NASA Contractor Report 3552

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

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

CP	Linearized orifice coefficient for active control servovalve $= -\frac{\partial Qsv}{\partial P_1}\ 3.16 \times 10^{-11} m^5 \cdot N^{-1} \cdot sec^{-1} (0.01334\ in^3/sec/psi)$
CP_o	linearized orifice coefficient for shock strut orifice $= \frac{\partial Qo}{\partial P_1} = C_o/(2\sqrt{P_1 - P_2})$, $1.901 \times 10^{-9} m^5 \cdot N^{-1} \cdot sec^{-1} (0.8\ in^3/sec/psi)$
CQ	linearized orifice coefficient for active control servovalve: $= \frac{\partial Qsv}{\partial Xsv} = C_{sv}\sqrt{(P_S + P_R)/2}$, $8.61 m^2/sec (13{,}340\ in^3/sec/in)$
C_{sv}	orifice coefficient for active control servovalve: $= C_d W_{sv}\sqrt{2g_c/\rho}$, $0.00268 m^3 \cdot sec^{-1} \cdot N^{-1/2} (344.4\ in^3/(in\ lbf^{1/2}))$
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, $9.81 m/sec^2 (386.in/sec^2)$
g_c	gravitational acceleration constant $1\ kg \cdot m \cdot N^{-1} \cdot sec^{-2} (12\ slug \cdot in \cdot lbf^{-1} \cdot sec^{-2})$
i_1	input signal to electronic compensation networks, A
i_2	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)
KTIRE	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 . sec^2/in = 450. lbm)
M_U	upper mass, 8143. kg (558. slugs = 46.5 lbf. sec^2/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/m^2 (3000 . psi)
P_R	hydraulic return pressure, 0.0 N/m^2 (0.0 psi)
P_1	hydraulic pressure in shock strut piston, N/m^2 (psi)
P_2	pneumatic pressure in shock strut cylinder, N/m^2 (psi)
P_3	pressure in volume betweeen walls of shock strut piston and cylinder, N/m^2 (psi)
Q_o	flow rate through shock strut orifice from piston to cylinder, m^3/sec (in^3/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, 6.89×10^8 N/m^2 (1×10^5 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, 6.464×10^{-4} sec
τ_4	time constant in compensation, 6.464×10^{-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 in^3/sec/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.

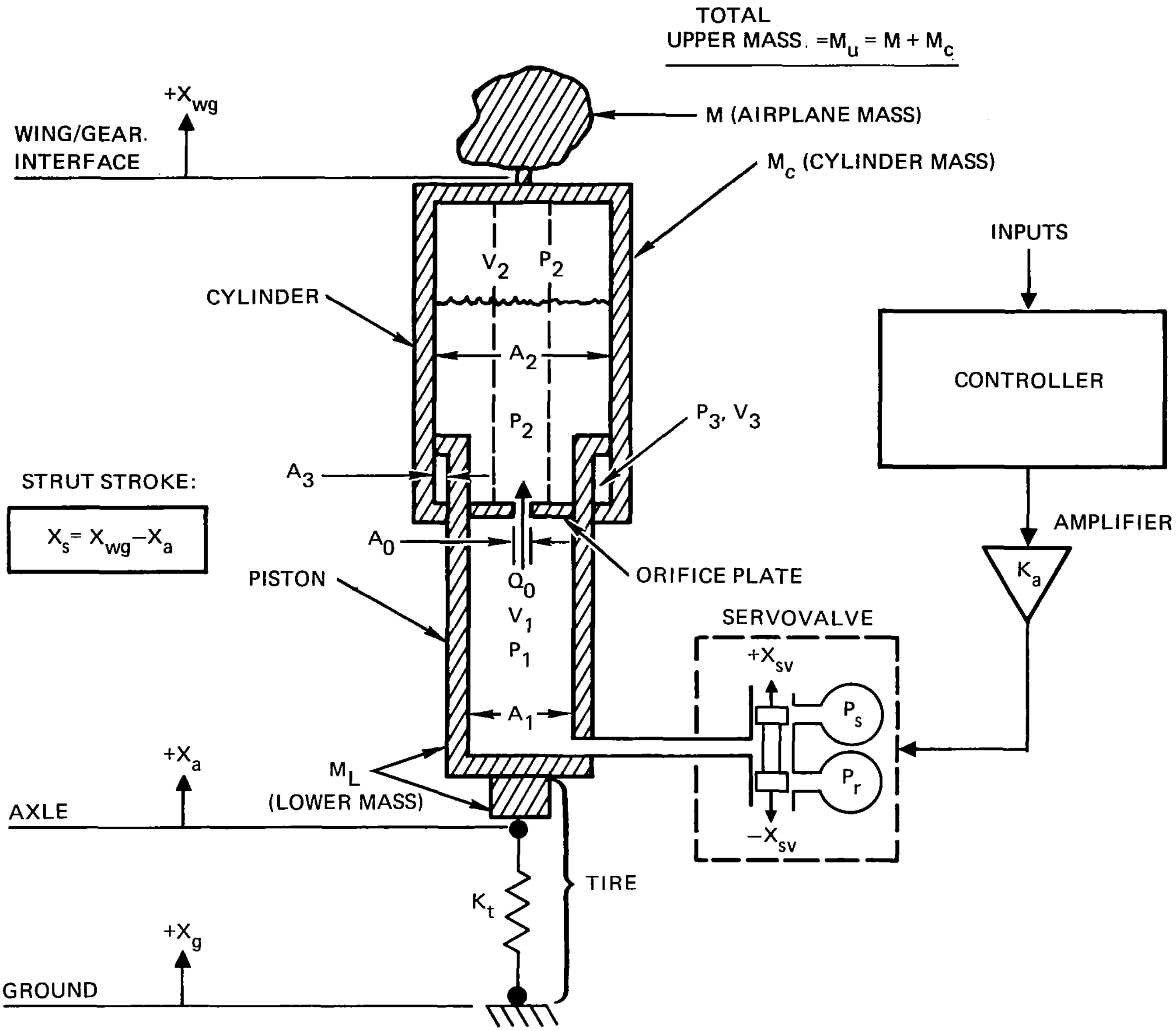


FIGURE 3-1 ILLUSTRATION OF VARIABLES USED IN NONLINEAR SIMULATION OF SIMPLIFIED VERTICAL DROP CASE

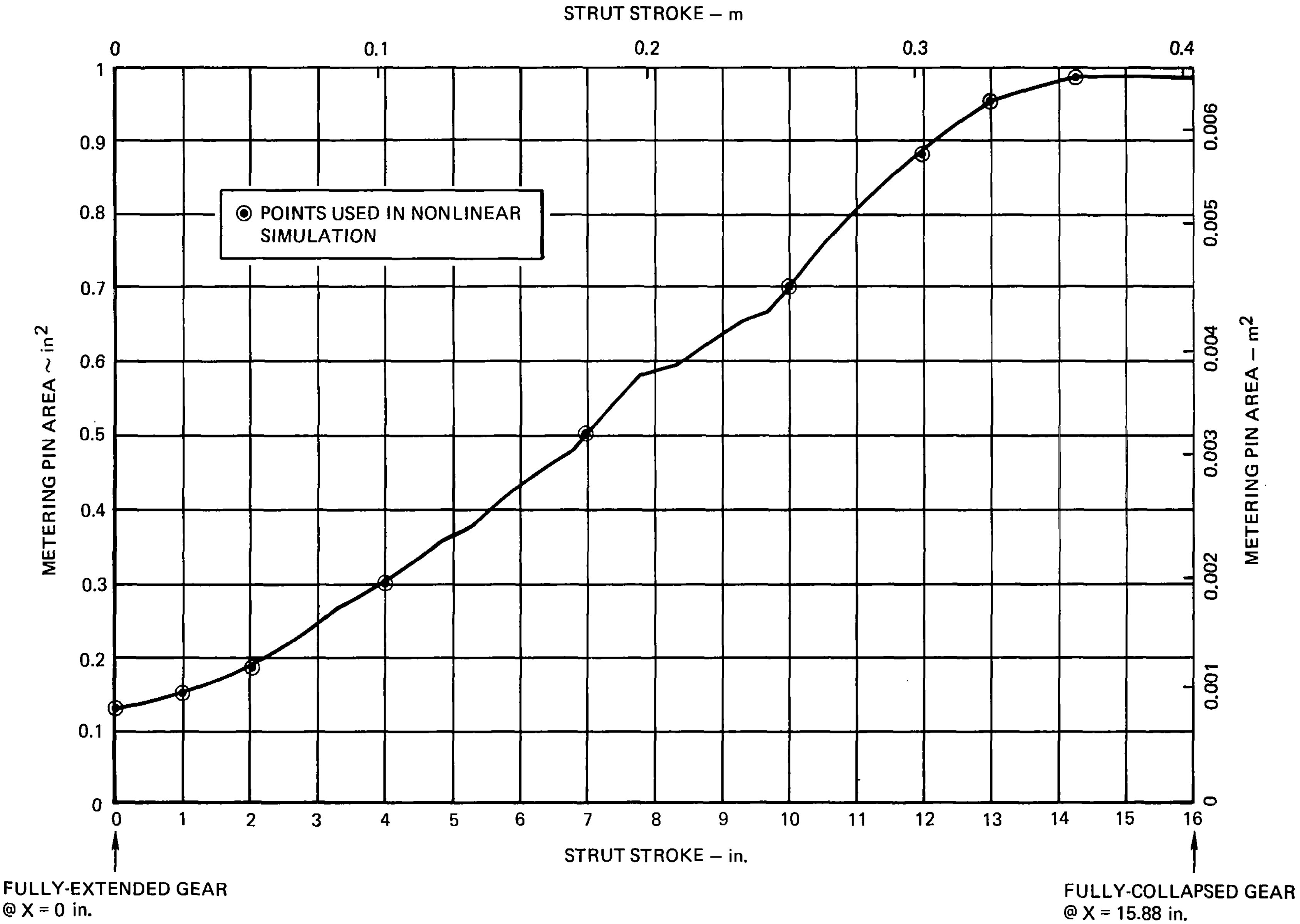


FIGURE 3-2. F-4 LANDING GEAR METERING PIN AREA VERSUS STRUT STROKE

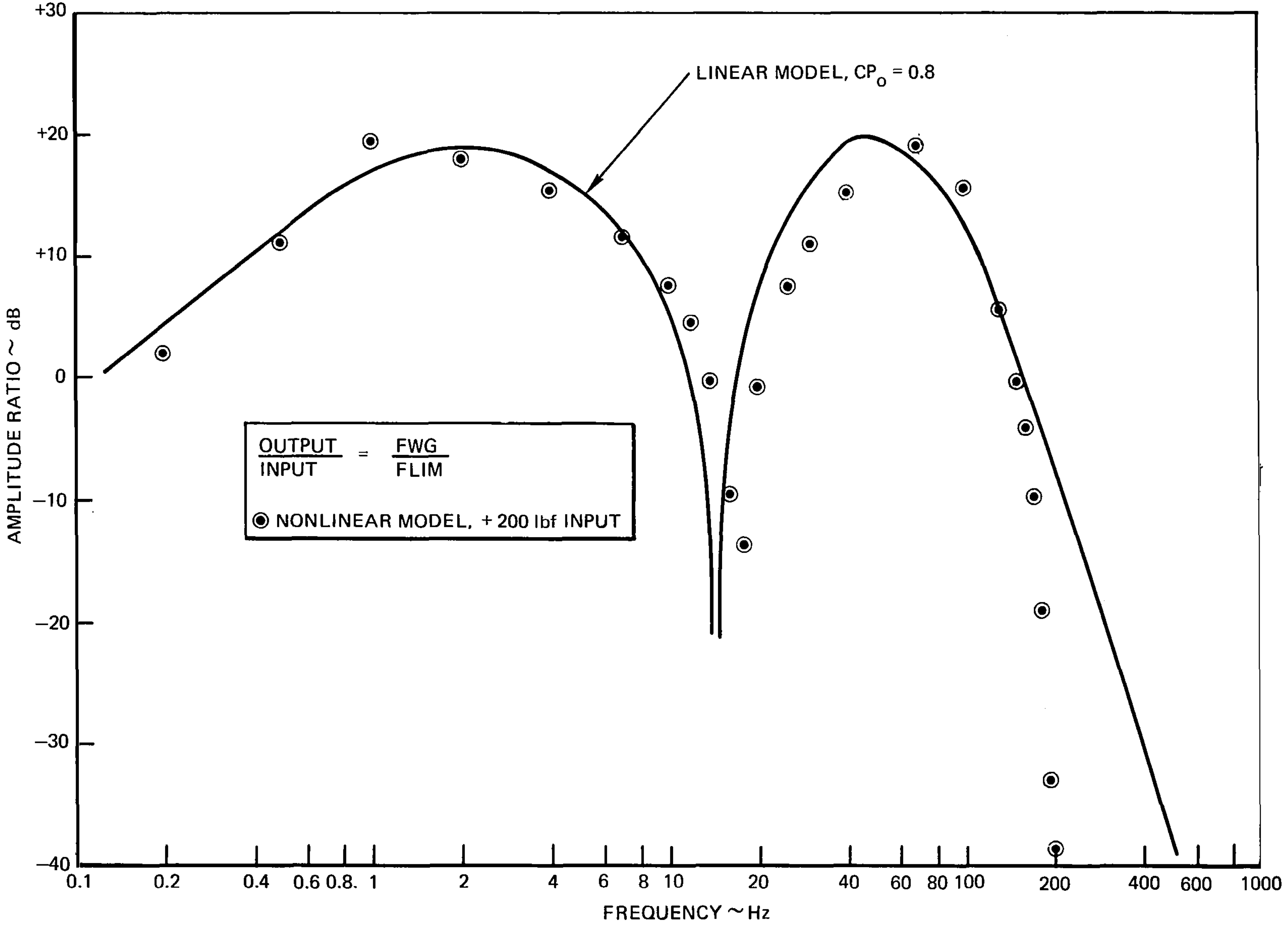


FIGURE 3-3 OPEN-LOOP, NO COMPENSATION FREQUENCY RESPONSE

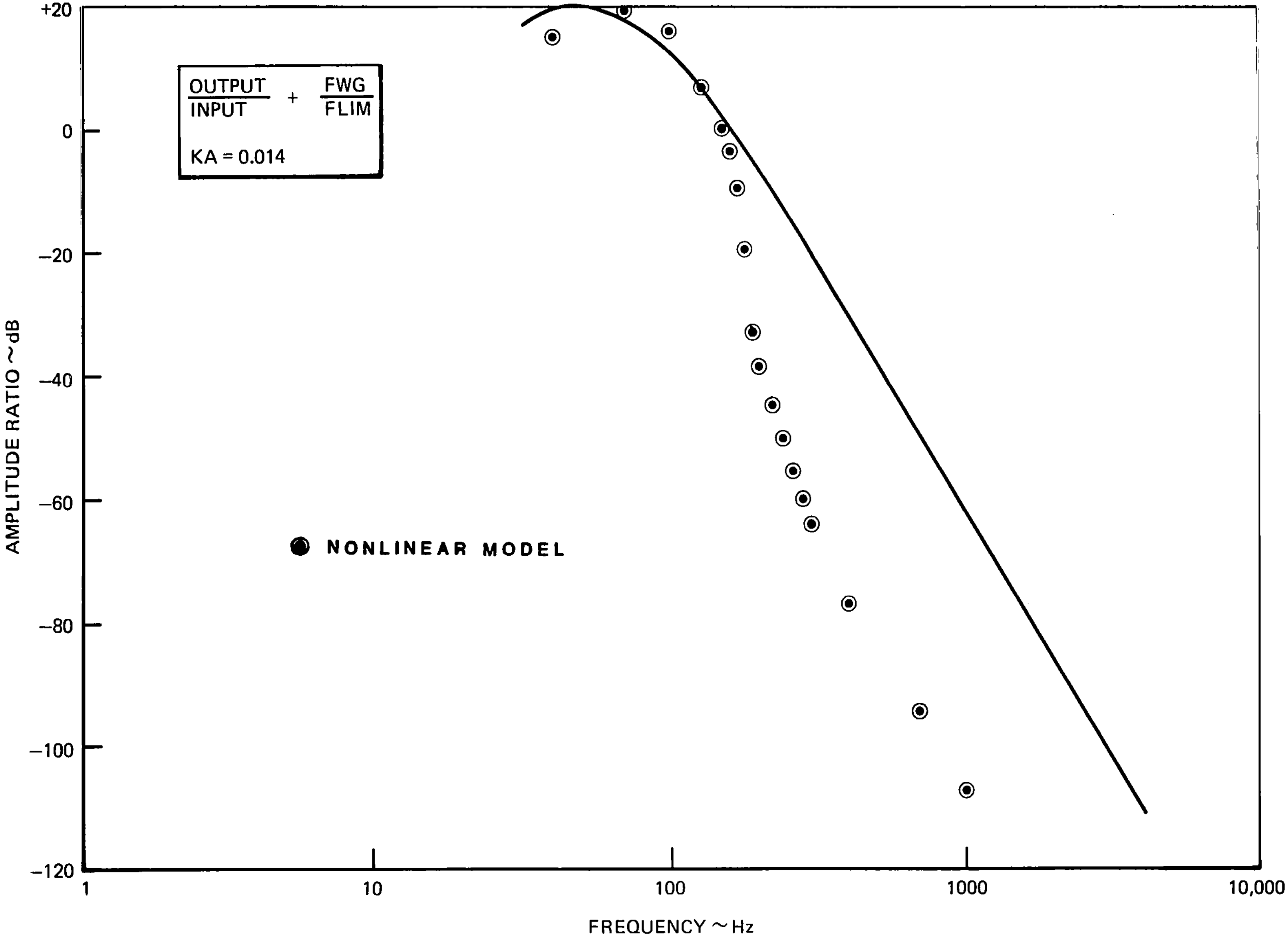


FIGURE 3-4. F-4 GEAR, OPEN-LOOP, NO COMPENSATION FREQUENCY RESPONSE

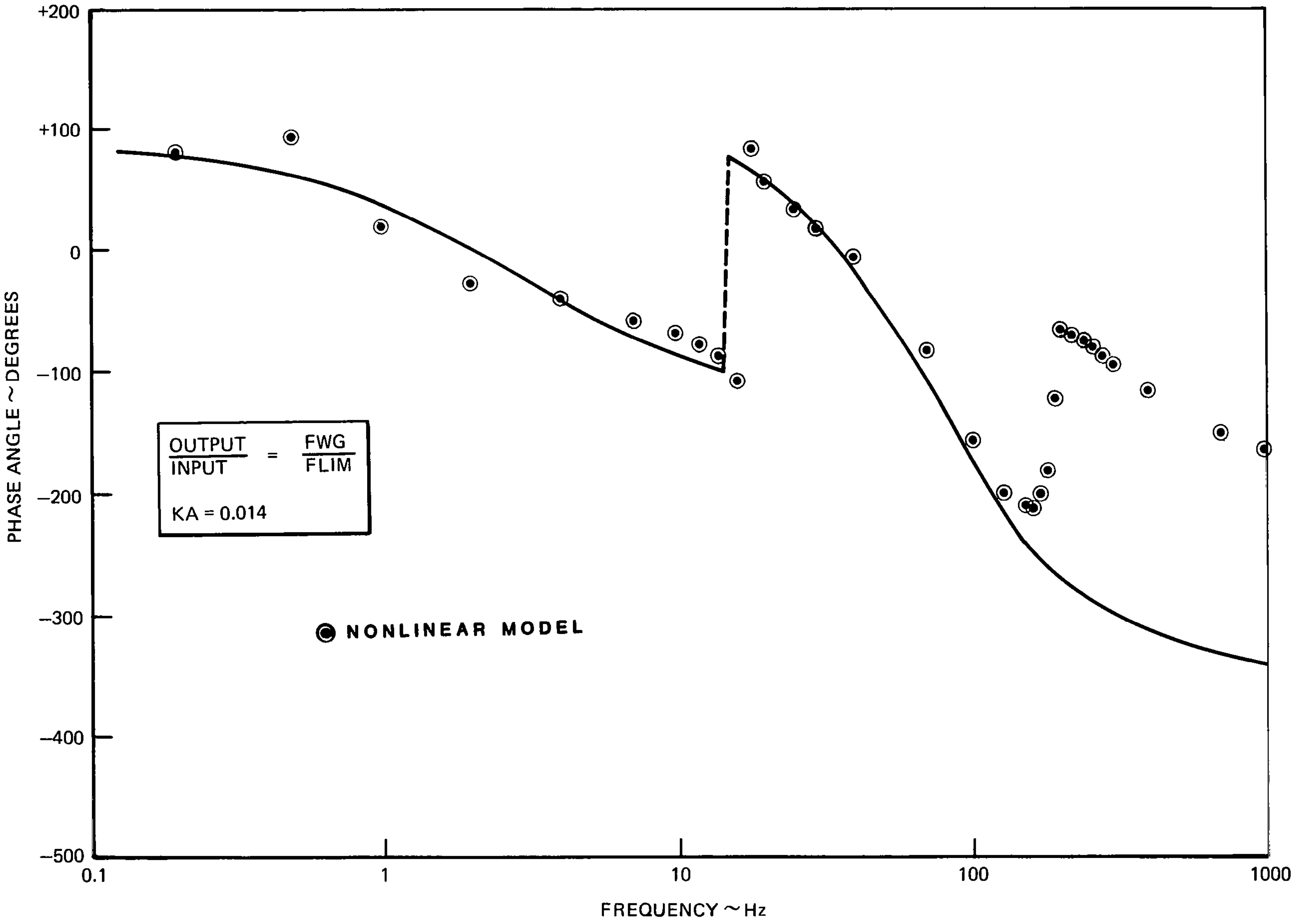


FIGURE 3-5. F-4 GEAR, OPEN-LOOP, NO COMPENSATION FREQUENCY RESPONSE

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.

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

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.

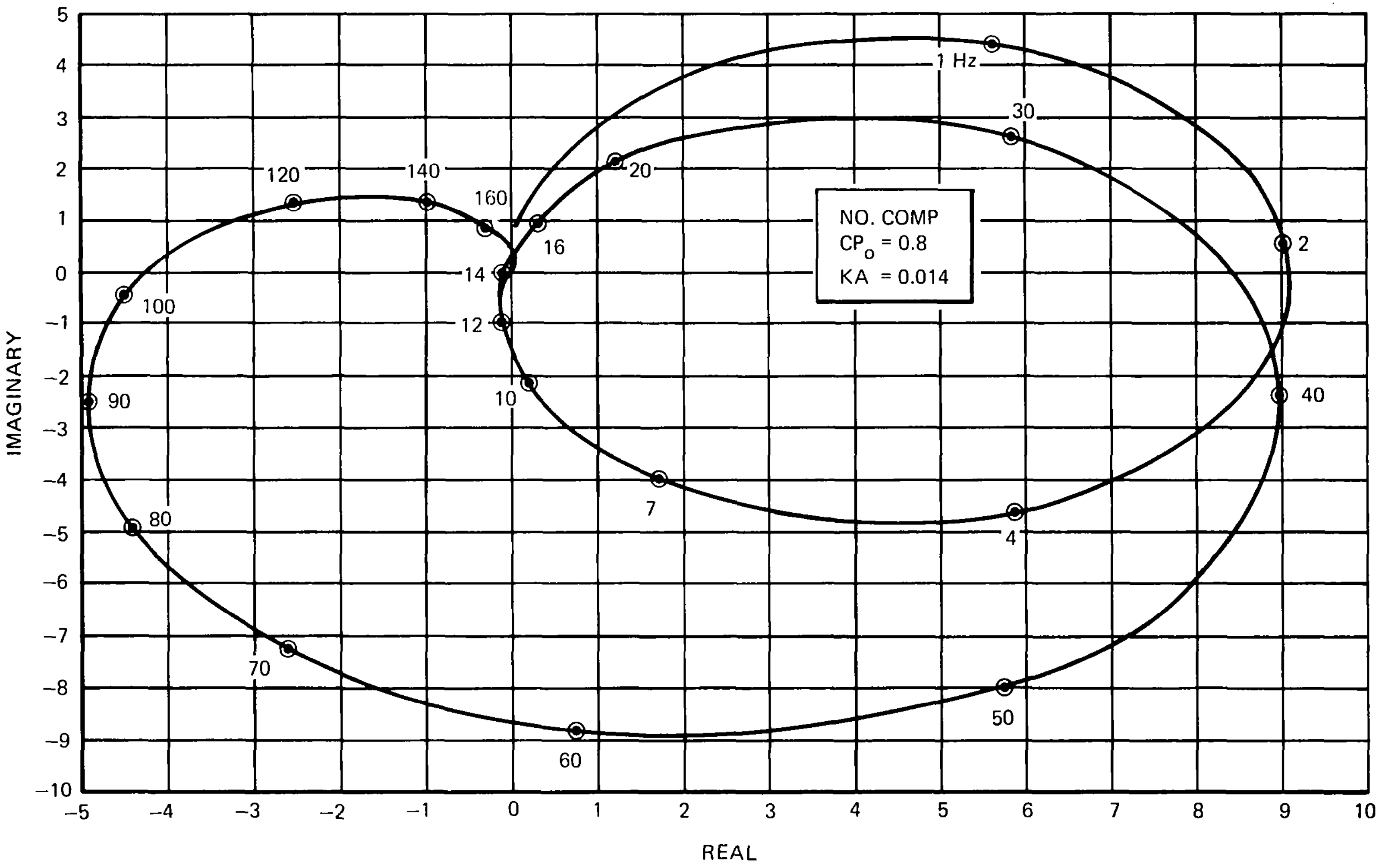


FIGURE 3-6. OPEN-LOOP LINEAR MODEL WITHOUT COMPENSATION

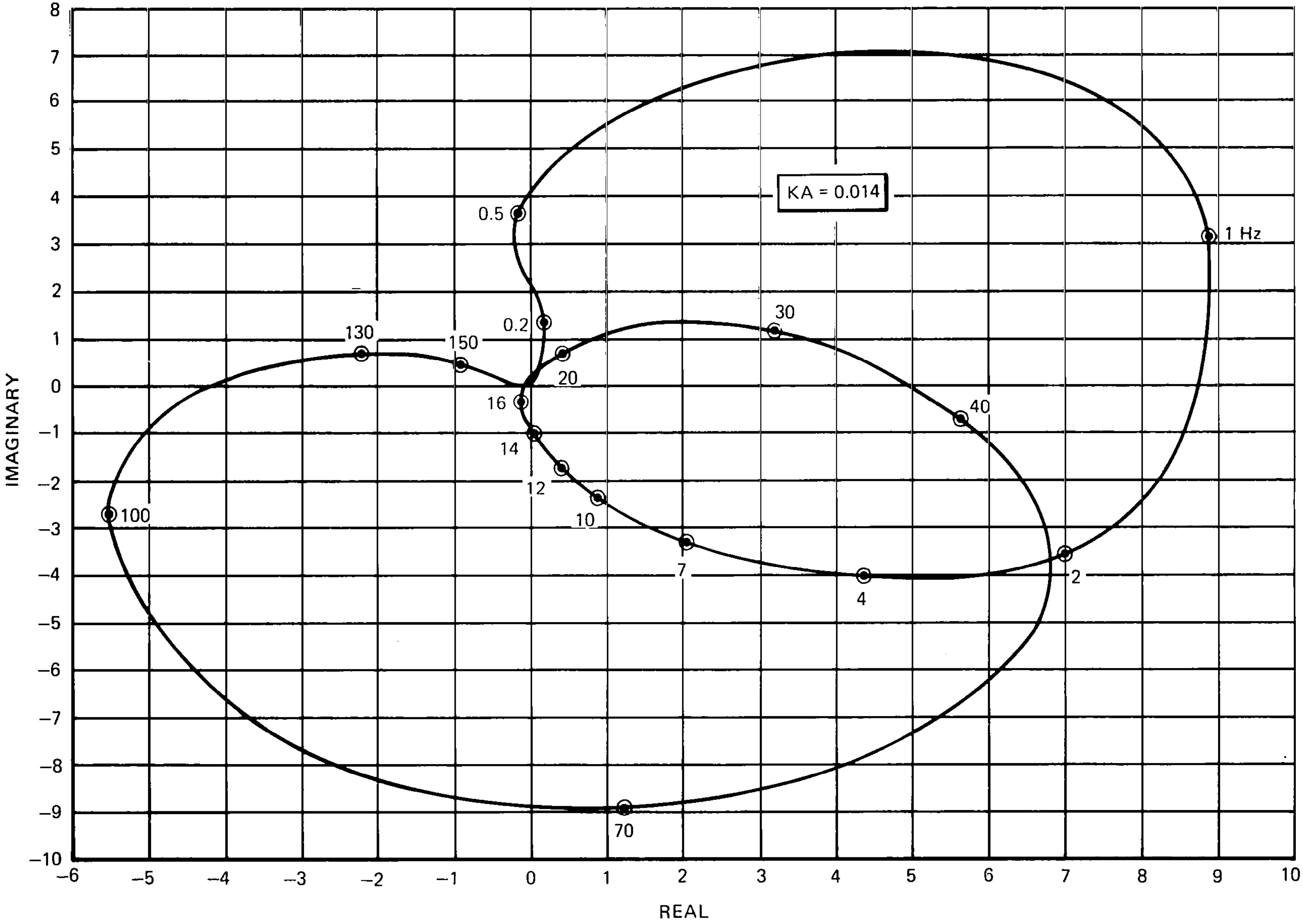


FIGURE 3-7. OPEN-LOOP NONLINEAR MODEL, 889.6N (± 200 LBF) INPUT

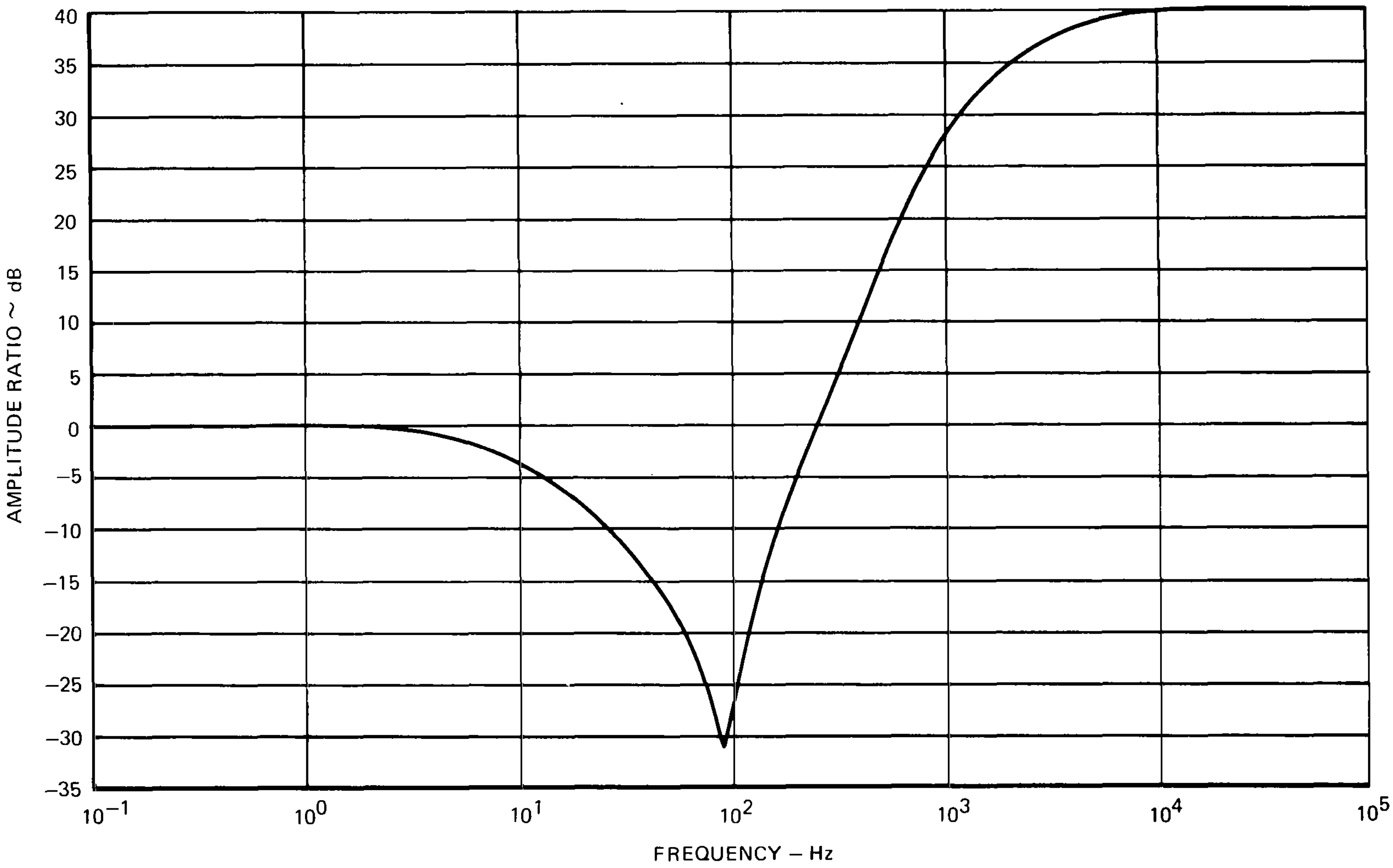


FIGURE 3-8 COMPENSATION

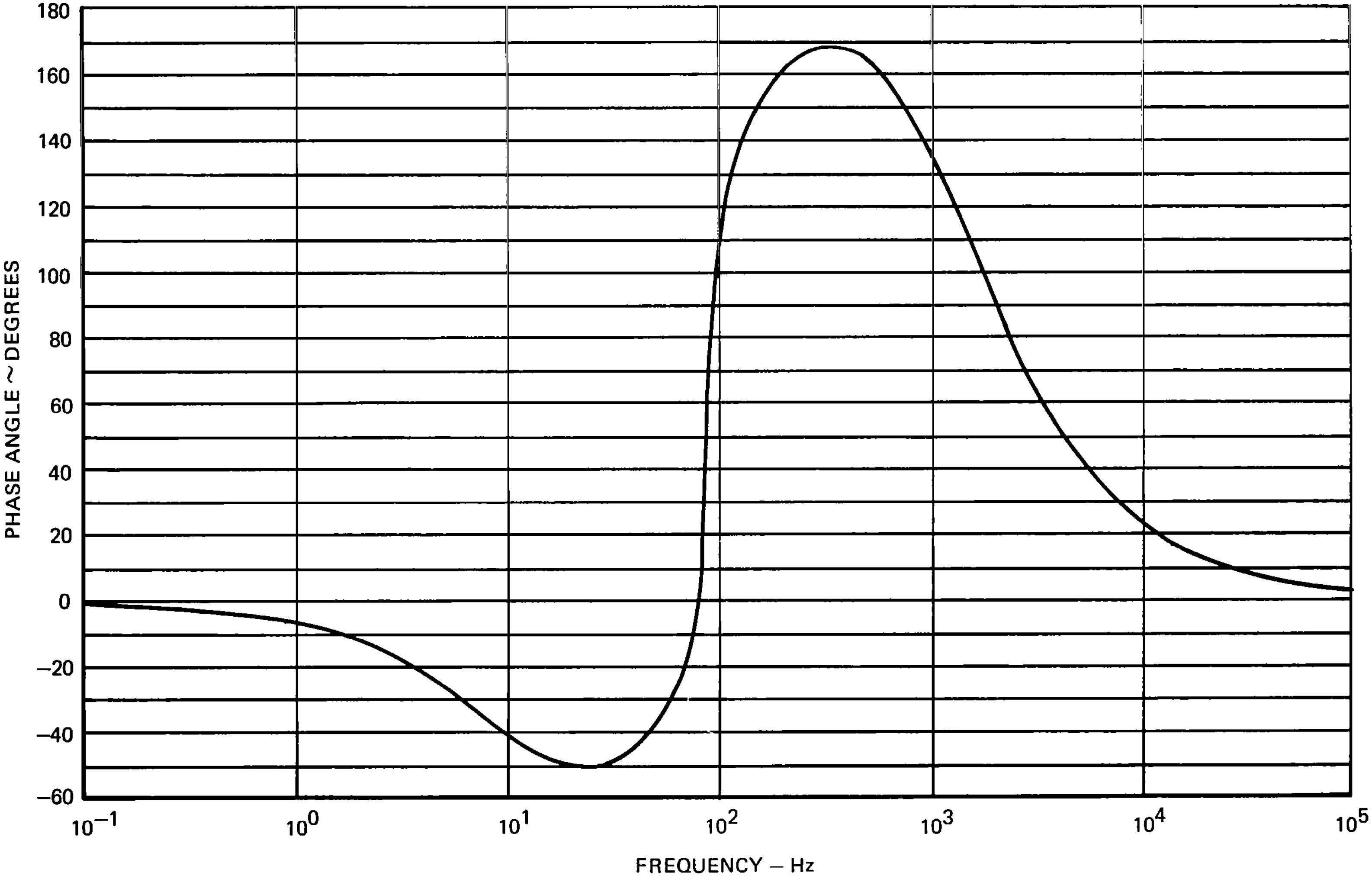


FIGURE 3-9 COMPENSATION

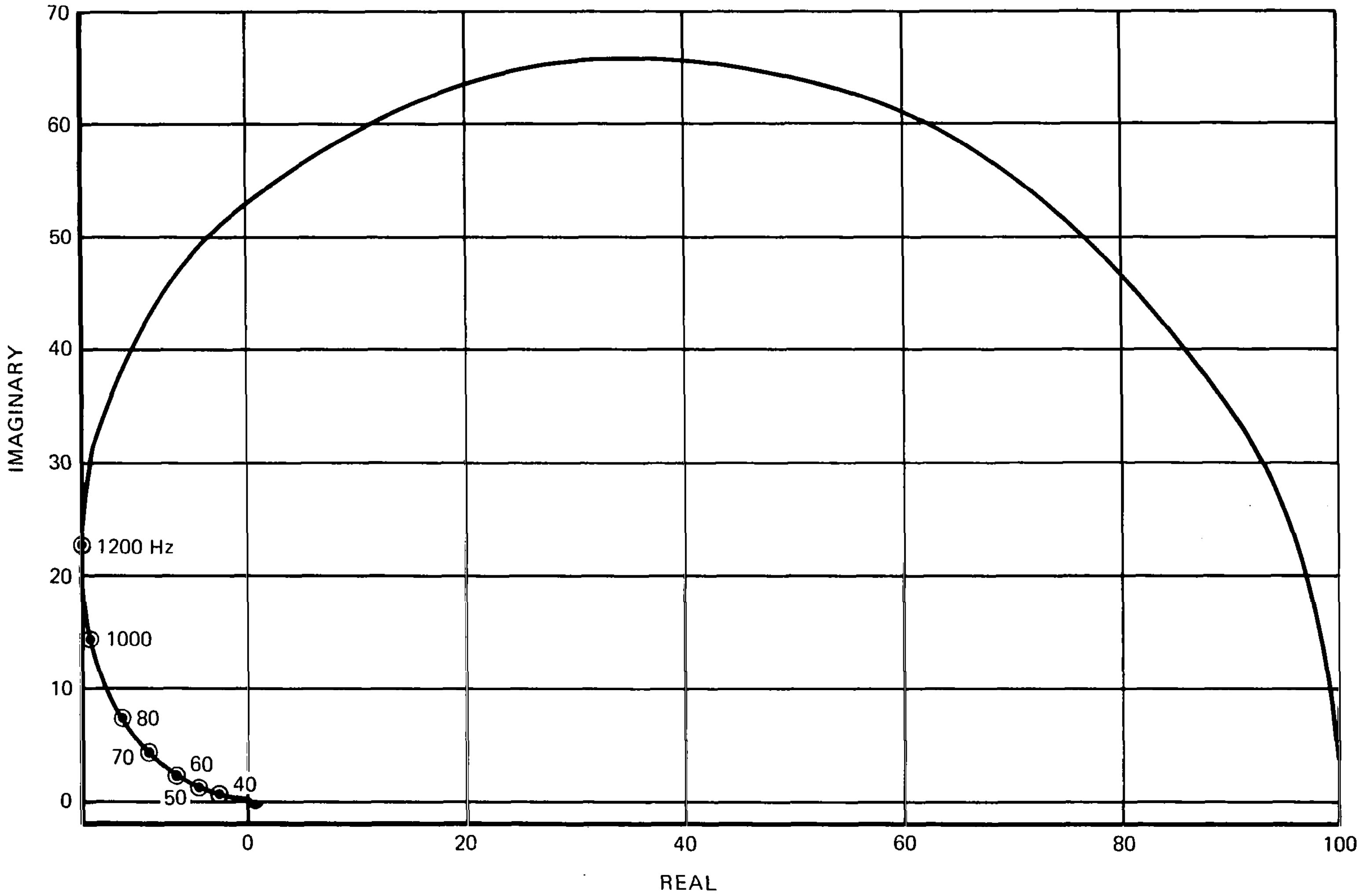


FIGURE 3-10 NYQUIST PLOT—COMPENSATION

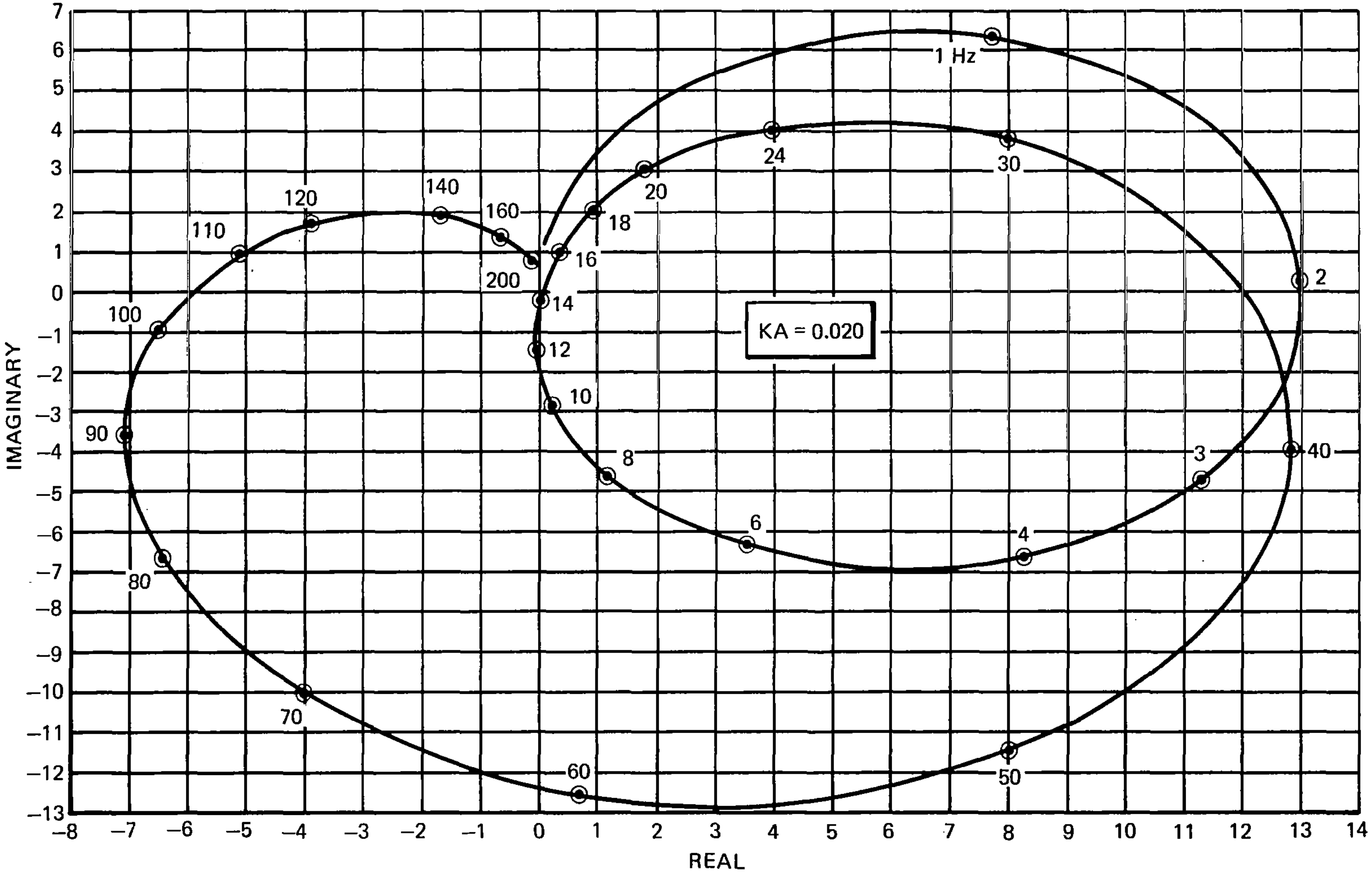


FIGURE 3-11 NO COMPENSATION

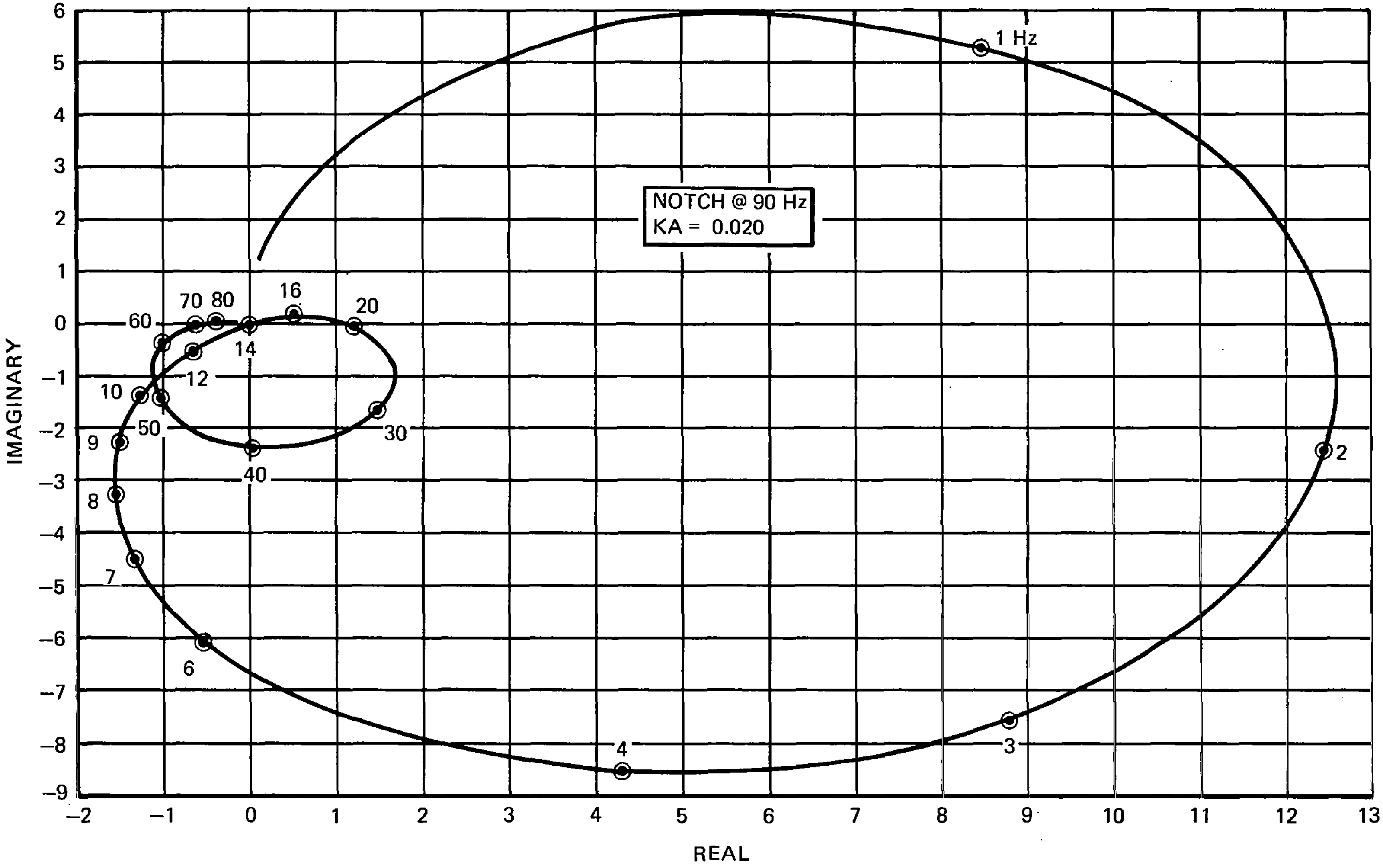


FIGURE 3-12. 90 Hz NOTCH

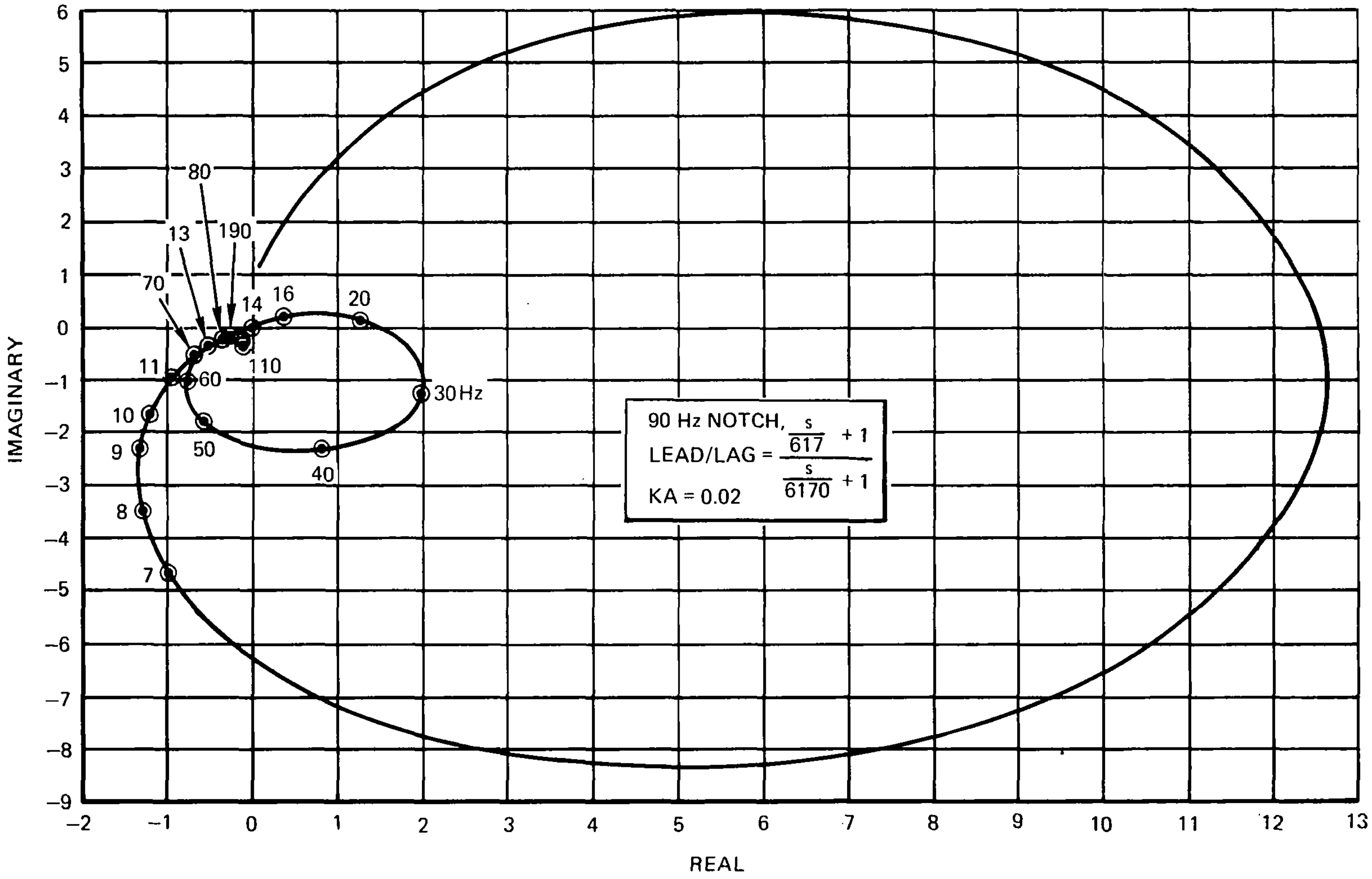


FIGURE 3-13. 90 Hz NOTCH AND LEAD/LAG

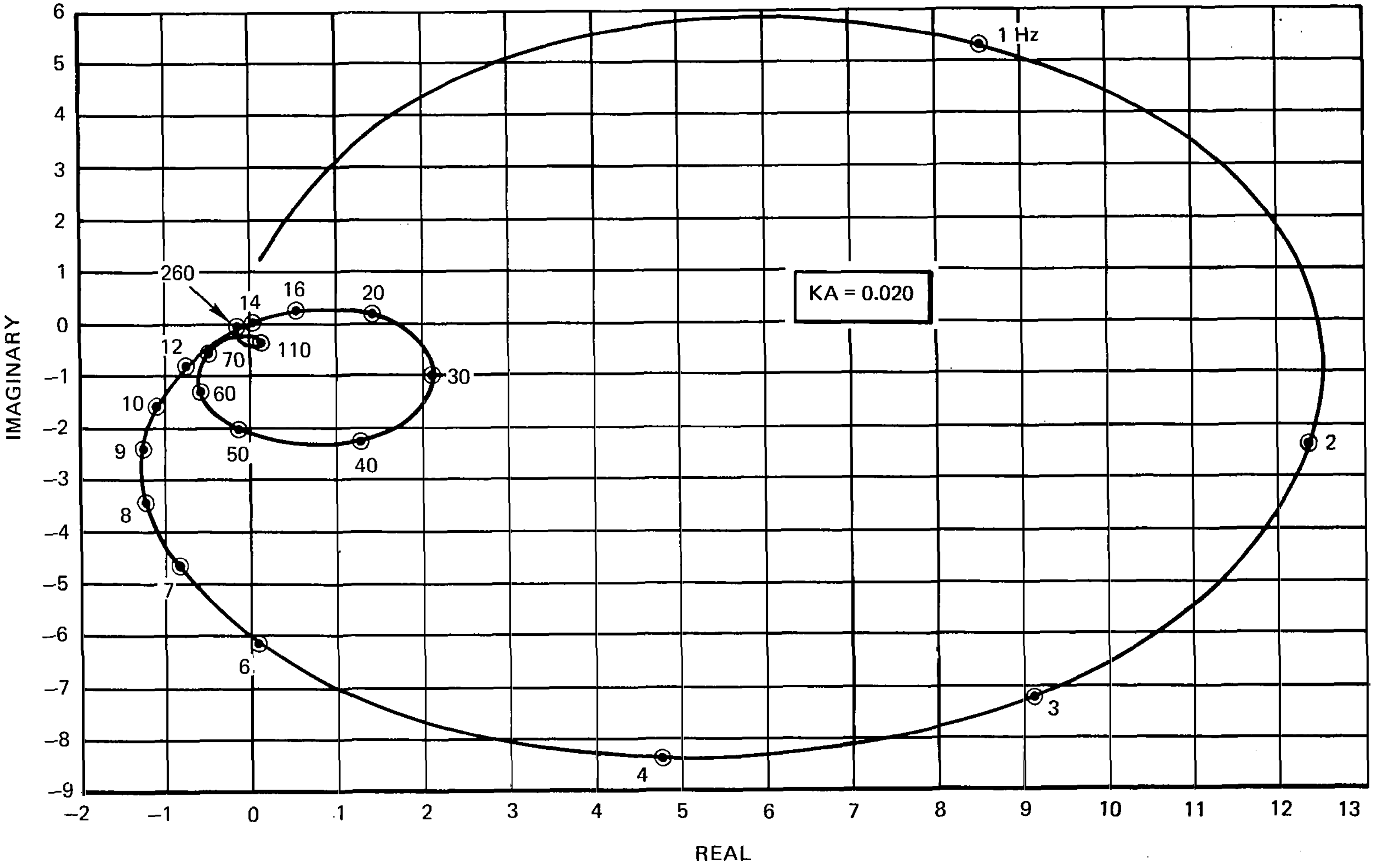


FIGURE 3-14 TOTALLY COMPENSATED LOOP

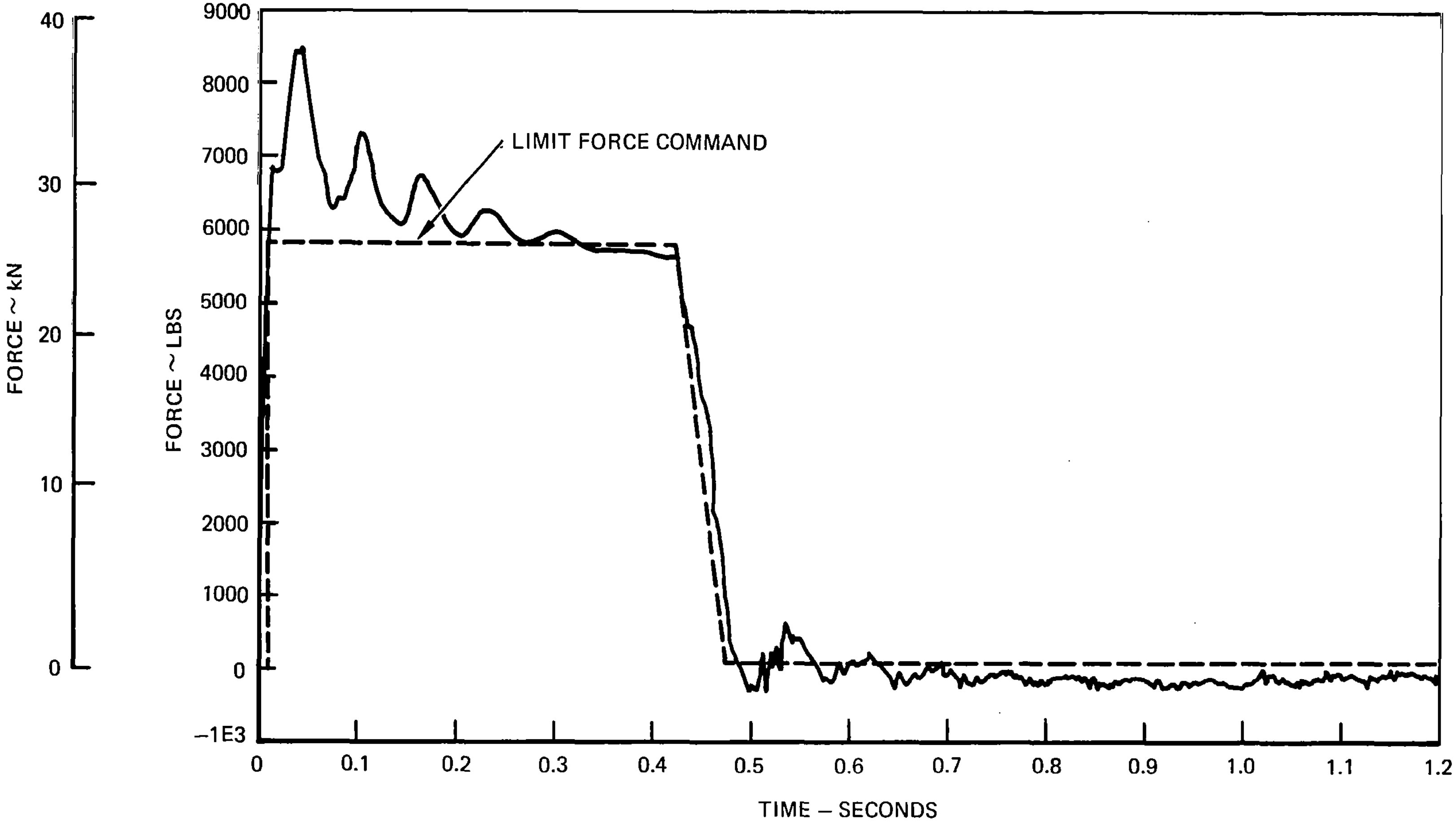


FIGURE 3-15 CASE 2 COMP: NOTCH AT 90 Hz

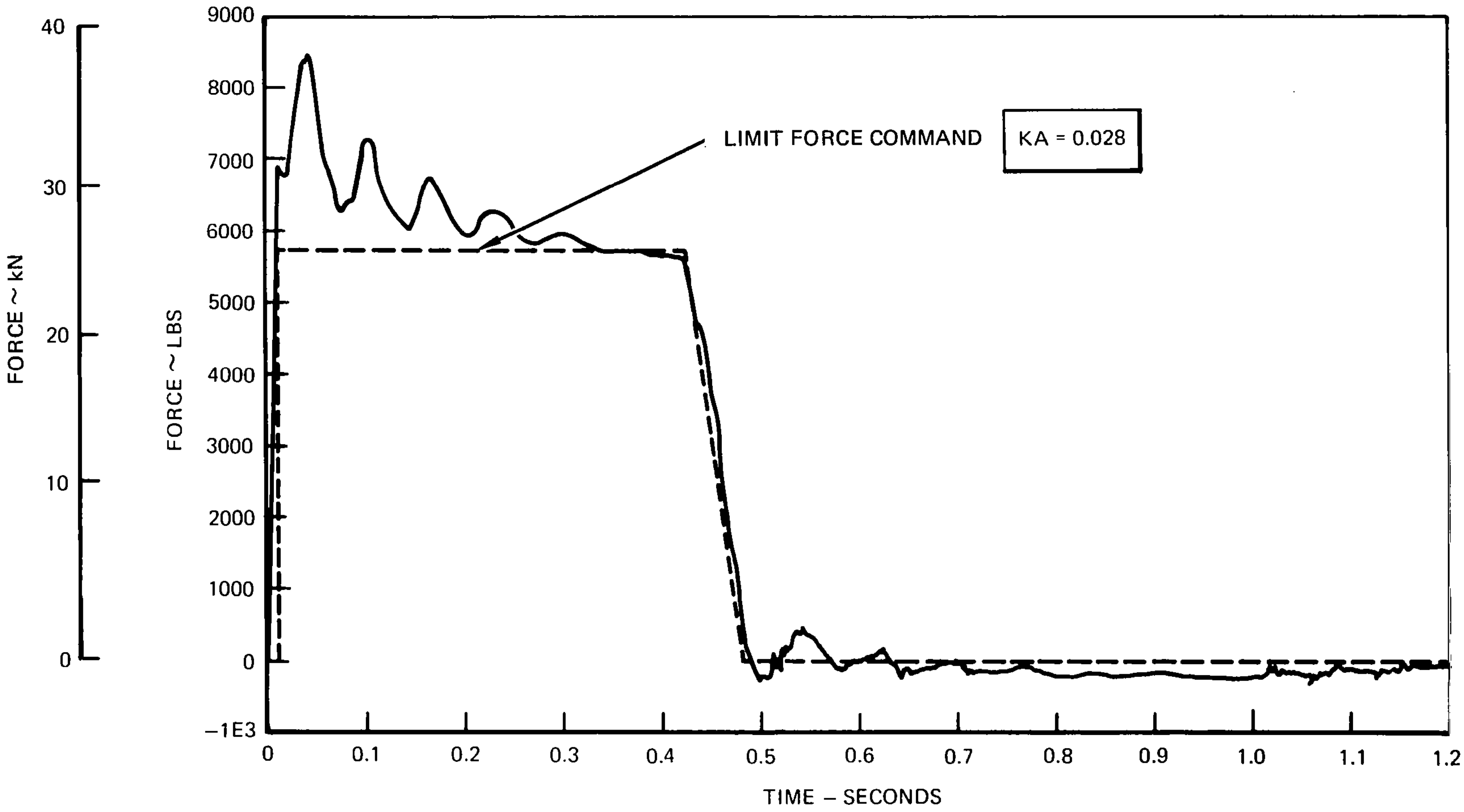


FIGURE 3-16 COMPENSATION – NOTCH @ 90 Hz + LEAD/LAG @ 617, 6170 RAD/SEC

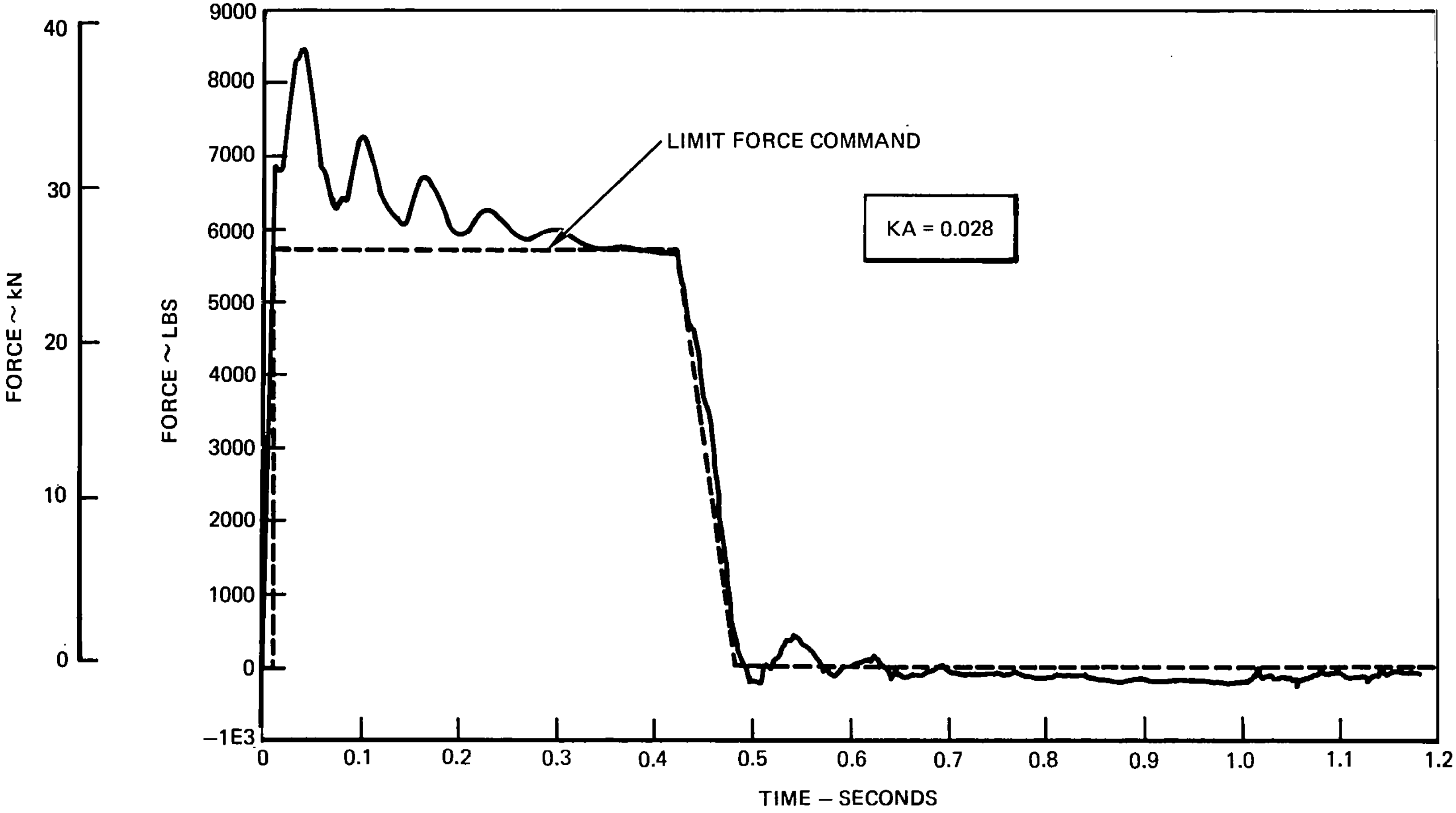


FIGURE 3-17 TOTALLY COMPENSATED LOOP

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.

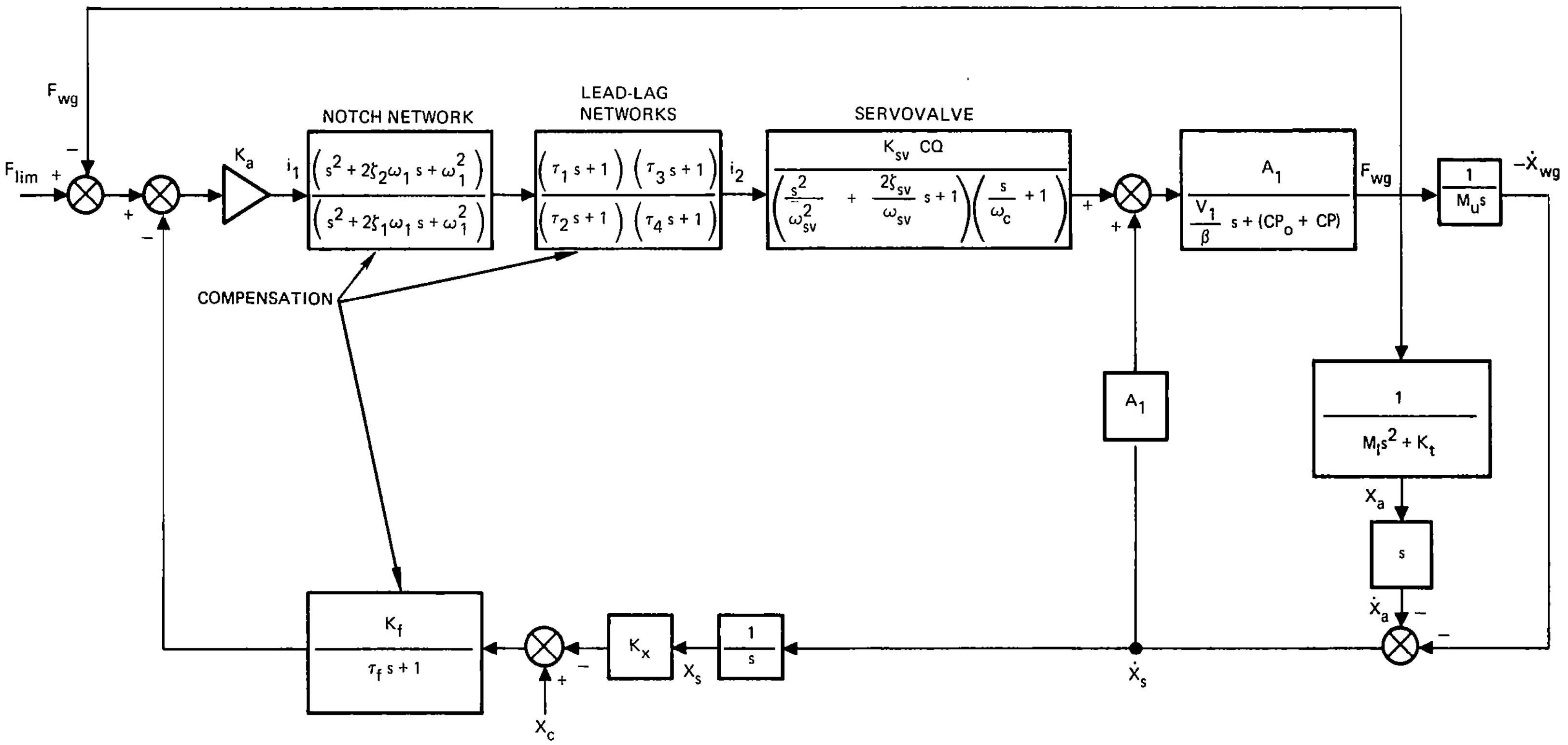


FIGURE 3-18 BLOCK DIAGRAM OF LINEAR MATH MODEL

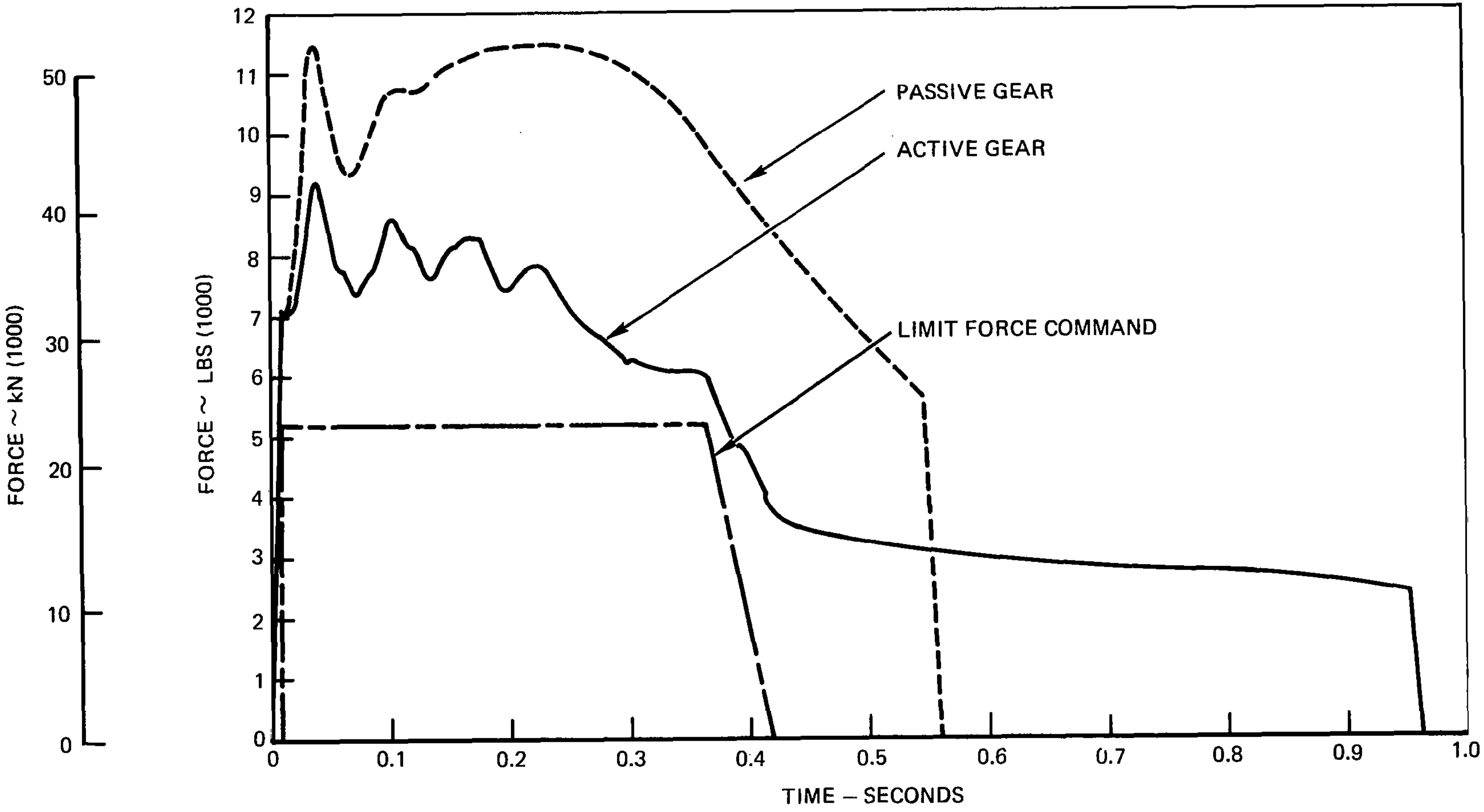


FIGURE 3-19 CASE 1

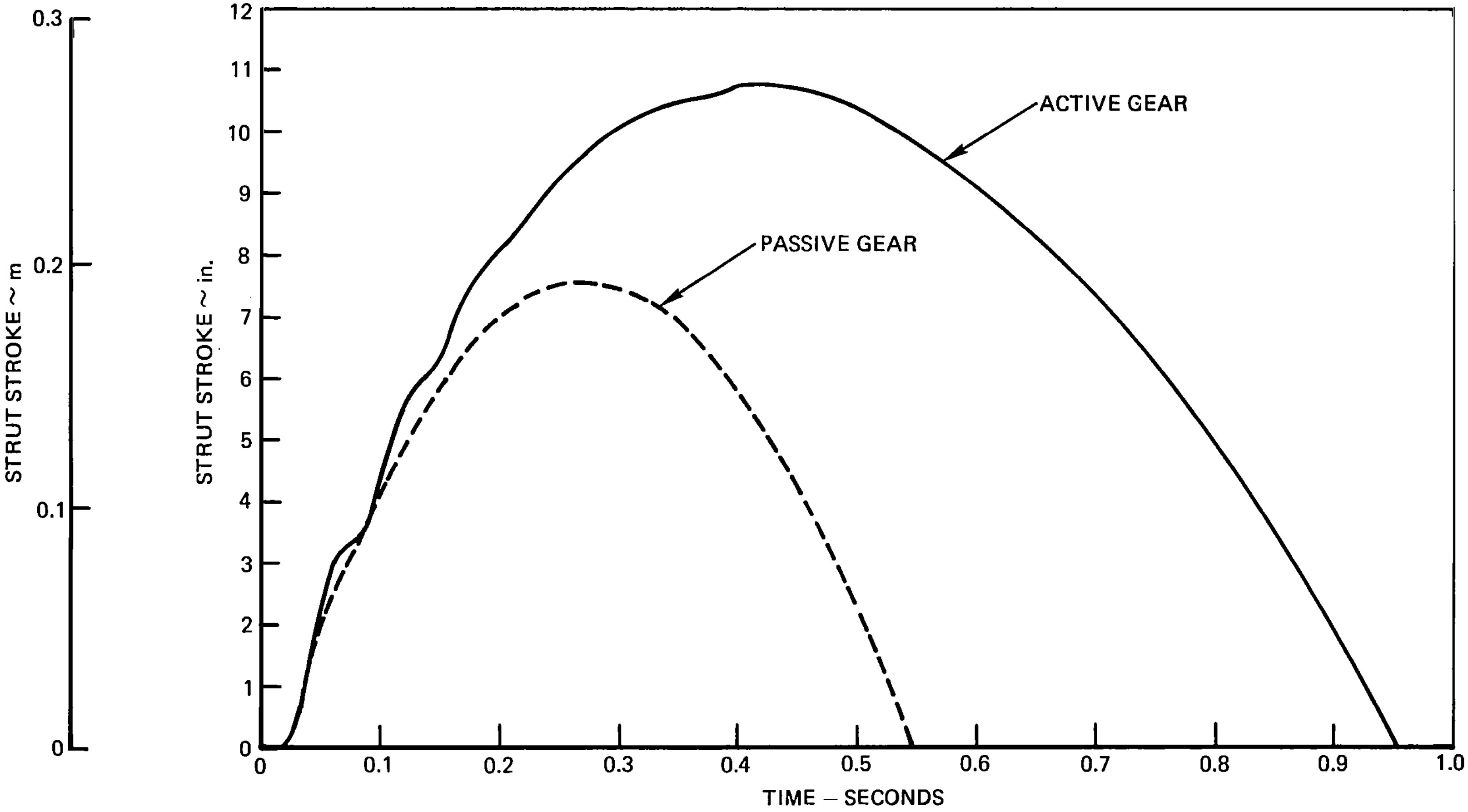


FIGURE 3-20 CASE 1

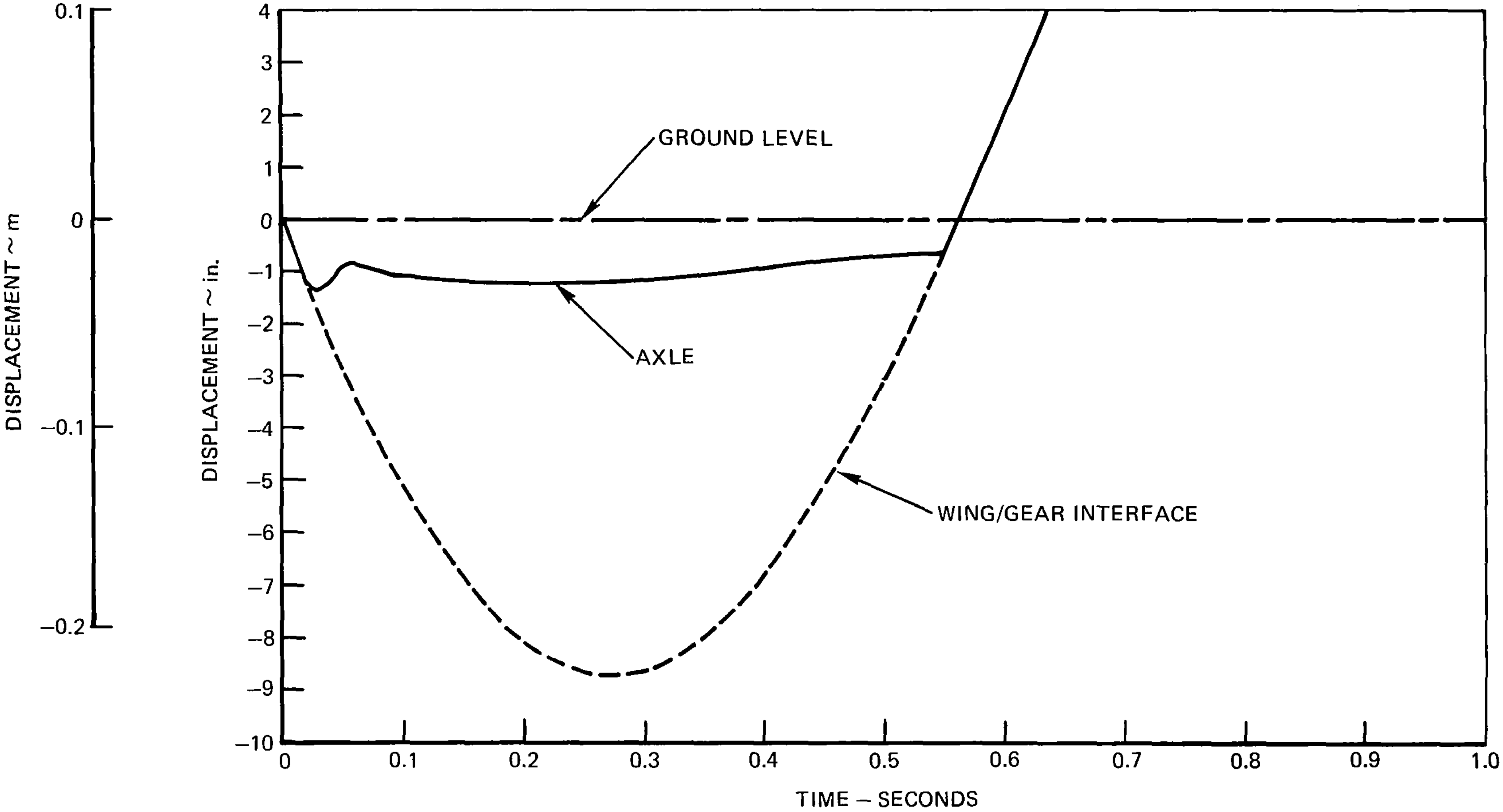


FIGURE 3-21 CASE 1 PASSIVE GEAR

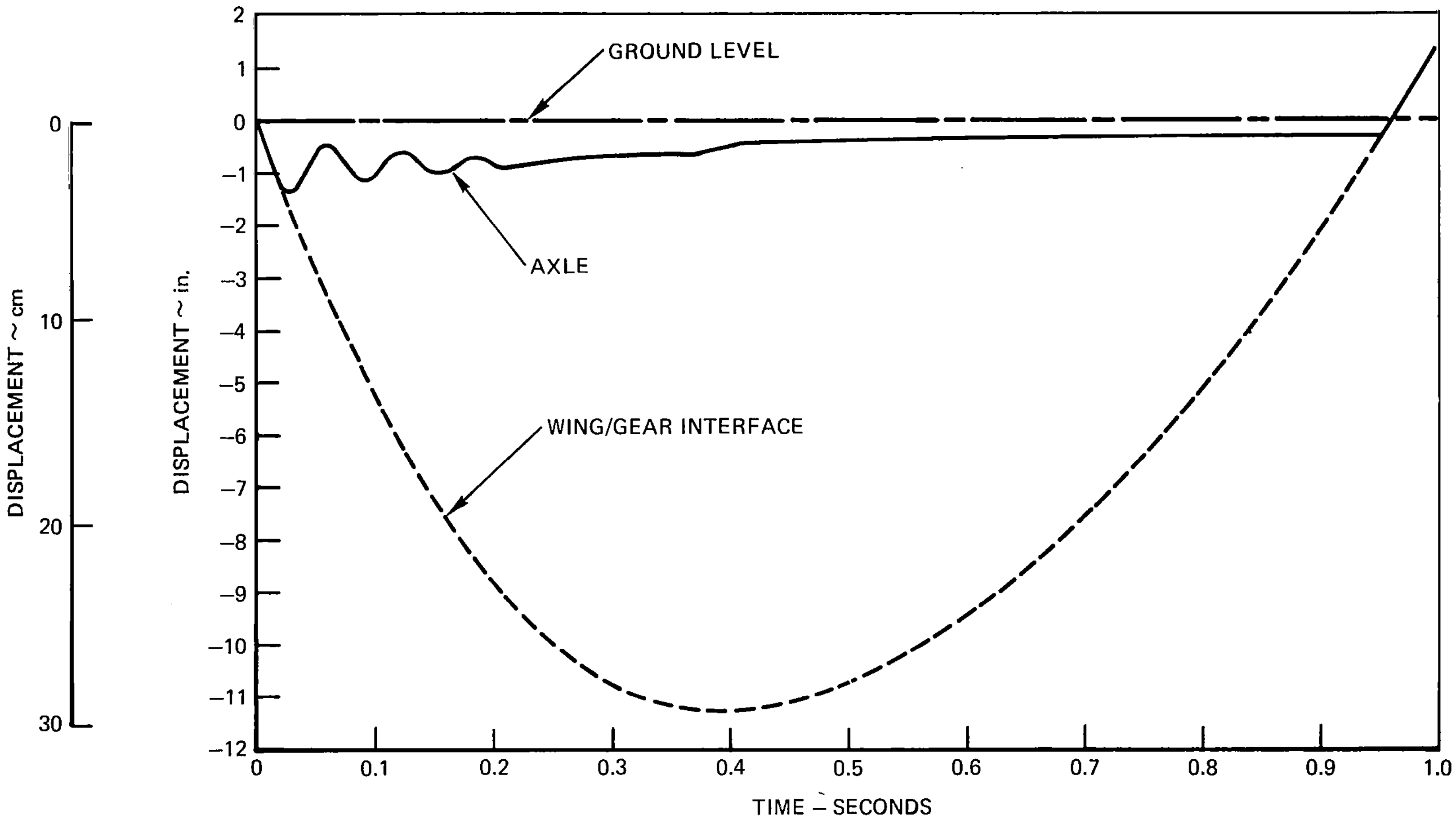


FIGURE 3-22. CASE 1 ACTIVE GEAR

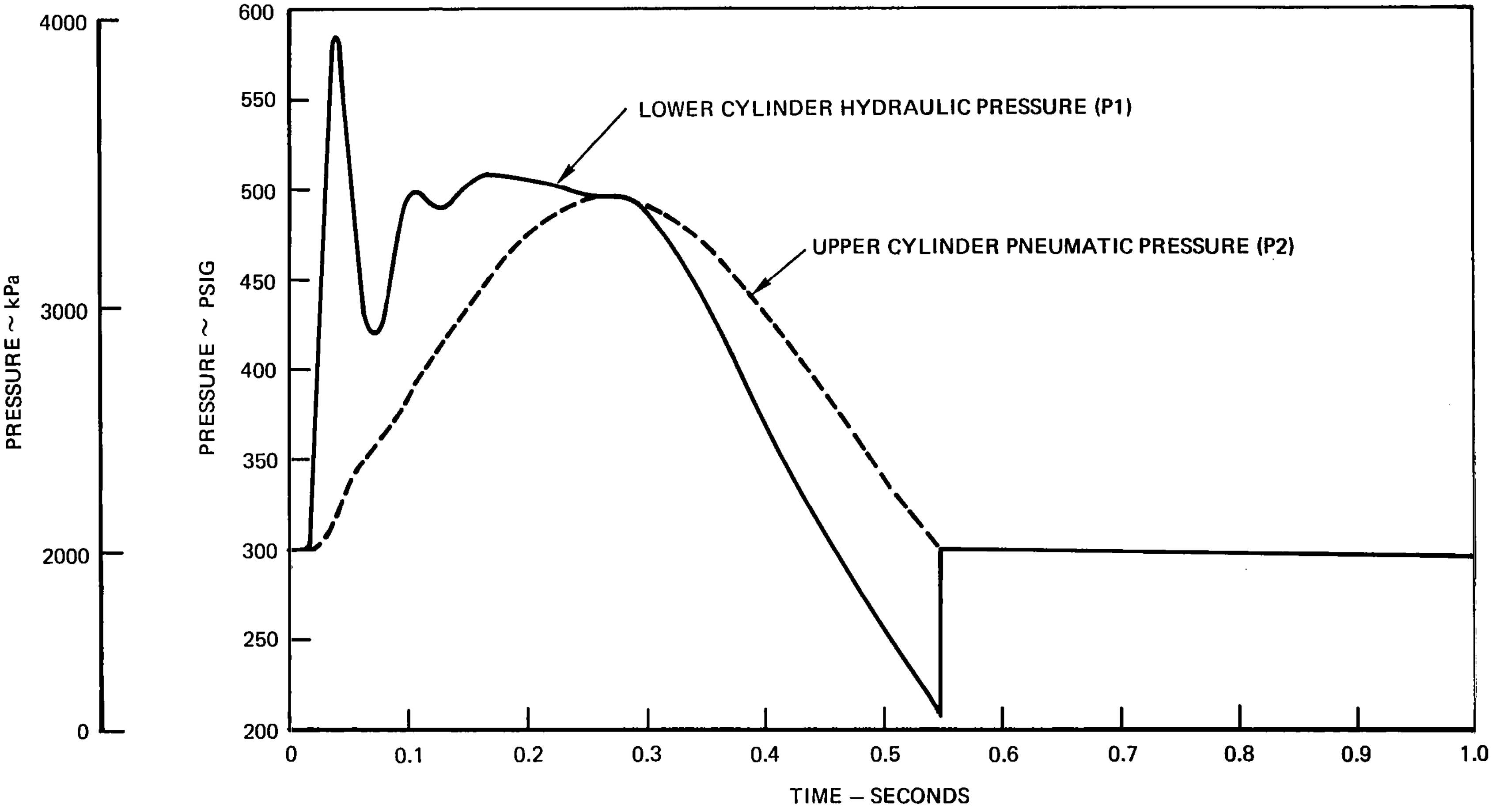


FIGURE 3-23 CASE 1 PASSIVE GEAR

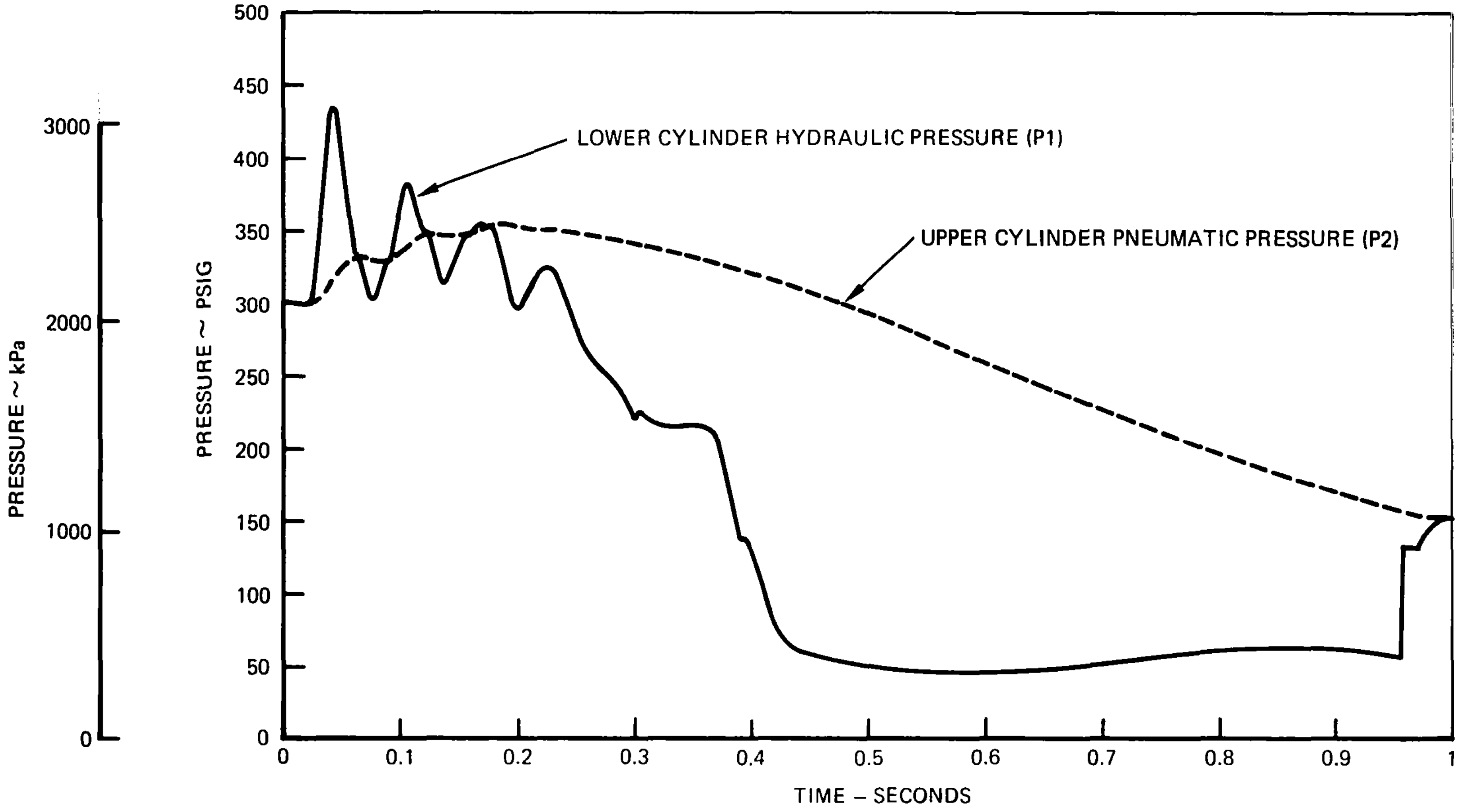


FIGURE 3-24 CASE 1 ACTIVE GEAR

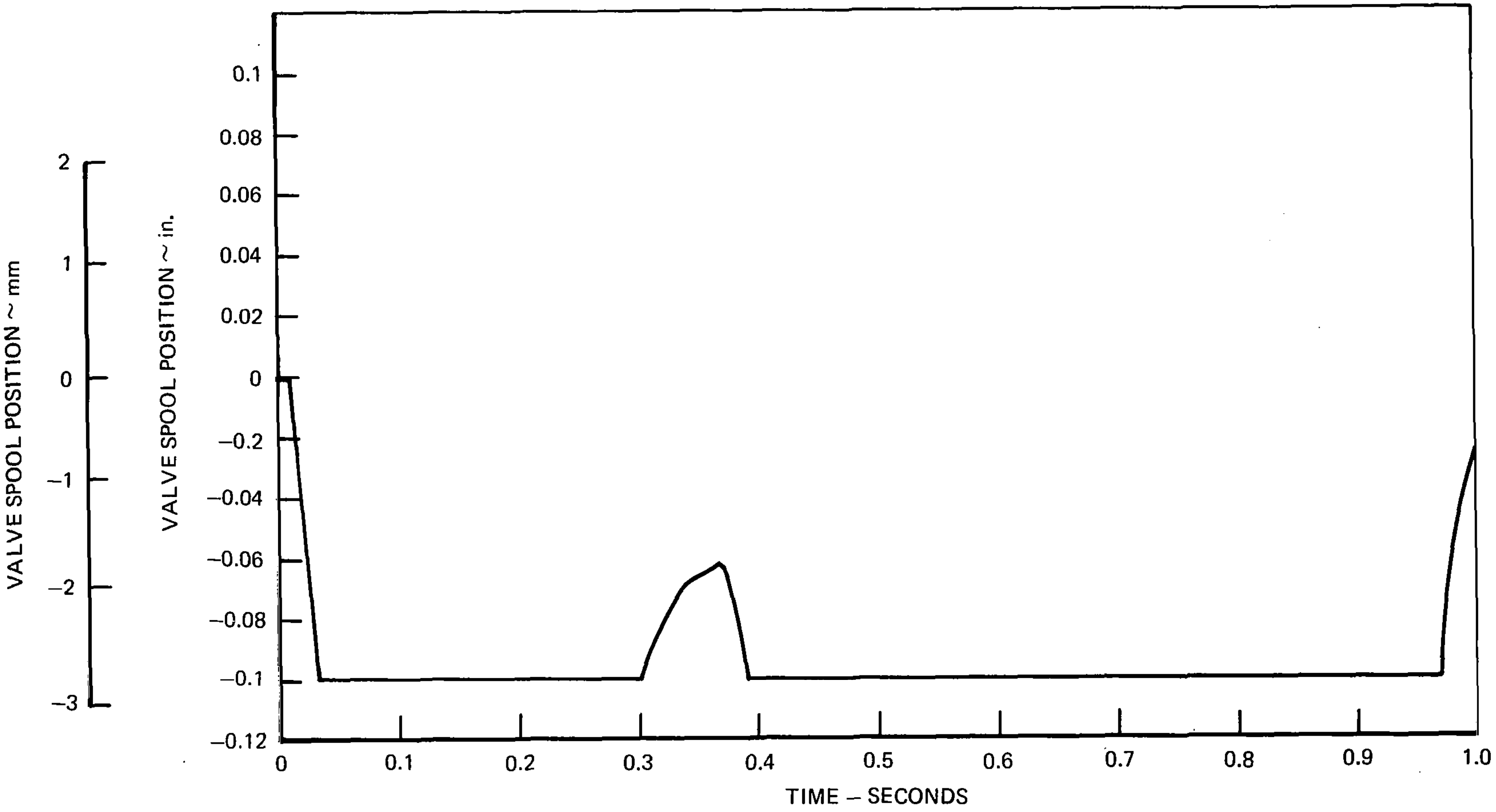


FIGURE 3-25 CASE 1 ACTIVE GEAR

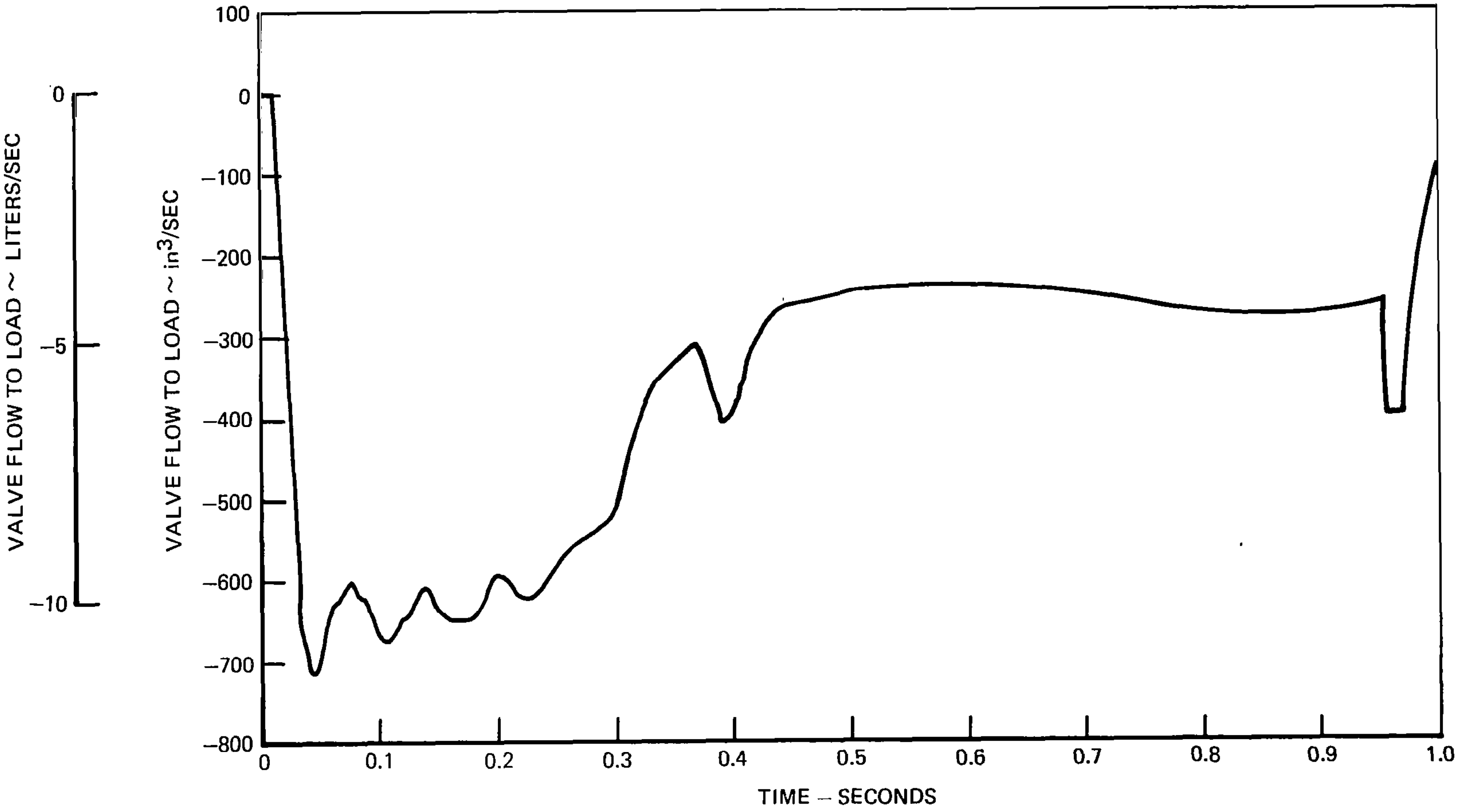


FIGURE 3-26 CASE 1 ACTIVE GEAR

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.

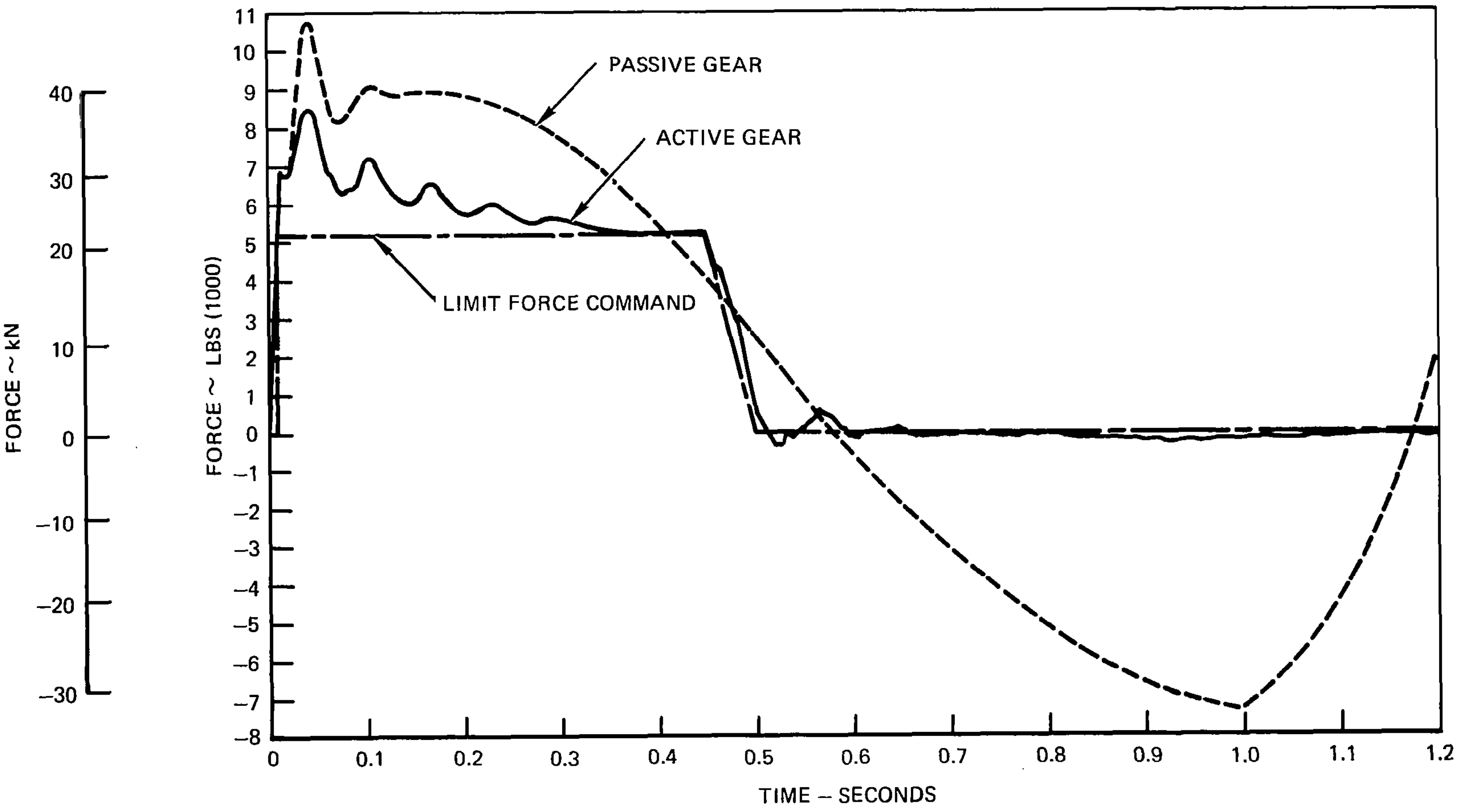


FIGURE 3-27 CASE 2

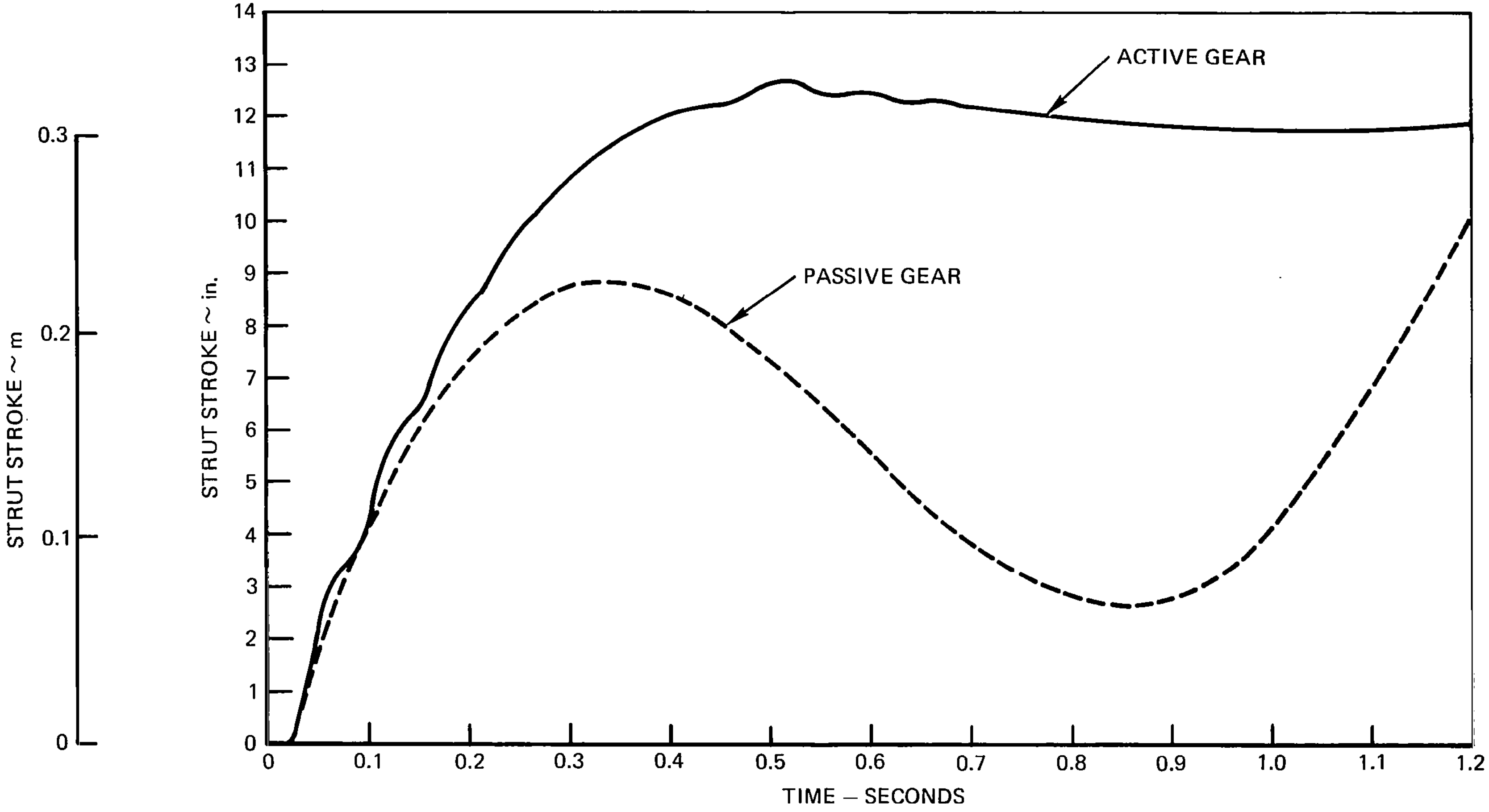


FIGURE 3-28 CASE 2

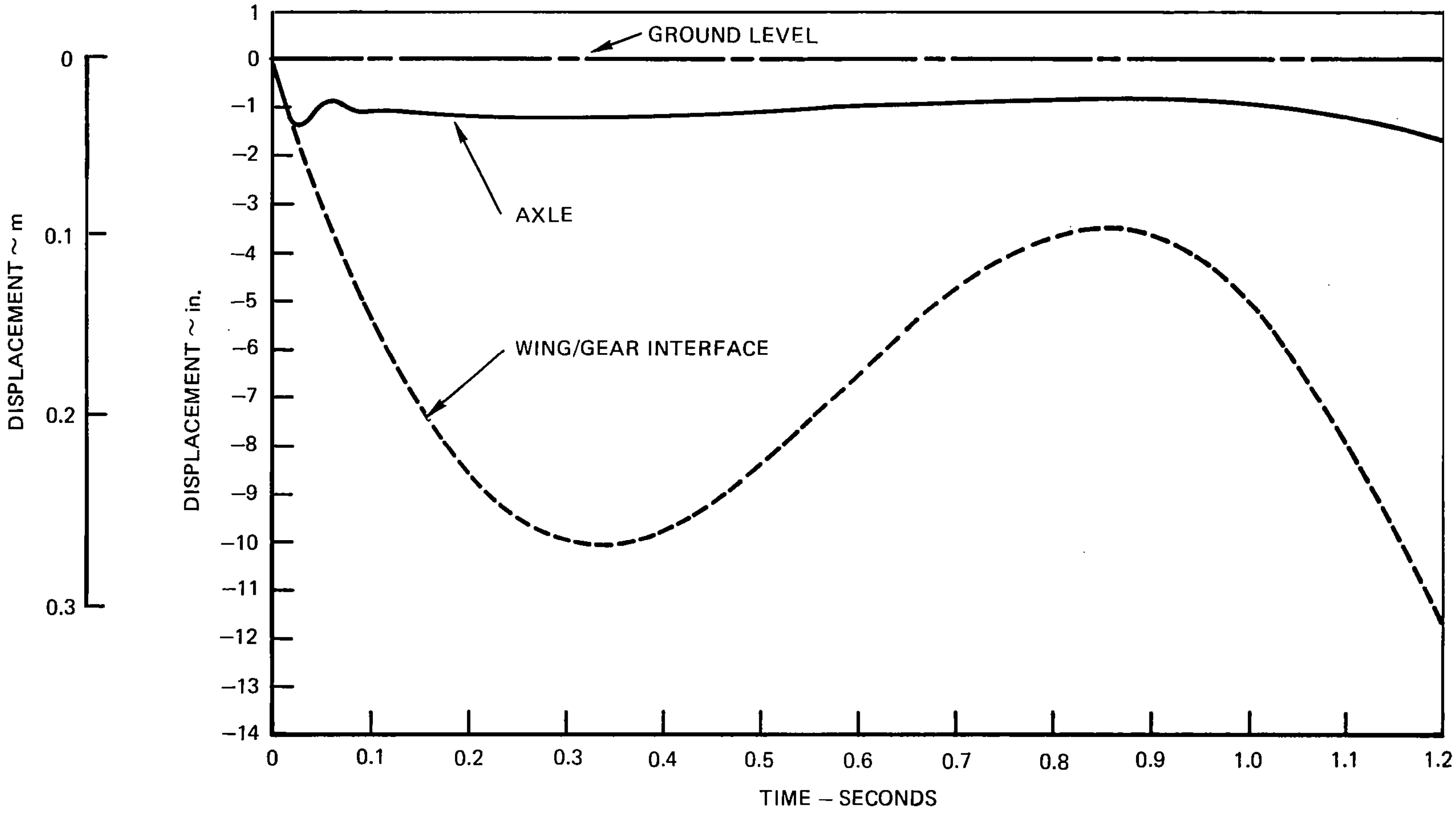


FIGURE 3-29 CASE 2 PASSIVE GEAR

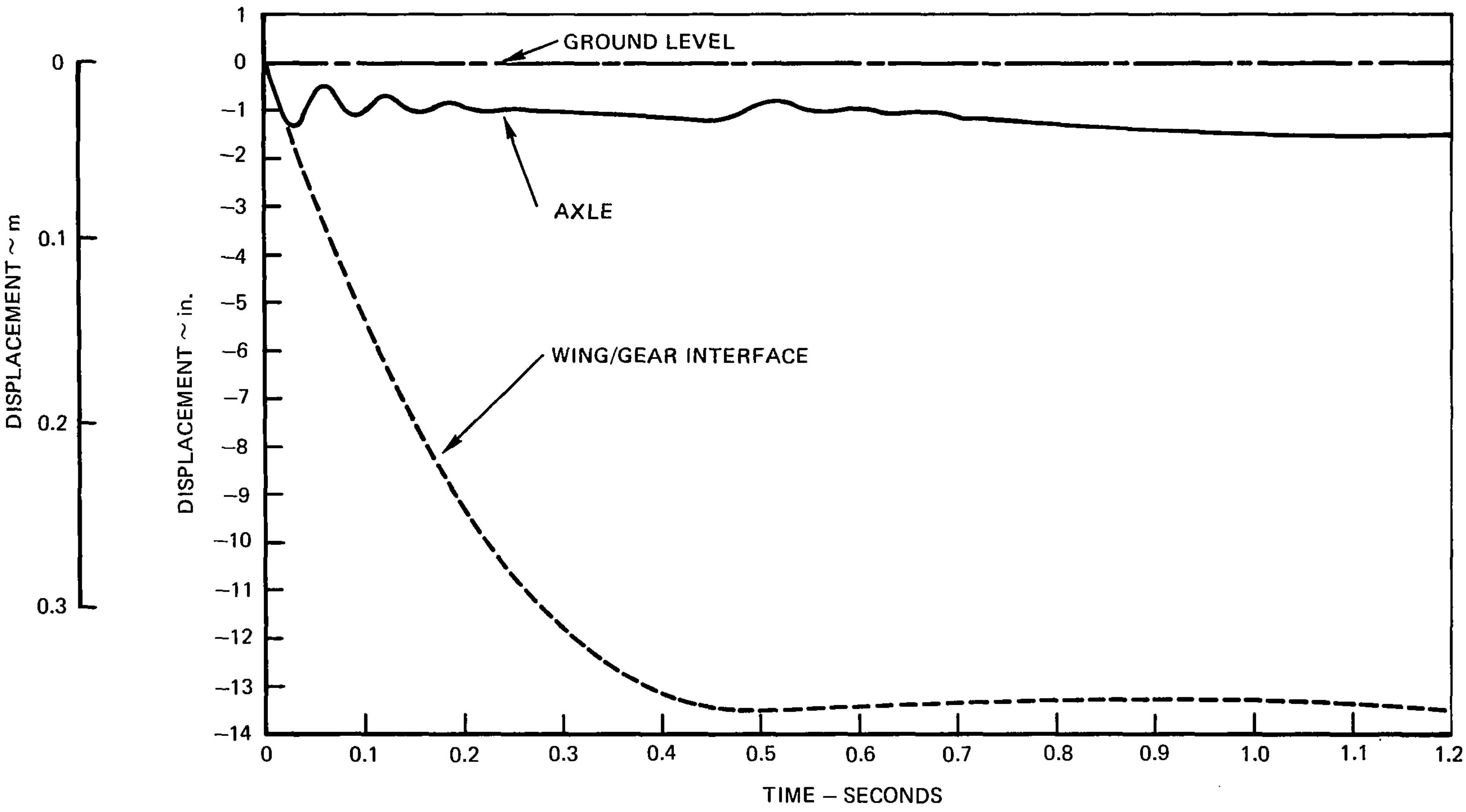


FIGURE 3-30 CASE 2 ACTIVE GEAR

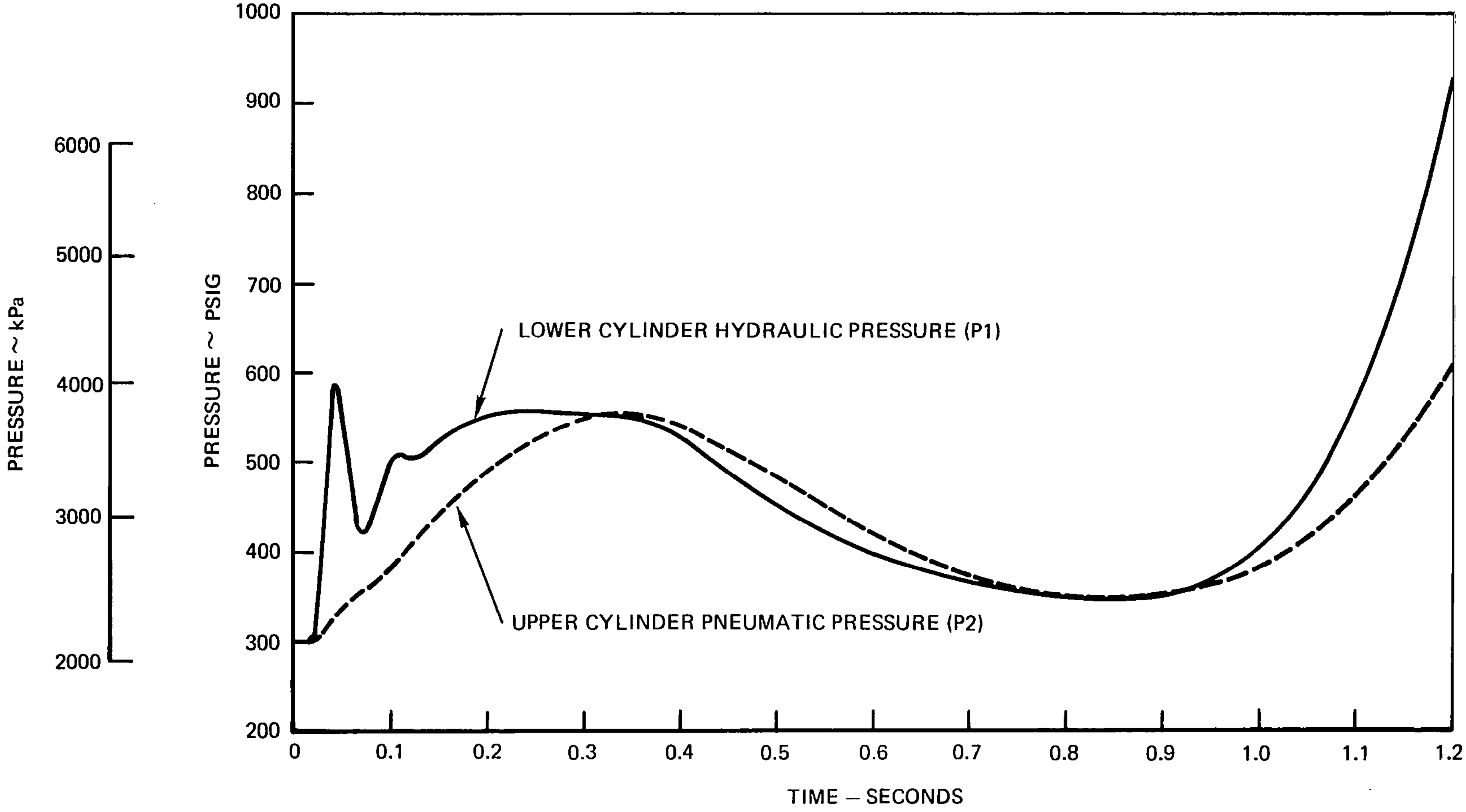


FIGURE 3-31 CASE 2 PASSIVE GEAR

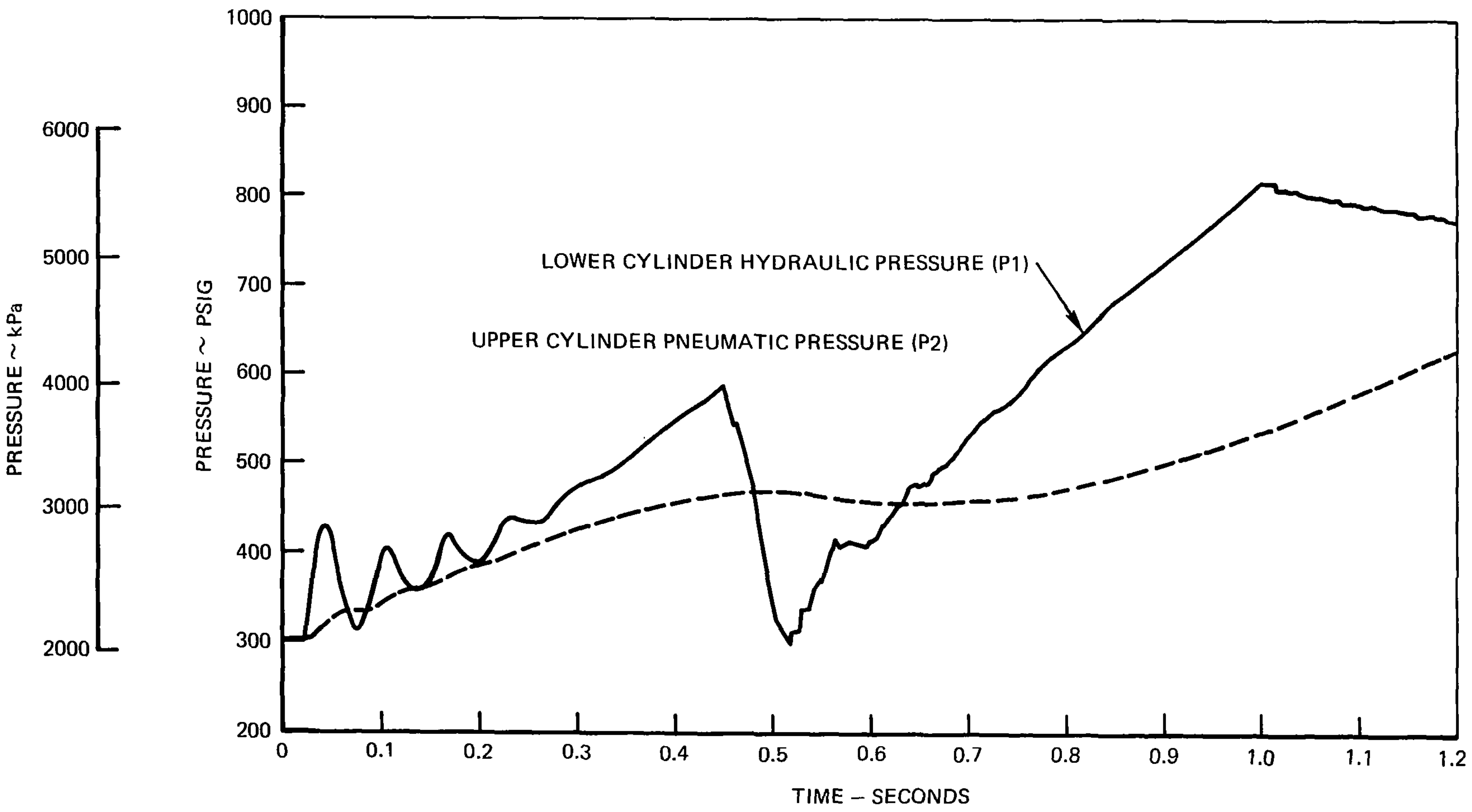


FIGURE 3-32 CASE 2 ACTIVE GEAR

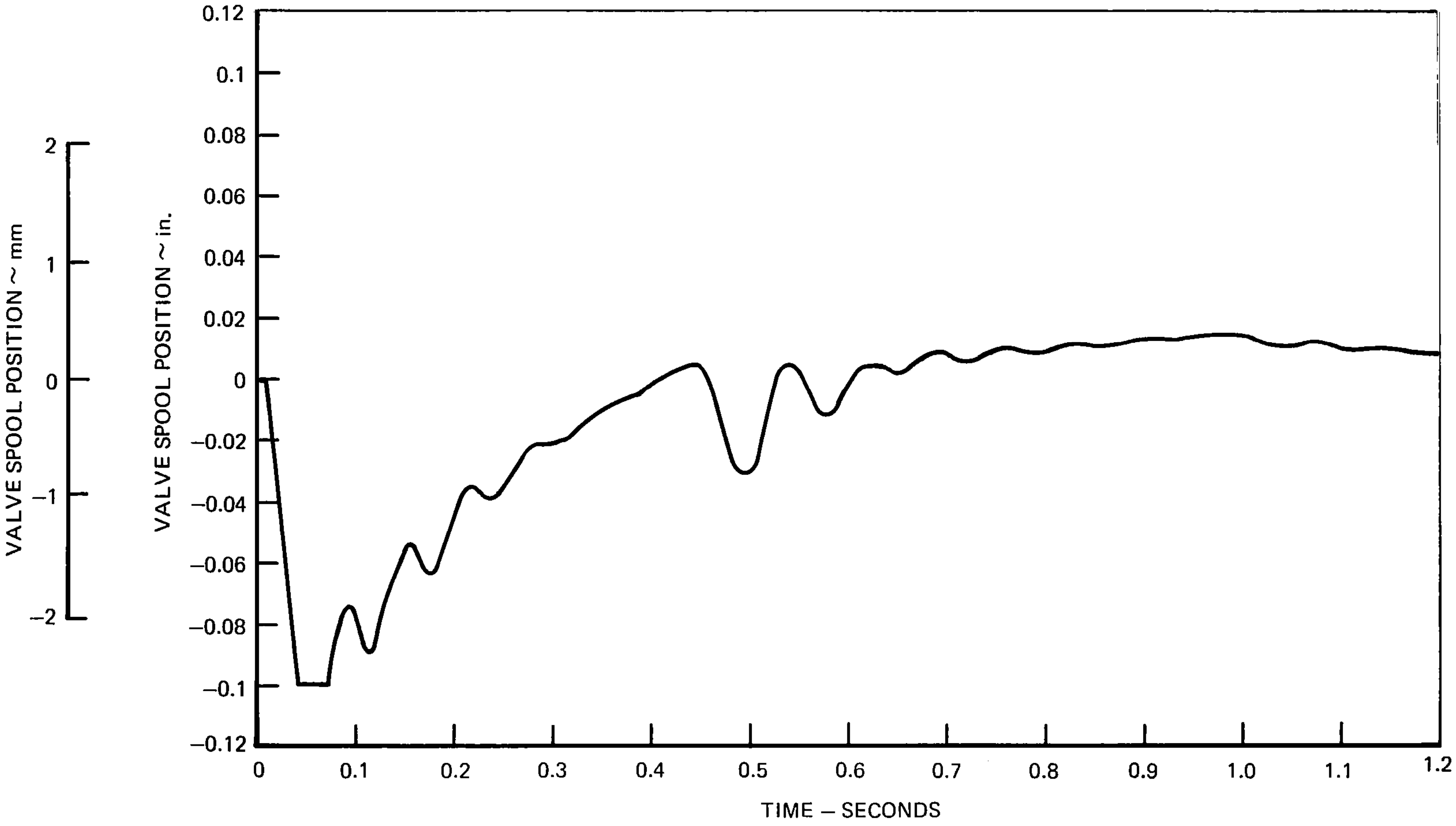


FIGURE 3-33 CASE 2 ACTIVE GEAR

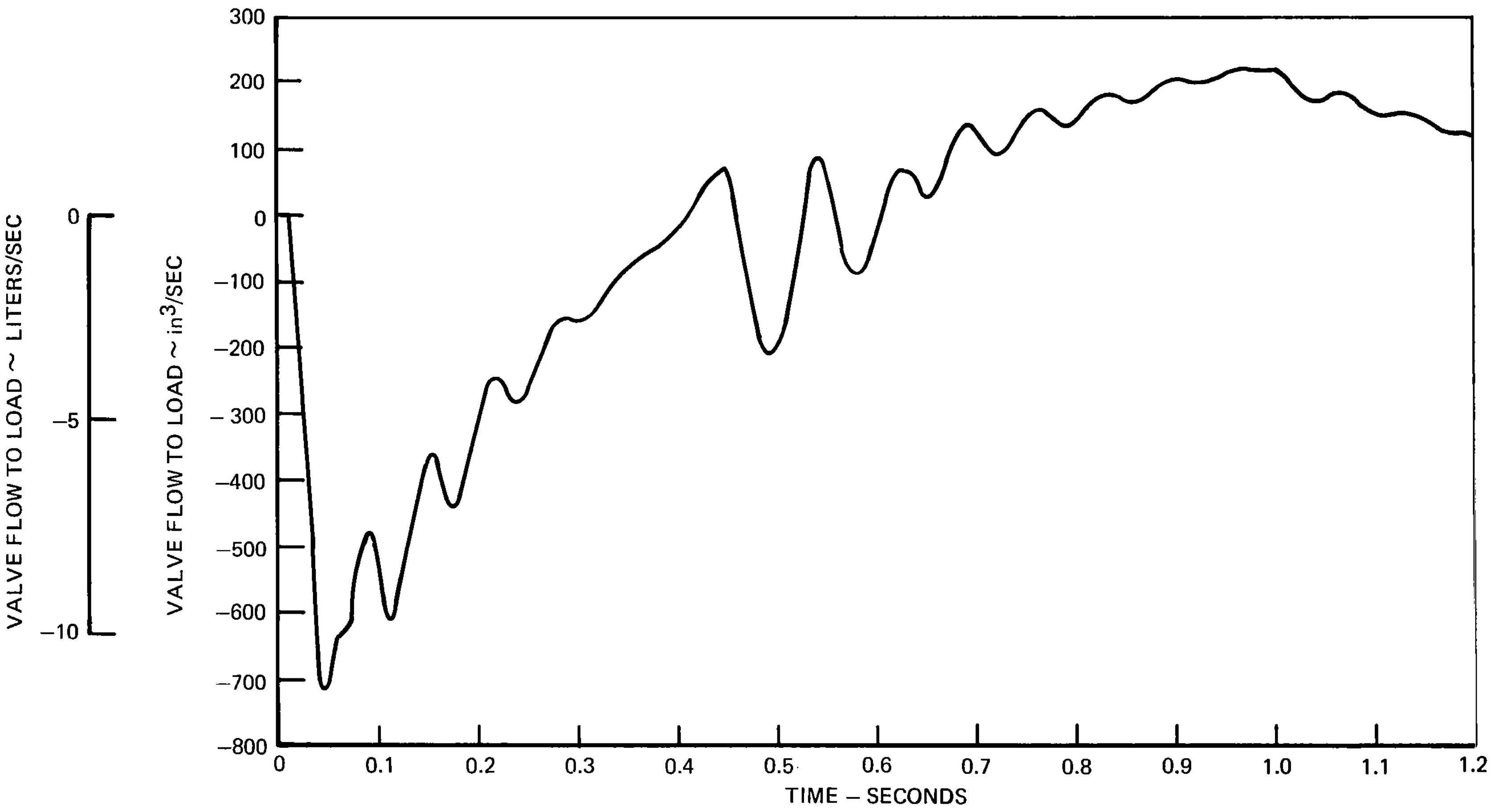


FIGURE 3-34 CASE 2 ACTIVE

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.

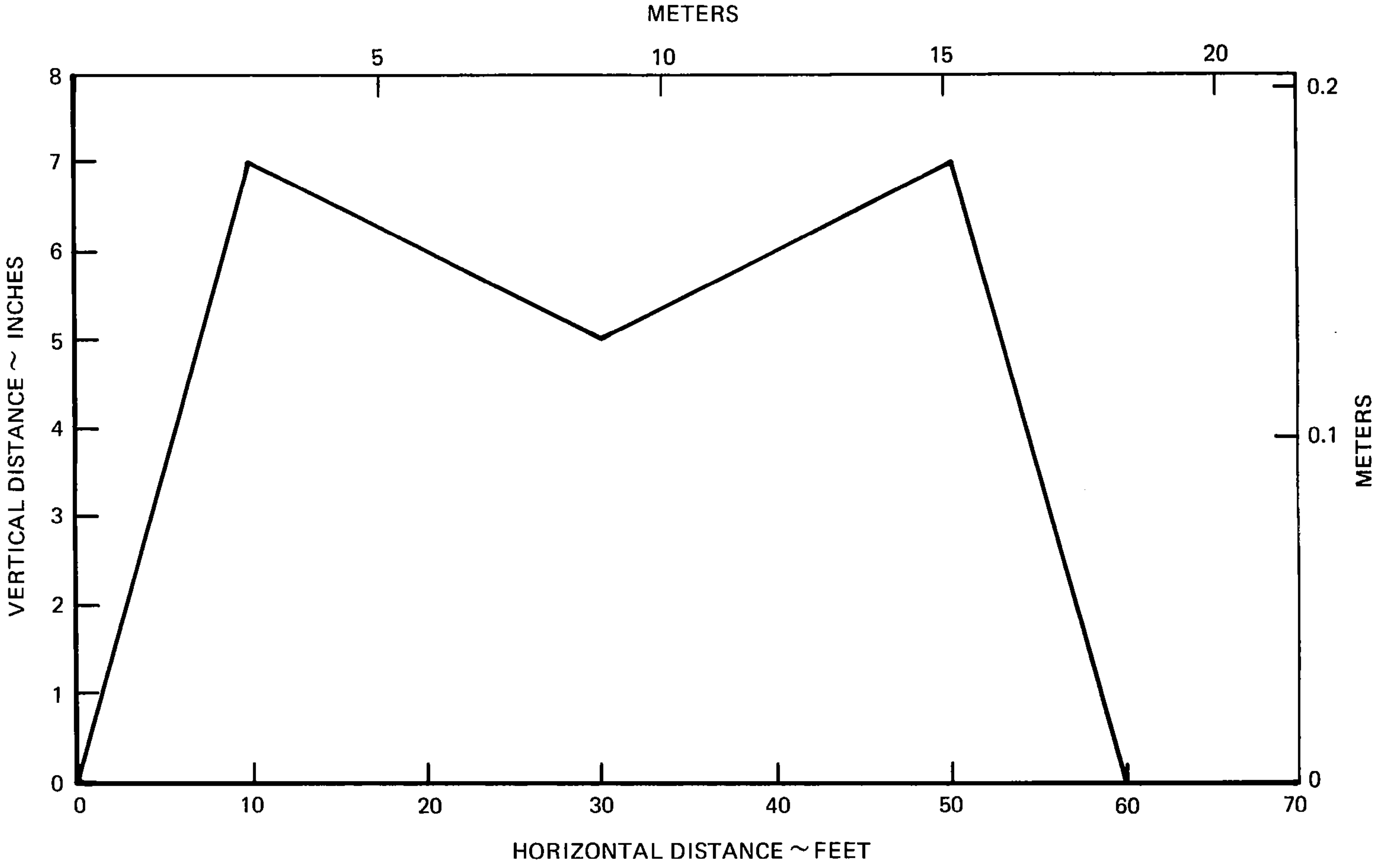


FIGURE 3-35. BOMB CRATER PROFILE

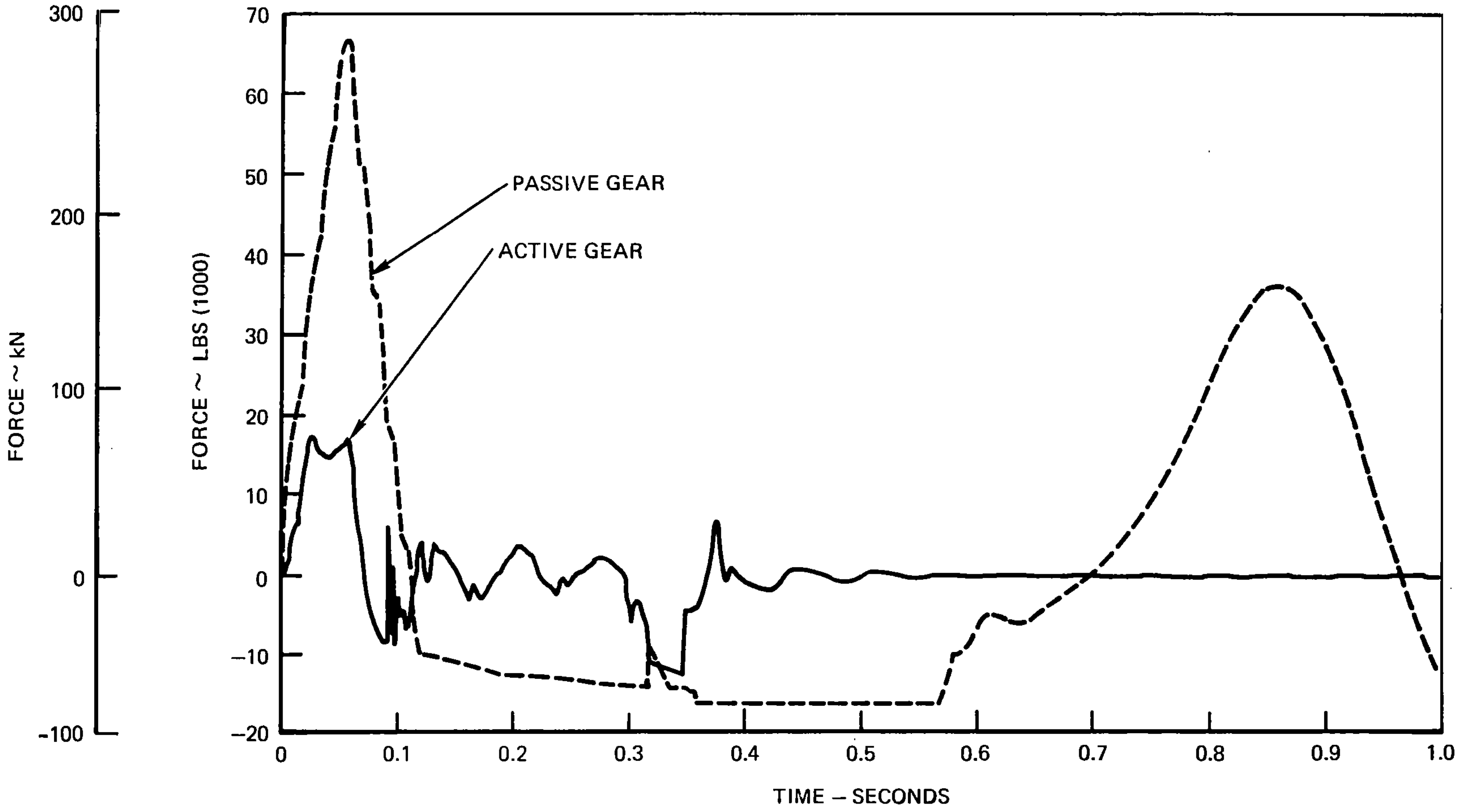


FIGURE 3-36 BOMB CRATER LANDING

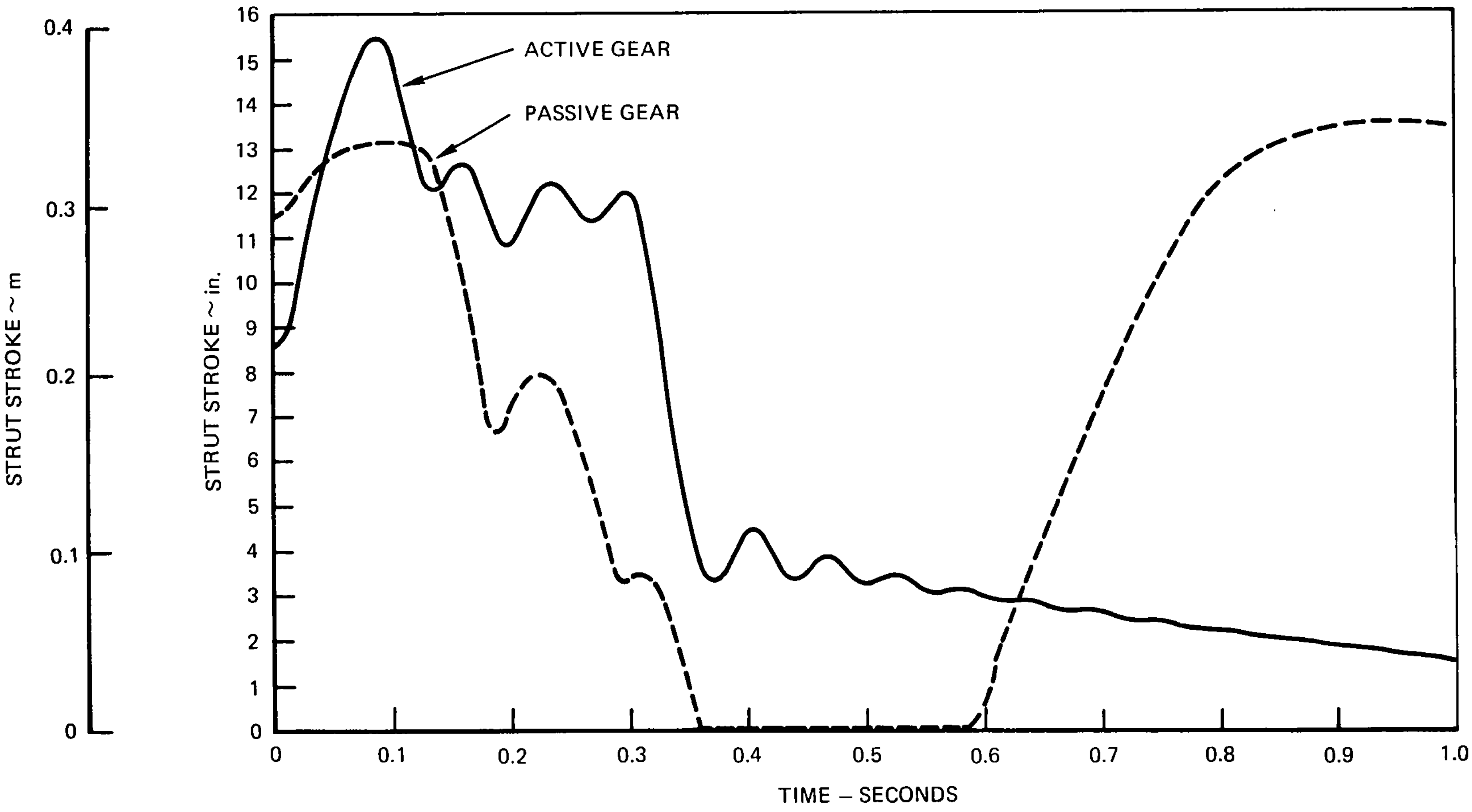


FIGURE 3-37 BOMB CRATER LANDING

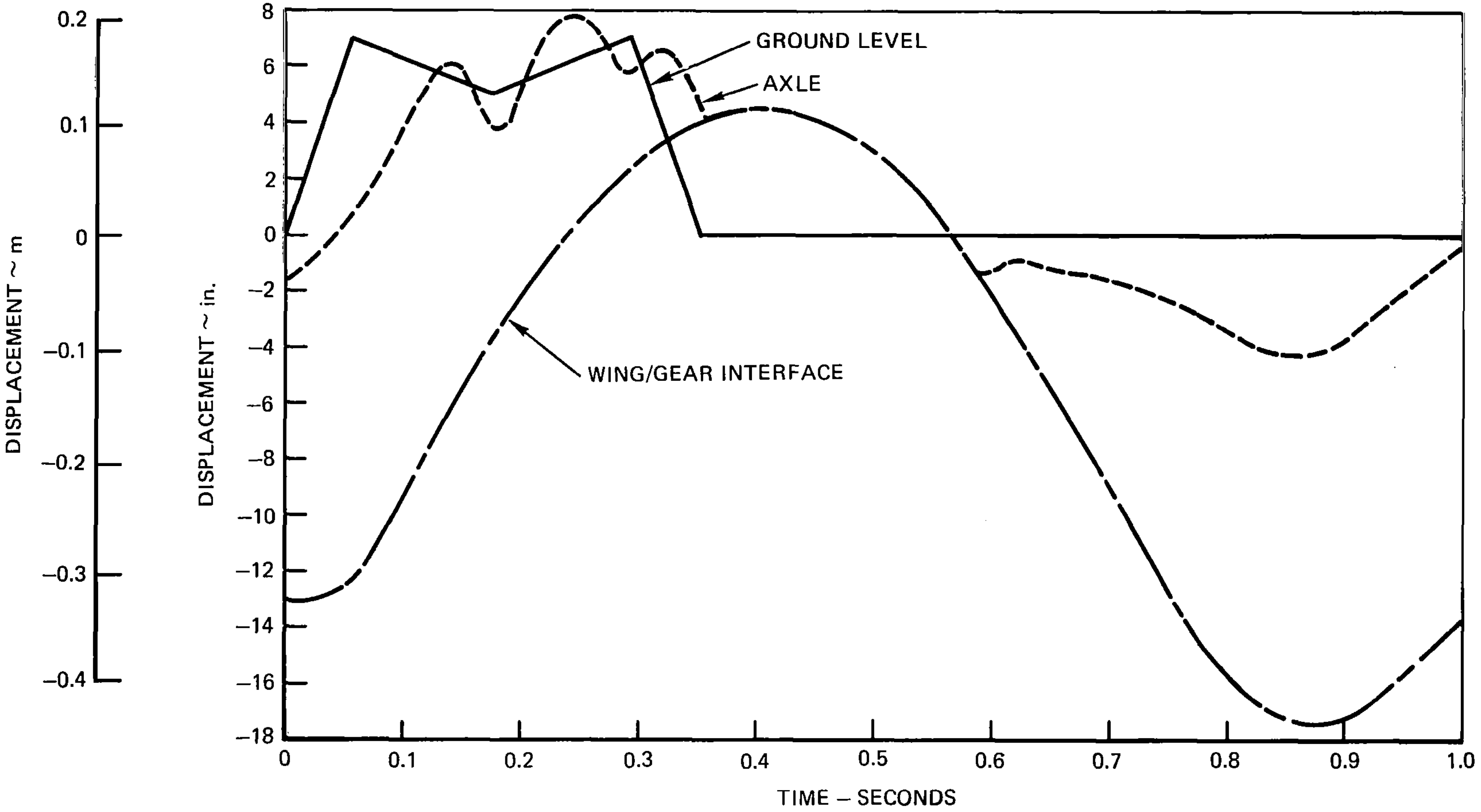


FIGURE 3-38 BOMB CRATER LANDING PASSIVE GEAR

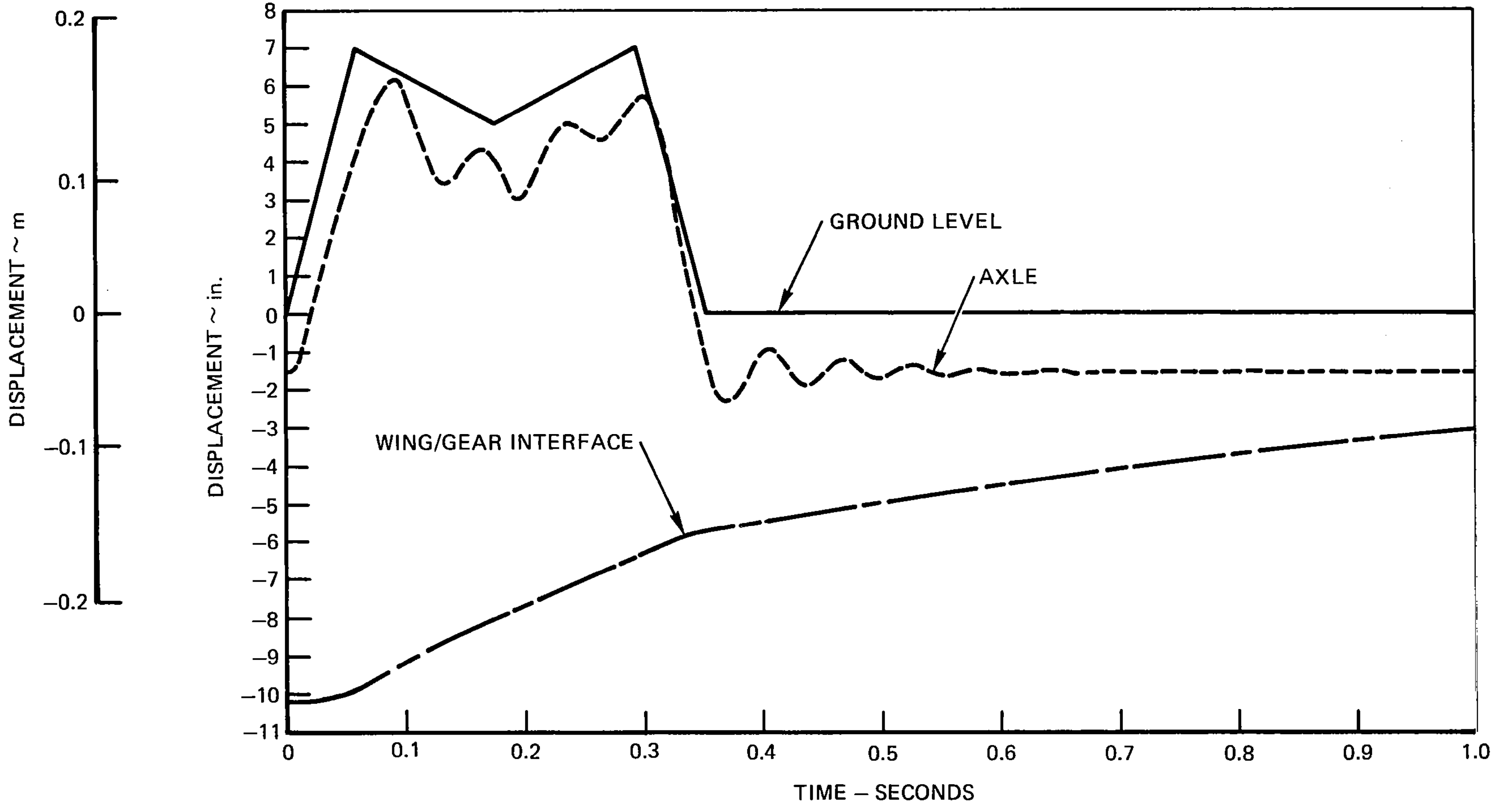


FIGURE 3-39 BOMB CRATER LANDING ACTIVE GEAR

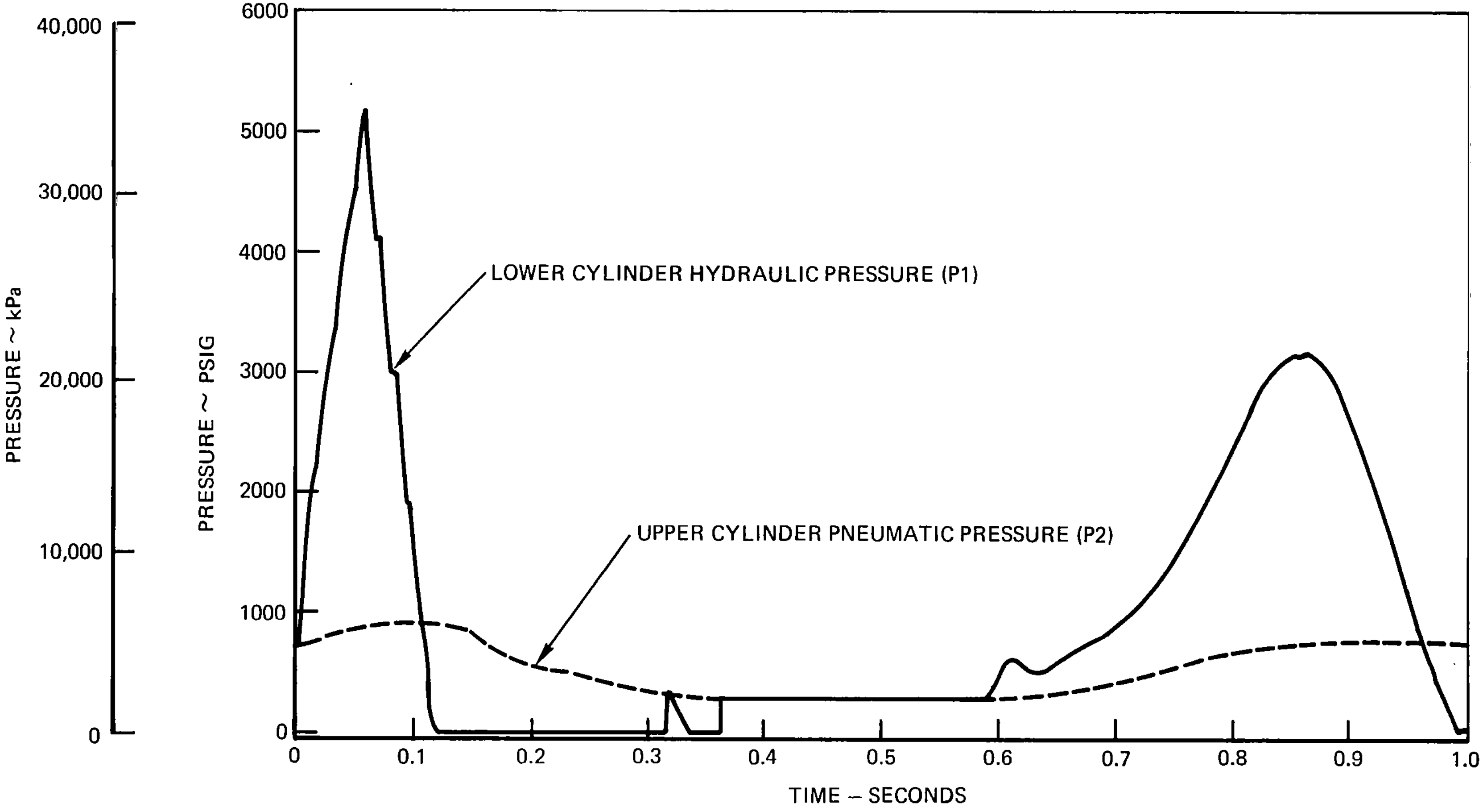


FIGURE 3-40 BOMB CRATER LANDING PASSIVE GEAR

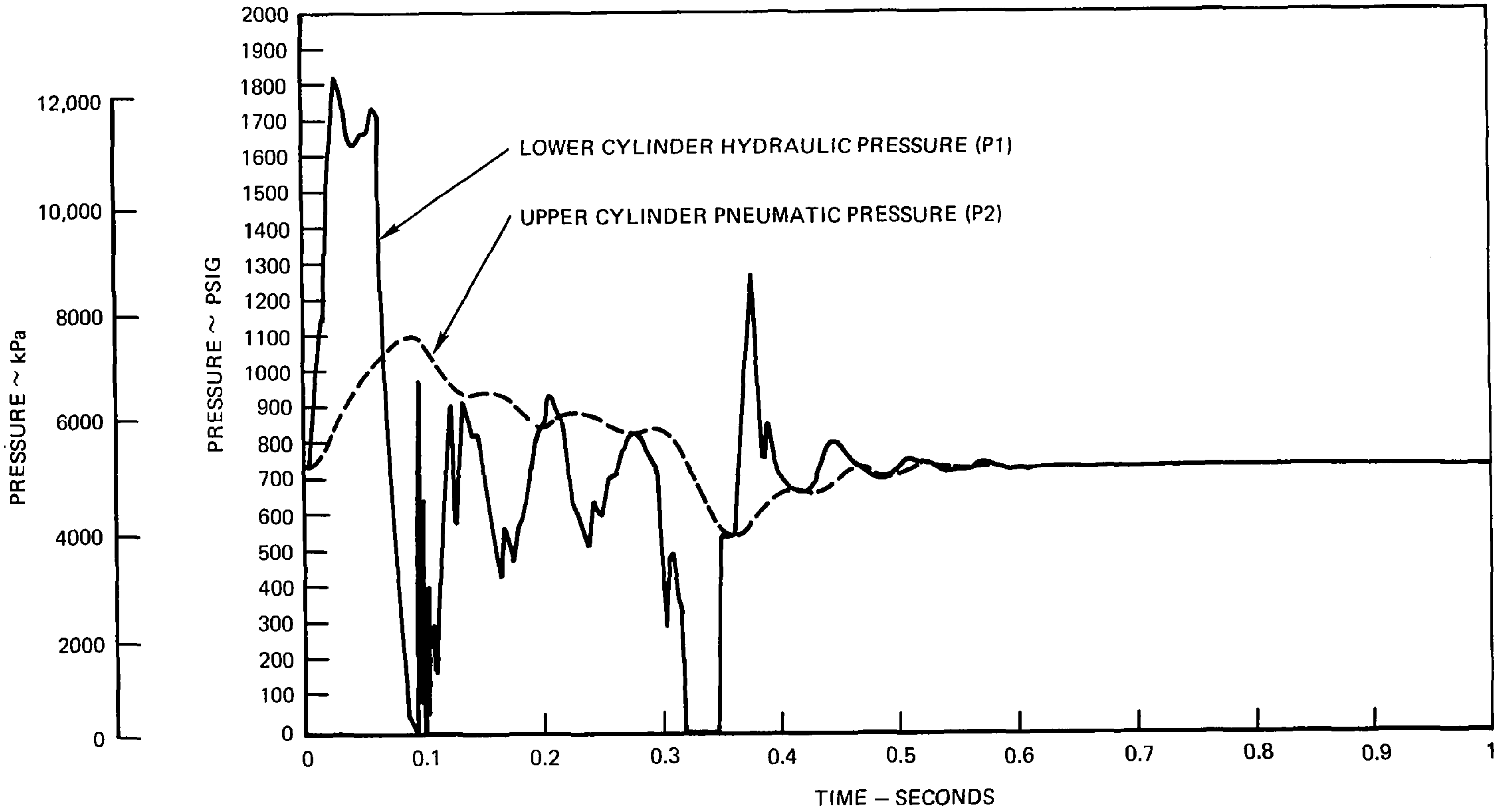


FIGURE 3-41 BOMB CRATER LANDING ACTIVE GEAR

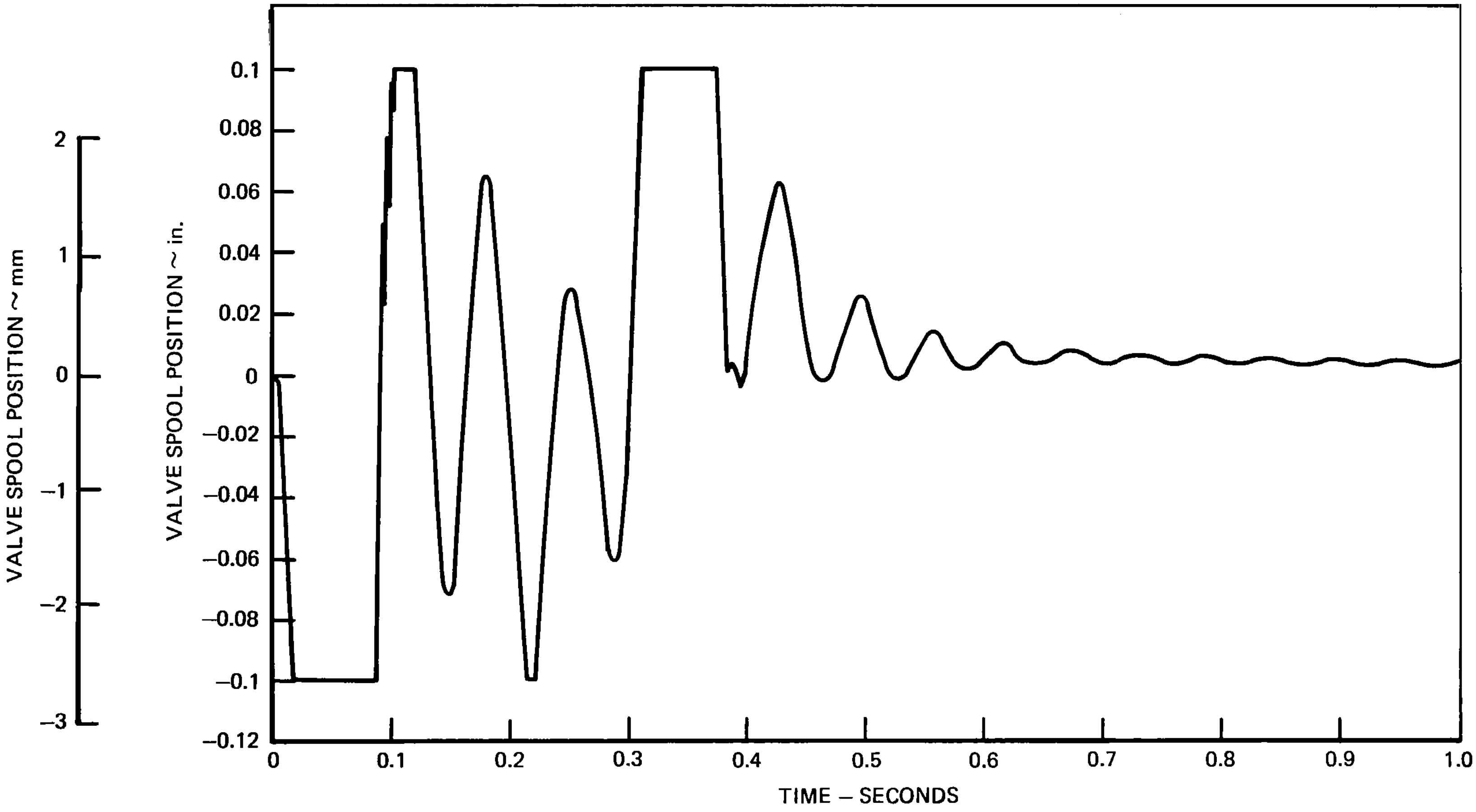


FIGURE 3-42 BOMB CRATER LANDING ACTIVE GEAR

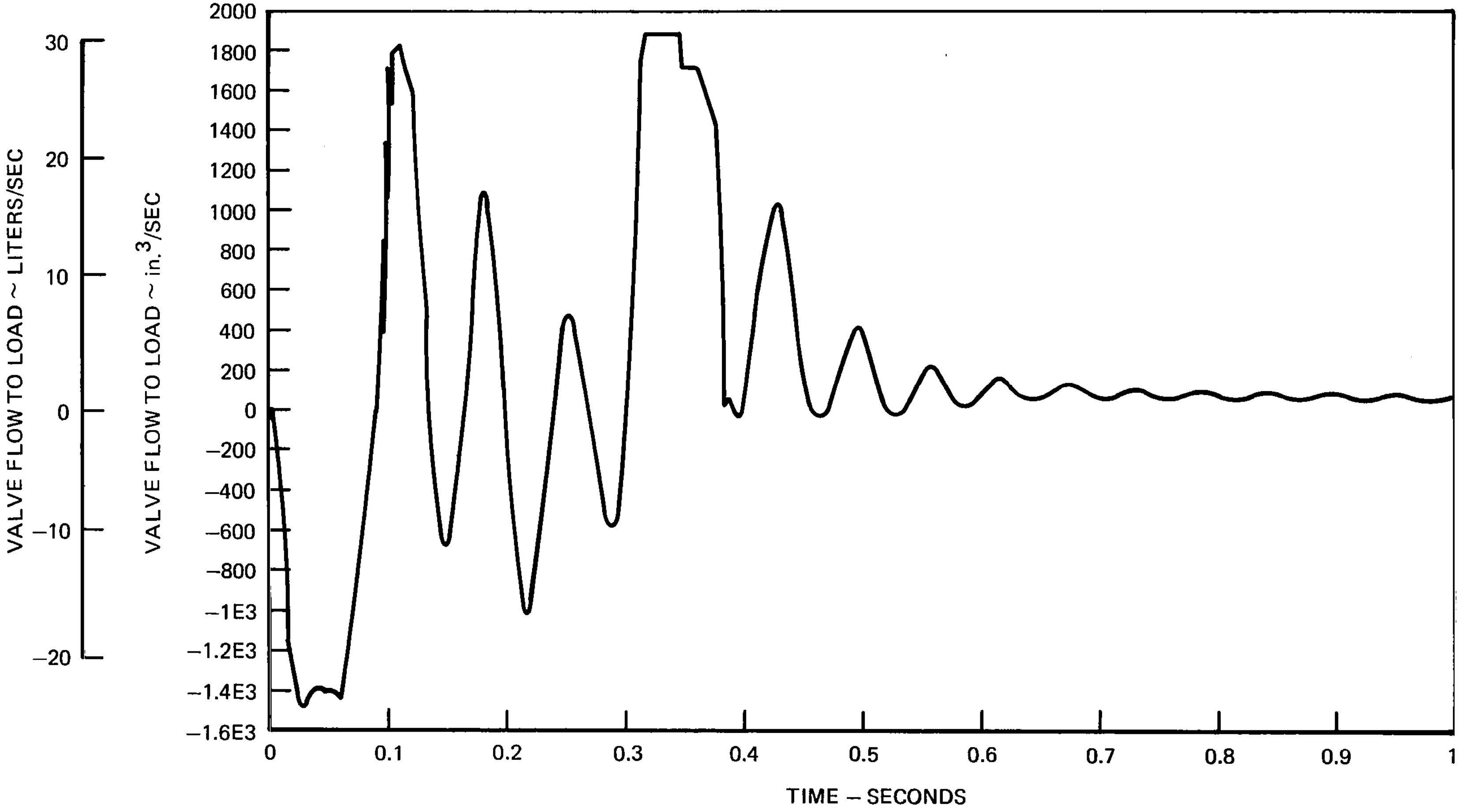
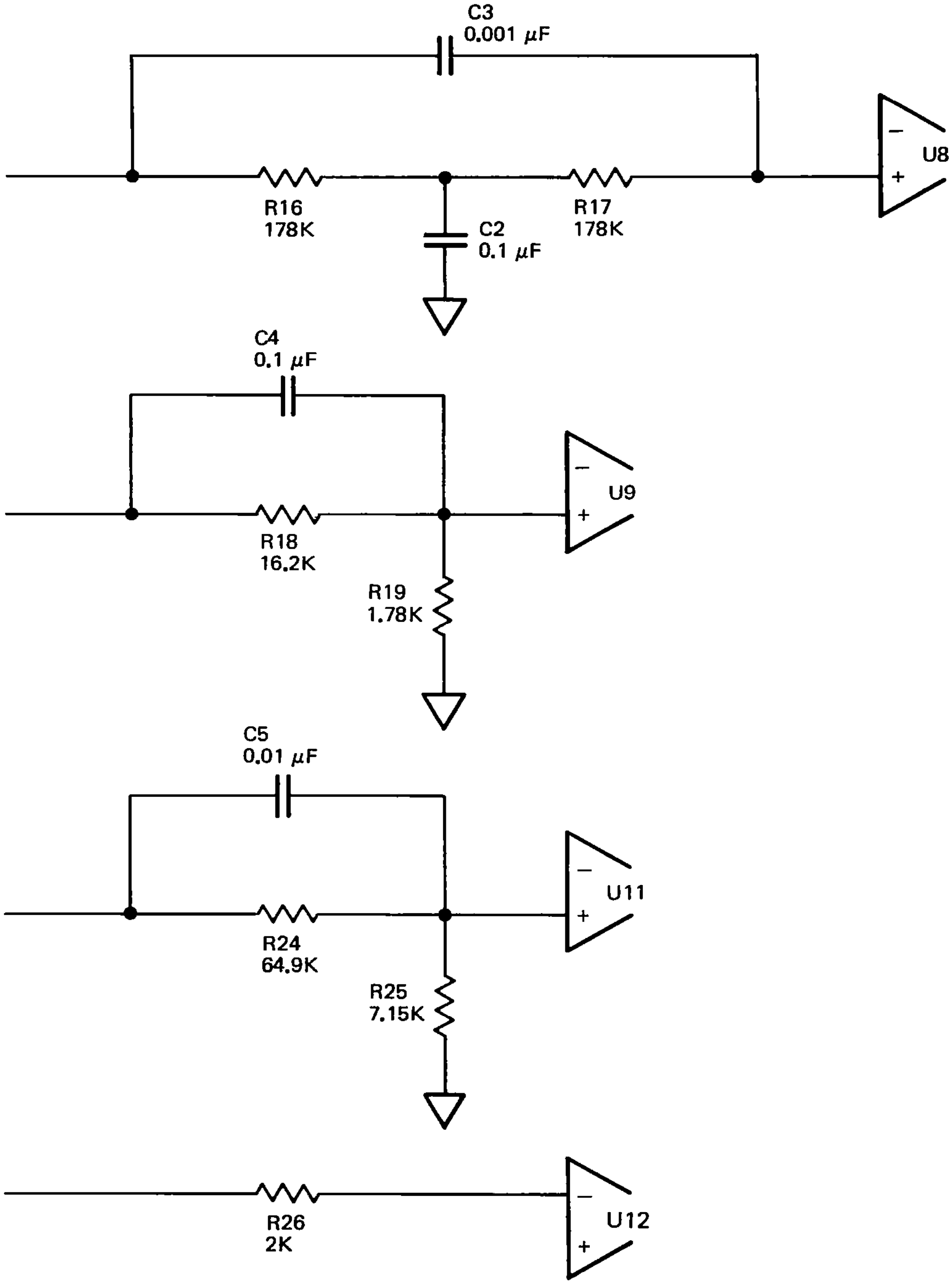


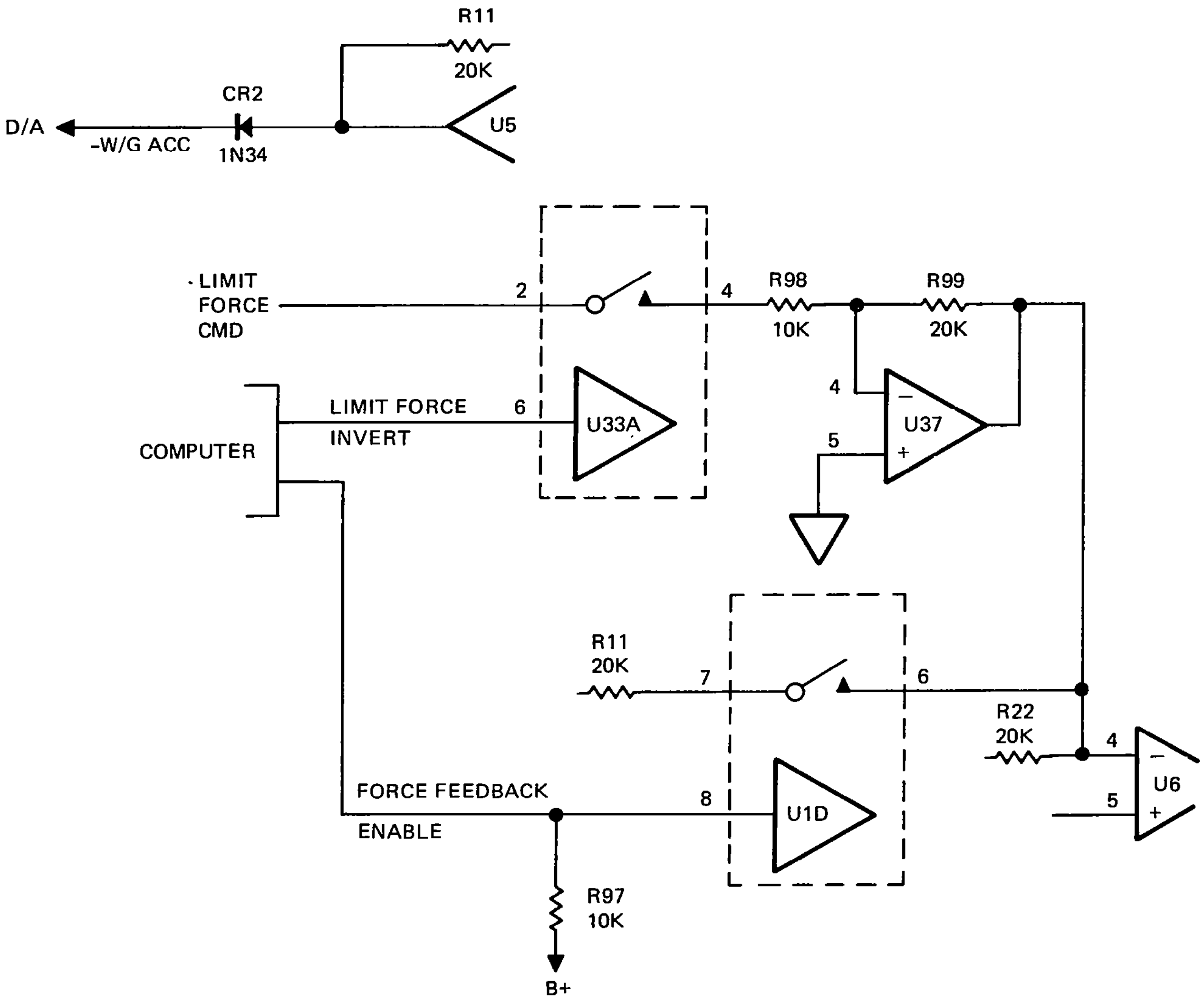
FIGURE 3-43 BOMB CRATER LANDING ACTIVE GEAR

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.

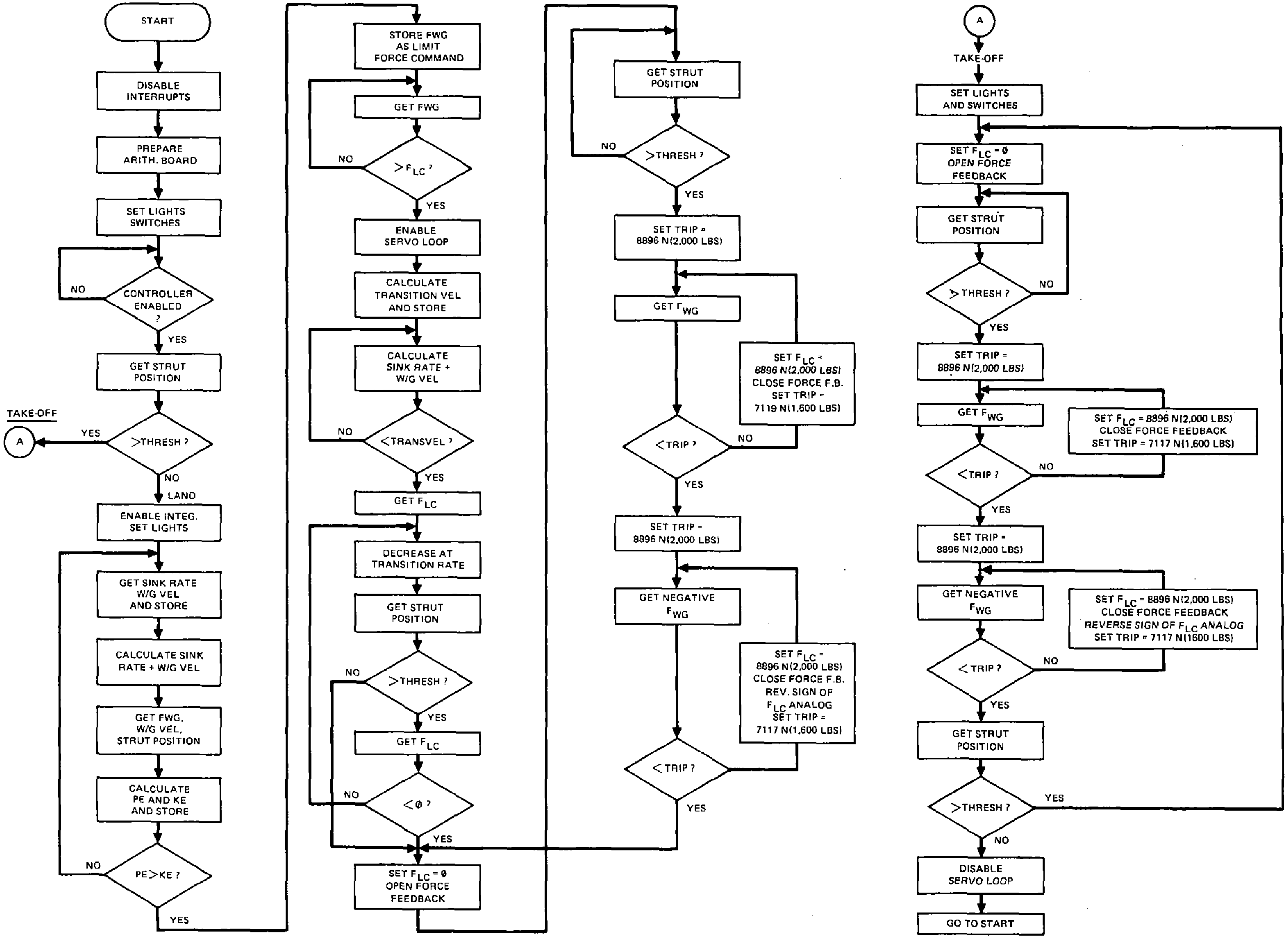


FIGURE 5-1 SOFTWARE FLOW CHART

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 x 409.5 = 4423 bits/g.

Since the aircraft weight is:

8.184×10^4 N (18,398 lb)

the scale factor in terms of force is:

0.05404 bits/N (0.2404 bits/lb)

(2) W/G Velocity:

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

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

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 v/m/sec/ (0.1 v/in/sec).

Digitally the scale factor is:

(3.94 v/m/sec)(409.5 bits/v) = 1614 bits/m/sec (40.95 bits/in/sec).

(3) Sink rate

The sink rate is scaled at

3.94 v/m/sec (0.1 v/in/sec)

or digitally at

1614 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 v for 0.508 m (20 in).

Its scale factor is then

19.96 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 v/m (0.3575 v/in).

Digitally the scale factor is

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

The maximum strut displacement is equivalent to:

(0.4034 m)(5766 bits/m) = 2325 bits

which is 0915 HEXADECIMAL (H).

(5) Work potential of the strut:

$$WP = Fwg\ (Xmax - Xs) = M\ddot{X}wg\ (Xmax - Xs)$$

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

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

WP is then $(8.184 \times 10^4 * 0.0254 = 2079$ 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,

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

The scale factor of WP is therefore:

$$\frac{6.4745\times10^5}{2079} = 3.114\times10^2 \text{bits/N-m} \quad (35.19 \text{ bits/lbf.in})$$

(6) Kinetic Energy:

$$KE = \tfrac{1}{2}\, W/g\ (V\ tot)^2 \text{ where } V\ tot = V \text{ touchdown} + \int_0^{\tau} \ddot{X}wgdt$$

If Vtot = 0.0254 m/sec (1 in/sec) then

$$KE = \tfrac{1}{2}\, \frac{(8.184\times10^4 N)}{(9.807\ m/sec^2)}\ (0.0254\ m/sec)^2 = 2.692 \text{ Nm } (23.83 \text{ lb in})$$

Digitally, from (2),

Vtot = (0.0254 m/sec)(3.94 v/m/sec)(409.5 bits/v) = 40.95 bits.

Then $KE = (40.95)^2 = 1676.9$ 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:

8.184×10^4 N (18,398 lbs_f) of F_{1I},

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

8184 N/v (1840 lbs_f/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 N/sec (10^5 lbf/sec)

or digitally at a rate of

2.226×10^4 bits/sec.

<u>(8) Transition velocity (Vt):</u>

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

W = 8.178×10^4 N (18,398 lb) and R = 4.445×10^5 (10^5 lb/sec)

then:

$$Vt = \frac{F_{1I}2}{2(9.178 \times 10^4/9.8)(4.445)10^5} = 1.348 \times 10^{-10}\ F_{1I}2$$

Therefore:

4.445 N (1 lb) produces:

2.663×10^{-9} m/sec (1.049×10^{-7}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:

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

The scale factor of Vt is therefore:

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

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

1614 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)=

0.00000000000001011010111001101010101011011100000001 Binary (B)

which equals:

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

The exponent is -14(D)

The bias in the arithmetic board is:

07F HEXIDECIMAL (H) or 127 (D)

Therefore the number must be applied with a bias of

127 -14 = 113 (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(D) = 6D (H) = 01101101 (B)

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

$$\overset{\text{Sign}}{0}\overbrace{01101101}^{\text{Exp.}}\overbrace{01101011100110101010110}^{\text{Fraction}}$$

$$\underbrace{00110110}_{M+3}\underbrace{10110101}_{M+2}\underbrace{11001101}_{M+1}\underbrace{01010110}_{M}$$

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

                        ;****************************************************
                        ;      PROGRAM FOR AN ELECTROHYDRAULIC ACTIVE
                        ;      CONTROL AIRCRAFT LANDING GEAR
                        ;****************************************************
                        ;  NOTES:
                        ;  RAM LOCATION 3D0EH ADDED AS A TEMP LOC
                        ;  FOR FLIM 2/13/80
                        ;****************************************************
                        ;  REVISED FOR F4 GEAR 6/28/81
                                ORG     00
0000'   F3              START:  DI              ;DISABLE INTERRUPTS
0001'   21 3FFF                 LXI     H,3FFFH ;INIT. STACK
0004'   F9                      SPHL
0005'   3E 82                   MVI     A,82H   ;INIT. MATH BOARD
0007'   D3 EB                   OUT     0EBH
0009'   3E 00                   MVI     A,00    ;SET MEM. BASE ADD.
000B'   D3 A1                   OUT     0A1H
000D'   3E 80                   MVI     A,80H
000F'   D3 A2                   OUT     0A2H
0011'   21 0092                 LXI     H,0092H ;STRUT THRESH.=1 IN.
                                                ;MULT THRESH BY 16
0014'   CD 0289'                CALL    ANM     ;FOR LATER USE
0017'   22 3F8A                 SHLD    3F8AH   ;LABLE BXTHR
001A'   3E 4C                   MVI     A,4CH   ;SET LIGHTS,SWITCHES
001C'   D3 EA                   OUT     0EAH
                        ;****************************************************
                        ;     OUTPUT MUX0-MUX4 FOR A/D BOARD CHECK
                        ;     ALSO LOOK FOR CONTROLLER ENABLED
                        ;****************************************************
001E'   16 03           TL1:    MVI     D,3
0020'   06 FF           TL2:    MVI     B,0FFH
0022'   0E 05                   MVI     C,5
0024'   7A              TL3:    MOV     A,D
0025'   CD 0251'                CALL    IN1
0028'   22 F708                 SHLD    0F708H  ;OUTPUT TO DAC0
002B'   DB E9                   IN      0E9H    ;CONTROLLER ENABLED?
002D'   1F                      RAR
002E'   DA 0042'                JC      L1      ;YES,JUMP TO L1
0031'   05                      DCR     B
0032'   C2 0024'                JNZ     TL3
0035'   06 FF                   MVI     B,0FFH
0037'   0D                      DCR     C
0038'   C2 0024'                JNZ     TL3
003B'   15                      DCR     D
003C'   FA 001E'                JM      TL1
003F'   C3 0020'                JMP     TL2
```

```
                        ;***************************************************
                        ;      CONTROLLER HAS BEEN ENABLED
                        ;***************************************************
0042'   3E 02           L1:     MVI     A,02
0044'   CD 0251'                CALL    IN1     ;GET STRUT POS FOR LAND/TO. DEC.
0047'   2A 3F8A                 LHLD    3F8AH   ;GET STRUT THRESHOLD
004A'   EB                      XCHG            ;PUT IN DE
004B'   2A 3F86                 LHLD    3F86H   ;LOAD HL WITH STRUT POSITION
004E'   CD 0282'                CALL    SUB2    ;CALC. THRESHOLD-STRUT
0051'   DA 01BD'                JC      L12A    ;YES, JUMP TO 12A
                        ;**************************************************
                        ;      LANDING - MAKE PREPARATIONS
                        ;**************************************************
0054'   3E 03                   MVI     A,03
0056'   CD 0251'                CALL    IN1     ;GET SINK RATE
0059'   22 3F88                 SHLD    3F88H   ;STORE IT
005C'   21 0915                 LXI     H,0915H ;MULT XMAX BY 16 TO SHIFT INTO
005F'   CD 0289'                CALL    ANM     ;UPPER 12 BITS
0062'   22 3F8C                 SHLD    3F8CH   ;STORE IT
                        ;**************************************************
                        ;     ENABLE INTEGRATOR
                        ;     START ENERGY CALCULATIONS
                        ;**************************************************
0065'   3E 9E                   MVI     A,9EH
0067'   D3 EA                   OUT     0EAH    ;ENABLE INTEGRATOR
0069'   CD 0220'        L8:     CALL    IN3
006C'   EB                      XCHG
006D'   2A 3F8C                 LHLD    3F8CH
0070'   EB                      XCHG
0071'   7B                      MOV     A,E
0072'   95                      SUB     L
0073'   6F                      MOV     L,A
0074'   7A                      MOV     A,D
0075'   9C                      SBB     H
0076'   67                      MOV     H,A
0077'   22 8004                 SHLD    8004H
007A'   AF                      XRA     A
007B'   CD 028E'                CALL    MATH
007E'   2A 8000                 LHLD    8000H
0081'   22 3F8E                 SHLD    3F8EH
0084'   2A 8002                 LHLD    8002H
0087'   22 3F90                 SHLD    3F90H
008A'   2A 3F88                 LHLD    3F88H
008D'   EB                      XCHG
008E'   2A 3F84                 LHLD    3F84H
0091'   CD 0282'                CALL    SUB2
```

```
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.
                               00133                             ;GREATER THAN FLIM?
00D8'    F2 00CF'              00134           JP       CHACEL   ;NO-LOOP TILL IT IS
(00DB-00E0) = 00 (NOP)         00135           ;CALL    SPTH     ;HAS GEAR STARTED STROKE?
                               00136           ;JP      CHACEL   ;LOOP TILL GEAR ) THRESHOLD
00E1'    3E 9F                 00137           MVI      A,9FH
00E3'    D3 EA                 00138           OUT      0EAH     ;ENABLE SERVOLOOP
```

```
                         ;*****************************************************
                         ;      GEAR IS NOW UNDER ACTIVE CONTROL
                         ;*****************************************************
00E5'   2A 3D0E                  LHLD    3D0EH    ;GET ORIGINAL FLIM TO CALCULATE
00E8'   22 8000                  SHLD    8000H    ;TRANSITION VELOCITY
00EB'   21 0000                  LXI     H,0000
00EE'   22 8002                  SHLD    8002H
00F1'   3E 08                    MVI     A,08
00F3'   CD 028E'                 CALL    MATH
00F6'   3E 06                    MVI     A,06
00F8'   CD 028E'                 CALL    MATH
00FB'   3E 36                    MVI     A,36H
00FD'   32 8004                  STA     8004H
0100'   3E B5                    MVI     A,0B5H
0102'   32 8005                  STA     8005H
0105'   3E CD                    MVI     A,0CDH
0107'   32 8006                  STA     8006H
010A'   3E 56                    MVI     A,56H
010C'   32 8007                  STA     8007H
010F'   3E 02                    MVI     A,02
0111'   CD 028E'                 CALL    MATH
0114'   2A 8000                  LHLD    8000H
0117'   22 3F92                  SHLD    3F92H
011A'   2A 8002                  LHLD    8002H
011D'   22 3F94                  SHLD    3F94H
                         ;*****************************************************
                         ;      TRANSITION VELOCITY STORED AS FLOATING PT,32 BIT
                         ;      NUMBER.  START COMPARING THIS AGAINST (SINK RATE
                         ;      -W/G VEL.) TO DETERMINE START OF TRANSITION
                         ;*****************************************************
0120'   2A 3F88          L4:     LHLD    3F88H
0123'   EB                       XCHG
0124'   3E 00                    MVI     A,00
0126'   CD 0251'                 CALL    IN1
0129'   CD 0282'                 CALL    SUB2
012C'   22 8000                  SHLD    8000H
012F'   21 0000                  LXI     H,0000
0132'   22 8002                  SHLD    8002H
0135'   3E 08                    MVI     A,08
0137'   CD 028E'                 CALL    MATH
013A'   2A 3F92                  LHLD    3F92H
013D'   22 8004                  SHLD    8004H
0140'   2A 3F94                  LHLD    3F94H
0143'   22 8006                  SHLD    8006H
0146'   3E 0A                    MVI     A,0AH
0148'   CD 028E'                 CALL    MATH
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01B3'   3E 9D          00231   L14:    MVI     A,9DH
01B5'   D3 EA          00232           OUT     0EAH     ;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    0F70AH   ;SET LIMIT FORCE CMD=0 LBS.
01C3'   3E A9          00240           MVI     A,0A9H
01C5'   D3 EA          00241           OUT     0EAH     ;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           LHLD    8000H
01D6'   22 F708        00247           SHLD    0F708H   ;OUTPUT W/G ACCEL TO DAC0
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    0F708H   ;OUTPUT W/G ACCEL TO DAC0
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     0EAH     ;OF LIMIT FORCE CMD (ANALOG)
01F5'   22 F70A        00258           SHLD    0F70AH   ;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    0F70AH   ;SET LIMIT FORCE CMD=2000 LBS
0204'   3E AD          00263   L14A:   MVI     A,0ADH
0206'   D3 EA          00264           OUT     0EAH     ;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       0A1H
014D'   E6 20            00186            ANI      20H
014F'   CA 0120'         00187            JZ       L4
                         00188    ;*****************************************************
                         00189    ;      TRANSITION PHASE
                         00190    ;*****************************************************
0152'   2A 3D0E          00191            LHLD     3D0EH    ;FLIM
0155'   11 FFFE          00192            LXI      D,0FFFEH
0158'   22 F70A          00193    L5:     SHLD     0F70AH
015B'   19               00194            DAD      D
015C'   CD 020E'         00195    EXST:   CALL     SPTH     ;CHECK (THRESH.-STRUT POS'N)
015F'   F2 016C'         00196            JP       L12
0162'   01 1BD0          00197            LXI      B,1BD0H
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     0F70AH   ;SET FLC=0 LBS.
0172'   3E 99            00208            MVI      A,99H
0174'   D3 EA            00209            OUT      0EAH     ;OPEN FORCE FEEDBACK
0176'   CD 020E'         00210    FLO:    CALL     SPTH     ;CHECK STRUT POS'N.
0179'   F2 0176'         00211            JP       FLO
017C'   01 1EE0          00212            LXI      B,1EE0H  ;SET BC TO 2000 LBS.
017F'   CD 0220'         00213    L15:    CALL     IN3
0182'   2A 8000          00214            LHLD     8000H
0185'   22 F708          00215            SHLD     0F708H   ;OUTPUT W/G ACCEL. TO DAC0
0188'   CD 027D'         00216            CALL     FTEST
018B'   D2 01AD'         00217            JNC      L13
018E'   01 1EE0          00218            LXI      B,1EE0H  ;SET BC TO 2000 LBS.
0191'   CD 0266'         00219    L16:    CALL     IN4
0194'   22 F708          00220            SHLD     0F708H   ;OUTPUT W/G ACCEL TO DAC0
0197'   CD 027D'         00221            CALL     FTEST
019A'   DA 016C'         00222            JC       L12
019D'   21 1EE0          00223            LXI      H,1EE0H  ;SET HL TO 2000 LBS.
01A0'   3E 95            00224            MVI      A,95H    ;CLOSE F FDBK & REV. SIGN
01A2'   D3 EA            00225            OUT      0EAH     ;OF LIMIT FORCE CMD (ANALOG)
01A4'   22 F70A          00226            SHLD     0F70AH   ;SET LIMIT FORCE CMD=2000 LBS
01A7'   01 1800          00227            LXI      B,1800H  ;SET BC TO 1600 LBS
01AA'   C3 0191'         00228            JMP      L16
01AD'   21 1EE0          00229    L13:    LXI      H,1EE0H  ;SET HL TO 2000 LBS
01B0'   22 F70A          00230            SHLD     0F70AH   ;SET LIMIT FORCE CMD=2000 LBS
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0216'   EB                        XCHG
0217'   2A 3F86                   LHLD     3F86H    ;GET STRUT POSITION
021A'   CD 0282'                  CALL     SUB2     ;SUBTRACT STRUT FROM THRESH.
021D'   D1                        POP      D
021E'   E1                        POP      H
021F'   C9                        RET
                          ;******************************************************
                          ;     ROUTINE TO INPUT AND STORE DATA FROM MUX0,1 & 2
                          ;******************************************************
0220'   3E 01             IN3:    MVI      A,01
0222'   21 F701                   LXI      H,0F701H
0225'   77                        MOV      M,A
0226'   2B                        DCX      H
0227'   36 01                     MVI      M,01
0229'   7E                M1:     MOV      A,M
022A'   07                        RLC
022B'   D2 0229'                  JNC      M1
022E'   36 00                     MVI      M,00
0230'   2A F704                   LHLD     0F704H
0233'   22 8000                   SHLD     8000H
0236'   22 3F80                   SHLD     3F80H
0239'   3E 00                     MVI      A,00
023B'   21 F701                   LXI      H,0F701H
023E'   77                        MOV      M,A
023F'   2B                        DCX      H
0240'   36 01                     MVI      M,01
0242'   7E                M2:     MOV      A,M
0243'   07                        RLC
0244'   D2 0242'                  JNC      M2
0247'   36 00                     MVI      M,00
0249'   2A F704                   LHLD     0F704H
024C'   22 3F84                   SHLD     3F84H
024F'   3E 02             STP:    MVI      A,02
0251'   21 F701           IN1:    LXI      H,0F701H
0254'   77                        MOV      M,A
0255'   2B                        DCX      H
0256'   36 01                     MVI      M,01
0258'   7E                M3:     MOV      A,M
0259'   07                        RLC
025A'   D2 0258'                  JNC      M3
025D'   36 00                     MVI      M,00
025F'   2A F704                   LHLD     0F704H
0262'   22 3F86                   SHLD     3F86H
0265'   C9                        RET
                          ;******************************************************
                          ;     ROUTINE TO INPUT AND STORE DATA FROM MUX4
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                             00323   ;*****************************************************
0266'    3E 04               00324   IN4:     MVI       A,04
0268'    21 F701             00325            LXI       H,0F701H
026B'    77                  00326            MOV       M,A
026C'    2B                  00327            DCX       H
026D'    36 01               00328            MVI       M,01
026F'    7E                  00329   M4:      MOV       A,M
0270'    07                  00330            RLC
0271'    D2 026F'            00331            JNC       M4
0274'    36 00               00332            MVI       M,00
0276'    2A F704             00333            LHLD      0F704H
0279'    22 3F96             00334            SHLD      3F96H
027C'    C9                  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       0A0H
0290'    DB A7               00368   WAIT:    IN        0A7H
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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   PGA:   MVI     M,00
  02A7'   36 C0                   00395          MVI     M,0C0H
  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   R2:    LXI     H,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)
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                         ASSEMBLED AT 3D10

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                      ;*****************************************************
                      ;      PROGRAM FOR AN ELECTROHYDRAULIC ACTIVE
                      ;      CONTROL AIRCRAFT LANDING GEAR
                      ;*****************************************************
                      ;  NOTES:
                      ;  RAM LOCATION 3D0EH ADDED AS A TEMP LOC
                      ;  FOR FLIM 2/13/80
                      ;*****************************************************
                      ;  REVISED FOR F4 GEAR 6/28/81
                              ORG     3D10H
3D10'   F3            START:  DI              ;DISABLE INTERRUPTS
3D11'   21 3FFF               LXI     H,3FFFH ;INIT. STACK
3D14'   F9                    SPHL
3D15'   3E 82                 MVI     A,82H   ;INIT. MATH BOARD
3D17'   D3 EB                 OUT     0EBH
3D19'   3E 00                 MVI     A,00    ;SET MEM. BASE ADD.
3D1B'   D3 A1                 OUT     0A1H
3D1D'   3E 80                 MVI     A,80H
3D1F'   D3 A2                 OUT     0A2H
3D21'   21 0092               LXI     H,0092H ;STRUT THRESH.=1 IN.
                                              ;MULT THRESH BY 16
3D24'   CD 3F99'              CALL    ANM     ;FOR LATER USE
3D27'   22 3F8A               SHLD    3F8AH   ;LABLE BXTHR
3D2A'   3E 4C                 MVI     A,4CH   ;SET LIGHTS,SWITCHES
3D2C'   D3 EA                 OUT     0EAH
                      ;*****************************************************
                      ;      OUTPUT MUX0-MUX4 FOR A/D BOARD CHECK
                      ;      ALSO LOOK FOR CONTROLLER ENABLED
                      ;*****************************************************
3D2E'   16 03         TL1:    MVI     D,3
3D30'   06 FF         TL2:    MVI     B,0FFH
3D32'   0E 05                 MVI     C,5
3D34'   7A            TL3:    MOV     A,D
3D35'   CD 3F61'              CALL    IN1
3D38'   22 F708               SHLD    0F708H  ;OUTPUT TO DAC0
3D3B'   DB E9                 IN      0E9H    ;CONTROLLER ENABLED?
3D3D'   1F                    RAR
3D3E'   DA 3D52'              JC      L1      ;YES,JUMP TO L1
3D41'   05                    DCR     B
3D42'   C2 3D34'              JNZ     TL3
3D45'   06 FF                 MVI     B,0FFH
3D47'   0D                    DCR     C
3D48'   C2 3D34'              JNZ     TL3
3D4B'   15                    DCR     D
3D4C'   FA 3D2E'              JM      TL1
3D4F'   C3 3D30'              JMP     TL2
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                     ;*****************************************************
                     ;     CONTROLLER HAS BEEN ENABLED
                     ;*****************************************************
3D52'   3E 02        L1:     MVI     A,02
3D54'   CD 3F61'             CALL    IN1       ;GET STRUT POS FOR LAND/TO. DEC.
3D57'   2A 3F8A              LHLD    3F8AH     ;GET STRUT THRESHOLD
3D5A'   EB                   XCHG              ;PUT IN DE
3D5B'   2A 3F86              LHLD    3F86H     ;LOAD HL WITH STRUT POSITION
3D5E'   CD 3F92'             CALL    SUB2      ;CALC. THRESHOLD-STRUT
3D61'   DA 3ECD'             JC      L12A      ;YES, JUMP TO 12A
                     ;****************************************************
                     ;     LANDING - MAKE PREPARATIONS
                     ;****************************************************
3D64'   3E 03                MVI     A,03
3D66'   CD 3F61'             CALL    IN1       ;GET SINK RATE
3D69'   22 3F88              SHLD    3F88H     ;STORE IT
3D6C'   21 0915              LXI     H,0915H ;MULT XMAX BY 16 TO SHIFT INTO
3D6F'   CD 3F99'             CALL    ANM       ;UPPER 12 BITS
3D72'   22 3F8C              SHLD    3F8CH     ;STORE IT
                     ;****************************************************
                     ;    ENABLE INTEGRATOR
                     ;    START ENERGY CALCULATIONS
                     ;****************************************************
3D75'   3E 9E                MVI     A,9EH
3D77'   D3 EA                OUT     0EAH      ;ENABLE INTEGRATOR
3D79'   CD 3F30'     L8:     CALL    IN3
3D7C'   EB                   XCHG
3D7D'   2A 3F8C              LHLD    3F8CH
3D80'   EB                   XCHG
3D81'   7B                   MOV     A,E
3D82'   95                   SUB     L
3D83'   6F                   MOV     L,A
3D84'   7A                   MOV     A,D
3D85'   9C                   SBB     H
3D86'   67                   MOV     H,A
3D87'   22 8004              SHLD    8004H
3D8A'   AF                   XRA     A
3D8B'   CD 3F9E'             CALL    MATH
3D8E'   2A 8000              LHLD    8000H
3D91'   22 3F8E              SHLD    3F8EH
3D94'   2A 8002              LHLD    8002H
3D97'   22 3F90              SHLD    3F90H
3D9A'   2A 3F88              LHLD    3F88H
3D9D'   EB                   XCHG
3D9E'   2A 3F84              LHLD    3F84H
3DA1'   CD 3F92'             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-3DFO) = 00 (NOP)          00135           ;CALL    SPTH     ;HAS GEAR STARTED STROKE?
                                00136           ;JP      CHACEL   ;LOOP TILL GEAR ) THRESHOLD
  3DF1'    3E 9F                00137           MVI      A,9FH
  3DF3'    D3 EA                00138           OUT      0EAH     ;ENABLE SERVOLOOP
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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       0A1H
3E5D'    E6 20                 00186            ANI      20H
3E5F'    CA 3E30'              00187            JZ       L4
                               00188   ;*************************************************
                               00189   ;      TRANSITION PHASE
                               00190   ;*************************************************
3E62'    2A 3D0E               00191            LHLD     3D0EH    ;FLIM
3E65'    11 FFFE               00192            LXI      D,0FFFEH
3E68'    22 F70A               00193   L5:      SHLD     0F70AH
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 1BD0               00197            LXI      B,1BD0H
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     0F70AH   ;SET FLC=0 LBS.
3E82'    3E 99                 00208            MVI      A,99H
3E84'    D3 EA                 00209            OUT      0EAH     ;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            LHLD     8000H
3E95'    22 F708               00215            SHLD     0F708H   ;OUTPUT W/G ACCEL. TO DAC0
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     0F708H   ;OUTPUT W/G ACCEL TO DAC0
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      0EAH     ;OF LIMIT FORCE CMD (ANALOG)
3EB4'    22 F70A               00226            SHLD     0F70AH   ;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
3EC0'    22 F70A               00230            SHLD     0F70AH   ;SET LIMIT FORCE CMD=2000 LBS
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3EC3'    3E 9D                    00231   L14:     MVI      A,9DH
3EC5'    D3 EA                    00232            OUT      0EAH     ;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     0F70AH   ;SET LIMIT FORCE CMD= 0 LBS.
3ED3'    3E A9                    00240            MVI      A,0A9H
3ED5'    D3 EA                    00241            OUT      0EAH     ;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     0F708H   ;OUTPUT W/G ACCEL TO DAC0
3EE9'    CD 3F8D'                 00248            CALL     FTEST
3EEC'    D2 3F0E'                 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     0F708H   ;OUTPUT W/G ACCEL TO DAC0
3EF8'    CD 3F8D'                 00253            CALL     FTEST
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      0EAH     ;OF LIMIT FORCE CMD (ANALOG)
3F05'    22 F70A                  00258            SHLD     0F70AH   ;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     0F70AH   ;SET LIMIT FORCE CMD=2000 LBS
3F14'    3E AD                    00263   L14A:    MVI      A,0ADH
3F16'    D3 EA                    00264            OUT      0EAH     ;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                        XCHG
3F27'   2A 3F86                   LHLD    3F86H    ;GET STRUT POSITION
3F2A'   CD 3F92'                  CALL    SUB2     ;SUBTRACT STRUT FROM THRESH.
3F2D'   D1                        POP     D
3F2E'   E1                        POP     H
3F2F'   C9                        RET
                          ;*****************************************************
                          ;      ROUTINE TO INPUT AND STORE DATA FROM MUX0,1 & 2
                          ;*****************************************************
3F30'   3E 01             IN3:    MVI     A,01
3F32'   21 F701                   LXI     H,0F701H
3F35'   77                        MOV     M,A
3F36'   2B                        DCX     H
3F37'   36 01                     MVI     M,01
3F39'   7E                M1:     MOV     A,M
3F3A'   07                        RLC
3F3B'   D2 3F39'                  JNC     M1
3F3E'   36 00                     MVI     M,00
3F40'   2A F704                   LHLD    0F704H
3F43'   22 8000                   SHLD    8000H
3F46'   22 3F80                   SHLD    3F80H
3F49'   3E 00                     MVI     A,00
3F4B'   21 F701                   LXI     H,0F701H
3F4E'   77                        MOV     M,A
3F4F'   2B                        DCX     H
3F50'   36 01                     MVI     M,01
3F52'   7E                M2:     MOV     A,M
3F53'   07                        RLC
3F54'   D2 3F52'                  JNC     M2
3F57'   36 00                     MVI     M,00
3F59'   2A F704                   LHLD    0F704H
3F5C'   22 3F84                   SHLD    3F84H
3F5F'   3E 02             STP:    MVI     A,02
3F61'   21 F701           IN1:    LXI     H,0F701H
3F64'   77                        MOV     M,A
3F65'   2B                        DCX     H
3F66'   36 01                     MVI     M,01
3F68'   7E                M3:     MOV     A,M
3F69'   07                        RLC
3F6A'   D2 3F68'                  JNC     M3
3F6D'   36 00                     MVI     M,00
3F6F'   2A F704                   LHLD    0F704H
3F72'   22 3F86                   SHLD    3F86H
3F75'   C9                        RET
                          ;*****************************************************
                          ;      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 A0                   00367   MATH:   OUT     0A0H
3FA0'   DB A7                   00368   WAIT:   IN      0A7H
```

```
3FA2'   E6 01                        ANI     01
3FA4'   C2 3FA0'                     JNZ     WAIT
3FA7'   C9                           RET
                        ;****************************************************
                        ;****************************************************
                        ;      THE FOLLOWING ARE SPECIAL CHECK-OUT ROUTINES
                        ;      AND NOT PART OF THE MAIN PROGRAM
                        ;****************************************************
                        ;****************************************************
                        ;
                        ;
                        ;****************************************************
                        ;      ROUTINE TO INPUT A VALUE FROM A/D & STORE IN RAM
                        ;****************************************************
3FA8'   F3                           DI
3FA9'   3E 00                        MVI     A,00
3FAB'   CD 3F61'                     CALL    IN1
3FAE'   CF                           RST     01H
3FAF'   00                           NOP
3FB0'   00                           NOP
                        ;****************************************************
                        ;      ROUTINE TO DO PGA TEST ON A/D
                        ;****************************************************
3FB1'   F3                           DI
3FB2'   21 F701                      LXI     H,0F701H
3FB5'   36 00                PGA:    MVI     M,00
3FB7'   36 C0                        MVI     M,0C0H
3FB9'   C3 3FB5'                     JMP     PGA
3FBC'   00                           NOP
                        ;****************************************************
                        ;      ROUTINE TO OUTPUT A VALUE TO DAC0 & DAC1
                        ;****************************************************
3FBD'   F3                           DI
3FBE'   00                           NOP
3FBF'   21 0000              R2:     LXI     H,0000
3FC2'   22 F708                      SHLD    0F708H
3FC5'   22 F70A                      SHLD    0F70AH
3FC8'   00                           NOP
3FC9'   00                           NOP
3FCA'   00                           NOP
3FCB'   C3 3FBF'                     JMP     R2
                                     END

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MACROS:

SYMBOLS:
ANM     3F99'   CHACEL  3DDF'   EXST    3E6C'   FLO     3E86'
FLOA    3ED7'   FTEST   3F8D'   IN1     3F61'   FN3     3F30'
IN4     3F76'   L1      3D52'   L10     3DD2'   L11     3DD5'
L12     3E7C'   L12A    3ECD'   L13     3EBD'   L13A    3F0E'
L14     3EC3'   L14A    3F14'   L15     3E8F'   L15A    3EE0'
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)
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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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