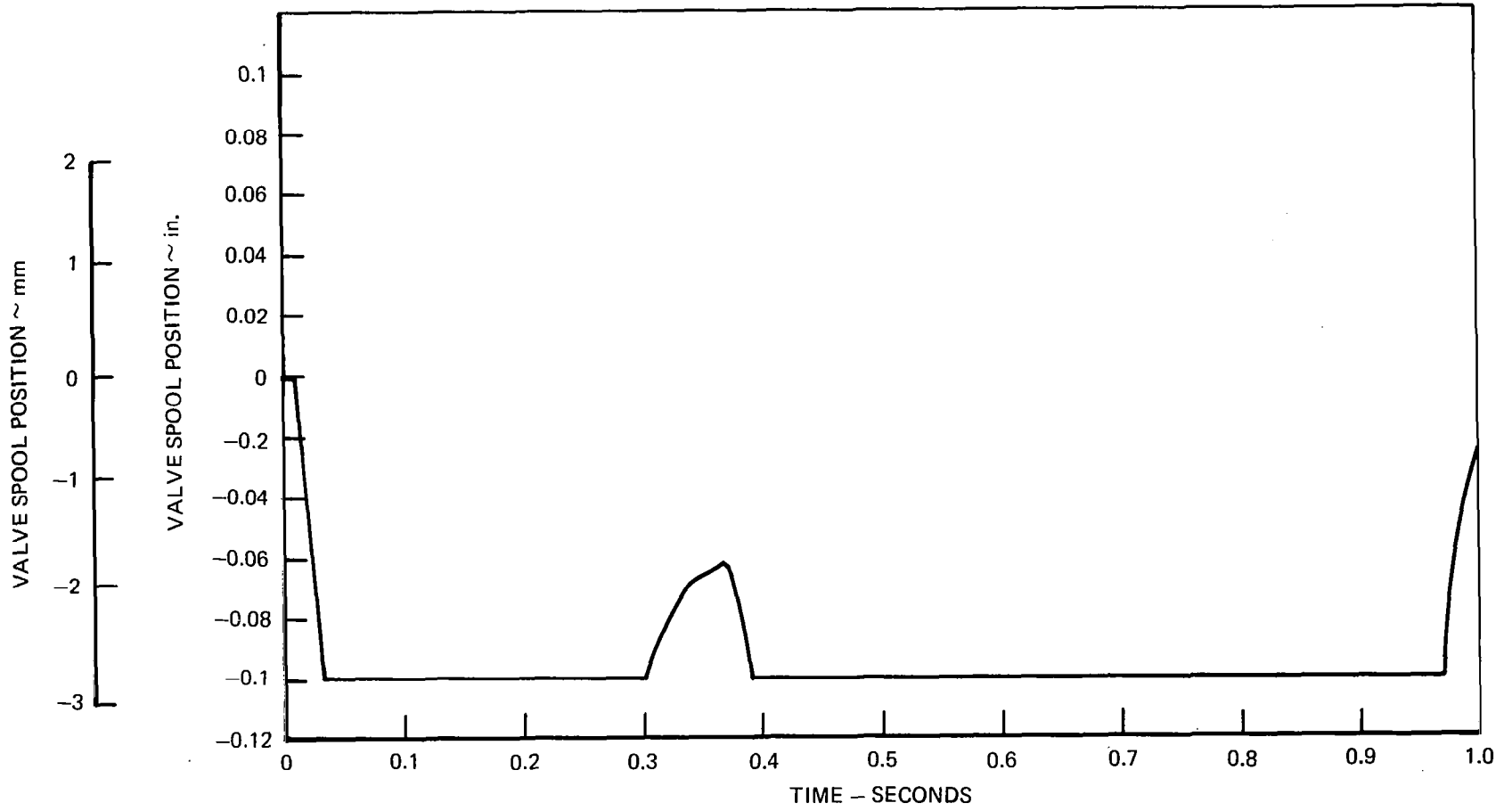


FIGURE 3-25 CASE 1 ACTIVE GEAR

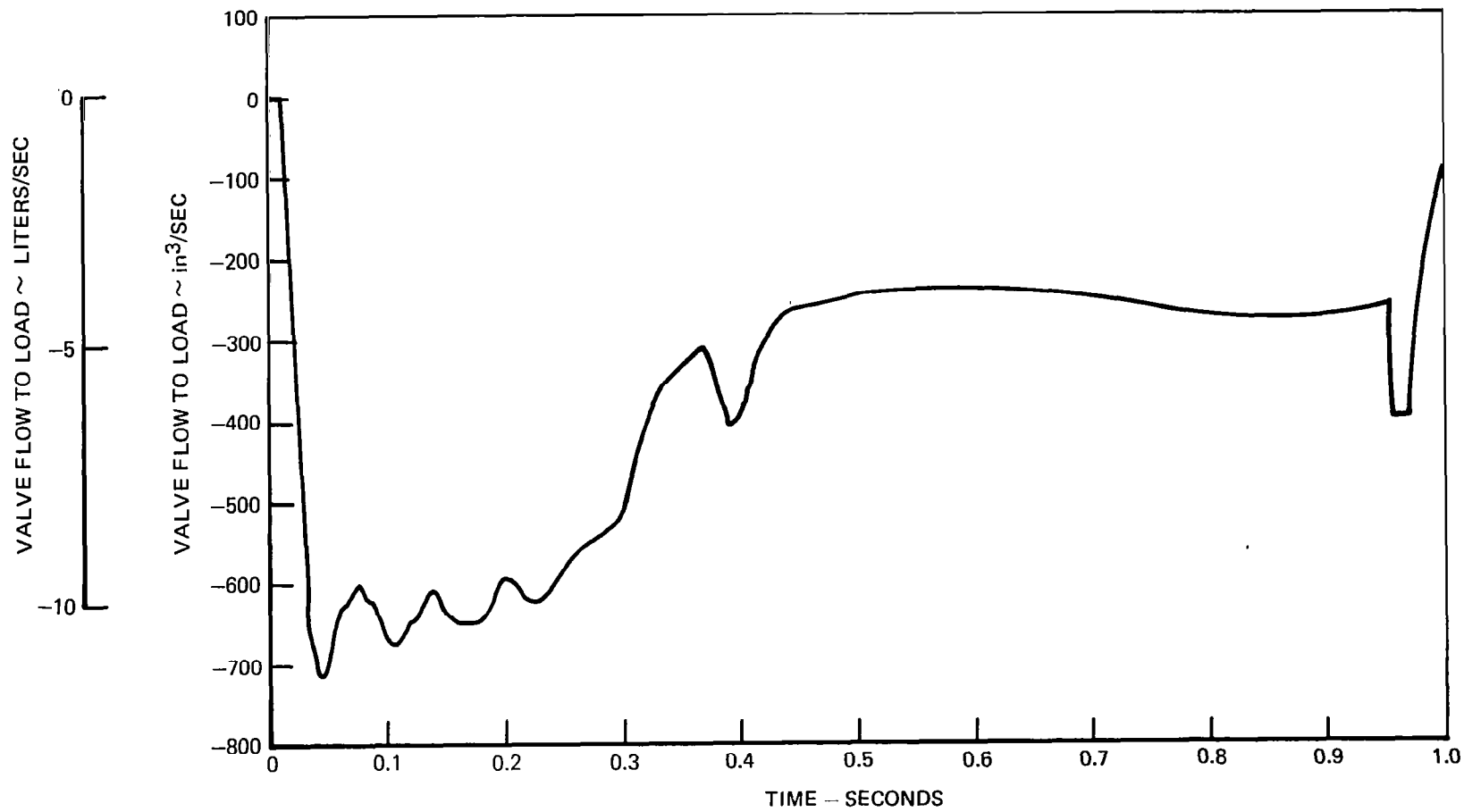


FIGURE 3-26 CASE 1 ACTIVE GEAR

Command limit force is set automatically by the controller. Figure 3-19 shows the resultant wing/gear force transients for the active and passive gears. Active control reduces the peak force 20 percent below the passive gear case. Figure 3-20 compares the strut stroke between the two cases. The active gear uses significantly more stroke than the passive gear. Figures 3-21 and 3-22 show the vertical displacements of the ground level, landing gear axle, and wing/gear interface for the passive gear and the active gear, respectively. The displacements are positive in the up direction, and are all referenced to the condition where the gear is fully extended and barely in contact with the ground with zero tire compression. Thus, at the point of impact (at time = 0) all the variables are zero. When the axle displacement is below the ground level (which is constant), the tire is in compression; when it is above, the landing gear is off the ground. Also, when the wing gear interface displacement is the same as the axle displacement, the gear is fully extended. Thus, in Figure 3-21 for the passive gear, the landing gear becomes fully extended at 0.548 second and rebounds (i.e., leaves the ground) at 0.560 second. Note from Figure 3-22 that the active control causes the gear to remain in contact with the ground longer and when it rebounds, it does so at a lower upward velocity. Figures 3-23 and 3-24 show the lower and upper cylinder pressure transients for the passive and active gears, respectively. The pressures are significantly reduced in both cylinders as a result of active control. Finally, Figures 3-25 and 3-26 show the valve third stage spool displacement and the valve hydraulic flow rate to the gear respectively, for the active control case.

3.6.2 Vertical Drop, Case 2

The conditions for vertical drop case number 2 are as follows:

1. The sink rate prior to impact is 1.83 m/sec (72 in/sec).
2. The lift equals airplane weight (per gear) prior to and up to the point of impact, then lift is linearly reduced to 10 percent of airplane weight during the first second after impact, and lift is held constant at ten percent thereafter.
3. The ground level remains constant. Figures 3-27 through 3-34 show the transient response of the various variables of interest for the passive and active gear simulations. Active control in this case reduces the peak wing/gear force 22 percent below the passive gear case.

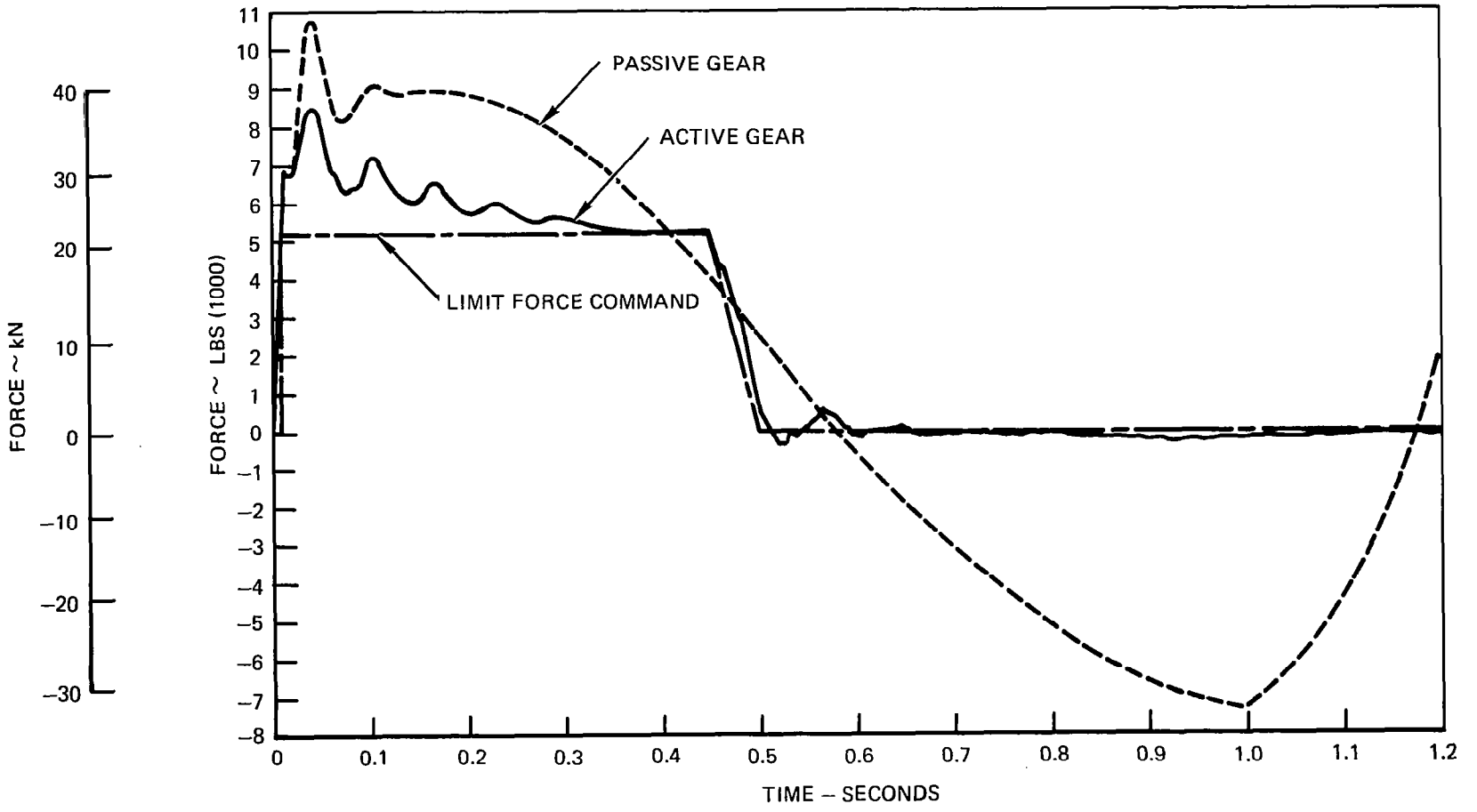


FIGURE 3-27 CASE 2

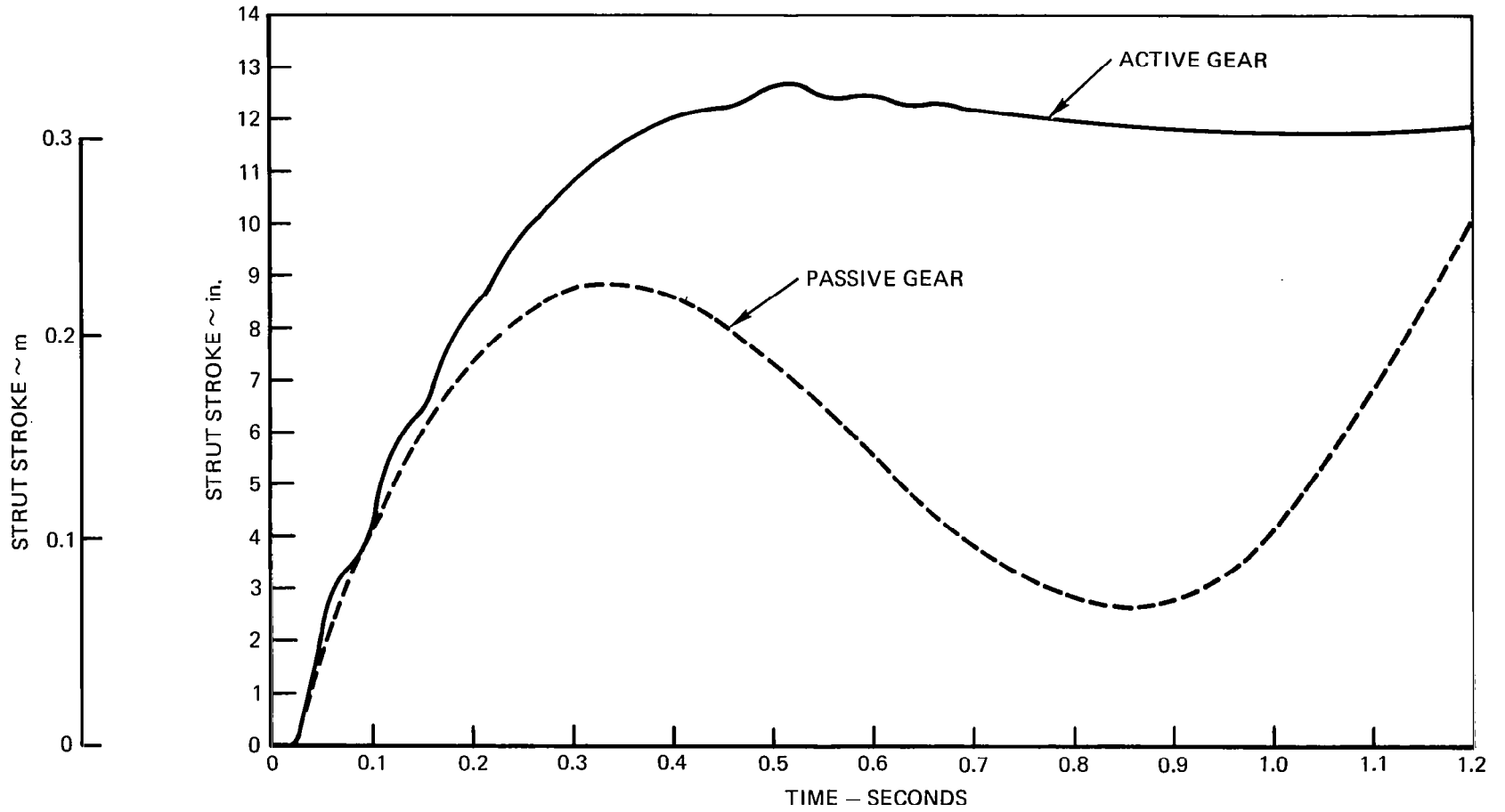


FIGURE 3-28 CASE 2

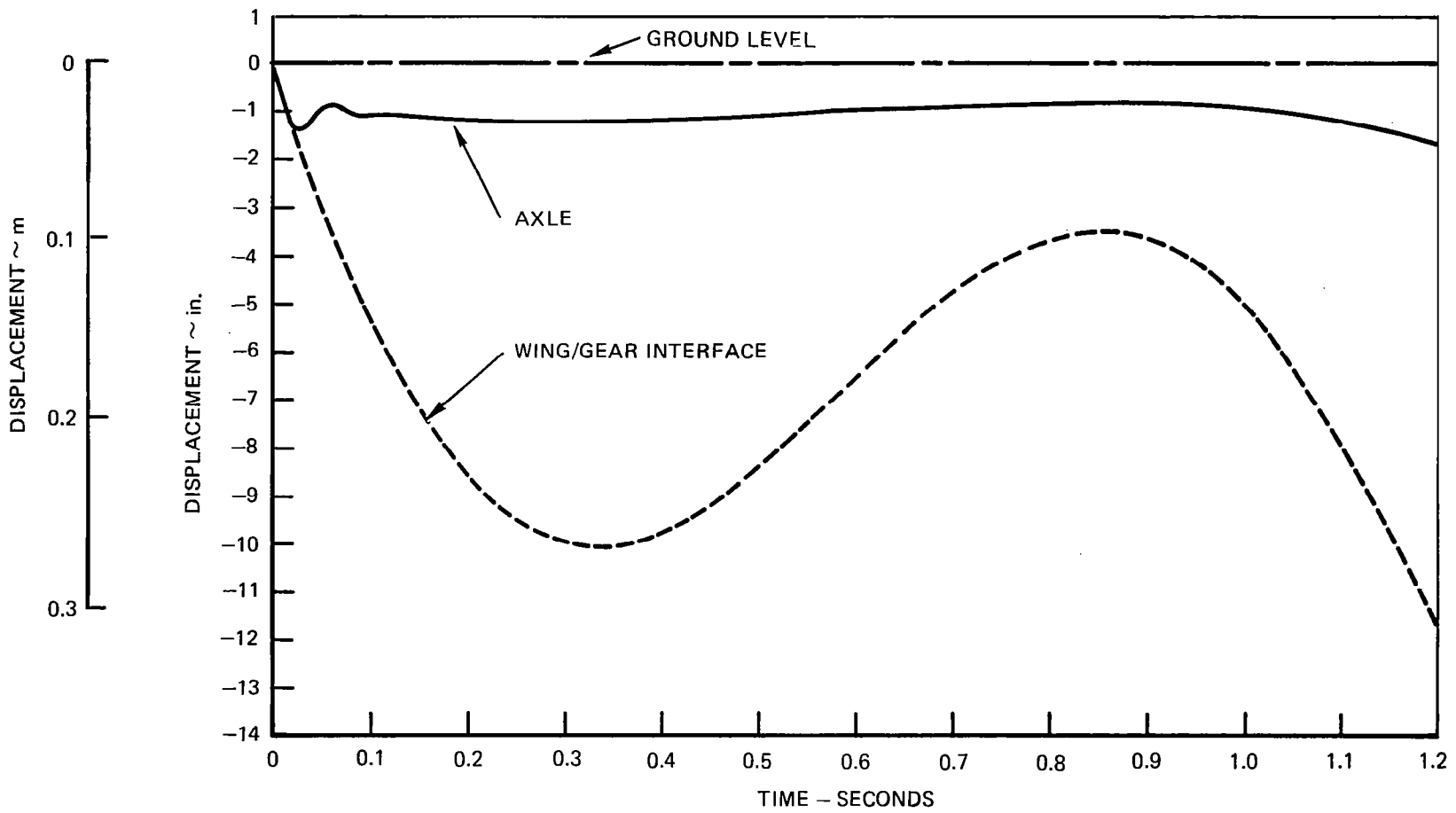


FIGURE 3-29 CASE 2 PASSIVE GEAR

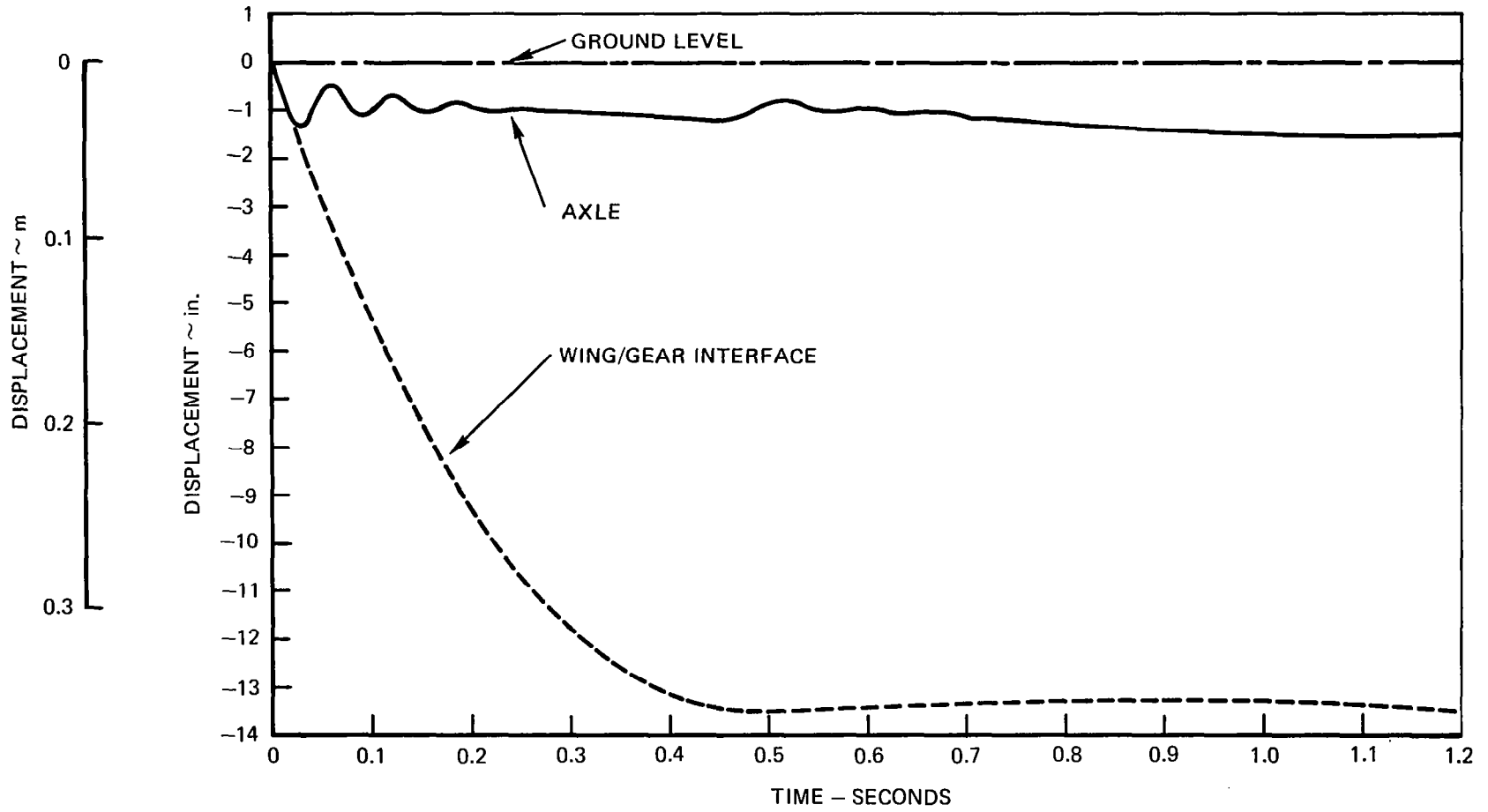


FIGURE 3-30 CASE 2 ACTIVE GEAR

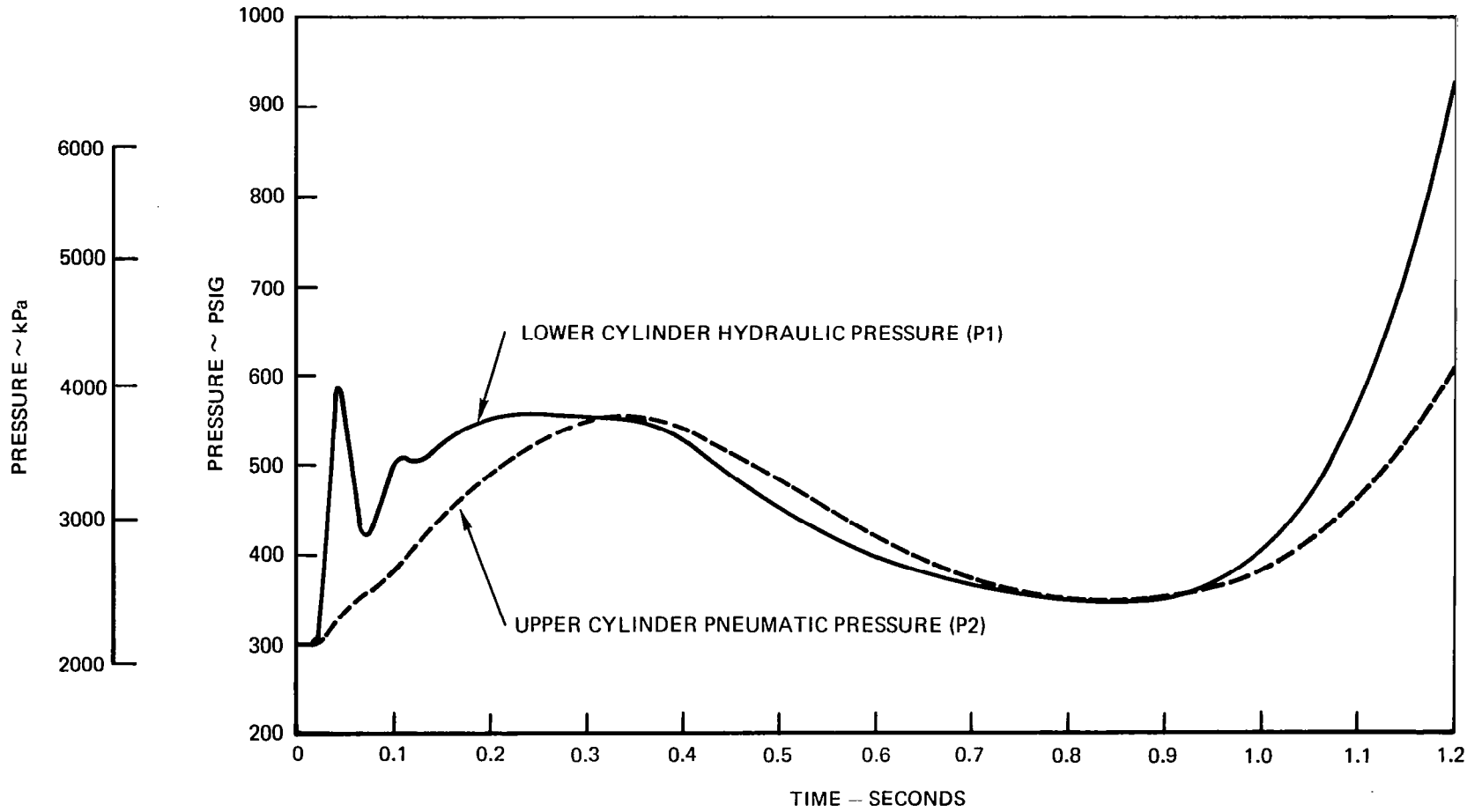


FIGURE 3-31 CASE 2 PASSIVE GEAR

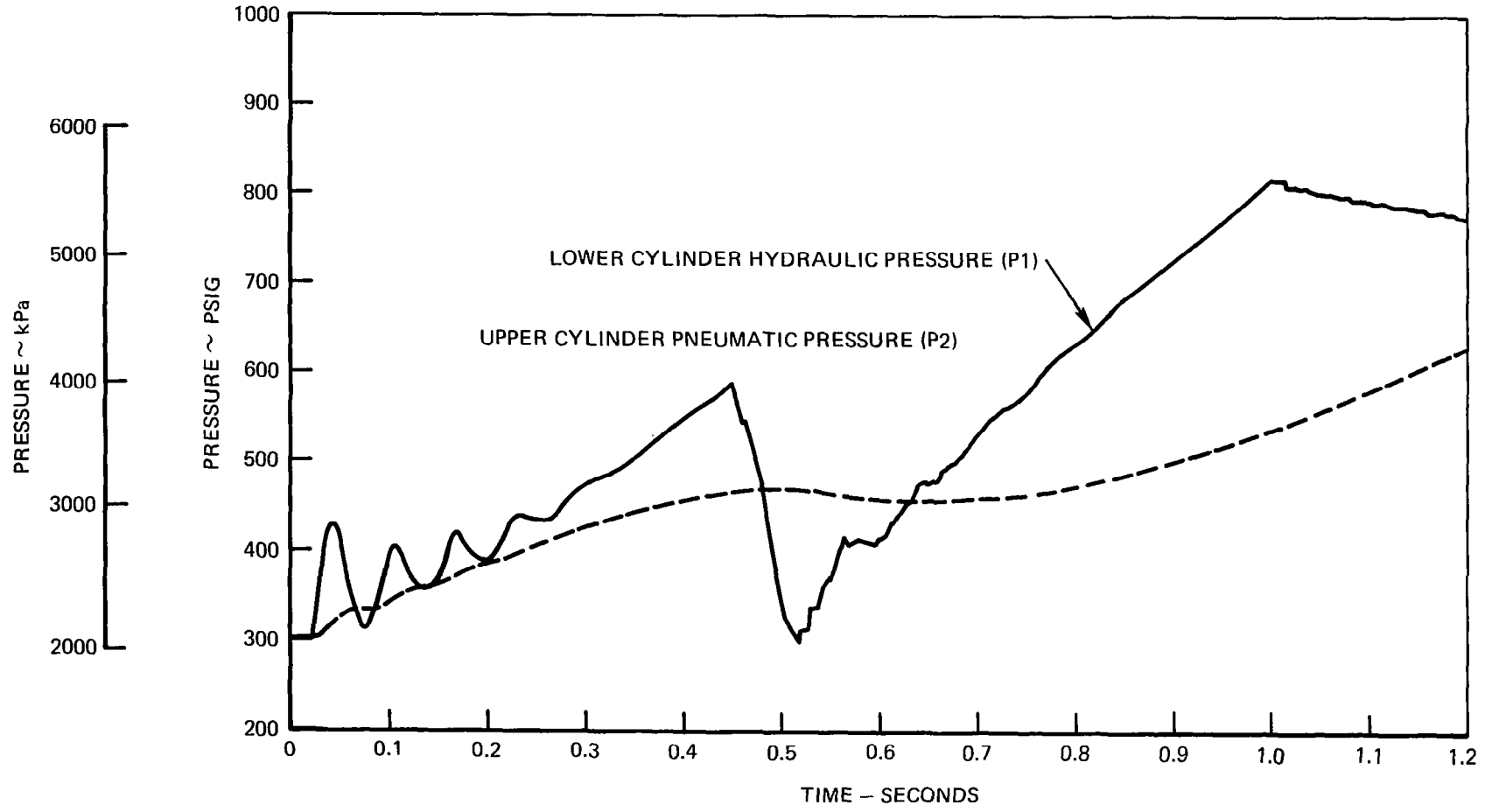


FIGURE 3-32 CASE 2 ACTIVE GEAR

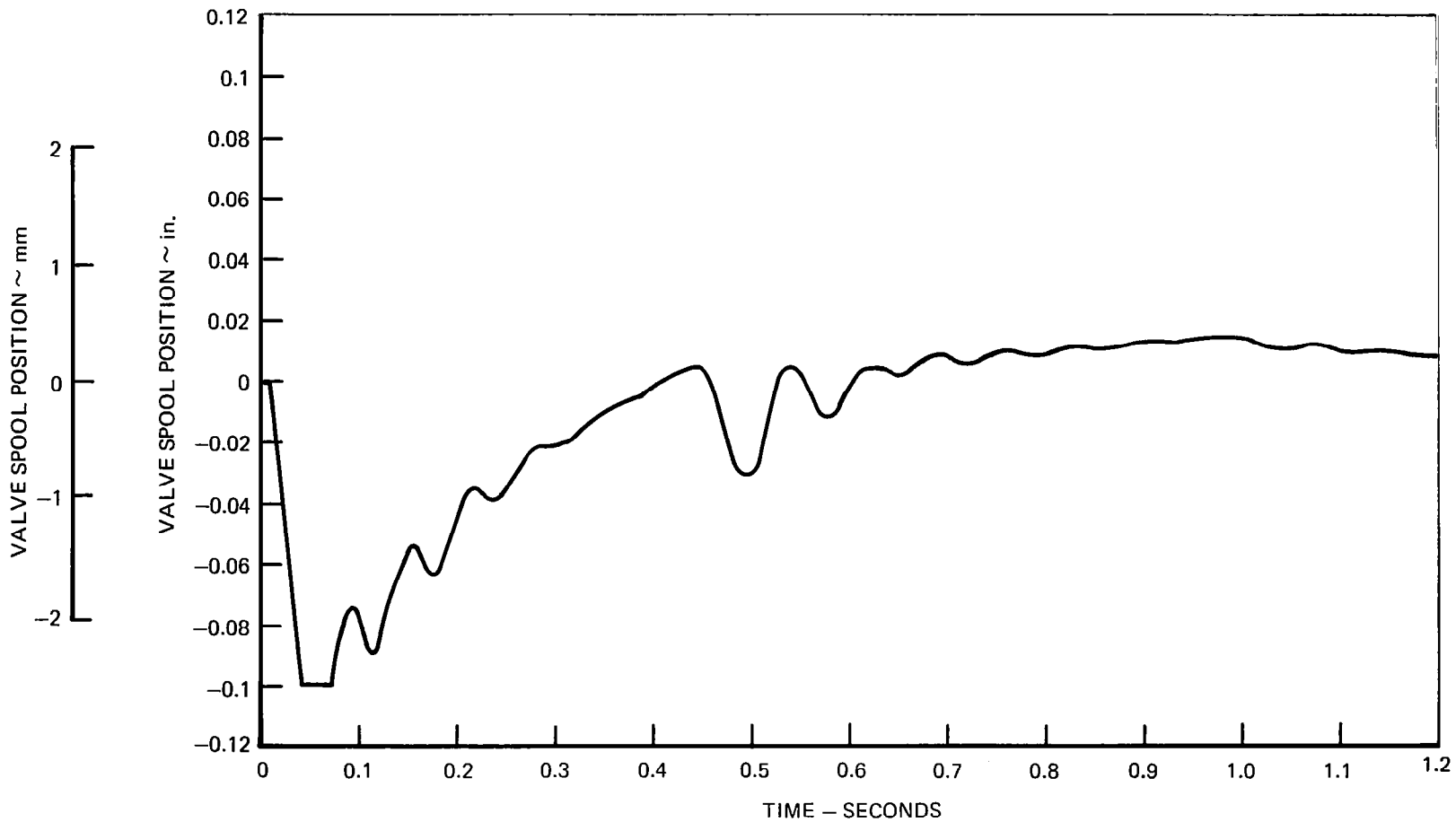


FIGURE 3-33 CASE 2 ACTIVE GEAR

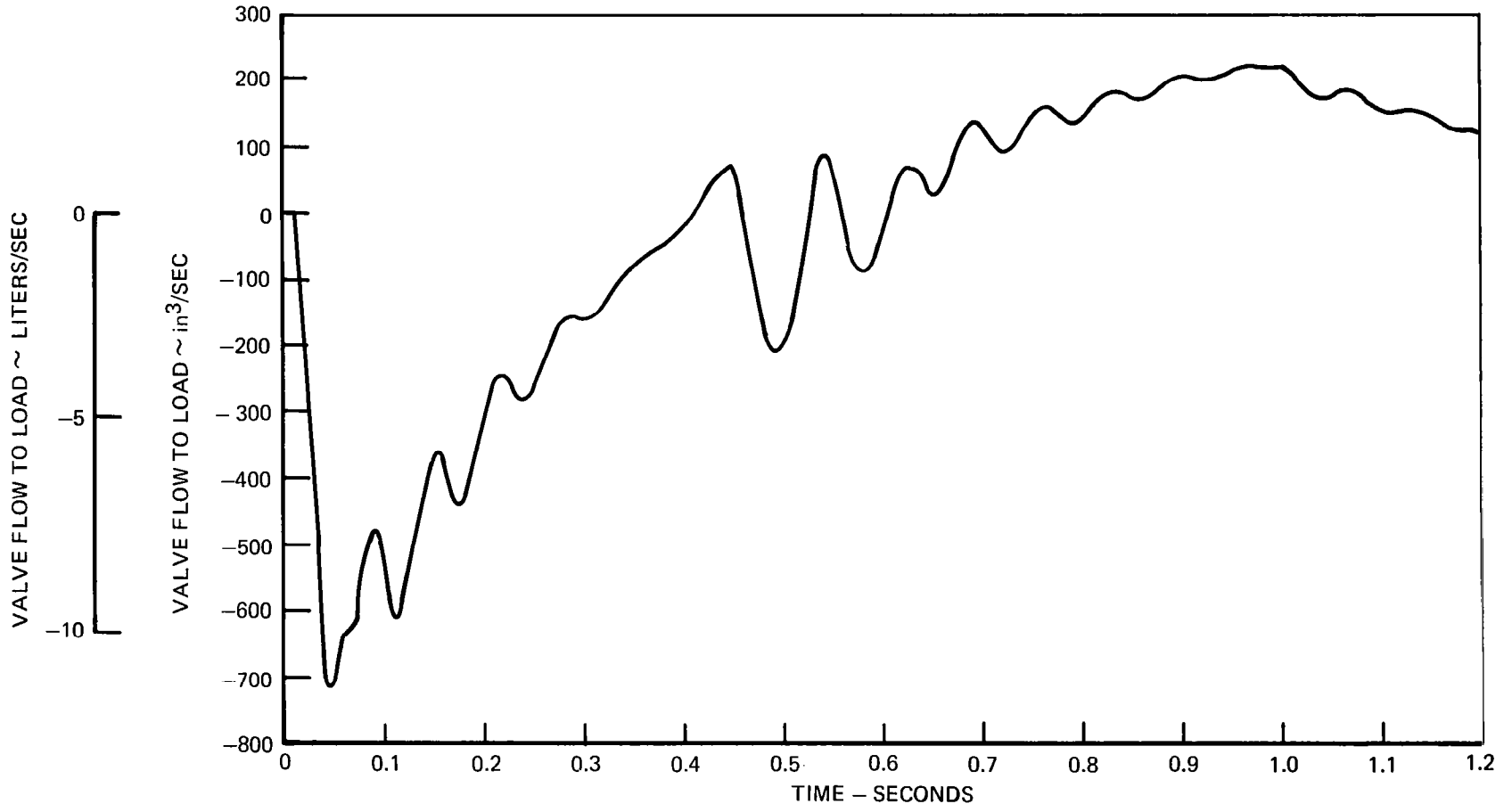


FIGURE 3-34 CASE 2 ACTIVE

3.6.3 Rollout Over Repaired Bomb Crater

Simulation of aircraft rollout over a repaired bomb crater (subsequent to an impact landing) was accomplished using the nonlinear vertical drop model. Initial conditions are calculated assuming the aircraft is in contact with the ground and the landing gear has reached an equilibrium condition in supporting the aircraft weight minus its lift. Assuming some horizontal speed for the aircraft, actual physical changes in ground level can be represented as transient changes which can be input into the nonlinear model. For this case a Class I repaired bomb crater was used. This was chosen because it was the worst-case profile out of all those supplied by NASA in support of this project. A diagram of the bomb crater is shown in Figure 3-35. The horizontal speed of the aircraft was assumed to be 51.8 m/sec (170 ft/sec). The command limit force is set to zero with a force deadband of ± 8.9 kN (± 2000 lbf) throughout the transient, consistent with the assumption that the disturbance occurs during rollout, subsequent to an impact landing. The lift is set to 10 percent of the aircraft weight (per gear) throughout the transient. Figures 3-36 through 3-43 show the transient response of the various variables of interest for the passive and active gear simulations. Active control in this case reduces the peak wing/gear force 74 percent below the passive gear case. Note also from Figures 3-38 and 3-39 that the passive gear leaves the ground three separate times during the transient, while the active gear leaves the ground only once, very briefly.

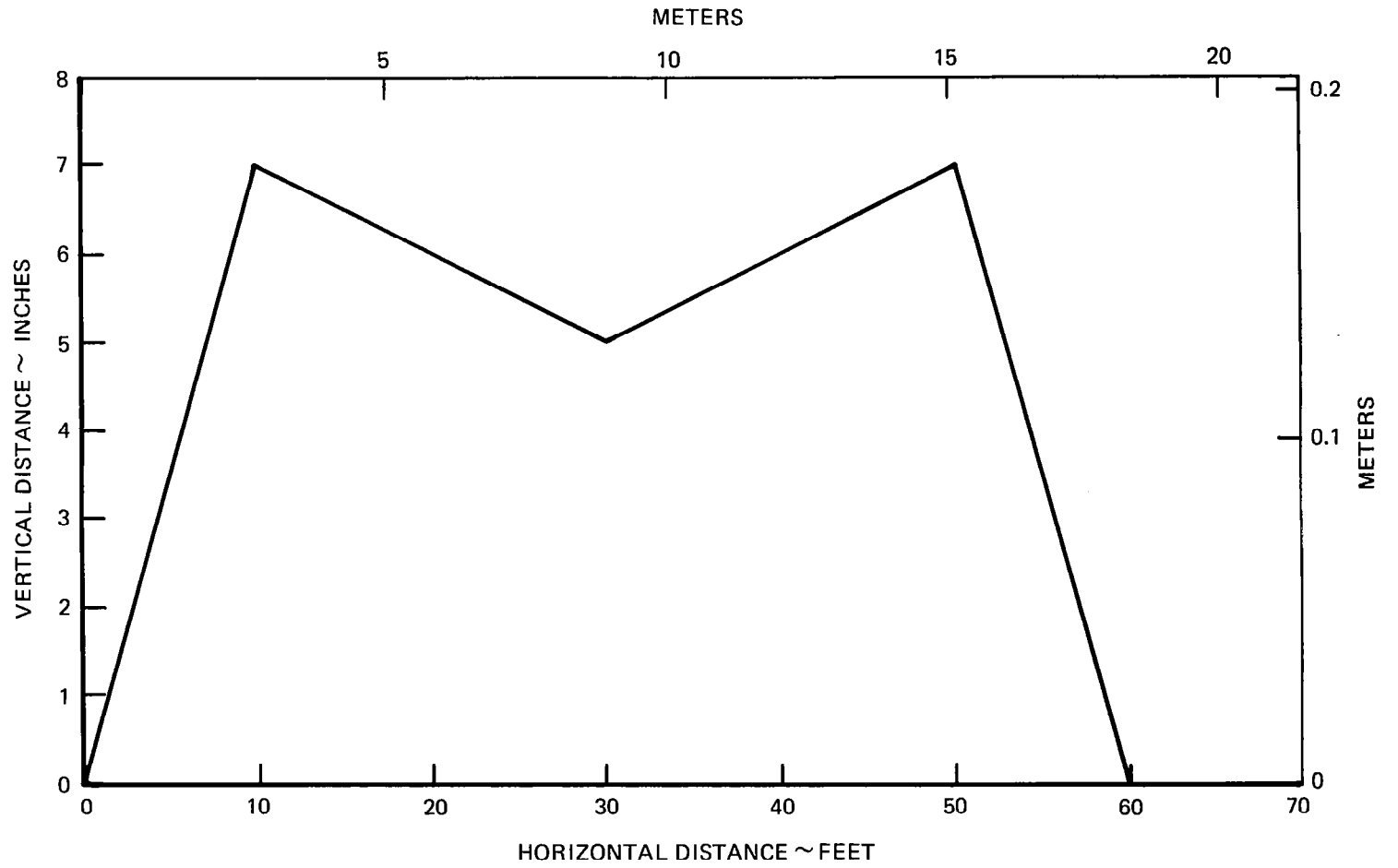


FIGURE 3-35. BOMB CRATER PROFILE

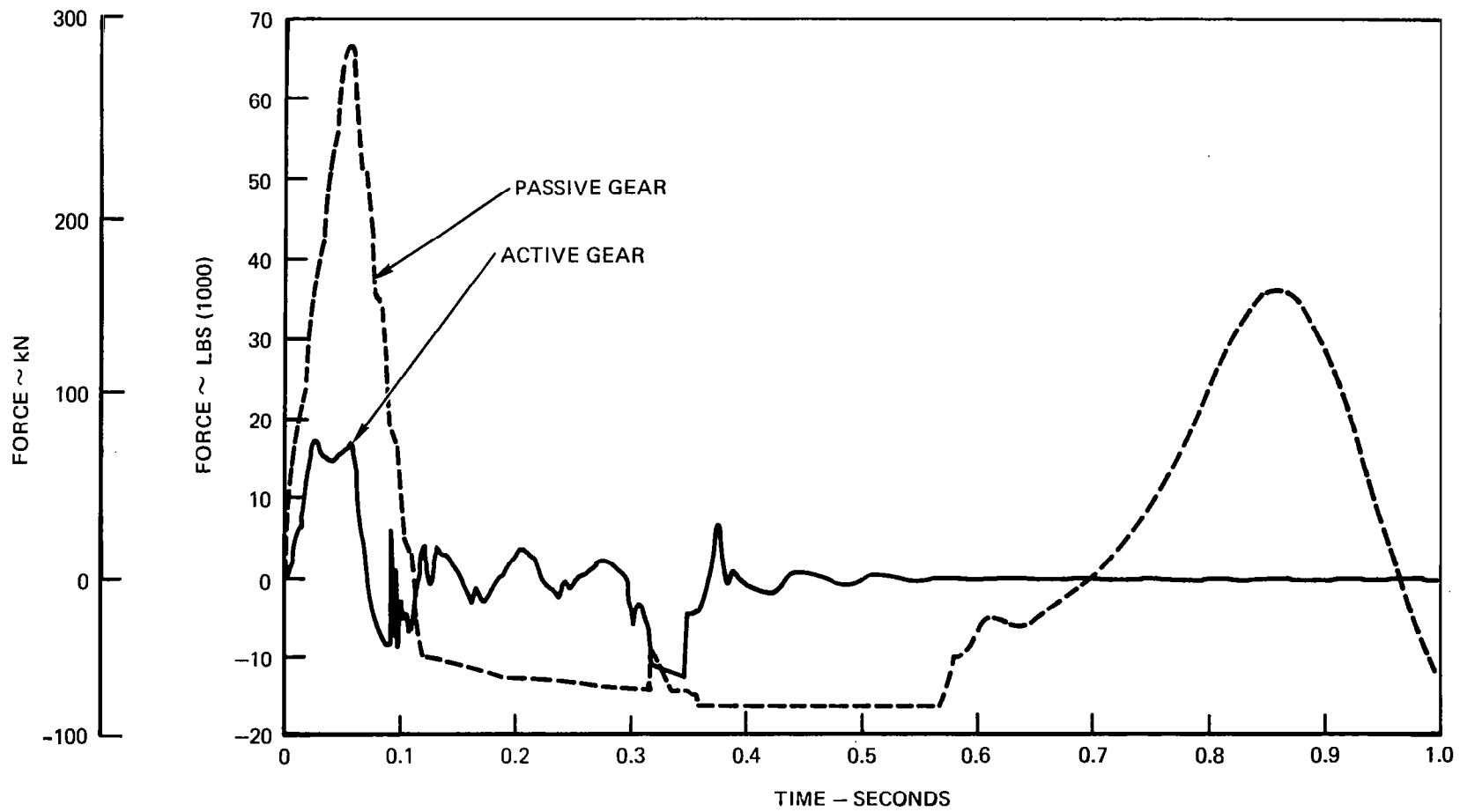


FIGURE 3-36 BOMB CRATER LANDING

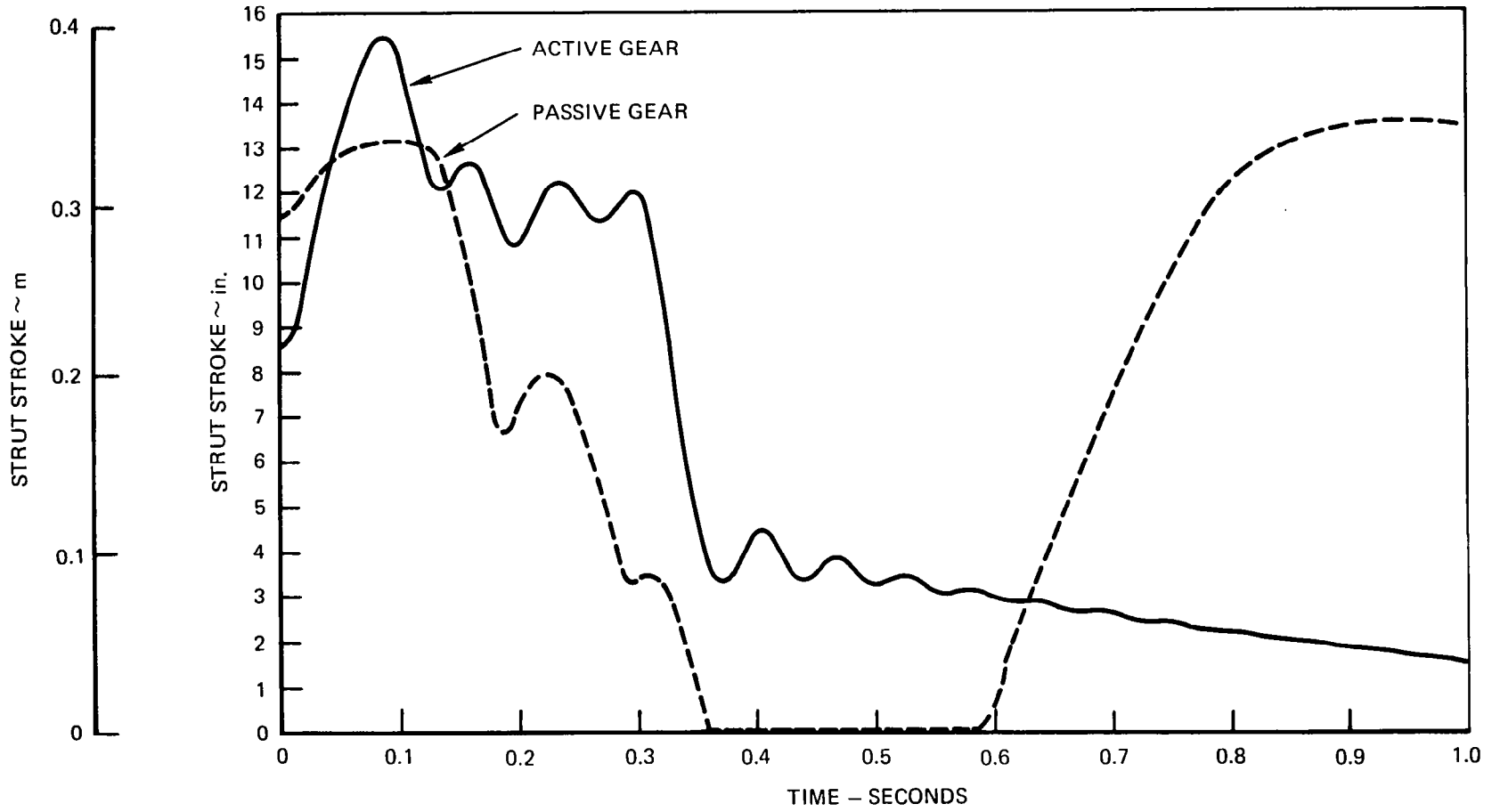


FIGURE 3-37 BOMB CRATER LANDING

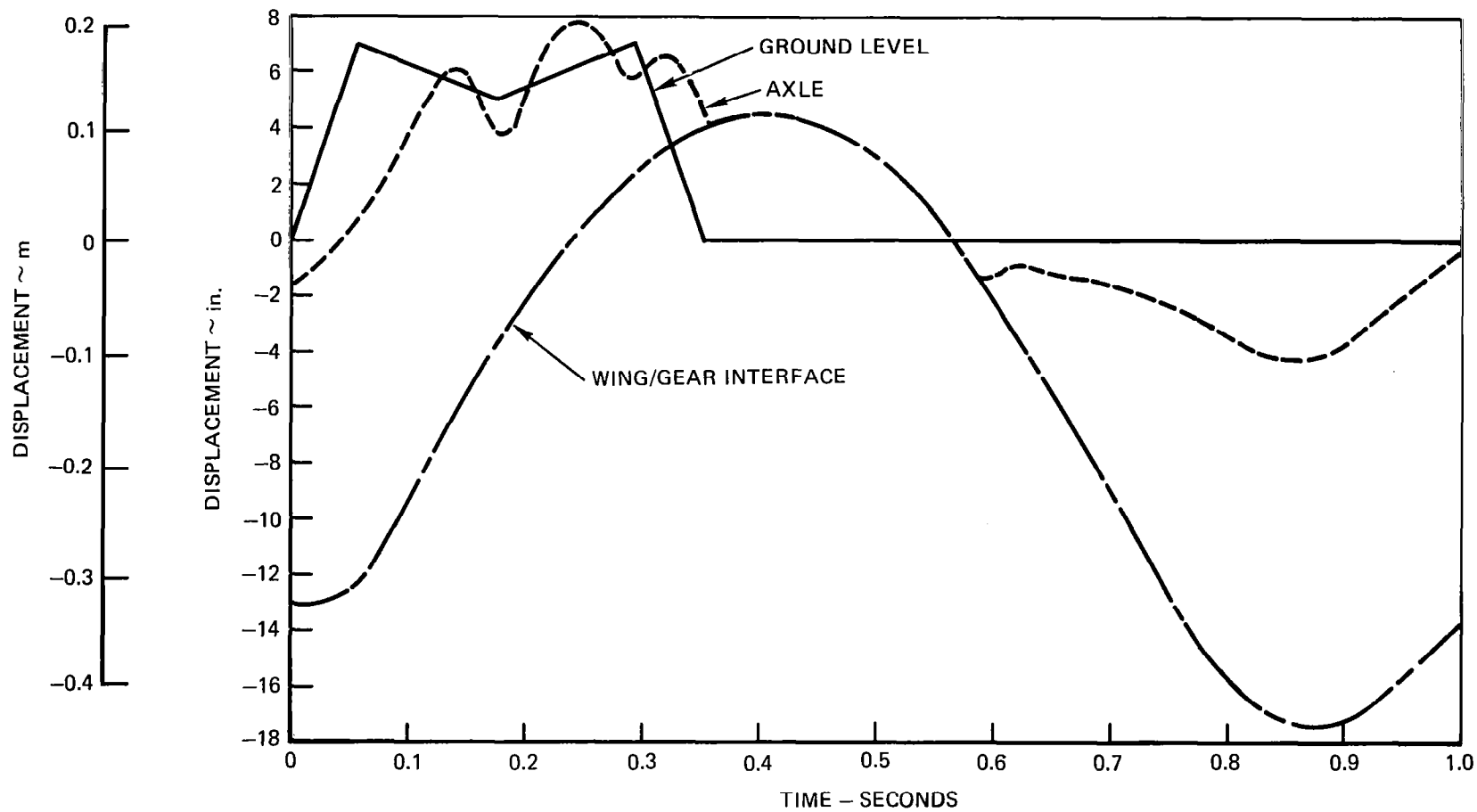


FIGURE 3-38 BOMB CRATER LANDING PASSIVE GEAR

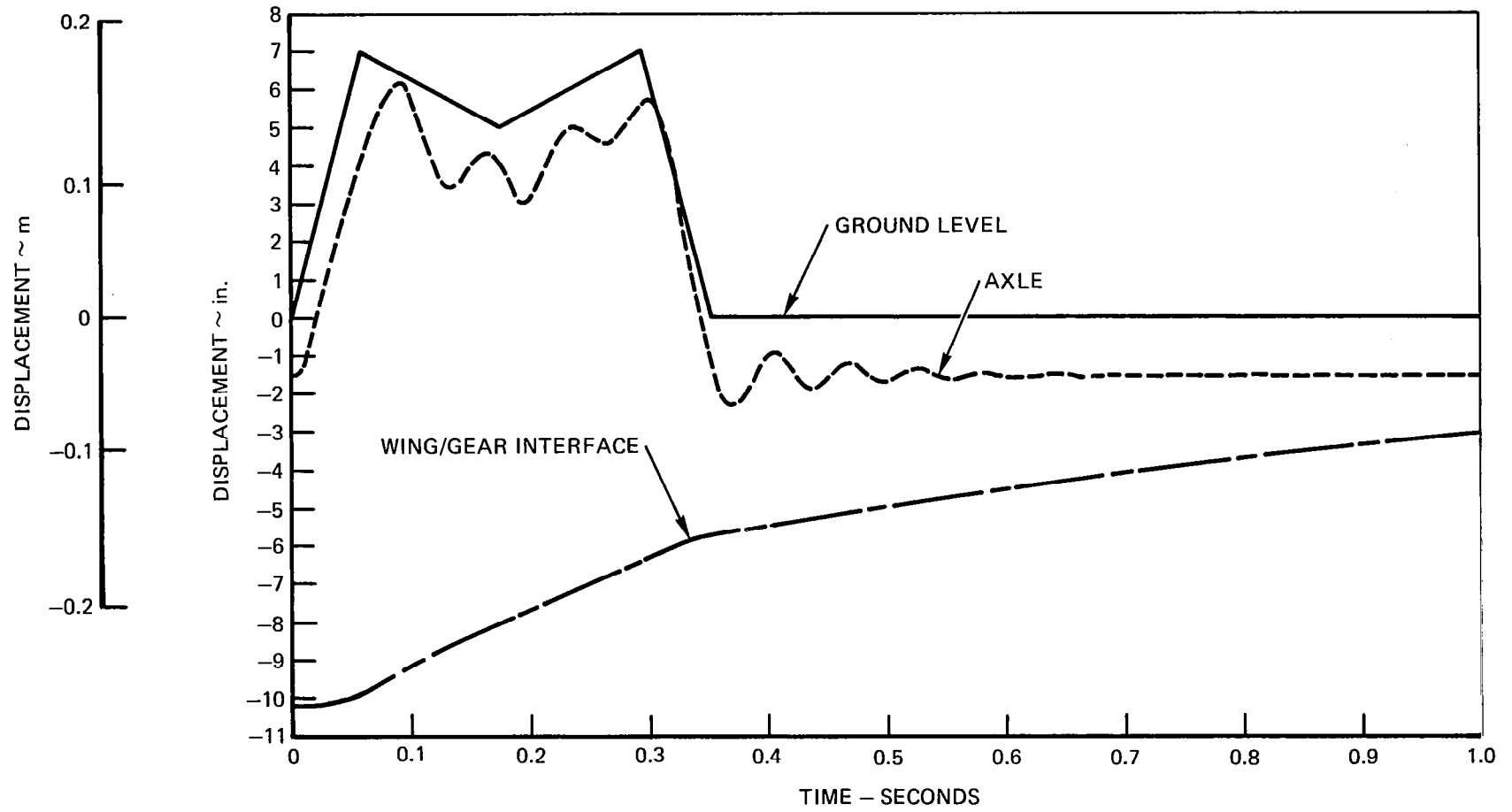


FIGURE 3-39 BOMB CRATER LANDING ACTIVE GEAR

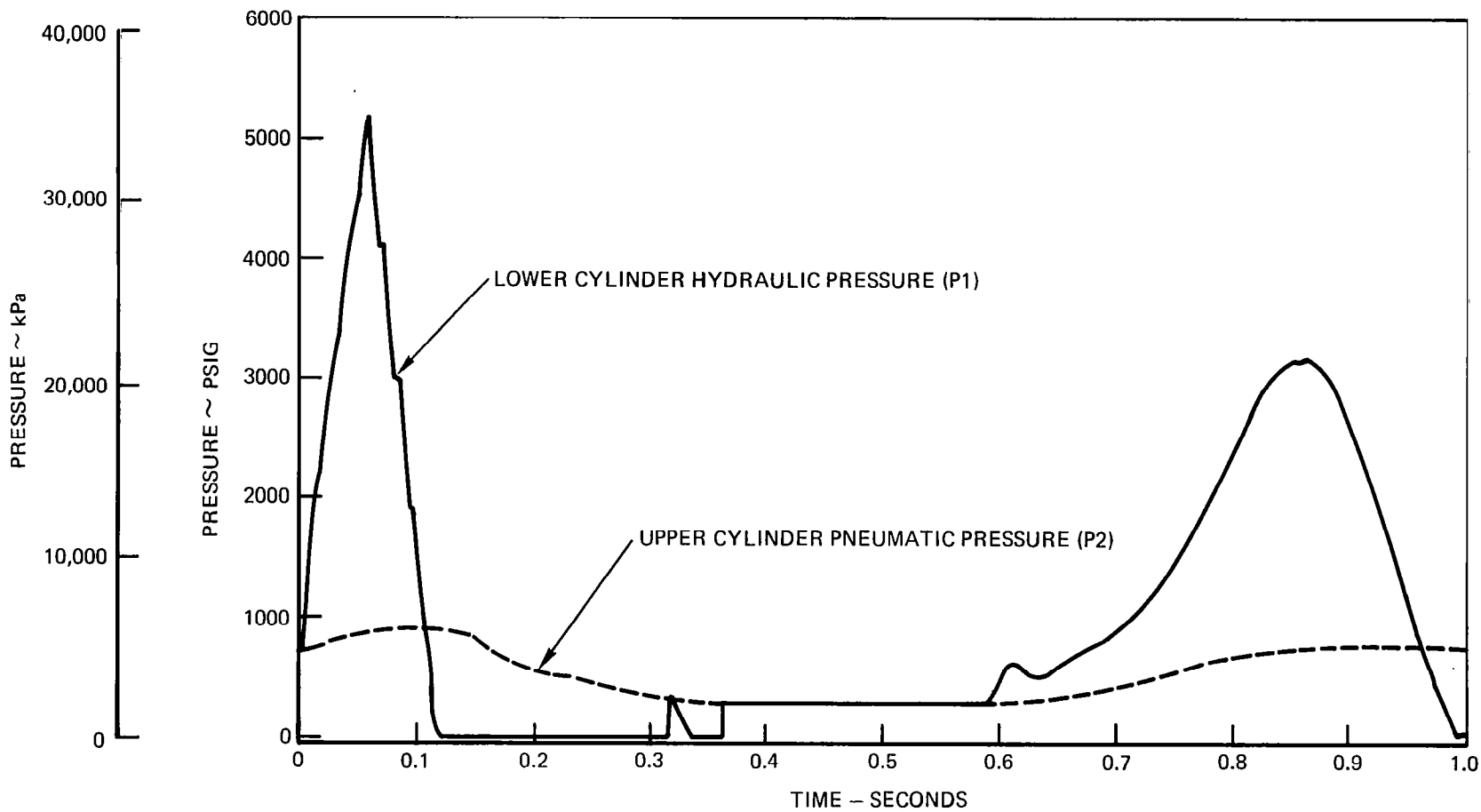


FIGURE 3-40 BOMB CRATER LANDING PASSIVE GEAR

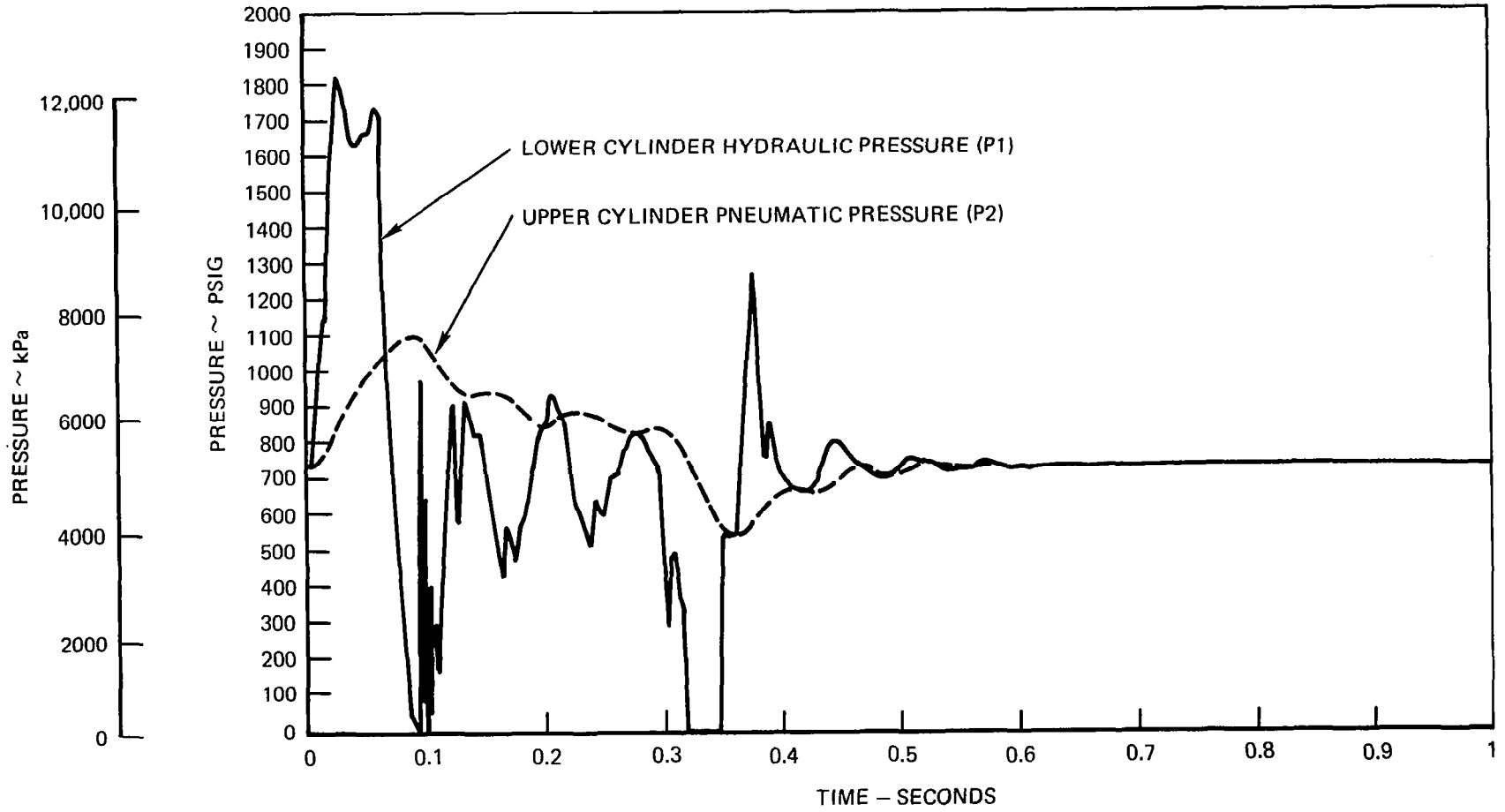


FIGURE 3-41 BOMB CRATER LANDING ACTIVE GEAR

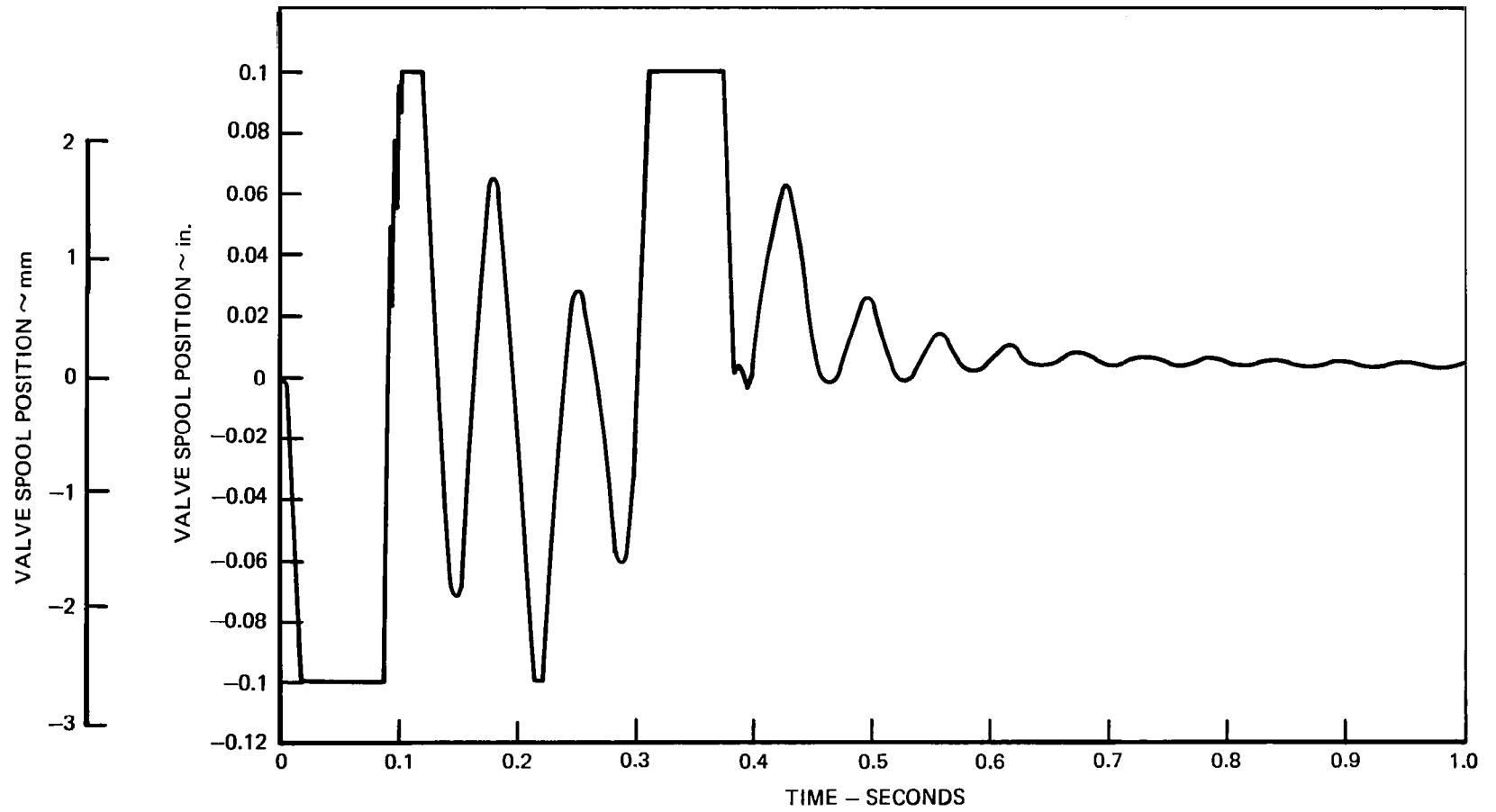


FIGURE 3-42 BOMB CRATER LANDING ACTIVE GEAR

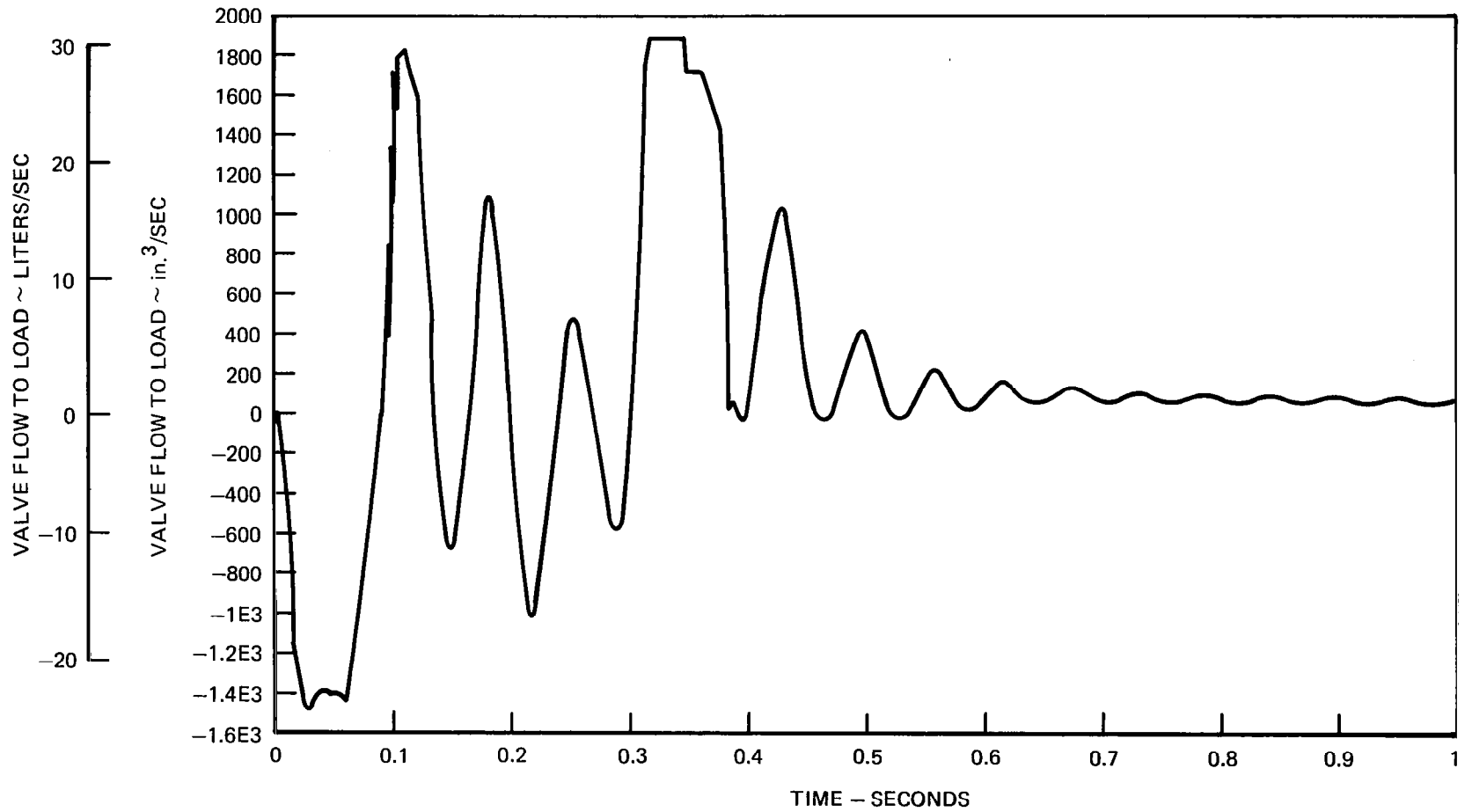
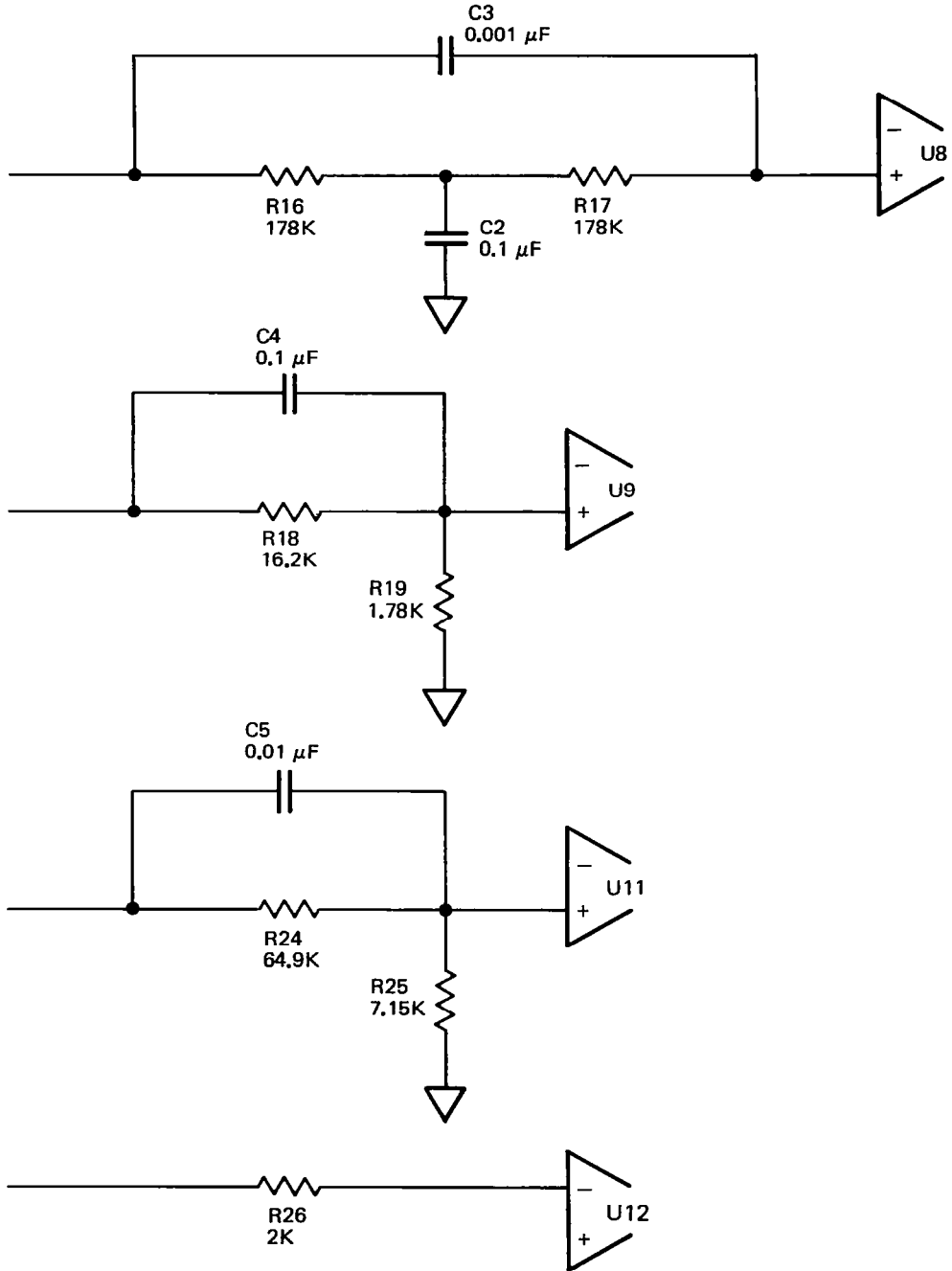


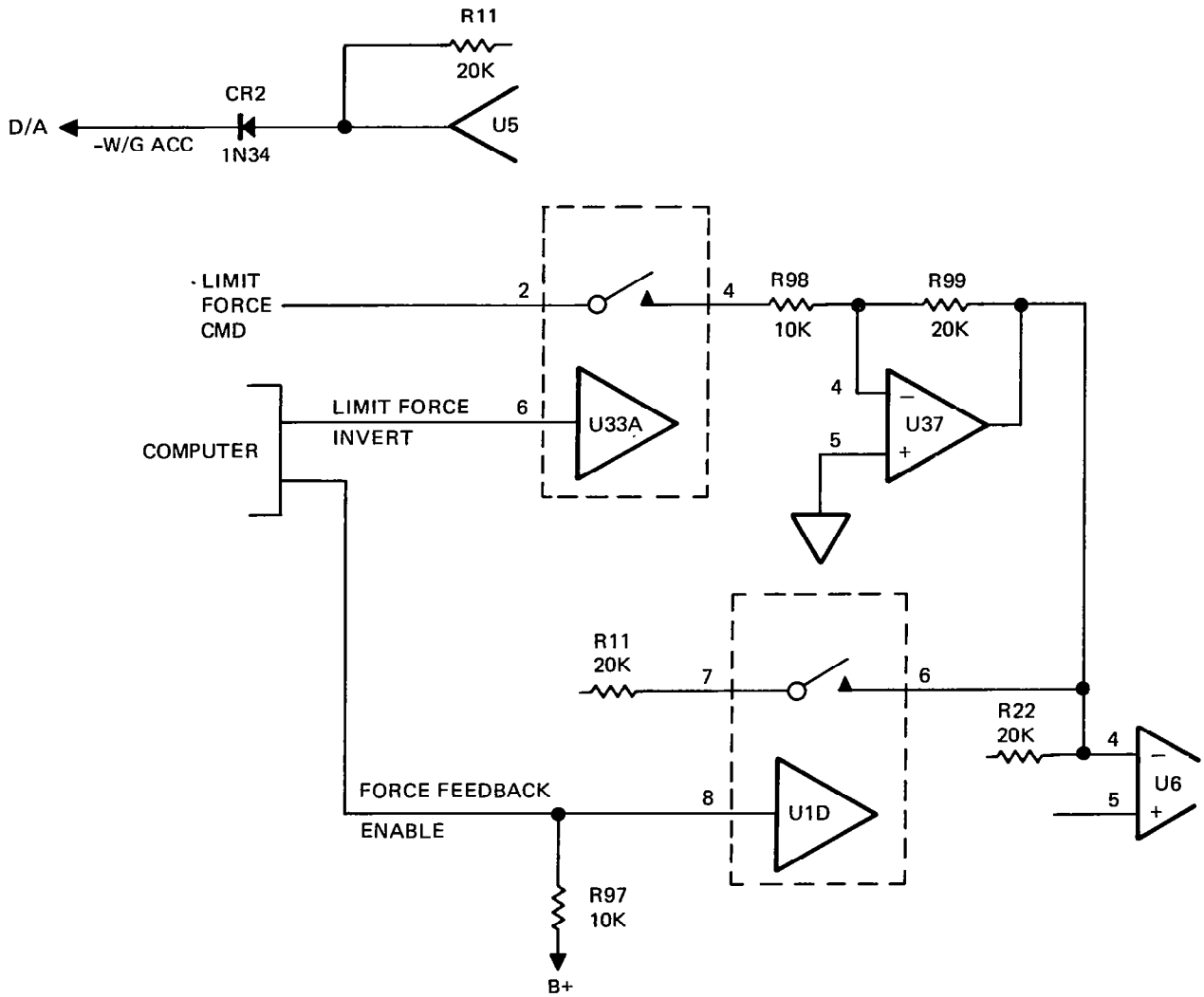
FIGURE 3-43 BOMB CRATER LANDING ACTIVE GEAR

4.0 HARDWARE

The analog electronic hardware is the same as that designed during the Reference 1 investigation (HR drawing 88000080-201) except for the following circuit changes:



The original hardware mechanization of Reference 1 did not include provisions for a force deadband. These provisions were subsequently added and consist of the following:



5.0 SOFTWARE

The digital software of the system described in Reference 1 was modified to be compatible with the F-4 landing gear. Changes were incorporated to reflect the new scaling which was necessitated by the new weight and strut stroke. The scaling is discussed in detail in Appendix A.

In addition, program changes made by NASA were incorporated, including a force deadband which is effective in the takeoff mode as well as the landing mode.

The software flow chart is shown in Figure 5-1 and the complete program is listed in Appendix B.

6.0 CONCLUSION

An analysis has been made on the active control landing gear concept applied to the F-4 aircraft. Servocontrol loops and signal shaping have been defined. The results of the analysis show that the active control landing gear can significantly reduce the loads transmitted to the aircraft for both landing impact cases and rollout over ground level perturbations. For the vertical drop landing impact cases analyzed, reductions in wing/gear interface force of 20 to 22 percent were achieved from the conventional passive gear case. For the case of rollout over a repaired bomb crater, a reduction of 74 percent was achieved.

7.0 RECOMMENDATIONS

Based on the conclusion of this report it is recommended that the study be continued by investigating the following areas:

1. The benefits of the ACLG vs. any penalties involved such as cost, weight, and the effect on aircraft structure and hydraulic systems.
2. The possibility that under extremely uneven landing conditions the gear could be depleted of fluid and the effect of such depletion.
3. Requirements for landing at higher sink rates, i.e., 3.05 m/sec (10 ft/sec).
4. The design of a flightworthy ACLG for the F-4 aircraft.
5. The application of the results of this analysis to other aircraft systems.

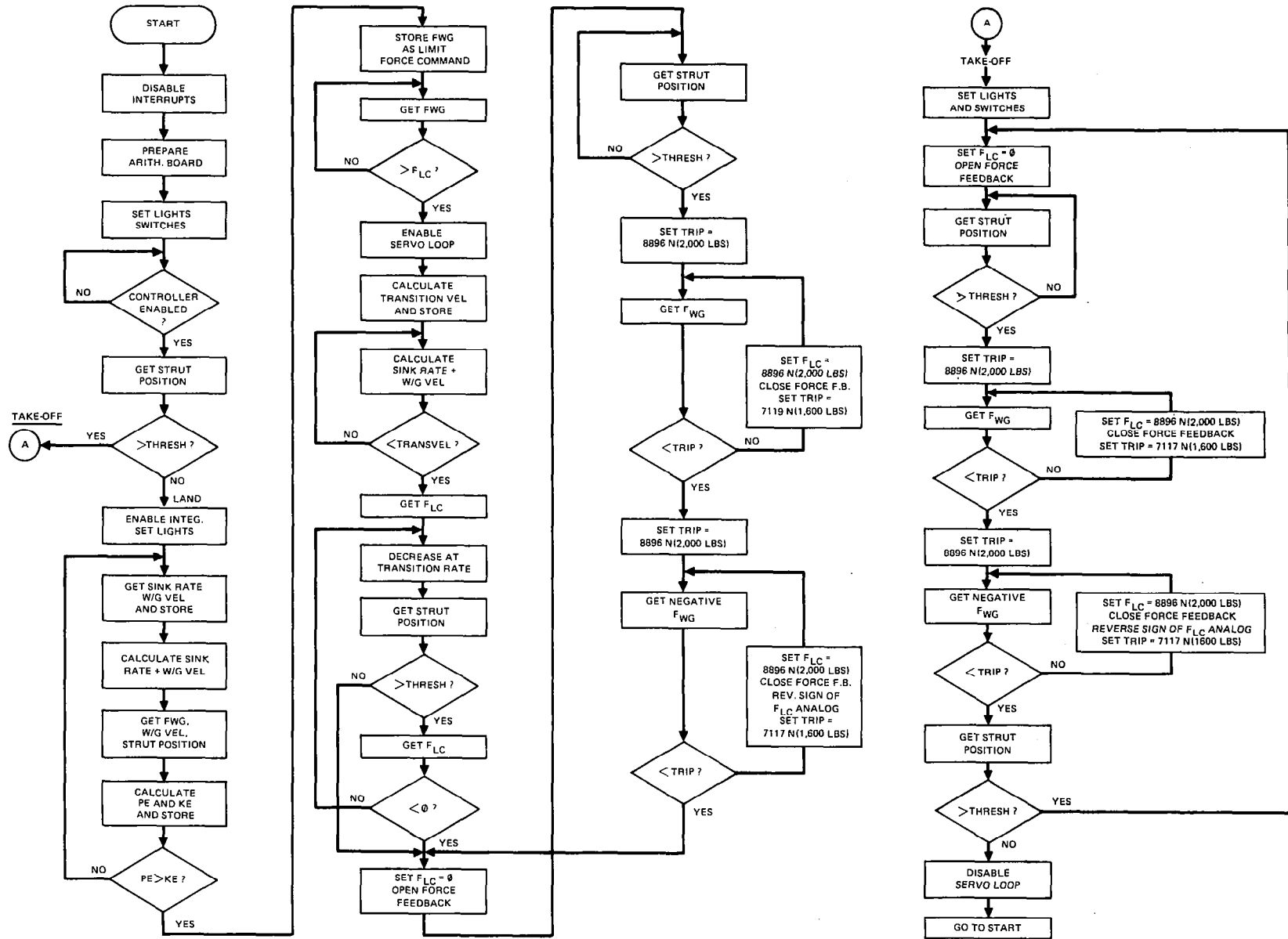


FIGURE 5-1 SOFTWARE FLOW CHART

APPENDIX A

DIGITAL SCALING

Since the stroke of the strut is 0.4034 m (15.88 in) it is anticipated that a (0.51m) potentiometer will be used to measure strut displacement.

It is further anticipated that the wing/gear interface accelerometer will be the same as that used in the system described in Reference 1.

Based on these assumptions the digital scaling is as follows:

(1) W/G acceleration:

The scale factor of the accelerometer is 2.85 v/g. The accelerometer signal is attenuated to 0.6316 of its value and then amplified by a factor of 6 in the analog circuitry to produce a scale factor of 10.8 v/g. Since 10 v = 4095 bits the digital acceleration scale factor is:

$$10.8 \times 409.5 = 4423 \text{ bits/g.}$$

Since the aircraft weight is:

$$8.184 \times 10^4 \text{ N (18,398 lb)}$$

the scale factor in terms of force is:

$$0.05404 \text{ bits/N (0.2404 bits/lb)}$$

(2) W/G Velocity:

As stated above, the accelerometer scale factor is 2.85 v/g

$$\text{or } \frac{2.85\text{v}}{9.807\text{m/sec}^2} \quad \text{or: } 0.2907 \text{ v/m/sec}^2 (0.00738 \text{ v/in/sec}^2)$$

In the analog circuitry this signal is amplified by a factor of

$$(0.6316)(21.47) = 13.56$$

and integrated to produce w/g velocity. The velocity scale factor is then:

$$(0.2907)(13.56) = 3.94 \text{ v/m/sec/ (0.1 v/in/sec).}$$

Digitally the scale factor is:

$$(3.94 \text{ v/m/sec})(409.5 \text{ bits/v}) = 1614 \text{ bits/m/sec (40.95 bits/in/sec).}$$

(3) Sink rate

The sink rate is scaled at

$$3.94 \text{ v/m/sec (0.1 v/in/sec)}$$

or digitally at

$$1614 \text{ bits/m/sec (40.95 bits/in/sec)}$$

to match the scaling of the w/g velocity signal.

(4) Strut displacement:

The strut potentiometer produces

$$10 \text{ v for } 0.508 \text{ m (20 in).}$$

Its scale factor is then

$$19.96 \text{ v/m. (0.5 v/in).}$$

The potentiometer signal is multiplied by 0.715 in the analog circuitry to produce a scale factor of:

$$19.96 (0.715) = 14.08 \text{ v/m (0.3575 v/in).}$$

Digitally the scale factor is

$$(14.08 \text{ v/m (409.5 } \frac{\text{bits}}{\text{v}})) = 5766 \text{ bits/m (146.4 bits/in).}$$

The maximum strut displacement is equivalent to:

$$(0.4034 \text{ m})(5766 \text{ bits/m}) = 2325 \text{ bits}$$

which is 0915 HEXADECIMAL (H).

(5) Work potential of the strut:

$$WP = F_{wg} (X_{max} - X_s) = \ddot{M}X_{wg} (X_{max} - X_s)$$

If $\ddot{X}_{wg} = 1 \text{ g}$ and $X_{max} - X_s = 0.0254 \text{ m (1 in)}$ then

$$\ddot{M}X_{wg} = 8.184 \times 10^4 \text{ N (18,398 lb.)}$$

$$WP \text{ is then } (8.184 \times 10^4 * 0.0254 = 2079 \text{ N-m (18,398 lbf ins)})$$

As pointed out in (1) and (4) above, 1 g is equivalent to:

10.8 v and 0.0254 m (1 in) is equivalent to 0.3575 v.

Digitally then,

$$WP = (10.8 \text{ v})(409.5 \frac{\text{bits}}{\text{v}})(0.3575 \text{ v})(409.5 \frac{\text{bits}}{\text{v}}) = 6.4745 \times 10^5 \text{ bits.}$$

The scale factor of WP is therefore:

$$\frac{6.4745 \times 10^5}{2079} = 3.114 \times 10^2 \text{ bits/N-m (35.19 bits/lbf.in)}$$

(6) Kinetic Energy:

$$KE = \frac{1}{2} W/g (V \text{ tot})^2 \text{ where } V \text{ tot} = V \text{ touchdown} + \int_0^{\tau} X \text{wgd}t$$

If $V_{\text{tot}} = 0.0254 \text{ m/sec (1 in/sec)}$ then

$$KE = \frac{1}{2} \frac{(8.184 \times 10^4 \text{ N})}{(9.807 \text{ m/sec}^2)} (0.0254 \text{ m/sec})^2 = 2.692 \text{ Nm (23.83 lb in)}$$

Digitally, from (2),

$$V_{\text{tot}} = (0.0254 \text{ m/sec})(3.94 \text{ v/m/sec})(409.5 \text{ bits/v}) = 40.95 \text{ bits.}$$

$$\text{Then } KE = (40.95)^2 = 1676.9 \text{ bits.}$$

Therefore the scale factor for KE is:

$$\frac{1676.9 \text{ bits}}{2.692 \text{ N-m}} = 622.9 \text{ bits/N-m} = (70.37 \text{ bits/lb in})$$

which is twice the scale factor of WP, from (5) above.

Therefore, to compare KE to WP it must be divided by 2. This is accomplished in the software by a right shift.

(7) Decrease of limit force command during transition:

10 v. corresponds to:

$$8.184 \times 10^4 \text{ N (18,398 lbs}_f\text{) of } F_{1I},$$

so that the scale factor of F_{1I} is:

$$8184 \text{ N/v (1840 lbs}_f\text{/v.)}$$

Digitally the scale factor is:

$$\frac{(8184 \text{ N/v})}{409.5 \text{ bits/v}} = 19.98 \frac{\text{N}}{\text{bit}} (4.49 \text{ lbf/bit}) = 0.05 \text{ bit/N} (0.22 \text{ bit/lbf})$$

During transition F_{1I} is decreased at a rate of

$$4.44810^5 \text{ N/sec} (10^5 \text{ lbf/sec})$$

or digitally at a rate of

$$2.226 \times 10^4 \text{ bits/sec.}$$

(8) Transition velocity (Vt):

$$Vt = \frac{F_{1I}^2}{2(W/g)R}$$

$W = 8.178 \times 10^4 \text{ N} (18,398 \text{ lb})$ and $R = 4.445 \times 10^5 (10^5 \text{ lb/sec})$

then:

$$Vt = \frac{F_{1I}^2}{2(8.178 \times 10^4/9.8)(4.445)10^5} = 1.348 \times 10^{-10} F_{1I}^2$$

Therefore:

4.445 N (1 lb) produces:

$$2.663 \times 10^{-9} \text{ m/sec} (1.049 \times 10^{-7} \text{ in/sec})$$

From (7) the digital scale factor of F_{1I} is $0.05 \frac{\text{bit}}{\text{N}}$

so that the digital signal produced is:

$$(4.445 \times 0.05)^2 = 0.0494 \text{ bits.}$$

The scale factor of Vt is therefore:

$$\frac{0.0494}{2.663 \times 10^{-9}} = 1.86 \times 10^7 \text{ bits/m/sec} (4.724 \times 10^5 \text{ bits/in/sec})$$

From (2) and (3) the scale factor for Vtot is:

$$1614 \text{ bits/m/sec (40.95 bits/in/sec)}$$

Therefore, in order to compare Vtot to Vt, Vt must be multiplied

$$\frac{1614}{1.885 \times 10^7} = 0.00008669$$

in the arithmetic board which is accomplished as follows:

0.0000869 DECIMAL (D)=

0.0000000000000101101011100110101010101101110000001 Binary (B)

which equals:

$$1.01101011100110101010110 \times 2^{-14}(\text{B})$$

The exponent is -14(D)

The bias in the arithmetic board is:

$$07\text{F HEXIDECIMAL (H) or } 127 \text{ (D)}$$

Therefore the number must be applied with a bias of

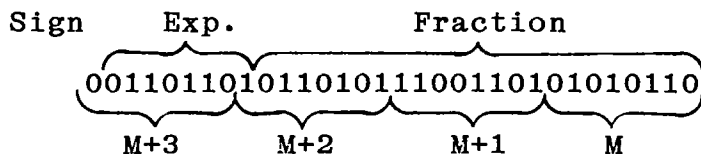
$$127 - 14 = 113 \text{ (D).}$$

In addition, a factor must be applied due to the fact that the numbers from the A/D converter are stored in the most significant 12 bits of the 16 so that the number for Vtot is too high by a factor of 16. Vt is a function of FLI^2 and is too high by a factor of $(16)^2$. The net result is that Vt is too high by a factor of 16. It must therefore be reduced by a factor of 16 or 2^4 .

Therefore the exponent of the applied number is:

$$113 - 4 = 109(\text{D}) = 6\text{D (H)} = 01101101 \text{ (B)}$$

A sign bit ("0" for positive) must precede the exponent. The format of the applied number is:



Therefore, if this is stored in memory starting at address M, the contents of memory are:

M	36(H)
M+1	B5(H)
M+2	CD(H)
M+3	56(H)

APPENDIX B

MICROPROCESSOR PROGRAM

The microprocessor program is listed in the following pages. It should be pointed out that for three-byte instructions, the listing of the last two bytes is in an order which is reversed from the order in which the bytes are stored in memory. This is a peculiarity of the assembler which was used.

ASSEMBLED AT 0000

MACRO-80 3.34 04-NOV-79 PAGE 1

```

00001 ;*****
00002 ; PROGRAM FOR AN ELECTROHYDRAULIC ACTIVE
00003 ; CONTROL AIRCRAFT LANDING GEAR
00004 ;*****
00005 ; NOTES:
00006 ; RAM LOCATION 3D0EH ADDED AS A TEMP LOC
00007 ; FOR FLIM 2/13/80
00008 ;*****
00009 ; REVISED FOR F4 GEAR 6/28/81
00010 ORG 00
00011 START: DI ;DISABLE INTERRUPTS
00012 LXI H,3FFFH ;INIT. STACK
00013 SPHL
00014 MVI A,82H ;INIT. MATH BOARD
00015 OUT 0EBH
00016 MVI A,00 ;SET MEM. BASE ADD.
00017 OUT 0A1H
00018 MVI A,80H
00019 OUT 0A2H
00020 LXI H,0092H ;STRUT THRESH.=1 IN.
00021 ;MULT THRESH BY 16
00022 CALL ANM ;FOR LATER USE
00023 SHLD 3F8AH ;LABLE BXTHR
00024 MVI A,4CH ;SET LIGHTS,SWITCHES
00025 OUT 0EAH
00026 ;*****
00027 ; OUTPUT MUXO-MUX4 FOR A/D BOARD CHECK
00028 ; ALSO LOOK FOR CONTROLLER ENABLED
00029 ;*****
00030 TL1: MVI D,3
00031 TL2: MVI B,0FFH
00032 MVI C,5
00033 TL3: MOV A,D
00034 CALL IN1
00035 SHLD 0F708H ;OUTPUT TO DAC0
00036 IN 0E9H ;CONTROLLER ENABLED?
00037 RAR
00038 JC L1 ;YES,JUMP TO L1
00039 DCR B
00040 JNZ TL3
00041 MVI B,0FFH
00042 DCR C
00043 JNZ TL3
00044 DCR D
00045 JM TL1
00046 JMP TL2

0000' F3
0001' 21 3FFF
0004' F9
0005' 3E 82
0007' D3 EB
0009' 3E 00
000B' D3 A1
000D' 3E 80
000F' D3 A2
0011' 21 0092

0014' CD 0289'
0017' 22 3F8A
001A' 3E 4C
001C' D3 EA

001E' 16 03
0020' 06 FF
0022' 0E 05
0024' 7A
0025' CD 0251'
0028' 22 F708
002B' DB E9
002D' 1F
002E' DA 0042'
0031' 05
0032' C2 0024'
0035' 06 FF
0037' 0D
0038' C2 0024'
003B' 15
003C' FA 001E'
003F' C3 0020'

```

```

00047 ;*****
00048 ; CONTROLLER HAS BEEN ENABLED
00049 ;*****
0042' 3E 02 00050 L1: MVI A,02
0044' CD 0251' 00051 CALL IN1 ;GET STRUT POS FOR LAND/TO. DEC.
0047' 2A 3F8A 00052 LHL 3F8AH ;GET STRUT THRESHOLD
004A' EB 00053 XCHG ;PUT IN DE
004B' 2A 3F86 00054 LHL 3F86H ;LOAD HL WITH STRUT POSITION
004E' CD 0282' 00055 CALL SUB2 ;CALC. THRESHOLD-STRUT
0051' DA 01BD' 00056 JC L12A ;YES, JUMP TO 12A
00057 ;*****
00058 ; LANDING - MAKE PREPARATIONS
00059 ;*****
0054' 3E 03 00060 MVI A,03
0056' CD 0251' 00061 CALL IN1 ;GET SINK RATE
0059' 22 3F88 00062 SHLD 3F88H ;STORE IT
005C' 21 0915 00063 LXI H,0915H ;MULT XMAX BY 16 TO SHIFT INTO
005F' CD 0289' 00064 CALL ANM ;UPPER 12 BITS
0062' 22 3F8C 00065 SHLD 3F8CH ;STORE IT
00066 ;*****
00067 ; ENABLE INTEGRATOR
00068 ; START ENERGY CALCULATIONS
00069 ;*****
0065' 3E 9E 00070 MVI A,9EH
0067' D3 EA 00071 OUT 0EAH ;ENABLE INTEGRATOR
0069' CD 0220' 00072 L8: CALL IN3
006C' EB 00073 XCHG
006D' 2A 3F8C 00074 LHL 3F8CH
0070' EB 00075 XCHG
0071' 7B 00076 MOV A,E
0072' 95 00077 SUB L
0073' 6F 00078 MOV L,A
0074' 7A 00079 MOV A,D
0075' 9C 00080 SBB H
0076' 67 00081 MOV H,A
0077' 22 8004 00082 SHLD 8004H
007A' AF 00083 XRA A
007B' CD 028E' 00084 CALL MATH
007E' 2A 8000 00085 LHL 8000H
0081' 22 3F8E 00086 SHLD 3F8EH
0084' 2A 8002 00087 LHL 8002H
0087' 22 3F90 00088 SHLD 3F90H
008A' 2A 3F88 00089 LHL 3F88H
008D' EB 00090 XCHG
008E' 2A 3F84 00091 LHL 3F84H
0091' CD 0282' 00092 CALL SUB2

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0094' 22 8000          00093          SHLD      8000H
0097' 22 8004          00094          SHLD      8004H
009A' AF              00095          XRA       A
009B' CD 028E'        00096          CALL      MATH
;*****
00097          ;*****
00098          ;          DIVIDE KE BY 2 THEN DO A BYTE BY BYTE COMPARE
00099          ;          TO TEST IF PE)KE. DON'T BOTHER TO TEST LSB-IT
00100          ;          CONTAINS NO USEFUL DATA
00101          ;*****
009E' B7              00102          ORA       A          ;CLEAR CARRY
009F' 06 03           00103          MVI      B,3        ;SET A BYTE COUNTER
00A1' 21 8003         00104          LXI      H,8003H    ;GET KINETIC ENERGY
00A4' 7E              00105          L8A:     MOV      A,M    ;SHIFT RIGHT 3 BYTES AND
00A5' 1F              00106          RAR                      ;RE-SAVE
00A6' 77              00107          MOV      M,A
00A7' 2B              00108          DCX      H
00A8' 05              00109          DCR      B
00A9' C2 00A4'        00110          JNZ      L8A
00AC' 06 03           00111          MVI      B,03
00AE' 21 3F91         00112          LXI      H,3F91H
00B1' 11 8003         00113          LXI      D,8003H
00B4' 1A              00114          L9:     LDAX     D
00B5' BE              00115          CMP      M
00B6' C2 00C2'        00116          JNZ      L10
00B9' 1B              00117          DCX      D
00BA' 2B              00118          DCX      H
00BB' 05              00119          DCR      B
00BC' C2 00B4'        00120          JNZ      L9
00BF' C3 00C5'        00121          JMP      L11
00C2' D2 0069'        00122          L10:    JNC      L8
;*****
00123          ;*****
00124          ;          TIME TO INITIATE ACTIVE CONTROL
00125          ;*****
00C5' 2A 3F80         00126          L11:    LHLD     3F80H
00C8' 22 F70A         00127          SHLD     0F70AH
00CB' 22 3D0E         00128          SHLD     3D0EH      ;SAVE ORIGINAL "FLIM"
00CE' EB              00129          XCHG                      ;FLIM TO DE FOR COMPARE
00CF' CD 0220'        00130          CHACEL: CALL     IN3      ;GET W/G ACCEL.
00D2' 2A 3F80         00131          LHLD     3F80H      ;PUT NEW ACCEL INTO HL
00D5' CD 0282'        00132          CALL     SUB2       ;DE-HL IS NEW W/G ACCEL.
;*****
00D8' F2 00CF'        00133          ;*****
00134          ;          NO-LOOP TILL IT IS
(O0DB-00E0) = 00 (NOP) 00135          ;          ;CALL     SPTH      ;HAS GEAR STARTED STROKE?
00E1' 3E 9F          00136          ;          ;JP       CHACEL    ;LOOP TILL GEAR ) THRESHOLD
00E3' D3 EA          00137          MVI      A,9FH
00138          00138          OUT     0EAH      ;ENABLE SERVOLOOP

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00139 ;*****
00140 ; GEAR IS NOW UNDER ACTIVE CONTROL
00141 ;*****
00E5' 2A 3DOE 00142 LHL 3DOEH ;GET ORIGINAL FLIM TO CALCULATE
00E8' 22 8000 00143 SHLD 8000H ;TRANSITION VELOCITY
00EB' 21 0000 00144 LXI H,0000
00EE' 22 8002 00145 SHLD 8002H
00F1' 3E 08 00146 MVI A,08
00F3' CD 028E' 00147 CALL MATH
00F6' 3E 06 00148 MVI A,06
00F8' CD 028E' 00149 CALL MATH
00FB' 3E 36 00150 MVI A,36H
00FD' 32 8004 00151 STA 8004H
0100' 3E B5 00152 MVI A,0B5H
0102' 32 8005 00153 STA 8005H
0105' 3E CD 00154 MVI A,0CDH
0107' 32 8006 00155 STA 8006H
010A' 3E 56 00156 MVI A,56H
010C' 32 8007 00157 STA 8007H
010F' 3E 02 00158 MVI A,02
0111' CD 028E' 00159 CALL MATH
0114' 2A 8000 00160 LHL 8000H
0117' 22 3F92 00161 SHLD 3F92H
011A' 2A 8002 00162 LHL 8002H
011D' 22 3F94 00163 SHLD 3F94H
00164 ;*****
00165 ; TRANSITION VELOCITY STORED AS FLOATING PT,32 BIT
00166 ; NUMBER. START COMPARING THIS AGAINST (SINK RATE
00167 ; -W/G VEL.) TO DETERMINE START OF TRANSITION
00168 ;*****
0120' 2A 3F88 00169 L4: LHL 3F88H
0123' EB 00170 XCHG
0124' 3E 00 00171 MVI A,00
0126' CD 0251' 00172 CALL IN1
0129' CD 0282' 00173 CALL SUB2
012C' 22 8000 00174 SHLD 8000H
012F' 21 0000 00175 LXI H,0000
0132' 22 8002 00176 SHLD 8002H
0135' 3E 08 00177 MVI A,08
0137' CD 028E' 00178 CALL MATH
013A' 2A 3F92 00179 LHL 3F92H
013D' 22 8004 00180 SHLD 8004H
0140' 2A 3F94 00181 LHL 3F94H
0143' 22 8006 00182 SHLD 8006H
0146' 3E 0A 00183 MVI A,0AH
0148' CD 028E' 00184 CALL MATH

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01B3' 3E 9D          00231 L14: MVI A,9DH
01B5' D3 EA          00232 OUT OEAH ;CLOSE FORCE FEEDBACK
01B7' 01 1800        00233 LXI B,1800H ;SET BC TO 1600 LBS
01BA' C3 017F'      00234 JMP L15
00235 ;*****
00236 ; TAKEOFF MODE
00237 ;*****
01BD' 21 0000        00238 L12A: LXI H,0000
01C0' 22 F70A        00239 SHLD OF70AH ;SET LIMIT FORCE CMD='0 LBS.
01C3' 3E A9          00240 MVI A,0A9H
01C5' D3 EA          00241 OUT OEAH ;ENABLE SERVOLOOP & OPEN F FDBK
01C7' CD 020E'      00242 FLOA: CALL SPTH ;CHECK STRUT POSITION
01CA' F2 01C7'      00243 JP FLOA
01CD' 01 1EE0        00244 LXI B,1EE0H ;SET BC TO 2000 LBS
01D0' CD 0220'      00245 L15A: CALL IN3
01D3' 2A 8000        00246 LHL D,8000H
01D6' 22 F708        00247 SHLD OF708H ;OUTPUT W/G ACCEL TO DACO
01D9' CD 027D'      00248 CALL FTEST
01DC' D2 01FE'      00249 JNC L13A
01DF' 01 1EE0        00250 LXI B,1EE0H ;SET BC TO 2000 LBS
01E2' CD 0266'      00251 L16A: CALL IN4
01E5' 22 F708        00252 SHLD OF708H ;OUTPUT W/G ACCEL TO DACO
01E8' CD 027D'      00253 CALL FTEST
01EB' DA 01BD'      00254 JC L12A
01EE' 21 1EE0        00255 LXI H,1EE0H ;SET HL TO 2000 LBS
01F1' 3E A5          00256 MVI A,0A5H ;CLOSE F FDBK & REVERSE SIGN
01F3' D3 EA          00257 OUT OEAH ;OF LIMIT FORCE CMD (ANALOG)
01F5' 22 F70A        00258 SHLD OF70AH ;SET LIMIT FORCE CMD=2000 LBS
01F8' 01 1800        00259 LXI B,1800H ;SET BC TO 1600 LBS
01FB' C3 01E2'      00260 JMP L16A
01FE' 21 1EE0        00261 L13A: LXI H,1EE0H ;SET HL TO 2000 LBS
0201' 22 F70A        00262 SHLD OF70AH ;SET LIMIT FORCE CMD=2000 LBS
0204' 3E AD          00263 L14A: MVI A,0ADH
0206' D3 EA          00264 OUT OEAH ;CLOSE FORCE FEEDBACK
0208' 01 1800        00265 LXI B,1800H ;SET BC TO 1600 LBS
020B' C3 01D0'      00266 JMP L15A
00267 ;*****
00268 ; ROUTINE TO SUBTRACT STRUT POS'N FROM THRESHOLD
00269 ;*****
020E' E5            00270 SPTH: PUSH H ;SPTH SETS SIGN FLAG POSITIVE
020F' D5            00271 PUSH D ;UNTIL STRUT POS'N ) THRESHOLD
0210' CD 024F'      00272 CALL STP ;GET STRUT POSITION
0213' 21 0B20        00273 LXI H,0B20H ;THRESHOLD 0160H=.05"
00274 ; ; 02D0H=.1"
00275 ; ; 0590H=.2"
00276 ; ; 0B20H=.4"

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014B' DB A1 00185 IN OAIH
014D' E6 20 00186 ANI 20H
014F' CA 0120' 00187 JZ L4
00188 ;*****
00189 ; TRANSITION PHASE
00190 ;*****
0152' 2A 3DOE 00191 LHL D 3DOEH ;FLIM
0155' 11 FFFE 00192 LXI D,OFFFEH
0158' 22 F70A 00193 L5: SHLD OF70AH
015B' 19 00194 DAD D
015C' CD 020E' 00195 EXST: CALL SPFH ;CHECK (THRESH.-STRUT POS'N)
015F' F2 016C' 00196 JP L12
0162' 01 1BDO 00197 LXI B,1BDOH
0165' 7D 00198 MOV A,L
0166' 91 00199 SUB C
0167' 7C 00200 MOV A,H
0168' 98 00201 SBB B
0169' D2 0158' 00202 JNC L5
00203 ;*****
00204 ; ROLLOUT PHASE
00205 ;*****
016C' 21 0000 00206 L12: LXI H,0000
016F' 22 F70A 00207 SHLD OF70AH ;SET FLC=0 LBS.
0172' 3E 99 00208 MVI A,99H
0174' D3 EA 00209 OUT OEAH ;OPEN FORCE FEEDBACK
0176' CD 020E' 00210 FLO: CALL SPFH ;CHECK STRUT POS'N.
0179' F2 0176' 00211 JP FLO
017C' 01 1EEO 00212 LXI B,1EEOH ;SET BC TO 2000 LBS.
017F' CD 0220' 00213 L15: CALL IN3
0182' 2A 8000 00214 LHL 8000H
0185' 22 F708 00215 SHLD OF708H ;OUTPUT W/G ACCEL. TO DACO
0188' CD 027D' 00216 CALL FTEST
018B' D2 01AD' 00217 JNC L13
018E' 01 1EEO 00218 LXI B,1EEOH ;SET BC TO 2000 LBS.
0191' CD 0266' 00219 L16: CALL IN4
0194' 22 F708 00220 SHLD OF708H ;OUTPUT W/G ACCEL TO DACO
0197' CD 027D' 00221 CALL FTEST
019A' DA 016C' 00222 JC L12
019D' 21 1EEO 00223 LXI H,1EEOH ;SET HL TO 2000 LBS.
01A0' 3E 95 00224 MVI A,95H ;CLOSE F FDBK & REV. SIGN
01A2' D3 EA 00225 OUT OEAH ;OF LIMIT FORCE CMD (ANALOG)
01A4' 22 F70A 00226 SHLD OF70AH ;SET LIMIT FORCE CMD=2000 LBS
01A7' 01 1800 00227 LXI B,1800H ;SET BC TO 1800 LBS
01AA' C3 0191' 00228 JMP L16
01AD' 21 1EEO 00229 L13: LXI H,1EEOH ;SET HL TO 2000 LBS
01B0' 22 F70A 00230 SHLD OF70AH ;SET LIMIT FORCE CMD=2000 LBS

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0216' EB 00277 XCHG
0217' 2A 3F86 00278 LHL 3F86H ;GET STRUT POSITION
021A' CD 0282' 00279 CALL SUB2 ;SUBTRACT STRUT FROM THRESH.
021D' D1 00280 POP D
021E' E1 00281 POP H
021F' C9 00282 RET
00283 ;*****
00284 ; ROUTINE TO INPUT AND STORE DATA FROM MUX0,1 & 2
00285 ;*****
0220' 3E 01 00286 IN3: MVI A,01
0222' 21 F701 00287 LXI H,OF701H
0225' 77 00288 MOV M,A
0226' 2B 00289 DCX H
0227' 36 01 00290 MVI M,01
0229' 7E 00291 M1: MOV A,M
022A' 07 00292 RLC
022B' D2 0229' 00293 JNC M1
022E' 36 00 00294 MVI M,00
0230' 2A F704 00295 LHL OF704H
0233' 22 8000 00296 SHLD 8000H
0236' 22 3F80 00297 SHLD 3F80H
0239' 3E 00 00298 MVI A,00
023B' 21 F701 00299 LXI H,OF701H
023E' 77 00300 MOV M,A
023F' 2B 00301 DCX H
0240' 36 01 00302 MVI M,01
0242' 7E 00303 M2: MOV A,M
0243' 07 00304 RLC
0244' D2 0242' 00305 JNC M2
0247' 36 00 00306 MVI M,00
0249' 2A F704 00307 LHL OF704H
024C' 22 3F84 00308 SHLD 3F84H
024F' 3E 02 00309 STP: MVI A,02
0251' 21 F701 00310 IN1: LXI H,OF701H
0254' 77 00311 MOV M,A
0255' 2B 00312 DCX H
0256' 36 01 00313 MVI M,01
0258' 7E 00314 M3: MOV A,M
0259' 07 00315 RLC
025A' D2 0258' 00316 JNC M3
025D' 36 00 00317 MVI M,00
025F' 2A F704 00318 LHL OF704H
0262' 22 3F86 00319 SHLD 3F86H
0265' C9 00320 RET
00321 ;*****
00322 ; ROUTINE TO INPUT AND STORE DATA FROM MUX4

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0266' 3E 04          00323 ;*****
0268' 21 F701       00324 IN4:  MVI    A,04
026B' 77            00325         LXI    H,0F701H
026C' 2B            00326         MOV    M,A
026D' 36 01         00327         DCX    H
026F' 7E            00328 M4:   MVI    M,01
0270' 07            00329         MOV    A,M
0271' D2 026F'     00330         RLC
0274' 36 00         00331         JNC    M4
0276' 2A F704       00332         MVI    M,00
0279' 22 3F96       00333         LHLD  0F704H
027C' C9            00334         SHLD  3F96H
                    00335         RET
                    00336 ;*****
                    00337 ;   ROUTINE TO SUBTRACT BC FROM HL
                    00338 ;*****
027D' 7D            00339 FTEST: MOV    A,L
027E' 91            00340         SUB    C
027F' 7C            00341         MOV    A,H
0280' 98            00342         SBB    B
0281' C9            00343         RET
                    00344 ;*****
                    00345 ;   ROUTINE FOR DOUBLE PRECISION SUBTRACT
                    00346 ;   HL=DE-HL
                    00347 ;*****
0282' 7B            00348 SUB2:  MOV    A,E
0283' 95            00349         SUB    L
0284' 6F            00350         MOV    L,A
0285' 7A            00351         MOV    A,D
0286' 9C            00352         SBB    H
0287' 67            00353         MOV    H,A
0288' C9            00354         RET
                    00355 ;*****
                    00356 ;   ROUTINE TO SHIFT VALUE IN HL LEFT 4 PLACES
                    00357 ;*****
0289' 29            00358 ANM:   DAD    H
028A' 29            00359         DAD    H
028B' 29            00360         DAD    H
028C' 29            00361         DAD    H
028D' C9            00362         RET
                    00363 ;*****
                    00364 ;   ROUTINE TO ACTIVATE MATH BOARD & WAIT FOR RESULT
                    00365 ;   ACCUMULATOR HAS OPCODE
                    00366 ;*****
028E' D3 A0         00367 MATH:  OUT    OAOH
0290' DB A7         00368 WAIT:  IN     OA7H

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0292' E6 01          00369      ANI      01
0294' C2 0290'      00370      JNZ      WAIT
0297' C9            00371      RET
00372 ;*****
00373 ;*****
00374 ; THE FOLLOWING ARE SPECIAL CHECK-OUT ROUTINES
00375 ; AND NOT PART OF THE MAIN PROGRAM
00376 ;*****
00377 ;*****
00378 ;
00379 ;
00380 ;*****
00381 ; ROUTINE TO INPUT A VALUE FROM A/D & STORE IN RAM
00382 ;*****
0298' F3            00383      DI
0299' 3E 00         00384      MVI      A,00
029B' CD 0251'      00385      CALL     IN1
029E' CF            00386      RST      01H
029F' 00            00387      NOP
02A0' 00            00388      NOP
00389 ;*****
00390 ; ROUTINE TO DO PGA TEST ON A/D
00391 ;*****
02A1' F3            00392      DI
02A2' 21 F701       00393      LXI      H,0F701H
02A5' 36 00         00394      MVI      M,00
02A7' 36 C0         00395      MVI      M,0COH
02A9' C3 02A5'      00396      JMP      PGA
02AC' 00            00397      NOP
00398 ;*****
00399 ; ROUTINE TO OUTPUT A VALUE TO DAC0 & DAC1
00400 ;*****
02AD' F3            00401      DI
02AE' 00            00402      NOP
02AF' 21 0000       00403      LXI      R2,0000
02B2' 22 F708       00404      SHLD     0F708H
02B5' 22 F70A       00405      SHLD     0F70AH
02B8' 00            00406      NOP
02B9' 00            00407      NOP
02BA' 00            00408      NOP
02BB' C3 02AF'      00409      JMP      R2
00410      END

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MACROS:

SYMBOLS:

ANM	0289'	CHACEL	00CF'	EXST	015C'	FLO	0176'
FLOA	01C7'	FTEST	027D'	IN1	0251'	IN3	0220'
IN4	0266'	L1	0042'	L10	00C2'	L11	00C5'
L12	016C'	L12A	01BD'	L13	01AD'	L13A	01FE'
L14	01B3'	L14A	0204'	L15	017F'	L15A	01D0'
L16	0191'	L16A	01E2'	L4	0120'	L5	0158'
L8	0069'	L8A	00A4'	L9	00B4'	M1	0229'
M2	0242'	M3	0258'	M4	026F'	MATH	028E'
PGA	02A5'	R2	02AF'	SPTH	020E'	START	0000'
STP	024F'	SUB2	0282'	TL1	001E'	TL2	0020'
TL3	0024'	WAIT	0290'				

NO FATAL ERROR(S)

ASSEMBLED AT 3D10

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00001 ;*****
00002 ; PROGRAM FOR AN ELECTROHYDRAULIC ACTIVE
00003 ; CONTROL AIRCRAFT LANDING GEAR
00004 ;*****
00005 ; NOTES:
00006 ; RAM LOCATION 3DOEH ADDED AS A TEMP LOC
00007 ; FOR FLIM 2/13/80
00008 ;*****
00009 ; REVISED FOR F4 GEAR 6/28/81
00010 ORG 3D10H
3D10' F3 00011 START: DI ;DISABLE INTERRUPTS
3D11' 21 3FFF 00012 LXI H,3FFFH ;INIT. STACK
3D14' F9 00013 SPHL
3D15' 3E 82 00014 MVI A,82H ;INIT. MATH BOARD
3D17' D3 EB 00015 OUT OEBH
3D19' 3E 00 00016 MVI A,00 ;SET MEM. BASE ADD.
3D1B' D3 A1 00017 OUT OA1H
3D1D' 3E 80 00018 MVI A,80H
3D1F' D3 A2 00019 OUT OA2H
3D21' 21 0092 00020 LXI H,0092H ;STRUT THRESH.=1 IN.
00021 ;MULT THRESH BY 16
3D24' CD 3F99' 00022 CALL ANM ;FOR LATER USE
3D27' 22 3F8A 00023 SHLD 3F8AH ;LABLE BXTHR
3D2A' 3E 4C 00024 MVI A,4CH ;SET LIGHTS,SWITCHES
3D2C' D3 EA 00025 OUT OEAH
00026 ;*****
00027 ; OUTPUT MUXO-MUX4 FOR A/D BOARD CHECK
00028 ; ALSO LOOK FOR CONTROLLER ENABLED
00029 ;*****
3D2E' 16 03 00030 TL1: MVI D,3
3D30' 06 FF 00031 TL2: MVI B,0FFH
3D32' 0E 05 00032 MVI C,5
3D34' 7A 00033 TL3: MOV A,D
3D35' CD 3F61' 00034 CALL IN1
3D38' 22 F708 00035 SHLD 0F708H ;OUTPUT TO DACO
3D3B' DB E9 00036 IN OE9H ;CONTROLLER ENABLED?
3D3D' 1F 00037 RAR
3D3E' DA 3D52' 00038 JC L1 ;YES,JUMP TO L1
3D41' 05 00039 DCR B
3D42' C2 3D34' 00040 JNZ TL3
3D45' 06 FF 00041 MVI B,0FFH
3D47' 0D 00042 DCR C
3D48' C2 3D34' 00043 JNZ TL3
3D4B' 15 00044 DCR D
3D4C' FA 3D2E' 00045 JM TL1
3D4F' C3 3D30' 00046 JMP TL2
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00047 ;*****
00048 ; CONTROLLER HAS BEEN ENABLED
00049 ;*****
3D52' 3E 02 00050 L1: MVI A,02
3D54' CD 3F61' 00051 CALL IN1 ;GET STRUT POS FOR LAND/TO. DEC.
3D57' 2A 3F8A 00052 LHL D 3F8AH ;GET STRUT THRESHOLD
3D5A' EB 00053 XCHG ;PUT IN DE
3D5B' 2A 3F86 00054 LHL D 3F86H ;LOAD HL WITH STRUT POSITION
3D5E' CD 3F92' 00055 CALL SUB2 ;CALC. THRESHOLD-STRUT
3D61' DA 3ECD' 00056 JC L12A ;YES, JUMP TO 12A
00057 ;*****
00058 ; LANDING - MAKE PREPARATIONS
00059 ;*****
3D64' 3E 03 00060 MVI A,03
3D66' CD 3F61' 00061 CALL IN1 ;GET SINK RATE
3D69' 22 3F88 00062 SHLD 3F88H ;STORE IT
3D6C' 21 0915 00063 LXI H,0915H ;MULT XMAX BY 16 TO SHIFT INTO
3D6F' CD 3F99' 00064 CALL ANM ;UPPER 12 BITS
3D72' 22 3F8C 00065 SHLD 3F8CH ;STORE IT
00066 ;*****
00067 ; ENABLE INTEGRATOR
00068 ; START ENERGY CALCULATIONS
00069 ;*****
3D75' 3E 9E 00070 MVI A,9EH
3D77' D3 EA 00071 OUT OEAH ;ENABLE INTEGRATOR
3D79' CD 3F30' 00072 L8: CALL IN3
3D7C' EB 00073 XCHG
3D7D' 2A 3F8C 00074 LHL D 3F8CH
3D80' EB 00075 XCHG
3D81' 7B 00076 MOV A,E
3D82' 95 00077 SUB L
3D83' 6F 00078 MOV L,A
3D84' 7A 00079 MOV A,D
3D85' 9C 00080 SBB H
3D86' 67 00081 MOV H,A
3D87' 22 8004 00082 SHLD 8004H
3D8A' AF 00083 XRA A
3D8B' CD 3F9E' 00084 CALL MATH
3D8E' 2A 8000 00085 LHL D 8000H
3D91' 22 3F8E 00086 SHLD 3F8EH
3D94' 2A 8002 00087 LHL D 8002H
3D97' 22 3F90 00088 SHLD 3F90H
3D9A' 2A 3F88 00089 LHL D 3F88H
3D9D' EB 00090 XCHG
3D9E' 2A 3F84 00091 LHL D 3F84H
3DA1' CD 3F92' 00092 CALL SUB2

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3DA4' 22 8000      00093      SHLD      8000H
3DA7' 22 8004      00094      SHLD      8004H
3DAA' AF          00095      XRA       A
3DAB' CD 3F9E'    00096      CALL      MATH
00097      ;*****
00098      ; DIVIDE KE BY 2 THEN DO A BYTE BY BYTE COMPARE
00099      ; TO TEST IF PE)KE. DON'T BOTHER TO TEST LSB-IT
00100      ; CONTAINS NO USEFUL DATA
00101      ;*****
3DAE' B7          00102      ORA       A      ;CLEAR CARRY
3DAF' 06 03       00103      MVI      B,3     ;SET A BYTE COUNTER
3DB1' 21 8003     00104      LXI      H,8003H ;GET KINETIC ENERGY
3DB4' 7E         00105      L8A:     MOV      A,M     ;SHIFT RIGHT 3 BYTES AND
3DB5' 1F         00106      RAR                      ;RE-SAVE
3DB6' 77         00107      MOV      M,A
3DB7' 2B         00108      DCX      H
3DB8' 05         00109      DCR      B
3DB9' C2 3DB4'   00110      JNZ      L8A
3DBC' 06 03       00111      MVI      B,03
3DBE' 21 3F91     00112      LXI      H,3F91H
3DC1' 11 8003     00113      LXI      D,8003H
3DC4' 1A         00114      L9:      LDAX   D
3DC5' BE         00115      CMP      M
3DC6' C2 3DD2'   00116      JNZ      L10
3DC9' 1B         00117      DCX      D
3DCA' 2B         00118      DCX      H
3DCB' 05         00119      DCR      B
3DCC' C2 3DC4'   00120      JNZ      L9
3DCF' C3 3DD5'   00121      JMP      L11
3DD2' D2 3D79'   00122      L10:     JNC      L8
00123      ;*****
00124      ; TIME TO INITIATE ACTIVE CONTROL
00125      ;*****
3DD5' 2A 3F80     00126      L11:     LHLD   3F80H
3DD8' 22 F70A     00127      SHLD   0F70AH
3DDB' 22 3D0E     00128      SHLD   3D0EH      ;SAVE ORIGINAL "FLIM"
3DDE' EB         00129      XCHG                      ;FLIM TO DE FOR COMPARE
3DDF' CD 3F30'   00130      CHACEL: CALL  IN3      ;GET W/G ACCEL.
3DE2' 2A 3F80     00131      LHLD   3F80H      ;PUT NEW ACCEL INTO HL
3DE5' CD 3F92'   00132      CALL  SUB2      ;DE-HL IS NEW W/G ACCEL.
00133                      ;GREATER THAN FLIM?
3DE8' F2 3DDF'   00134      JP     CHACEL    ;NO-LOOP TILL IT IS
(3DEB-3DF0) = 00 (NOP) 00135      ;CALL  SPTH      ;HAS GEAR STARTED STROKE?
00136                      ;JP     CHACEL    ;LOOP TILL GEAR ) THRESHOLD
3DF1' 3E 0F       00137      MVI   A,0FH
3DF3' D3 EA       00138      OUT  0EAH      ;ENABLE SERVULOOP
    
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00139 ;*****
00140 ; GEAR IS NOW UNDER ACTIVE CONTROL
00141 ;*****
3DF5' 2A 3D0E 00142 LHLD 3D0EH ;GET ORIGINAL FLIM TO CALCULATE
3DF8' 22 8000 00143 SHLD 8000H ;TRANSITION VELOCITY
3DFB' 21 0000 00144 LXI H,0000
3DFE' 22 8002 00145 SHLD 8002H
3E01' 3E 08 00146 MVI A,08
3E03' CD 3F9E' 00147 CALL MATH
3E06' 3E 06 00148 MVI A,06
3E08' CD 3F9E' 00149 CALL MATH
3E0B' 3E 36 00150 MVI A,36H
3E0D' 32 8004 00151 STA 8004H
3E10' 3E B5 00152 MVI A,0B5H
3E12' 32 8005 00153 STA 8005H
3E15' 3E CD 00154 MVI A,0CDH
3E17' 32 8006 00155 STA 8006H
3E1A' 3E 56 00156 MVI A,56H
3E1C' 32 8007 00157 STA 8007H
3E1F' 3E 02 00158 MVI A,02
3E21' CD 3F9E' 00159 CALL MATH
3E24' 2A 8000 00160 LHLD 8000H
3E27' 22 3F92 00161 SHLD 3F92H
3E2A' 2A 8002 00162 LHLD 8002H
3E2D' 22 3F94 00163 SHLD 3F94H
00164 ;*****
00165 ; TRANSITION VELOCITY STORED AS FLOATING PT,32 BIT
00166 ; NUMBER. START COMPARING THIS AGAINST (SINK RATE
00167 ; -W/G VEL.) TO DETERMINE START OF TRANSITION
00168 ;*****
3E30' 2A 3F88 00169 L4: LHLD 3F88H
3E33' EB 00170 XCHG
3E34' 3E 00 00171 MVI A,00
3E36' CD 3F61' 00172 CALL IN1
3E39' CD 3F92' 00173 CALL SUB2
3E3C' 22 8000 00174 SHLD 8000H
3E3F' 21 0000 00175 LXI H,0000
3E42' 22 8002 00176 SHLD 8002H
3E45' 3E 08 00177 MVI A,08
3E47' CD 3F9E' 00178 CALL MATH
3E4A' 2A 3F92 00179 LHLD 3F92H
3E4D' 22 8004 00180 SHLD 8004H
3E50' 2A 3F94 00181 LHLD 3F94H
3E53' 22 8006 00182 SHLD 8006H
3E56' 3E 0A 00183 MVI A,0AH
3E58' CD 3F9E' 00184 CALL MATH

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3E5B' DB A1 00185 IN OAIH
3E5D' E6 20 00186 ANI 2OH
3E5F' CA 3E30' 00187 JZ L4
00188 ;*****
00189 ; TRANSITION PHASE
00190 ;*****
3E62' 2A 3DOE 00191 LHL D 3DOEH ;FLIM
3E65' 11 FFFE 00192 LXI D,OFFFEH
3E68' 22 F70A 00193 L5: SHLD OF70AH
3E6B' 19 00194 DAD D
3E6C' CD 3F1E' 00195 EXST: CALL SPTH ;CHECK (THRESH.-STRUT POS'N)
3E6F' F2 3E7C' 00196 JP L12
3E72' 01 1BDO 00197 LXI B,1BDOH
3E75' 7D 00198 MOV A,L
3E76' 91 00199 SUB C
3E77' 7C 00200 MOV A,H
3E78' 98 00201 SBB B
3E79' D2 3E68' 00202 JNC L5
00203 ;*****
00204 ; ROLLOUT PHASE
00205 ;*****
3E7C' 21 0000 00206 L12: LXI H,0000
3E7F' 22 F70A 00207 SHLD OF70AH ;SET FLC=0 LBS.
3E82' 3E 99 00208 MVI A,99H
3E84' D3 EA 00209 OUT OEAH ;OPEN FORCE FEEDBACK
3E86' CD 3F1E' 00210 FLO: CALL SPTH ;CHECK STRUT POS'N.
3E89' F2 3E86' 00211 JP FLO
3E8C' 01 1EE0 00212 LXI B,1EE0H ;SET BC TO 2000 LBS.
3E8F' CD 3F30' 00213 L15: CALL IN3
3E92' 2A 8000 00214 LHL D 8000H
3E95' 22 F708 00215 SHLD OF708H ;OUTPUT W/G ACCEL. TO DACO
3E98' CD 3F8D' 00216 CALL FTEST
3E9B' D2 3EBD' 00217 JNC L13
3E9E' 01 1EE0 00218 LXI B,1EE0H ;SET BC TO 2000 LBS.
3EA1' CD 3F76' 00219 L16: CALL IN4
3EA4' 22 F708 00220 SHLD OF708H ;OUTPUT W/G ACCEL TO DACO
3EA7' CD 3F8D' 00221 CALL FTEST
3EAA' DA 3E7C' 00222 JC L12
3EAD' 21 1EE0 00223 LXI H,1EE0H ;SET HL TO 2000 LBS.
3EB0' 3E 95 00224 MVI A,95H ;CLOSE F FDBK & REV. SIGN
3EB2' D3 EA 00225 OUT OEAH ;OF LIMIT FORCE CMD (ANALOG)
3EB4' 22 F70A 00226 SHLD OF70AH ;SET LIMIT FORCE CMD=2000 LBS
3EB7' 01 1800 00227 LXI B,1800H ;SET BC TO 1600 LBS
3EBA' C3 3EA1' 00228 JMP L16
3EBD' 21 1EE0 00229 L13: LXI H,1EE0H ;SET HL TO 2000 LBS
3ECO' 22 F70A 00230 SHLD OF70AH ;SET LIMIT FORCE CMD=2000 LBS

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3EC3' 3E 9D 00231 L14: MVI A,9DH
3EC5' D3 EA 00232 OUT OEAH ;CLOSE FORCE FEEDBACK
3EC7' 01 1800 00233 LXI B,1800H ;SET BC TO 1600 LBS
3ECA' C3 3E8F' 00234 JMP L15
00235 ;*****
00236 ; TAKEOFF MODE
00237 ;*****
3ECD' 21 0000 00238 L12A: LXI H,0000
3ED0' 22 F70A 00239 SHLD OF70AH ;SET LIMIT FORCE CMD= 0 LBS.
3ED3' 3E A9 00240 MVI A,0A9H
3ED5' D3 EA 00241 OUT OEAH ;ENABLE SERVOLOOP & OPEN F FDBK
3ED7' CD 3F1E' 00242 FLOA: CALL SPTH ;CHECK STRUT POSITION
3EDA' F2 3ED7' 00243 JP FLOA
3EDD' 01 1EE0 00244 LXI B,1EE0H ;SET BC TO 2000 LBS
3EE0' CD 3F30' 00245 L15A: CALL IN3
3EE3' 2A 8000 00246 LHLD 8000H
3EE6' 22 F708 00247 SHLD OF708H ;OUTPUT W/G ACCEL TO DACO
3EE9' CD 3F8D' 00248 CALL FTST
3EEC' D2 3FOE' 00249 JNC L13A
3EEF' 01 1EE0 00250 LXI B,1EE0H ;SET BC TO 2000 LBS
3EF2' CD 3F76' 00251 L16A: CALL IN4
3EF5' 22 F708 00252 SHLD OF708H ;OUTPUT W/G ACCEL TO DACO
3EF8' CD 3F8D' 00253 CALL FTST
3EFB' DA 3ECD' 00254 JC L12A
3EFE' 21 1EE0 00255 LXI H,1EE0H ;SET HL TO 2000 LBS
3F01' 3E A5 00256 MVI A,0A5H ;CLOSE F FDBK & REVERSE SIGN
3F03' D3 EA 00257 OUT OEAH ;OF LIMIT FORCE CMD (ANALOG)
3F05' 22 F70A 00258 SHLD OF70AH ;SET LIMIT FORCE CMD=2000 LBS
3F08' 01 1800 00259 LXI B,1800H ;SET BC TO 1600 LBS
3F0B' C3 3EF2' 00260 JMP L16A
3F0E' 21 1EE0 00261 L13A: LXI H,1EE0H ;SET HL TO 2000 LBS
3F11' 22 F70A 00262 SHLD OF70AH ;SET LIMIT FORCE CMD=2000 LBS
3F14' 3E AD 00263 L14A: MVI A,0ADH
3F16' D3 EA 00264 OUT OEAH ;CLOSE FORCE FEEDBACK
3F18' 01 1800 00265 LXI B,1800H ;SET BC TO 1600 LBS
3F1B' C3 3EE0' 00266 JMP L15A
00267 ;*****
00268 ; ROUTINE TO SUBTRACT STRUT POS'N FROM THRESHOLD
00269 ;*****
3F1E' E5 00270 SPTH: PUSH H ;SPTH SETS SIGN FLAG POSITIVE
3F1F' D5 00271 PUSH D ;UNTIL STRUT POS'N ) THRESHOLD
3F20' CD 3F5F' 00272 CALL STP ;GET STRUT POSITION
3F23' 21 0B20 00273 LXI H,0B20H ;THRESHOLD 0160H=.05"
00274 ; 02D0H=.1"
00275 ; 0590H=.2"
00276 ; 0B20H=.4"

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3F26'  EB          00277          XCHG
3F27'  2A 3F86     00278          LHL  3F86H ;GET STRUT POSITION
3F2A'  CD 3F92'   00279          CALL SUB2 ;SUBTRACT STRUT FROM THRESH.
3F2D'  D1          00280          POP   D
3F2E'  E1          00281          POP   H
3F2F'  C9          00282          RET
00283 ;*****
00284 ; ROUTINE TO INPUT AND STORE DATA FROM MUXO,1 & 2
00285 ;*****
3F30'  3E 01      00286 IN3:  MVI   A,01
3F32'  21 F701    00287          LXI   H,0F701H
3F35'  77         00288          MOV   M,A
3F36'  2B         00289          DCX   H
3F37'  36 01      00290          MVI   M,01
3F39'  7E         00291 M1:   MOV   A,M
3F3A'  07         00292          RLC
3F3B'  D2 3F39'  00293          JNC   M1
3F3E'  36 00      00294          MVI   M,00
3F40'  2A F704    00295          LHL  0F704H
3F43'  22 8000    00296          SHLD 8000H
3F46'  22 3F80    00297          SHLD 3F80H
3F49'  3E 00      00298          MVI   A,00
3F4B'  21 F701    00299          LXI   H,0F701H
3F4E'  77         00300          MOV   M,A
3F4F'  2B         00301          DCX   H
3F50'  36 01      00302          MVI   M,01
3F52'  7E         00303 M2:   MOV   A,M
3F53'  07         00304          RLC
3F54'  D2 3F52'  00305          JNC   M2
3F57'  36 00      00306          MVI   M,00
3F59'  2A F704    00307          LHL  0F704H
3F5C'  22 3F84    00308          SHLD 3F84H
3F5F'  3E 02      00309 STP:  MVI   A,02
3F61'  21 F701    00310 IN1:  LXI   H,0F701H
3F64'  77         00311          MOV   M,A
3F65'  2B         00312          DCX   H
3F66'  36 01      00313          MVI   M,01
3F68'  7E         00314 M3:   MOV   A,M
3F69'  07         00315          RLC
3F6A'  D2 3F68'  00316          JNC   M3
3F6D'  36 00      00317          MVI   M,00
3F6F'  2A F704    00318          LHL  0F704H
3F72'  22 3F86    00319          SHLD 3F86H
3F75'  C9          00320          RET
00321 ;*****
00322 ; ROUTINE TO INPUT AND STORE DATA FROM MUX4

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00323 ;*****
3F76' 3E 04 00324 IN4: MVI A,04
3F78' 21 F701 00325 LXI H,0F701H
3F7B' 77 00326 MOV M,A
3F7C' 2B 00327 DCX H
3F7D' 36 01 00328 MVI M,01
3F7F' 7E 00329 M4: MOV A,M
3F80' 07 00330 RLC
3F81' D2 3F7F' 00331 JNC M4
3F84' 36 00 00332 MVI M,00
3F86' 2A F704 00333 LHLD 0F704H
3F89' 22 3F96 00334 SHLD 3F96H
3F8C' C9 00335 RET
00336 ;*****
00337 ; ROUTINE TO SUBTRACT BC FROM HL
00338 ;*****
3F8D' 7D 00339 FTEST: MOV A,L
3F8E' 91 00340 SUB C
3F8F' 7C 00341 MOV A,H
3F90' 98 00342 SBB B
3F91' C9 00343 RET
00344 ;*****
00345 ; ROUTINE FOR DOUBLE PRECISION SUBTRACT
00346 ; HL=DE-HL
00347 ;*****
3F92' 7B 00348 SUB2: MOV A,E
3F93' 95 00349 SUB L
3F94' 6F 00350 MOV L,A
3F95' 7A 00351 MOV A,D
3F96' 9C 00352 SBB H
3F97' 67 00353 MOV H,A
3F98' C9 00354 RET
00355 ;*****
00356 ; ROUTINE TO SHIFT VALUE IN HL LEFT 4 PLACES
00357 ;*****
3F99' 29 00358 ANM: DAD H
3F9A' 29 00359 DAD H
3F9B' 29 00360 DAD H
3F9C' 29 00361 DAD H
3F9D' C9 00362 RET
00363 ;*****
00364 ; ROUTINE TO ACTIVATE MATH BOARD & WAIT FOR RESULT
00365 ; ACCUMULATOR HAS OPCODE
00366 ;*****
3F9E' D3 AO 00367 MATH: OUT OAOH
3FA0' DB A7 00368 WAIT: IN OA7H

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3FA2' E6 01 00369 ANI 01
3FA4' C2 3FA0' 00370 JNZ WAIT
3FA7' C9 00371 RET
00372 ;*****
00373 ;*****
00374 ; THE FOLLOWING ARE SPECIAL CHECK-OUT ROUTINES
00375 ; AND NOT PART OF THE MAIN PROGRAM
00376 ;*****
00377 ;*****
00378 ;
00379 ;
00380 ;*****
00381 ; ROUTINE TO INPUT A VALUE FROM A/D & STORE IN RAM
00382 ;*****
3FA8' F3 00383 DI
3FA9' 3E 00 00384 MVI A,00
3FAB' CD 3F61' 00385 CALL IN1
3FAE' CF 00386 RST 01H
3FAF' 00 00387 NOP
3FBO' 00 00388 NOP
00389 ;*****
00390 ; ROUTINE TO DO PGA TEST ON A/D
00391 ;*****
3FB1' F3 00392 DI
3FB2' 21 F701 00393 LXI H,0F701H
3FB5' 36 00 00394 PGA: MVI M,00
3FB7' 36 C0 00395 MVI M,0COH
3FB9' C3 3FB5' 00396 JMP PGA
3FBC' 00 00397 NOP
00398 ;*****
00399 ; ROUTINE TO OUTPUT A VALUE TO DAC0 & DAC1
00400 ;*****
3FBD' F3 00401 DI
3FBE' 00 00402 NOP
3FBF' 21 0000 00403 R2: LXI H,0000
3FC2' 22 F708 00404 SHLD 0F708H
3FC5' 22 F70A 00405 SHLD 0F70AH
3FC8' 00 00406 NOP
3FC9' 00 00407 NOP
3FCA' 00 00408 NOP
3FCB' C3 3FBF' 00409 JMP R2
00410 END

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MACROS:

SYMBOLS:

ANM	3F99'	CHACEL	3DDF'	EXST	3E6C'	FLO	3E86'
FLOA	3ED7'	FTEST	3F8D'	IN1	3F61'	PN3	3F30'
IN4	3F76'	L1	3D52'	L10	3DD2'	L11	3DD5'
L12	3E7C'	L12A	3ECD'	L13	3EBD'	L13A	3FOE'
L14	3EC3'	L14A	3F14'	L15	3E8F'	L15A	3EEO'
L16	3EA1'	L16A	3EF2'	L4	3E30'	L5	3E68'
L8	3D79'	L8A	3DB4'	L9	3DC4'	M1	3F39'
M2	3F52'	M3	3F68'	M4	3F7F'	MATH	3F9E'
PGA	3FB5'	R2	3FBF'	SPTH	3F1E'	START	3D10'
STP	3F5F'	SUB2	3F92'	TL1	3D2E'	TL2	3D30'
TL3	3D34'	WAIT	3FA0'				

NO FATAL ERROR(S)

8.0 REFERENCE

1. Ross, Irving and Edson, Ralph: An Electronic Control for an Electrohydraulic Active Control Aircraft Landing Gear. NASA Contractor Report 3113, April, 1979.

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16. Abstract HR Textron Inc., under NASA Contract NAS1-14459, has developed and designed a controller for an electrohydraulic active control landing gear for the F-4 aircraft. A controller, developed under NASA Contract NAS1-14459, was modified for this application. Simulation results indicate that during landing and rollout over repaired bomb craters the active gear effects a force reduction, relative to the passive gear, of approximately 70%.					
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