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ANALYSIS OF DYNAMIC AIRCRAFT RESPONSE TO  
BOMB DAMAGE REPAIR

AIR FORCE WEAPONS LABORATORY

NOVEMBER 1975

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# ANALYSIS OF DYNAMIC AIRCRAFT RESPONSE TO BOMB DAMAGE REPAIR

Lawrence D. Hokanson, Capt, USAF

November 1975

Final Report

Approved for public release; distribution unlimited.

AIR FORCE WEAPONS LABORATORY  
Air Force Systems Command  
Kirtland Air Force Base, NM 87117

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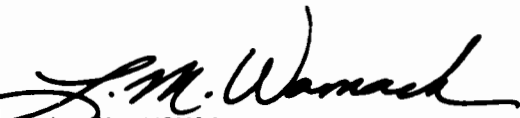
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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFWL-TR-75-138	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ANALYSIS OF DYNAMIC AIRCRAFT RESPONSE TO BOMB DAMAGE REPAIR	5. TYPE OF REPORT & PERIOD COVERED Final Report	
	6. PERFORMING ORG. REPORT NUMBER	
7. AUTHOR(s) Lawrence D. Hokanson, Capt, USAF	8. CONTRACT OR GRANT NUMBER(s)	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Weapons Laboratory (OL-AA/AFCEC) Kirtland AFB, NM 87117	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 63723F 21044B14	
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Weapons Laboratory (OL-AA/AFCEC) Kirtland AFB, NM 87117	12. REPORT DATE November 1975	
	13. NUMBER OF PAGES 54	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report) UNCLASSIFIED	
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Civil engineering Bomb damage repair Aircraft performance		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Expedient repair methods and settlement of expedient repair materials create roughness in repaired airfield pavement surfaces. The effect of this roughness on aircraft operated over a repair has been of serious concern to organic organizations designing repair procedures. An analysis is made of the dynamic response of F-4 aircraft when operated over an actual AM-2 mat Bomb Damage Repair (BDR) surface utilizing data obtained in FY73 BDR full scale testing. A computer code, entitled TAXI, yields the g loadings on various (over)		

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ABSTRACT (cont'd)

parts of the aircraft, the strut forces, and the strut displacements when the repair profile is used as program input. It was determined that a speed of 45 fps yields the largest responses. Running the program with variations of the profile to simulate settlement of the backfill indicated that the initial construction roughness creates more adverse effects than settlement within the repair area of up to 0.4 foot. Consequently, any effort to reduce roughness should concentrate on repair surface grading rather than improving the quality of the backfill material.

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## SECTION I

### INTRODUCTION

#### 1. BOMB DAMAGE REPAIR (BDR)

The increase in technology for weapons designed specifically to interdict airfield pavement surfaces has increased the demand for research and development (R&D) in repair techniques. This area of R&D is called Bomb Damage Repair (BDR), or Rapid Runway Repair (RRR), and has been centered for the last 4 years at the Air Force Weapons Laboratory (AFWL). Work has included development of techniques for the prediction of damage to various airfield pavement systems from any type of weapon (refs. 1 to 6), the upgrading of the currently recognized USAF BDR procedure outlined in AFR 93-2 (ref. 7), and the development of new repair techniques designed to counter specific damage threats (refs. 8 to 12). During these research programs, it was found that the time and effort required to complete a repair are dependent on two factors: the allowable initial roughness of the repair surface and the allowable deflections which result from the repair backfill consolidations.

#### 2. LACK OF CRITERIA

The BDR roughness problem is relatively new, and criteria for the roughness which an aircraft can tolerate have not been developed. This has compounded the problems associated with design of repair procedures, since optimization of any repair procedure requires knowledge of the acceptable amount of roughness. This roughness is composed of two factors. The first is the roughness built into the patch due to the expediency of the repair. The second consists of roughness which is added to the repair as the crater backfill materials consolidate under load or due to moisture. The lack of criteria is especially troublesome in that the required quality of backfill and the required backfill compaction effort are a function of the consolidation which can be tolerated; this in turn is a function of the acceptable roughness. Some criteria have been established for human tolerance to shock and vibration (ref. 13), but the criteria pertaining to the one-time-operation roughness which is acceptable without jeopardizing the capability of an aircraft to perform its mission remains to be defined.

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### 3. TAXI, A TOOL FOR DETERMINING ROUGHNESS EFFECT ON AIRCRAFT

Recent work at the Air Force Flight Dynamic Laboratory (AFFDL), sponsored by AFML, allows determination of the dynamic response of an aircraft to runway roughness profiles. This work, documented in AFML-TR-73-109, Volumes I and II (ref. 14), represents the first readily available tool for analyzing aircraft response to roughness. A general airplane/runway mathematical model capable of accurately simulating any airplane traversing a rigid runway profile was developed and programmed for a digital computer. The input data consist of aircraft characteristics and a profile of the runway section. The output consists of (1) forces and strut displacements in the nose and main gears and (2) accelerations at points along the centerline of the aircraft, such as the pilot station, aircraft center of gravity, and the tail of the aircraft. The program is particularly valuable in its ability to incorporate the following:

- a. Up to 15 structural modes of vibration
- b. Nonlinear strut characteristics
- c. Single or double air-chambered landing gear struts
- d. Articulated and nonarticulated landing gear struts
- e. Multiple landing gear struts
- f. Landing gear struts having conventional metering pins, metering tubes, or fluted metering pins

TAXI has been used for analyzing runways where significant pilot discomfort has been reported, and has been successful in locating runway areas requiring smoothing or other alteration to reduce undesirable aircraft response. These areas are often not apparent without an analytical tool of this type.

The BDR roughness problem is obvious, but the question of how adversely the roughness will affect the aircraft and crew must be answered. To test TAXI's reported aircraft response to BDR type roughness, instrumentation was placed aboard an F-4C aircraft by AFFDL, and runs at various speeds were made over a simulated AM-2 patch. The results were compared with the output of the TAXI code run under the same conditions. Excellent correlation between the actual test and code results were obtained (ref. 15).

### 4. FY73 AND FY74 BDR TESTING

As a part of the AFML effort to upgrade the BDR procedure contained in

AFR 93-2, tests under field conditions utilizing actual bomb damage to pavements were directed by AFWL and conducted by the Air Force Civil Engineering Center (AFCEC). These tests were conducted during the summers of 1973 and 1974 on specially constructed pavement sections at Tyndall AFB, FL (refs. 10, 11). The tests involved repairs made strictly in accordance with AFR 93-2 (ref. 7). Following placement of the AM-2 patches over the repair area, F-4 load cart obtained from the U.S. Army Engineer Waterways Experiment Station (WES) was used with a 30K load resting on a single wheel of an F-4 main gear. Trafficking of the repair patch was accomplished with up to 50 passes of this single wheel loading. Careful records of the elevations before, during, and after selected passes were kept. These form the basis for profiles used for determining aircraft response to BDR roughness. They also serve as a starting point to determine the effect of further consolidation within the debris backfill.

## 5. OBJECTIVES

The objective of this study is to determine what adverse effects can be expected as a result of increasing the deflection at the center of the repair. This in turn will give researchers on the BDR problem an indication of the compactive effort and material properties which will be required for the crater backfill materials.

## SECTION II

### DETERMINING F-4 RESPONSE TO BDR ROUGHNESS

#### 1. PROFILE SELECTION

a. Figure 1A shows the basic profile used in this study. Similar profiles from the 1973 and 1974 tests are shown in figures 1B, 1C, and 1D for comparative purposes. The completed AM-2 repair is shown in figure 2, and the load cart utilized for testing is shown in figure 3. The profile used represents the statically loaded profile with readings taken at 2 foot intervals on the final pass of the load cart. The condition of the repaired area after 38 passes (the total number made on this repair) represents the worst condition the aircraft would see if the gross weight of the aircraft were applied to the repair. As a result of the dynamic loading presented by the aircraft, strut forces can exceed the static gear load, and the force the repair sees is often greater than the static weight. No practical way of applying this dynamic loading to the repair existed, and the static condition was accepted as representative.

b. Figure 4 shows the imposition of additional deflection to the AM-2 repair. Total additional deflections of 0.1, 0.2, 0.3 and 0.4 foot were added to the repair at Ground Zero (GZ), or center point, of the repair. This deflection was added to the original profile by assuming a linear increase in additional deflection from 0.0 feet at the edge of the apparent crater to the specified maximum at the GZ.

#### 2. RUNNING THE TAXI CODE

a. Aircraft Properties: Standard F-4 aircraft input data, as detailed in AFWL-TR-73-109, Vol. II (ref. 14), were used for an F-4 at a gross weight of 58,000 pounds. These data are contained in appendix A.

b. Selection of Critical Speed: To determine critical speed, several runs were made on the original profile with 0.0 feet additional deflection. Examination of the responses to this profile at taxi speeds in the range of 20 to 60 fps indicated a critical speed existed somewhere in the range of 40 to 50.7 fps, and this range was therefore selected for closer examination. Results are shown in table 1 for runs of 20, 25, 30, 35, 40, 45, and 50.7, 55, and 60 fps. (50.7 fps corresponds to 30 knots.) The repair surface did not produce peak

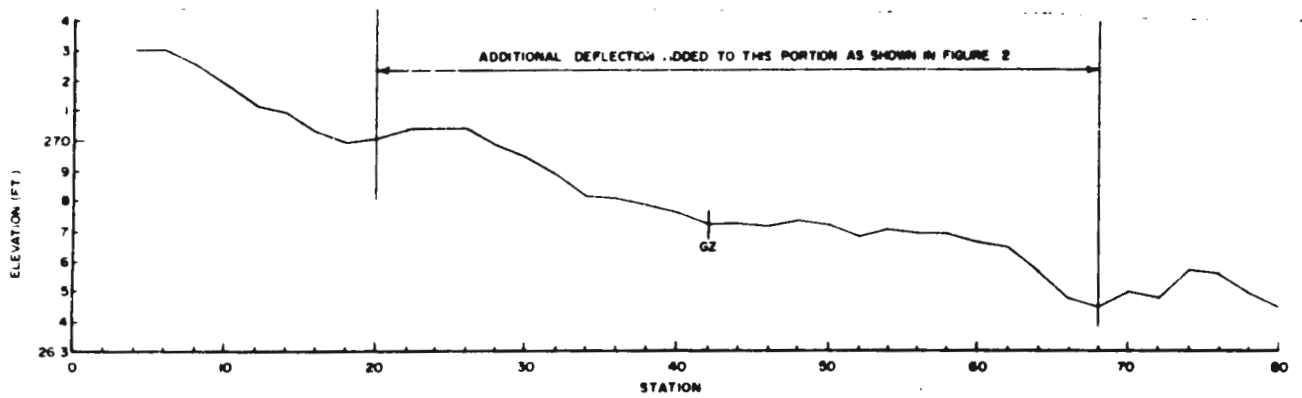


FIGURE 1A FY 73 BDR TEST 1-1 AM-2 PROFILE

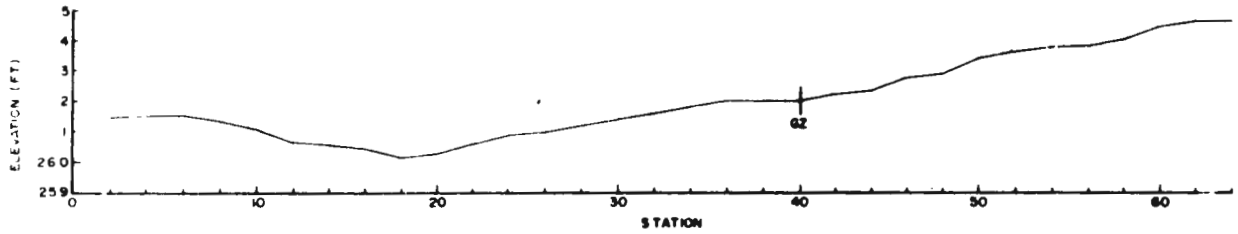


FIGURE 1B FY 73 BDR TEST 1-2 AM-2 PROFILE

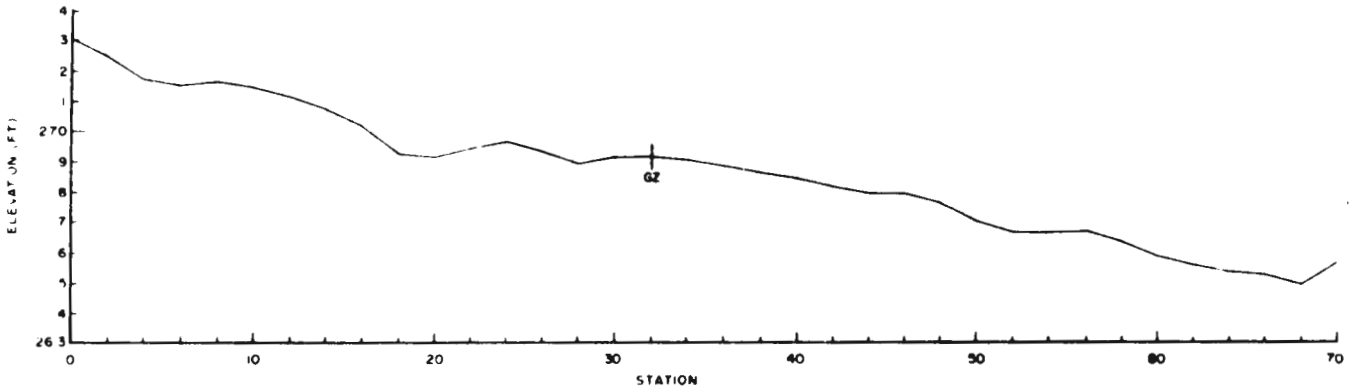


FIGURE 1C FY 74 BDR TEST 1 AM-2 PROFILE

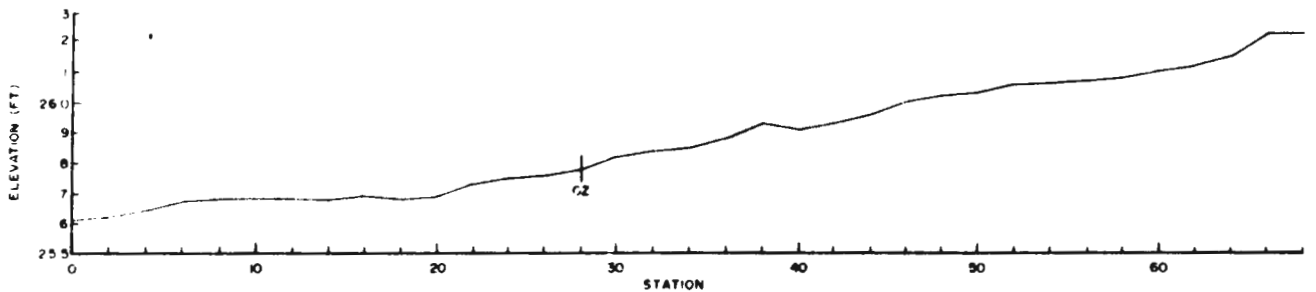


FIGURE 1D FY 74 BDR TEST 2 AM-2 PROFILE

Figure 1. Comparison of AM-2 Profiles for BDR Testing at Tyndall AFB, FL. All Tests Performed in Conformance with AFR 93-2 (FY 73 Test) or AFM 93-2 (FY 74 Test)



Figure 2. Completed Test Repair Site



Figure 3. Load Cart, F-4W/30K on F-4 Single Wheel

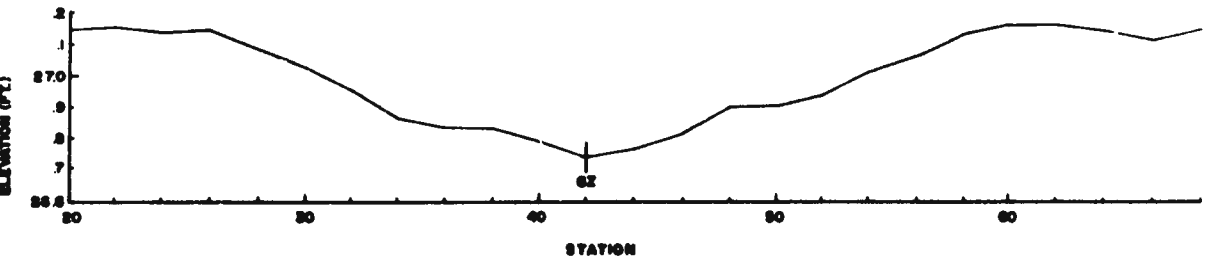
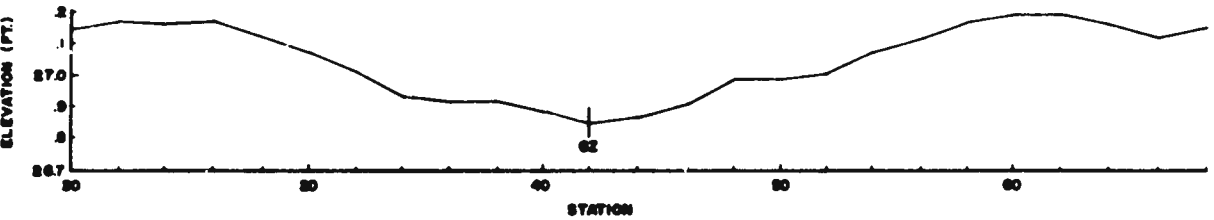
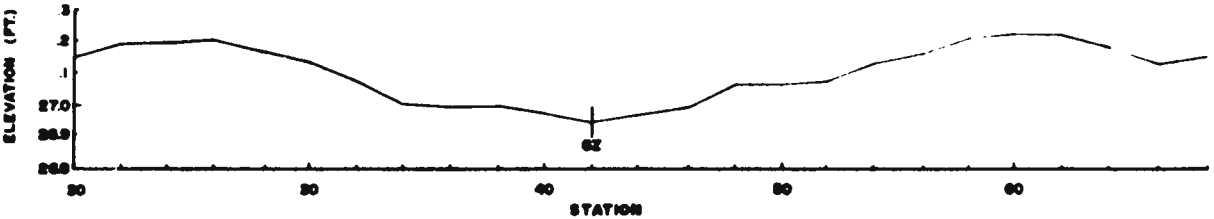
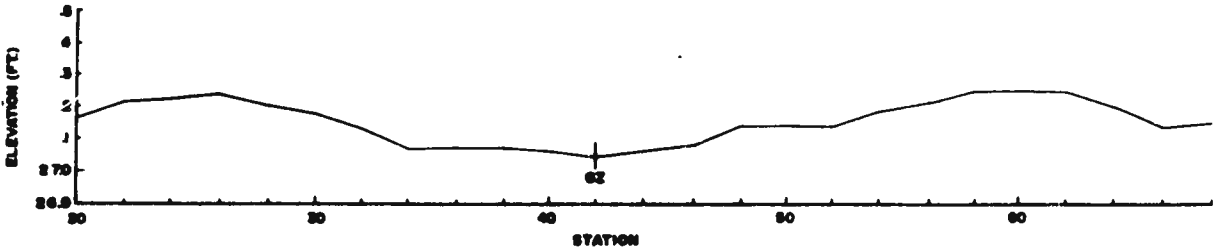
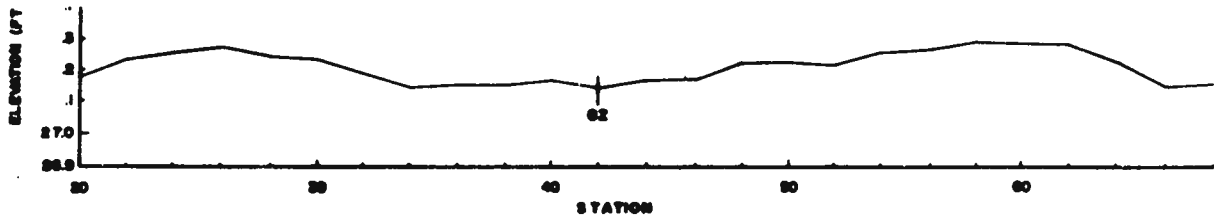


Figure 4. Addition of Deflections to Test 1-1, FY73 BDR Test, AM-2 Profile. Only deflected areas shown.

Table 1

RESPONSE TO FY73 BDR TEST PROFILE WITH 0.0 FEET ADDITIONAL DEFLECTION FORCES AND ACCELERATIONS OF F-4 AT GROSS WEIGHT OF 58,000 POUNDS

Speed (ft/sec)	20	25	30	35	40	45	50.7	55	60	Speed at Which Maximum (Minimum) Attained
FSM..Total force in nose gear strut (lb)	16,494 (88)	16,680 (89)	18,826 (91)	18,720 (99)	17,000 (90)	17,139 (91)	15,834 (84)	14,379 (76)	13,430 (71)	30
% of maximum										
NNOSE..Strut stroke, nose gear (in)	23.200	23.200	23.200	23.200	23.200	23.200	23.200	22.902 (99)	22.900 (99)	4
Maximum										
% of maximum										
Minimum	18.696 (129)	16.975 (118)	14.524 (100)	17.062 (113)	16.730 (116)	14.446	19.046 (132)	19.136 (132)	18.886 (131)	45
% of minimum										
FSM..Total force in all main gear struts (lb)	87,962 (60)	95,220 (69)	126,745 (91)	118,740 (86)	126,687 (92)	137,711	115,777 (84)	87,022 (63)	75,513 (55)	45
% of maximum										
Minimum	15.713 (99)	15.762 (99)	15.859 (100)	15.843 (100)	15.864 (100)	15.880	15.794 (100)	15.723 (99)	15.668 (98)	45
% of minimum										
TAIAC..Acceleration at tail station (G)	2.047 (44)	2.295 (49)	4.056 (86)	3.823 (81)	4.704	4.674 (99)	3.942 (84)	2.860 (61)	2.253 (48)	40
Maximum										
% of maximum										
Minimum (Maximum negative acceleration)	-1.768 (55)	-2.164 (68)	-2.979 (93)	-2.983 (93)	-2.883 (90)	-3.023 (94)	-3.203	-2.707 (84)	-2.908 (91)	50.7
% of minimum										
GEACC..Acceleration at Center of Gravity (G)	.739 (40)	.867 (77)	1.272 (68)	1.210 (65)	1.333 (72)	1.859	1.369 (74)	1.042 (56)	.791 (42)	45
Maximum										
% of maximum										
Minimum (Maximum negative acceleration)	-.574 (52)	-1.085 (99)	-.874 (80)	-1.078 (98)	-.928 (84)	-1.092 (99)	-1.098	-.837 (76)	-.808 (74)	
% of minimum										
PSA..Pilot Station Acceleration (G)	.517 (55)	.600 (64)	.825 (88)	.679 (72)	.720 (76)	.790 (84)	.942	.849 (90)	.692 (73)	50.7
Maximum										
% of maximum										
Minimum (Maximum Negative Acceleration)	-.452 (59)	-.585 (77)	-.759	-.660 (87)	-.683 (90)	-.656 (86)	-.557 (73)	-.630 (83)	-.626 (82)	30
% of minimum										
*Maximum Strut Stroke is 23.200 Inches										

values in all calculated responses at the same speed. For example, peak positive accelerations (g forces) at the tail station occurred at 40 fps, peak positive accelerations at the center of gravity (CG) of the aircraft occurred at 45 fps, and peak positive accelerations at the pilot station occurred at 50.7 fps. Table 2 shows the speeds at which peak values occurred, not only for 0.0 feet deflection but also for deflections of 0.1, 0.2, 0.3, and 0.4 foot.

It was concluded that the speed at which the peak values for all responses was obtained fluctuated but that a mean value of 45 fps was reasonable. To bracket the critical speed, the response to all deflected profiles at speeds of 40, 45, and 50.7 fps were examined.

### c. Tabulation of Results

Tables 1 and 3 to 6 report the peak values, both positive and negative, if significant, for all five conditions of the repair: 0.0, 0.1, 0.2, 0.3, and 0.4 foot additional deflection. In each case the maximum is noted, and responses at the other two speeds are shown in the proper engineering units and as a percent of the maximum value.

Tables 7 to 9 were composed from the information in tables 1 and 3 to 6 by combining results at each speed for all profile cases. Table 2 further breaks out the data by detailing the speeds at which maximum values of each response were attained for each profile.

Output graphs from TAXI are shown in appendix B for all responses of the F-4 at 45 fps traversing the AM-2 profile with 0.4 ft additional deflection.

Table 2  
SPEEDS AT WHICH MAXIMUM RESPONSE VALUE WERE ATTAINED ON FY 73 BDR TEST PROFILE

	0	-0.1	-0.2	-0.3	-0.4	Critical Speed Component of V <sub>CR</sub>
ADDITIONAL DEFLECTION (ft)						
MAXIMUM Total force in nose gear strut (lb)	less than 40	40 **	40 **	40 **	40 **	less than 40
MINIMUM Total force in nose gear (in)						
MAXIMUM	40	40, 45	40, 45	40	40	40
MINIMUM	40	40	40	40	40	40
WING Total force in all main gear struts (lb)						
MAXIMUM	45	45	45	45	45	45
MAIN Total force in main gear (in)						
MAXIMUM	45	45	45	45	45	45
MINIMUM	45	45	45	45	45	45
TAILAC Acceleration at tail station (G)						
MAXIMUM	40	40	40	40	45	40
MINIMUM (Maximum negative acceleration)	50.7	40	50.7	45	45	Random
CGACC Acceleration at Center of Gravity (G)						
MAXIMUM	45	45	45	45	45	45
MINIMUM (Maximum negative acceleration)	50.7	45	45	45	45	45
PSA Pilot Station Acceleration (G)						
MAXIMUM	50.7	50.7	45	40	50.7	50.7
MINIMUM (maximum negative acceleration)	less than 40	45	40	40	40	less than 40
* Maximum Attained at all Speeds						
** Lower Speed May Produce Larger Response, See Table 1						

Table 3  
 RESPONSE TO FY 73 BDR TEST PROFILE WITH 0.1 FOOT ADDITIONAL DEFLECTION  
 FORCES AND ACCELERATIONS OF F-4 AT GROSS WEIGHT OF 58,000 POUNDS

Speed (ft/acc)	40	45	50.7	Speed at which maximum (minimum) attained
FSN..Total force in nose gear strut (lb)				
Maximum	17659	17066	14912	40
% of Maximum	---	(96.6)	(84.4)	---
XNOSE..Strut stroke, nose gear (in)				
Maximum	23.200	23.200	23.007	40,45
% of maximum	---	---	(99.2)	---
Minimum	16.505	18.214	18.525	40
% of Minimum	---	(110.4)	(112.2)	---
FSN..Total force in all main gear struts (lb)				
Maximum	130172	137693	114582	45
% of maximum	(94.4)	---	(83.1)	---
XMAIN..Strut stroke, main gear (in)				
Maximum	15.872	15.880	15.818	45
% of maximum	(99.9)	---	(99.6)	---
Minimum	12.150	8.179	12.390	45
% of minimum	(148.6)	---	(151.5)	---
TAILAC..Acceleration at tail station (G)				
Maximum	4.862	4.692	4.011	40
% of maximum	---	(96.5)	(82.5)	---
Minimum (maximum negative acceleration)	-2.999	-2.988	-2.779	40
% of minimum	---	(99.6)	(92.7)	---
YACC..Acceleration at Center of Gravity (G)				
Maximum	1.413	1.872	1.260	45
% of maximum	(75.5)	---	(67.3)	---
Minimum (Maximum negative acceleration)	-.997	-1.148	-1.088	45
% of minimum	(86.8)	---	(94.8)	---
PSA..Pilot Station Acceleration (G)				
Maximum	.757	.776	.796	50.7
% of Maximum	(95.1)	(97.5)	---	---
Minimum (maximum negative acceleration)	-.702	-.720	-.598	45
% of minimum	(97.5)	---	(83.1)	---

Table 4  
 RESPONSE TO FY 73 BDR PROFILE WITH 0.2 FOOT ADDITIONAL DEFLECTION  
 FORCES AND ACCELERATIONS OF F-4 AT GROSS WEIGHT OF 58,000 POUNDS

	40	45	50.7	speed at which maximum (minimum) attained
<b>NOSE..Total force in nose gear strut (lb)</b>				
Maximum	17843	17084	15343	40
% of Maximum	---	(95.7)	(86.0)	---
<b>NOSE..Strut stroke, nose gear (in)</b>				
Maximum	23.200	23.200	23.100	40,45
% of maximum	---	---	(99.6)	---
Minimum	16.363	16.912	19.208	40
% of minimum	---	(103.4)	(117.4)	---
<b>MAIN..Total force in all main gear struts (lb)</b>				
Maximum	128254	137371	111015	45
% of maximum	(93.4)	---	(80.8)	---
<b>MAIN..Strut stroke, main gear (in)</b>				
Maximum	15.868	15.880	15.818	45
% of maximum	(99.9)	---	(99.6)	---
Minimum	12.204	8.285	12.467	45
% of minimum	(147.3)	---	(150.5)	---
<b>TAILAC..Acceleration at tail station (G)</b>				
Maximum	4.927	4.668	3.756	40
% of maximum	---	(94.7)	(76.2)	---
Minimum (maximum negative acceleration)	-2.232	-2.679	-2.884	50.7
% of Minimum	(94.7)	(92.9)	---	---
<b>CGACC..Acceleration at Center of Gravity (G)</b>				
Maximum	1.373	1.835	1.305	45
% of maximum	(74.8)	---	(71.1)	---
Minimum (maximum negative acceleration)	-1.081	-1.146	-1.115	45
% of minimum	(95.2)	---	(97.3)	---
<b>PSA..Pilot Station Acceleration (G)</b>				
Maximum	.736	.781	.685	45
% of Maximum	(94.2)	---	(87.7)	---
Minimum (maximum negative acceleration)	-.728	-.664	-.549	40
% of minimum	---	(91.2)	(75.4)	---

Table 5  
 RESPONSE TO FY 73 BDR TEST PROFILE WITH 0.3 FOOT ADDITIONAL DEFLECTION  
 FORCES AND ACCELERATIONS OF F-4 AT GROSS WEIGHT OF 58,000 POUNDS

Speed (ft/sec)	40	45	50.7	Speed at which maximum (minimum) attained
FSM..Total force in nose gear strut (lb)				
Maximum	18036	17051	16184	40
% of maximum	---	(94.5)	(89.2)	---
SNOSE..Strut stroke, nose gear (in)				
Maximum	23.200	23.200	23.200	---
% of maximum	---	---	---	---
Minimum	16.736	16.729	17.661	40
% of minimum	---	(103.0)	(105.6)	---
FSM..Total force in all main gear struts (lb)				
Maximum	127876	134108	107515	45
% of maximum	(95.4)	---	(80.2)	---
XMAIN..Strut stroke, main gear (in)				
Maximum	15.867	15.880	15.809	45
% of maximum	(99.8)	---	(99.5)	---
Minimum	12.300	8.575	12.201	45
% of minimum	(143.4)	---	(142.3)	---
TAILAC..Acceleration at tail station (G)				
Maximum	4.762	4.663	3.732	40
% of maximum	---	(97.9)	(78.4)	---
Minimum (Maximum negative acceleration)	-2.890	-3.065	-1.652	45
% of minimum	(94.3)	---	(93.2)	---
CGACC..Acceleration at Center of Gravity (G)				
Maximum	1.407	1.759	1.416	40
% of maximum	(80.0)	---	(80.5)	---
Minimum (Maximum negative acceleration)	-1.104	-1.171	-1.095	45
% of minimum	(94.3)	---	(93.5)	---
PSA..Pilot Station Acceleration (G)				
Maximum	.745	.717	.706	40
% of Maximum	---	(96.2)	(94.8)	---
Minimum (Maximum negative acceleration)	-.736	-.679	-.589	40
% of minimum	---	(92.3)	(80.1)	---

Table 6  
 RESPONSE TO FY 73 BDR TEST PROFILE WITH 0.4 FOOT ADDITIONAL DEFLECTION  
 FORCES AND ACCELERATIONS OF F-4 AT GROSS WEIGHT OF 58,000 POUNDS

Speed (ft/sec)	40	45	50.7	Speed at which maximum (minimum) attained
<b>FNH...Total force in nose gear strut (lb)</b>				
Maximum	18883	17901 (93.7)	16599 (89.9)	40
% of Maximum				
<b>XROSE...Strut stroke, nose gear (in)</b>				
Maximum	23.200	23.200	23.200	
% of Maximum				
Minimum	16.141	16.520 (102.1)	17.136 (106.2)	40
% of Minimum				
<b>BNW...Total force in all main gear struts (lb)</b>				
Maximum	128395 (93.9)	136808	113745 (83.1)	45
% of Maximum				
<b>YMAIN...Strut stroke, main gear (in)</b>				
Maximum	15.868 (99.9)	15.880	15.930 (99.7)	45
% of Maximum				
Minimum	12.258 (139.9)	8.762	11.936 (136.2)	45
% of Minimum				
<b>TAIAC...Acceleration at tail station (G)</b>				
Maximum	4.844 (98.8)	4.905	4.143 (84.5)	45
% of Maximum				
Minimum (maximum negative acceleration)	-2.732 (93.1)	-2.911	-2.779 (95.5)	45
% of Minimum				
<b>CGACC...Acceleration at Center of Gravity (G)</b>				
Maximum	1.330 (77.6)	1.714	1.177 (68.7)	45
% of Maximum				
Minimum (maximum negative acceleration)	-1.137 (96.3)	-1.181	-1.064 (90.1)	45
% of Minimum				
<b>PSA...Pilot Station Acceleration (G)</b>				
Maximum	8.46 (28.5)	6.11 (28.5)	8.57 (28.5)	50.7
% of Maximum				
Minimum (maximum negative acceleration)	-7.23 (91.1)	-7.11 (91.1)	-6.84 (95.2)	40
% of Minimum				

Table 7  
 RESPONSE TO FY 73 BDR TEST PROFILE AT 40 FPS ALL DEFLECTIONS  
 FORCES AND ACCELERATIONS OF F-4 AT GROSS WEIGHT OF 58,000 POUNDS

	0	-.1	-.2	-.3	-.4	Deflection at which max. min attained (ft)
<b>Additional Deflection (ft)</b>						
<b>PSM..Total force in nose gear strut (lb)</b>						
Maximum	17000 (92.1)	17659 (95.6)	17843 (96.6)	18036 (97.7)	18461	-.4
% of maximum						
<b>XNOSE..Strut stroke, nose gear (in)</b>						
Maximum	23.200	23.200	23.200	23.200	23.200	
% of maximum						
Minimum	16.790 (103.6)	16.505 (102.3)	16.363 (101.4)	16.236 (100.6)	16.141	-.4
% of minimum						
<b>PSM..Total force in all main gear struts (lb)</b>						
Maximum	126687 (97.3)	130172	128714 (98.5)	127876 (98.2)	128395 (98.6)	-.1
% of maximum						
<b>XPAIN..Strut stroke, main gear (in)</b>						
Maximum	15.864 (99.9)	16.472	15.868 (100.0)	15.867 (100.0)	15.868 (100.0)	-.1
% of maximum						
Minimum	12.275 (161.0)	12.150	12.204 (100.4)	12.300 (101.2)	12.258 (100.9)	-.1
% of minimum						
<b>TAILAC..Acceleration at tail station (G)</b>						
Maximum	4.704 (95.5)	4.865 (98.7)	4.927 (99.7)	4.762 (98.4)	4.866 (98.4)	-.2
% of maximum						
Minimum (Maximum negative acceleration)	-2.881 (105.5)	-2.999 (109.8)	-3.131 (105.8)	-2.890 (105.8)	-2.732 (105.8)	-.4
% of minimum						
<b>CGACF..Acceleration at Center of Gravity (G)</b>						
Maximum	1.131 (94.3)	1.611	1.611	1.611	1.611	-.1
% of maximum						
Minimum (Maximum negative acceleration)	-3.28 (81.6)	-3.97 (87.7)	-4.091 (96.0)	-4.004 (97.1)	-4.017 (97.1)	-.5
% of minimum						
<b>PSA..Pilot Station Acceleration (G)</b>						
Maximum	2.201 (95.1)	2.57 (89.7)	2.716 (87.2)	2.765 (88.3)	2.864 (88.3)	-.4
% of maximum						
Minimum (Maximum negative acceleration)	-2.681 (92.4)	-2.80 (95.4)	-2.828 (94.9)	-2.736 (95.4)	-2.721 (94.2)	-.1
% of minimum						

Table 8  
 RESPONSE TO FY 73 BDR TEST PROFILE AT 45 FPS, ALL DEFLECTIONS  
 FORCES AND ACCELERATIONS OF F-4 AT GROSS WEIGHT OF 58,000 POUNDS

	.0	-.1	-.2	-.3	-.4	Deflection at which max. defn attained (ft)
<b>ADDITIONAL DEFLECTION (ft)</b>						
<b>FSN..Total force in nose gear strut (lb)</b>						
Maximum	17139 (99.1)	17066 (98.6)	17084 (98.7)	17051 (98.6)	17301	-.4
% of maximum						
<b>NOSE...Strut stroke, nose gear (in)</b>						
Maximum	23.200	23.200	23.200	23.200	23.200	
% of maximum						
Minimum	17.466 (105.6)	18.214 (110.3)	16.912 (102.4)	16.729 (101.3)	16.520	-.4
% of minimum						
<b>FSM..Total force in all main gear struts (lb)</b>						
Maximum	137711 (99.9)	137893	137371 (99.6)	134108 (97.3)	136808 (99.2)	-.1
% of maximum						
<b>XPAIN..Strut stroke, main gear (in)</b>						
Maximum	15.880	15.880	15.880	15.880	15.880	
% of maximum						
Minimum	8.135	8.179 (100.5)	8.285 (101.8)	8.575 (105.4)	8.762 (107.7)	.0
% of minimum						
<b>TAILAC ..Acceleration at tail station (G)</b>						
Maximum	4.674 (95.3)	4.692 (95.7)	4.668 (95.2)	4.663 (95.1)	4.905	-.4
% of maximum						
Minimum (Maximum negative acceleration)	-3.023 (98.6)	-2.988 (97.5)	-2.679 (87.4)	-3.065 (95.0)	-2.911 (95.0)	-.3
% of minimum						
<b>CGACC...Acceleration at Center of Gravity (G)</b>						
Maximum	1.853 (99.3)	1.872	1.815 (98.0)	1.739 (94.0)	1.714 (91.6)	-.1
% of maximum						
Minimum (maximum negative acceleration)	-1.092 (92.5)	-1.148 (97.2)	-1.146 (97.0)	-1.171 (99.2)	-1.181	-.4
% of minimum						
<b>PSA..Pilot Station Acceleration (G)</b>						
Maximum	.780	.776	.761	.717	.673	-.0
% of maximum						
Minimum (maximum negative acceleration)	-.656 (91.1)	-.730 (98.2)	-.664 (98.9)	-.679 (90.4)	-.718 (85.2)	-.1
% of minimum						

Table 9  
 RESPONSE TO FY 73 BDR TEST PROFILE AT 50.7 FPS, ALL DEFLECTIONS  
 FORCES AND ACCELERATIONS OF F-4 AT GROSS WEIGHT OF 58,000 POUNDS

	0	-1	-2	-3	-4	Deflection at which max. defn. attained (ft)
<b>Additional Deflection (ft)</b>						
<b>FSN..Total force in nose gear strut (lb)</b>						
Maximum	15834 (95.4)	14912 (89.8)	15543 (92.4)	16024 (96.5)	16599	-4
% of maximum						
<b>XNOSE..Strut stroke, nose gear (in)</b>						
Maximum	23.200	23.007	23.100	23.200	23.200	
% of maximum						
Minimum	19.046 (111.1)	18.525 (108.1)	19.208 (112.1)	17.661 (103.1)	17.136	-4
% of minimum						
<b>FSM..Total force in all main gear struts (lb)</b>						
Maximum	115777	114582 (99.0)	111015 (95.9)	107515 (92.9)	113745 (98.2)	0
% of maximum						
<b>XMAIN..Strut stroke, main gear (in)</b>						
Maximum	15.794 (99.8)	15.818 (99.9)	15.818 (99.9)	15.809 (99.9)	15.830	-4
% of maximum						
Minimum	12.571 (105.3)	12.390 (103.8)	12.467 (104.4)	12.201 (102.2)	11.936	-4
% of minimum						
<b>TAILAC..Acceleration at tail station (G)</b>						
Maximum	3.942 (95.1)	4.011 (96.8)	3.756 (90.7)	3.732 (90.1)	4.143	-4
% of maximum						
Minimum (maximum negative acceleration)	-3.203	-2.779 (86.8)	-2.884 (90.0)	-2.857 (89.2)	-2.779 (86.8)	.0
% of minimum						
<b>CGACC..Acceleration at Center of Gravity (G)</b>						
Maximum	1.369 (96.7)	1.260 (89.0)	1.305 (92.2)	1.416 (90.7)	1.177 (83.1)	-3
% of maximum						
Minimum (maximum negative acceleration)	-1.098 (98.5)	-1.088 (97.6)	-1.115	-1.095 (98.2)	-1.064 (95.4)	-2
% of minimum						
<b>PSA..Pilot Station Acceleration (G)</b>						
Maximum	.942	.794 (84.5)	.685 (72.7)	.706 (74.9)	.857 (91.0)	.0
% of Maximum						
Minimum (maximum negative acceleration)	-1.557 (81.3)	-1.598 (86.9)	-1.544 (79.5)	-1.554 (83.2)	-1.688 (85.2)	-4
% of minimum						

## SECTION III

## ANALYSIS

## 1. EFFECTS OF VELOCITY VARIATION ON AIRCRAFT RESPONSE

a. Nose Gear Maximum Force and Strut Displacements: As mentioned earlier, the speed to be investigated was selected as 40 to 50.7 fps. While this speed was correct for maximum aircraft accelerations and maximum force and strut displacements of the main gear, it was found that the maximum force in the nose gear occurs at a somewhat lower speed. For the case of 0.0 feet additional deflection, this maximum force occurs at 30 fps. The strut displacement response is not as specific in defining a speed at which the maximum occurs (figure 5); however, table 2 indicates that a speed less than 40 fps causes the maximum response, regardless of additional deflection.

## b. Main Gear Maximum Force and Strut Displacements

The maximum displacements and force for the main gear occur consistently at 45 fps, regardless of the additional deflection, (figure 6 and table 2).

## c. Accelerations

## (1) Aircraft Tail Station

Figure 7 shows that the maximum accelerations, both positive and negative, on the tail of the aircraft occur in the lower portion of the selected 40 to 50.7 fps range. In general, the maximum negative acceleration is less selective in the speed at which it occurs than is the maximum positive acceleration, as indicated by the relatively slow reversal of the broad cusp of the convex upward curve on figure 7. This particular feature is noted for accelerations at the aircraft CG and at the pilot station as well. Table 2 indicates that the maximum positive acceleration in all deflection cases was obtained at a speed of 40 fps or less, while the maximum negative acceleration occurred in a random fashion, but definitely within the 40 to 50.7 fps range.

## (2) Aircraft CG Station

At this point, as seen in figure 8, the maximum positive acceleration and the maximum negative acceleration both occur near 45 fps. Table 2 shows that this is true regardless of the additional deflection of the repair surface.

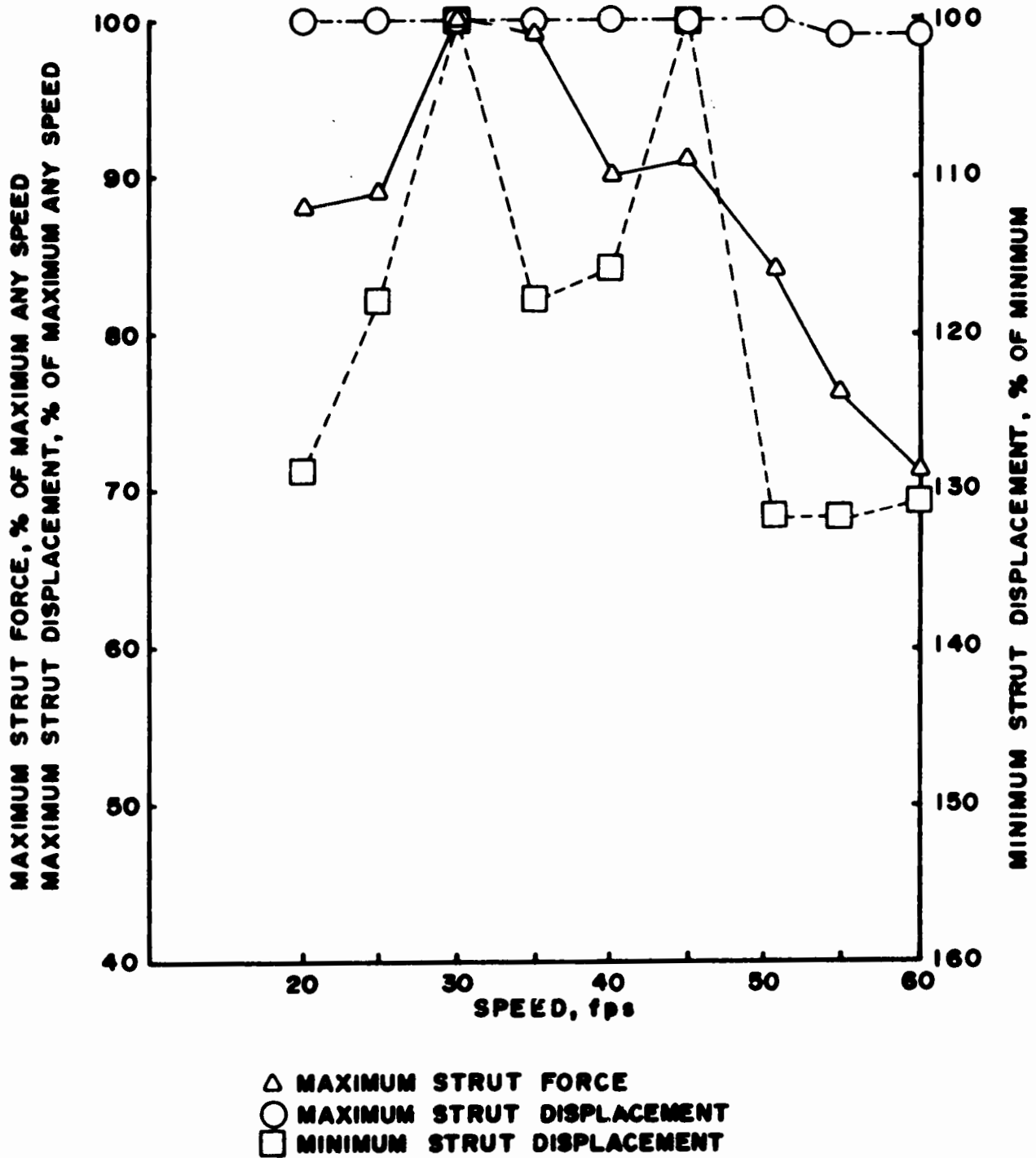


Figure 5. Nose Gear Maximum Force and Displacements as a Function of Speed, 0.0' Deflection

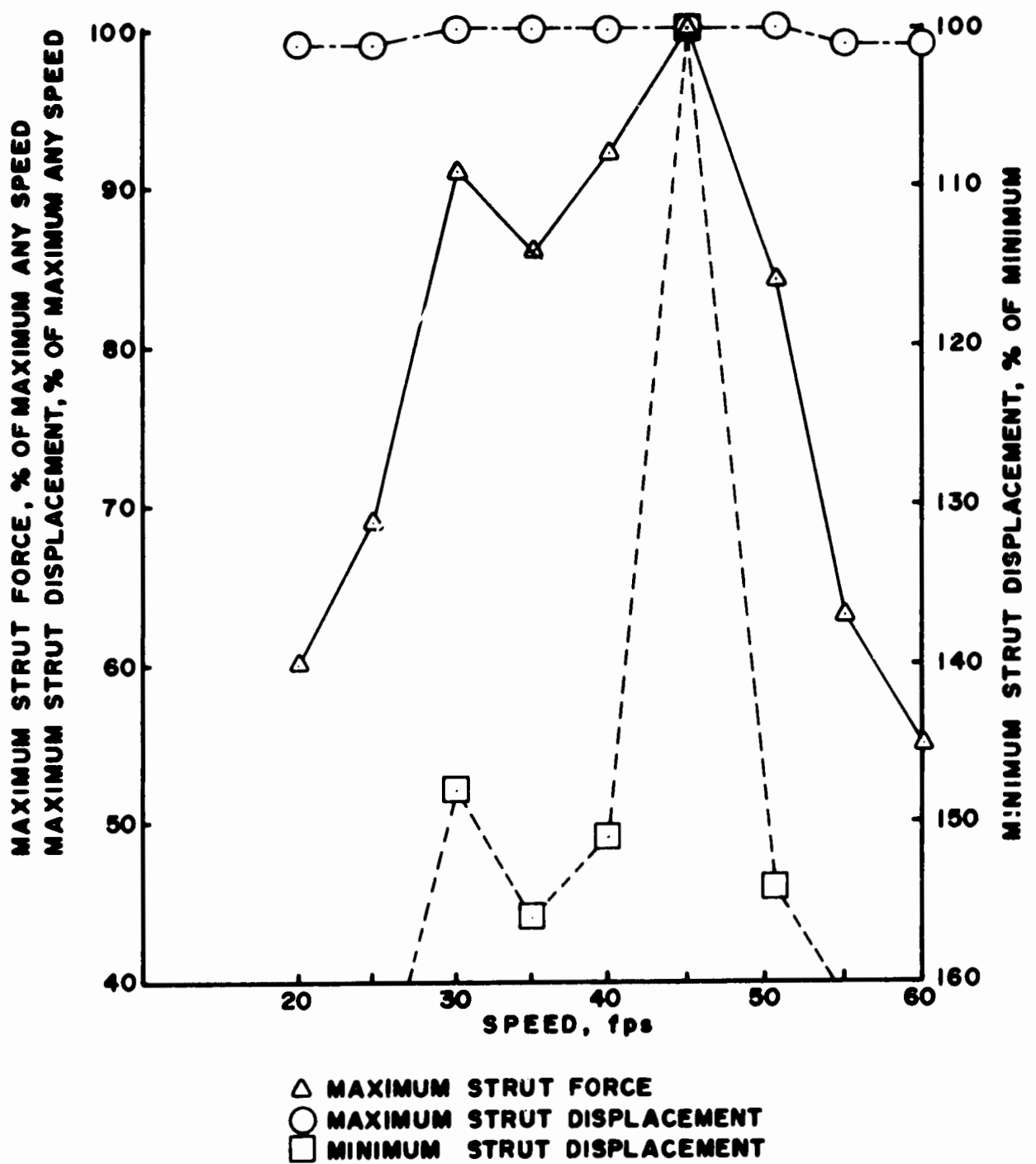


Figure 6. Main Gear Maximum Force and Displacements as a Function of Speed, 0.0' Deflection

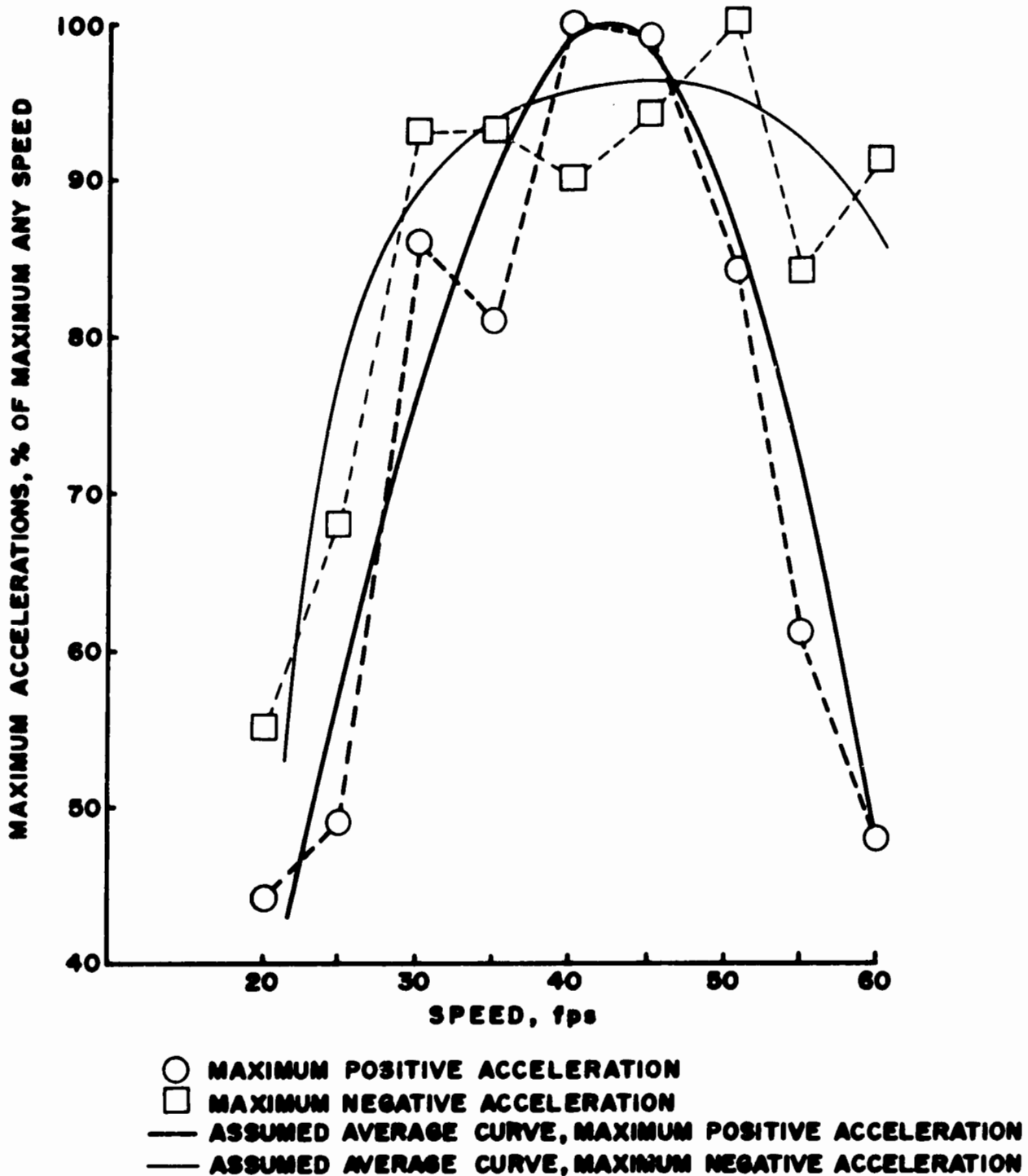


Figure 7. Maximum Accelerations, Aircraft Tail, as a Function of Speed, 0.0' Deflection

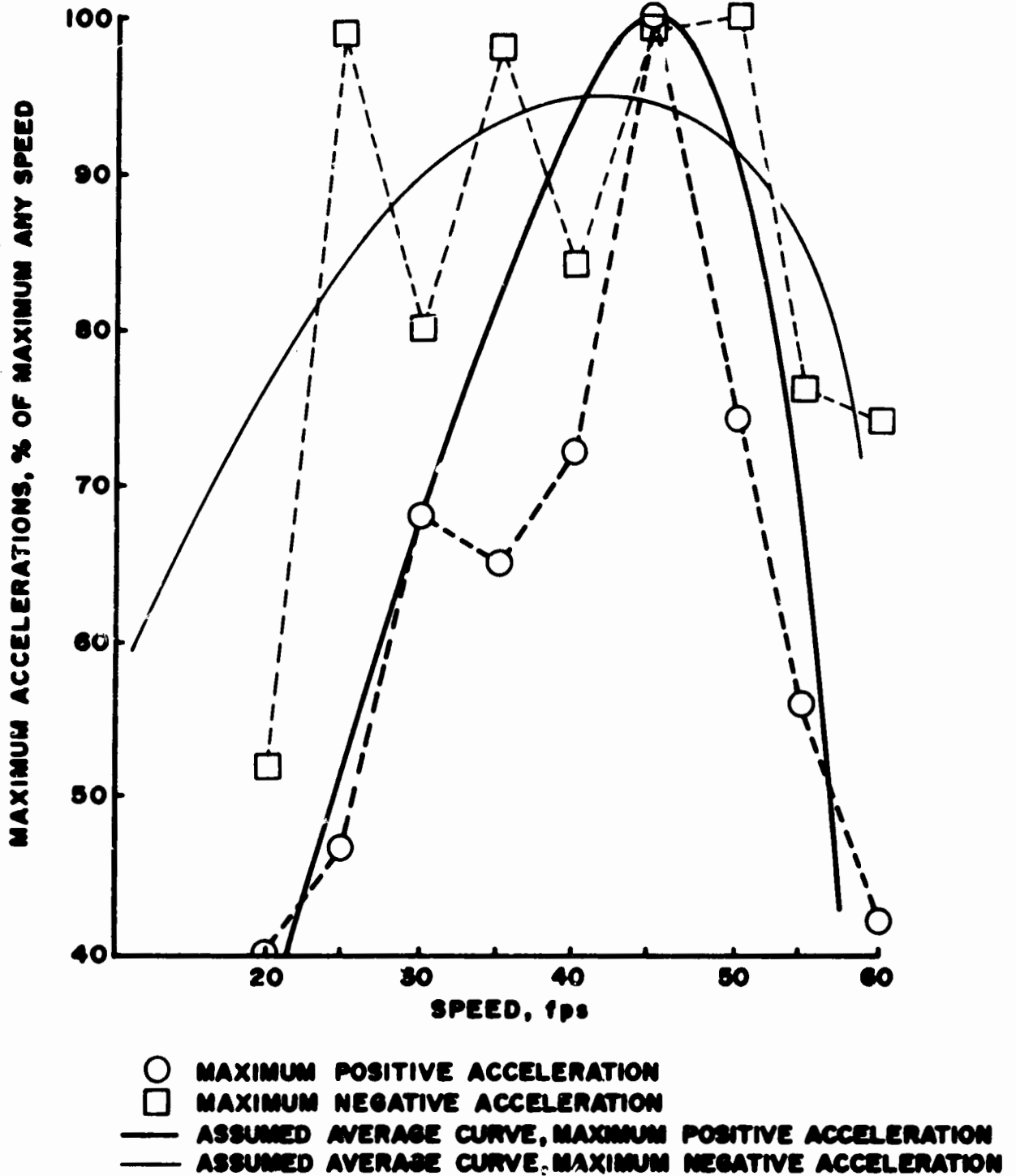


Figure 8. Maximum Accelerations, Aircraft Center of Gravity, as a Function of Speed, 0.0' Deflection

(3) Pilot Station

The pilot station presents an anomaly in that the maximum positive acceleration and the maximum negative accelerations do not occur at similar points (figure 9); however, this is true at all deflections, (table 2).

2. EFFECTS OF INCREASED DEFLECTION

a. Nose Gear Maximum Force and Strut Displacements

It is apparent from table 10 that the maximum response of the nose gear is obtained at large deflections. This is particularly true in the selected speed range of 40 to 50.7 fps.

b. Main Gear Maximum Force and Strut Displacements

Force in the main gear is independent of the additional deflections, as seen in table 10. However, the displacements, both maximum and minimum, increase with increasing deflection and speed.

c. Accelerations

(1) Aircraft Tail Station

The maximum negative acceleration at this point is random and indicates that no simple conclusion can be made regarding the effect of the increased deflection. The maximum positive acceleration increases with increasing deflection and increasing speed within the 40 to 50.7 fps range.

(2) Aircraft CG Station

The maximum negative acceleration is strongly affected by the increase in deflection, table 10. The maximum positive acceleration does not show this same characteristic.

(3) Pilot Station

The maximum pilot station acceleration is not dependent on the additional deflection. The maximum negative acceleration may be increased by the introduction of deflections.

3. HIGH SPEED RUNS

Other runs of TAXI were performed at higher speeds, but all responses decreased due to the increase in lift of the airfoil (table 1). For cases where the angle of attack for maximum coefficient of lift is not maintained by the aircraft crew during the takeoff roll, higher speeds may be more critical.

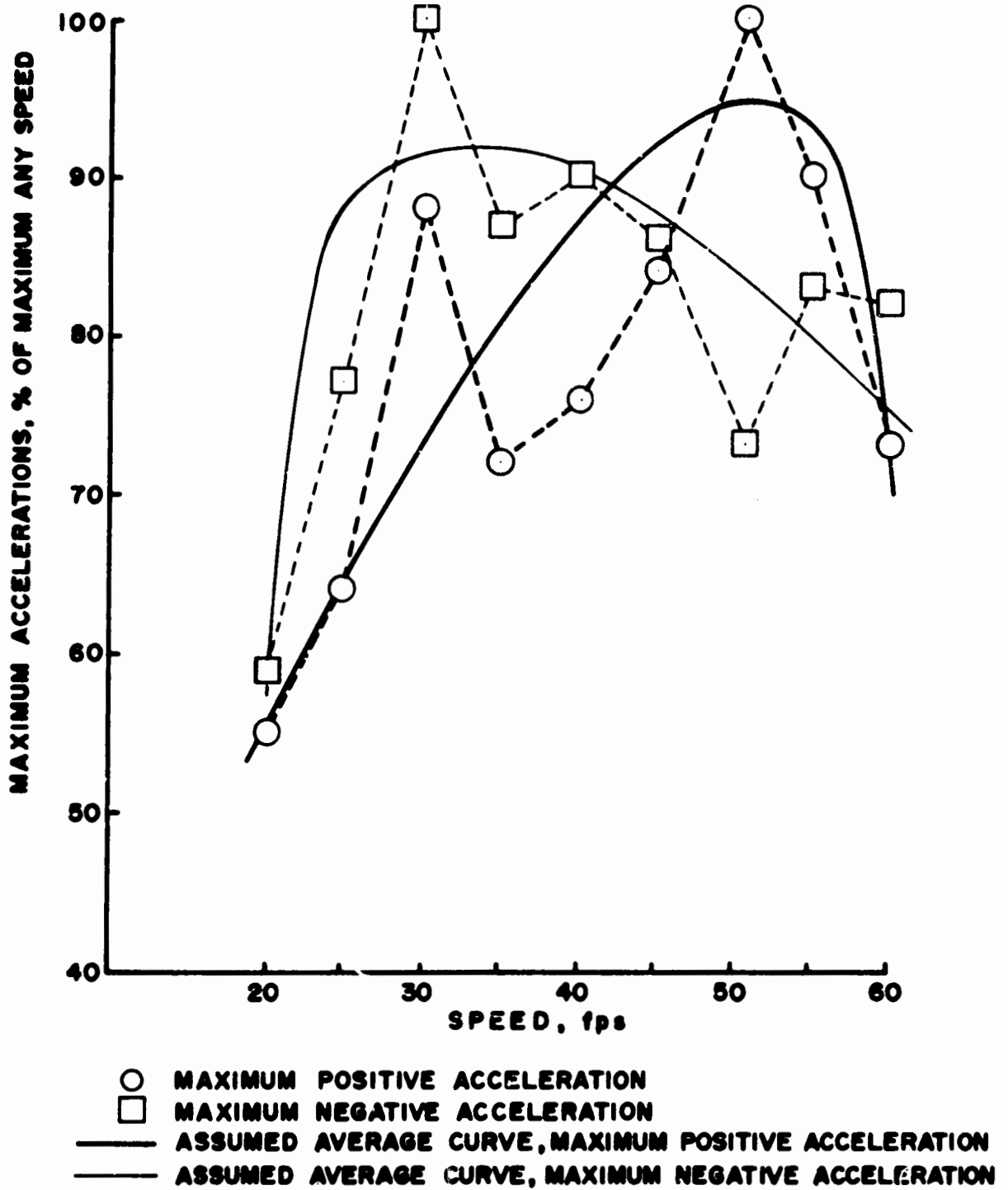


Figure 9. Maximum Accelerations, Aircraft Pilot Station, as a Function of Speed, 0.0' Deflection

Table 10  
DEFLECTIONS AT WHICH MAXIMUM RESPONSES WERE ATTAINED ON FY 73 BDR TEST PROFILE

Speed (ft/sec)	40	45	50.7
FSN..Total force in nose gear strut			
Maximum	-0.4	-0.4	-0.4
XNOSE..Strut stroke, nose gear			
Maximum	*	*	*
Minimum	-0.4	-0.4	-0.4
FSM..Total force in all main gear struts			
Maximum	-0.1	-0.1	0
XMAIN..Strut stroke, main gear			
Maximum	-0.1	*	-0.4
Minimum	-0.1	0	-0.4
TAILAC..Acceleration at tail station			
Maximum	-0.2	-0.4	-0.4
Minimum (maximum negative acceleration)	-0.2, -0.4	-0.3	0
CGACC..Acceleration at Center of Gravity			
Maximum	-0.1	-0.1	-0.3
Minimum (maximum negative acceleration)	-0.4	-0.4	-0.2
PSA..Pilot Station Acceleration			
Maximum	-0.4	-0	0
Minimum (maximum negative acceleration)	-0.3	-0.1	-0.4

\* Maximum Attained for All Deflections

#### 4. GENERAL DISCUSSION

Other than the testing at AFFDL (ref. 15), very few data pertaining to fighter aircraft operating over extreme roughness are available. It was found that short sections of AM-2 mat had been used at Ubon RTAFB, Thailand, during repair of a barrier cable. A questionnaire completed by pilots who had passed over this patch indicated that only a small bump was felt. The patch consisted of three sections of AM-2 (6 feet) with the standard 4 foot ramp on each end. The patch was located some 1500 feet from the end of the runway, and operations over it included takeoff, landing, and taxi maneuvers resulting from aborted takeoffs (ref. 16). Tests are currently being run to determine the adverse effect of multiple patch systems; however, the model for these mats is idealized as being smooth except for the end ramps.

SECTION IV  
CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS

a. The addition to the center position of an actual AM-2 repair of deflections measuring from 0.1 to 0.4 foot added no significant increases in the calculated F-4 aircraft responses. The roughness of the original patch, prior to addition of deflections, accounted for the majority of forces and strut deflections observed for the F-4.

b. At no time did the pilot station of the F-4 experience accelerations in excess of 0.942 g. The acceleration of the CG of the aircraft was a maximum of 1.872 g at a speed of 45 fps with 0.1 foot additional deflection. The maximum acceleration experienced by the tail section was 4.927 g at 40 fps on 0.2 foot additional deflection.

c. For a single repair case and the F-4 aircraft, the roughness created by increased compression or consolidation of the debris backfill is not significant in comparison to the original roughness built into BDR profiles during the repair process.

2. RECOMMENDATIONS

a. Determination of definite criteria for the amount of g loading, strut force, and strut stroke which combat aircraft are capable of absorbing in emergency conditions should be a priority task. Until these criteria are established, BDR procedures cannot be optimized. Future BDR research is dependent upon the establishment of such criteria.

b. Field tests should be designed to further establish the usefulness of the TAXI code for short wave length roughness, such as that experienced in bomb damage repair. This should validate the accuracy of the code for all aircraft models which are expected to utilize rapidly repaired runways in carrying out combat missions.

c. Analyses of the type contained in this report should be completed for other combat aircraft. Analyses for these aircraft and the F-4 should be performed with variations in lift coefficient to account for pilot technique

effects on aircraft response. The failure to attain and maintain the proper aircraft attitude for maximum coefficient of lift could induce increased loads on the aircraft and may make higher aircraft groundspeeds more critical than this report suggests.

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APPENDIX A  
F-4C AIRCRAFT DATA

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AIRPLANE: F-4

(Data common to all gross weights)

GENERAL AIRPLANE DATA

Fuselage station of pilot's station	129.0	in
Fuselage station of nose gear attachment point	85.5	in
Fuselage station of main gear attachment point	364.75	in
Fuselage station of tail location	600.0	in
Take-off thrust: Total airplane thrust		
Without afterburner	21,000.	lb
With afterburner	34,000.	lb
Take-off speed (for 37,500-pound gross weight)	282.0	fps
For take-off configuration: Lift coefficient	.83	
* See Table I		
Wing area	530.0	ft <sup>2</sup>
Drag coefficient	.11	

MAIN AND NOSE GEAR DATA

Unsprung weight of each main gear	440.0	lbs
Number of main gear struts	2	
Number of main gear tires per strut	1	
Unsprung weight of each nose gear	109.0	lbs
Number of tires on nose gear strut	2	
Main gear tire spring constant per strut	13,530.0	lbs/in
Nose gear tire spring constant per strut	15,600.0	lbs/in

MAIN GEAR STRUT PARAMETERS

Hydraulic piston area	13.74	in <sup>2</sup>
Pneumatic piston area: Primary	15.92	in <sup>2</sup>
Secondary	13.74	in <sup>2</sup>
Fully extended strut air volume: Primary	294.0	in <sup>3</sup>
Secondary	31.58	in <sup>3</sup>
Total strut stroke	15.88	in
Length from axle to waterline of CG	65.0	in
Orifice area	1.233	in <sup>2</sup>

NOSE GEAR STRUT PARAMETERS

Hydraulic piston area	10.23	in <sup>2</sup>
Pneumatic piston area	15.904	in <sup>2</sup>
Fully extended strut air volume	416.0	in <sup>3</sup>
Total strut stroke	24.0	in
Length from axle to CG waterline	65.0	in
Orifice area	1.361	in <sup>2</sup>

AIRPLANE: F-4 Cont'd

## MAIN GEAR METERING PIN DESCRIPTION (STROKE VS. NET ORIFICE AREA)

<u>STROKE</u>	<u>NET ORIFICE AREA</u>
0.000	.895
2.300	.895
3.300	.859
4.300	.760
5.300	.670
6.300	.570
7.300	.520
8.300	.478
9.300	.375
10.300	.309
11.300	.243
12.300	.176
13.300	.115
14.260	.062
15.260	.022
15.880	.022

## NOSE GEAR METERING PIN DESCRIPTION (STROKE VS. NET ORIFICE AREA)

<u>STROKE</u>	<u>NET ORIFICE AREA</u>
0.000	1.110
2.200	1.000
4.200	.850
6.200	.715
9.200	.625
11.200	.550
14.200	.495
16.200	.432
19.200	.380
20.660	.334
22.300	.229
23.200	.180

AIRPLANE F-4

GROSS WEIGHT CATEGORY

PARAMETER	MAX TAKE-OFF	MAX LANDING	MEDIUM TAKE-OFF	LIGHT TAKE-OFF
Gross Weight (lbs)	58,000	46,000	37,500	31,018
CG Location				
MAC (in)	192.48	192.48	192.48	192.48
L.E. MAC (in)	261.3	261.3	261.3	261.3
% of MAC	30.9	27.7	27.7	30.8
Fuselage Station (in)	320.8	314.00	314.00	320.35
Waterline (in)	13.87 Gear down	14.4 Gear down	28.4 Gear up	23.76 Gear up
Pitching Moment of Inertia (lb in sec <sup>2</sup> )	1.746X10 <sup>6</sup>	1.56X10 <sup>6</sup>	1.482X10 <sup>6</sup>	1.388X10 <sup>6</sup>
Main Landing Gear				
Tire Pressure (psi)	207.0	207.0	207.0	207.0
Strut Preload Pressure				
Primary: (psi)	18.0	18.0	18.0	18.0
Secondary: (psi)	619.0	619.0	619.0	619.0
Nose Landing Gear				
Tire Pressure (psi)	280.0	280.0	280.0	280.0
Strut Preload Pressure (psi)	112.5	112.5	112.5	112.5

F-4 FLEXIBILITY DATA

37,500-Pound Gross Weight

MODE #	MODAL DEFLECTION (in)				C G	POSITIVE UP		PILOT STATION	GENERALIZED MASS (Lbs sec <sup>2</sup> /in)	FREQUENCY (rad/sec)
	MAIN GEAR	NOSE GEAR	TAIL							
1	-.052	-.080	-.050	-.150	-.075	-.075	1.89	50.868		
2	-.040	.040	-.037	.025	.010	.010	0.24	64.684		
3	.050	-.205	.075	-.280	-.100	-.100	1.19	80.384		
4	.048	-.050	.050	-.110	-.010	-.010	0.49	116.180		
5	-.050	-.125	.001	.200	.038	.038	1.66	133.764		

Table A-1  
DRAG COEFFICIENT VARIATION WITH GROSS WEIGHT

<u>GROSS WEIGHT</u>	<u>CD</u>	<u>ROTATION SPEED</u>
58,000 pounds	0.236	319 fps
46,000 pounds	0.18	300 fps
37,000 pounds	0.11	282 fps
31,000 pounds	0.09	252 fps

Changes of the CD with gross weight are due to parasitic drag resulting from external stores.

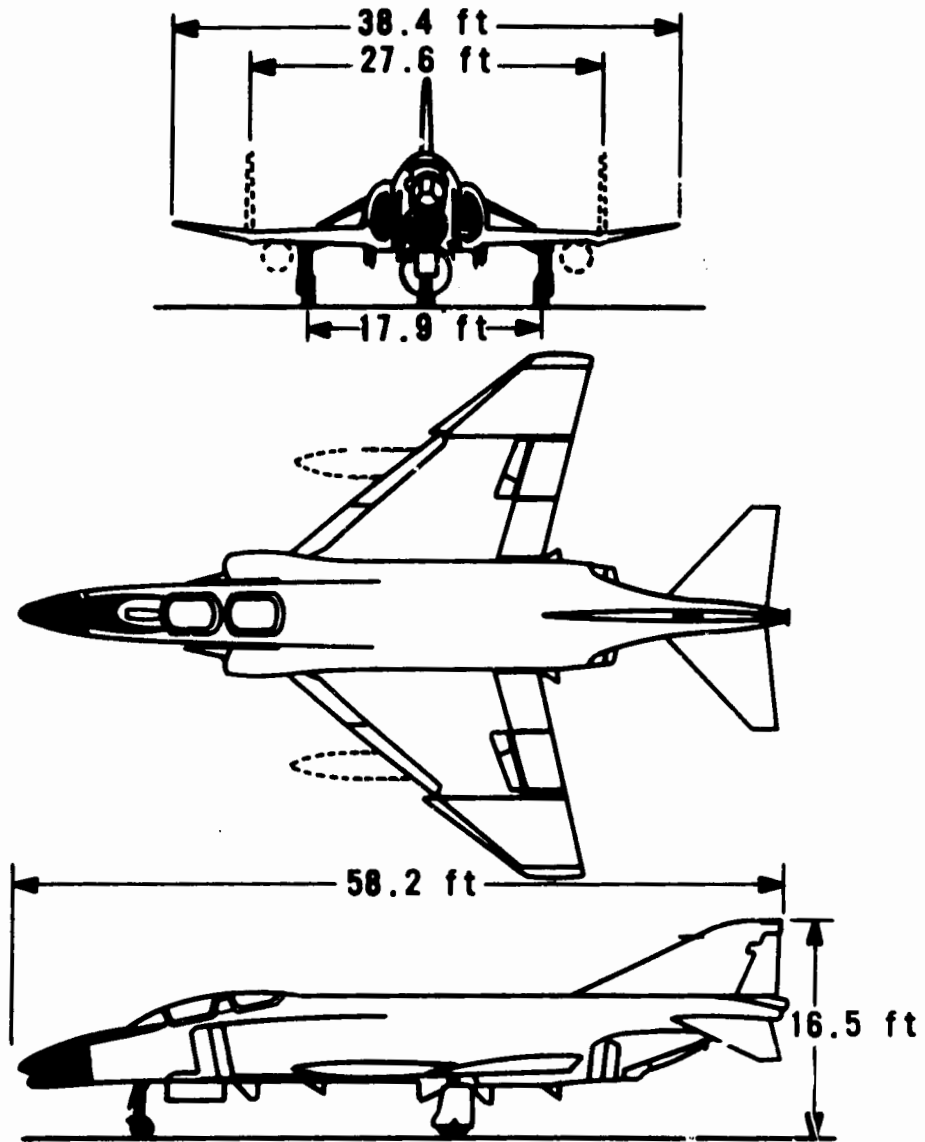


Figure A-1. F-4C Aircraft

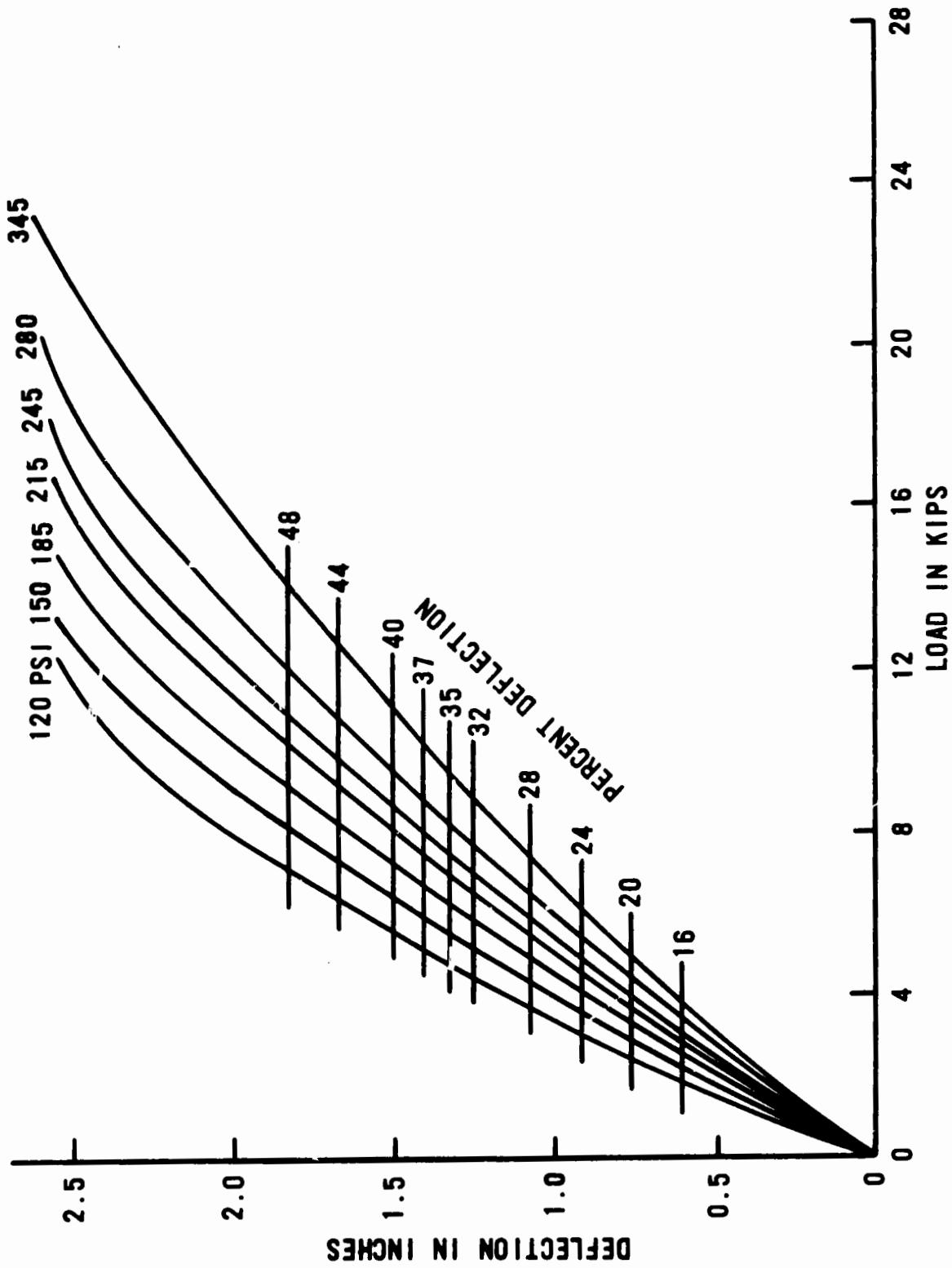


Figure A-2. F-4 Nose Gear Tire Load-Deflection Curves

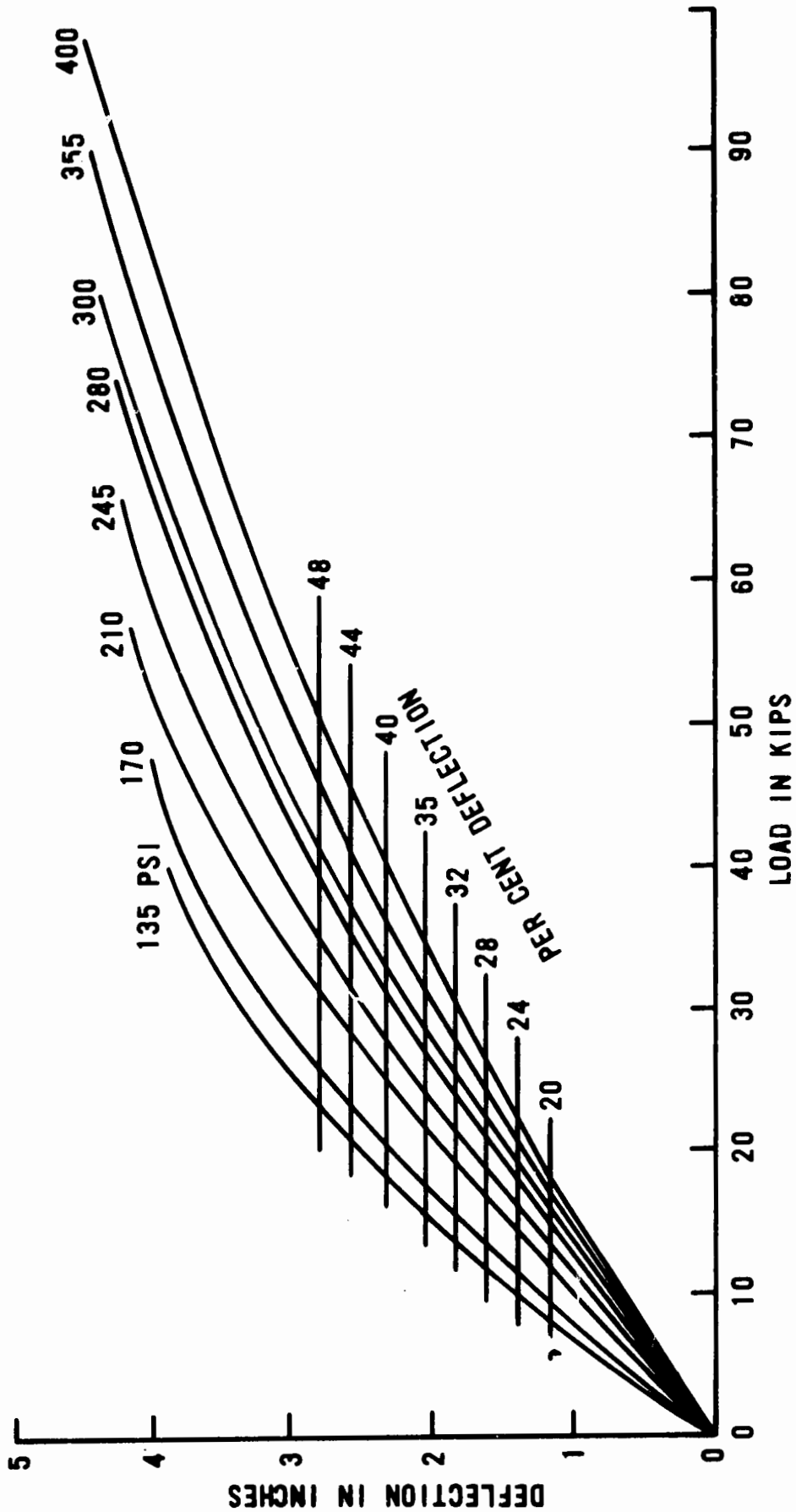


Figure A-3. F-4 Main Gear Tire Load-Deflection Curves

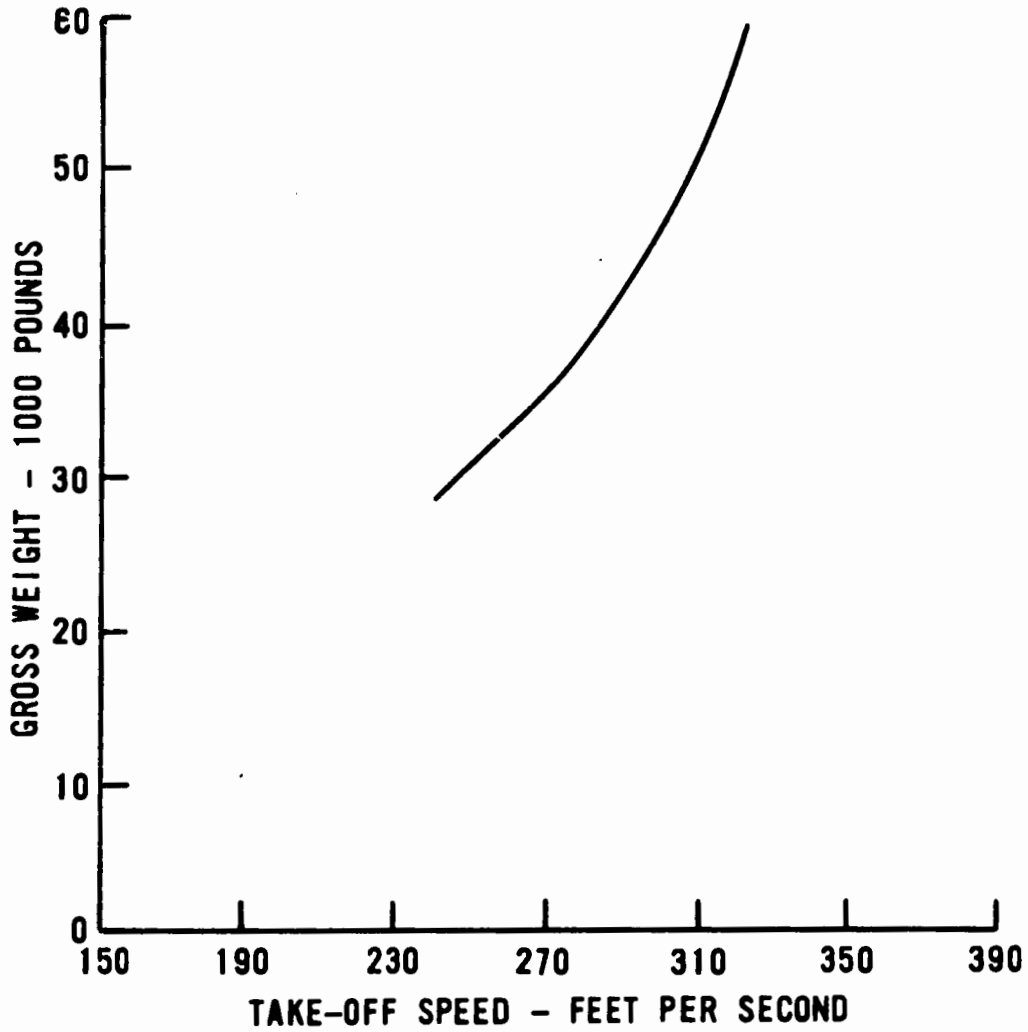
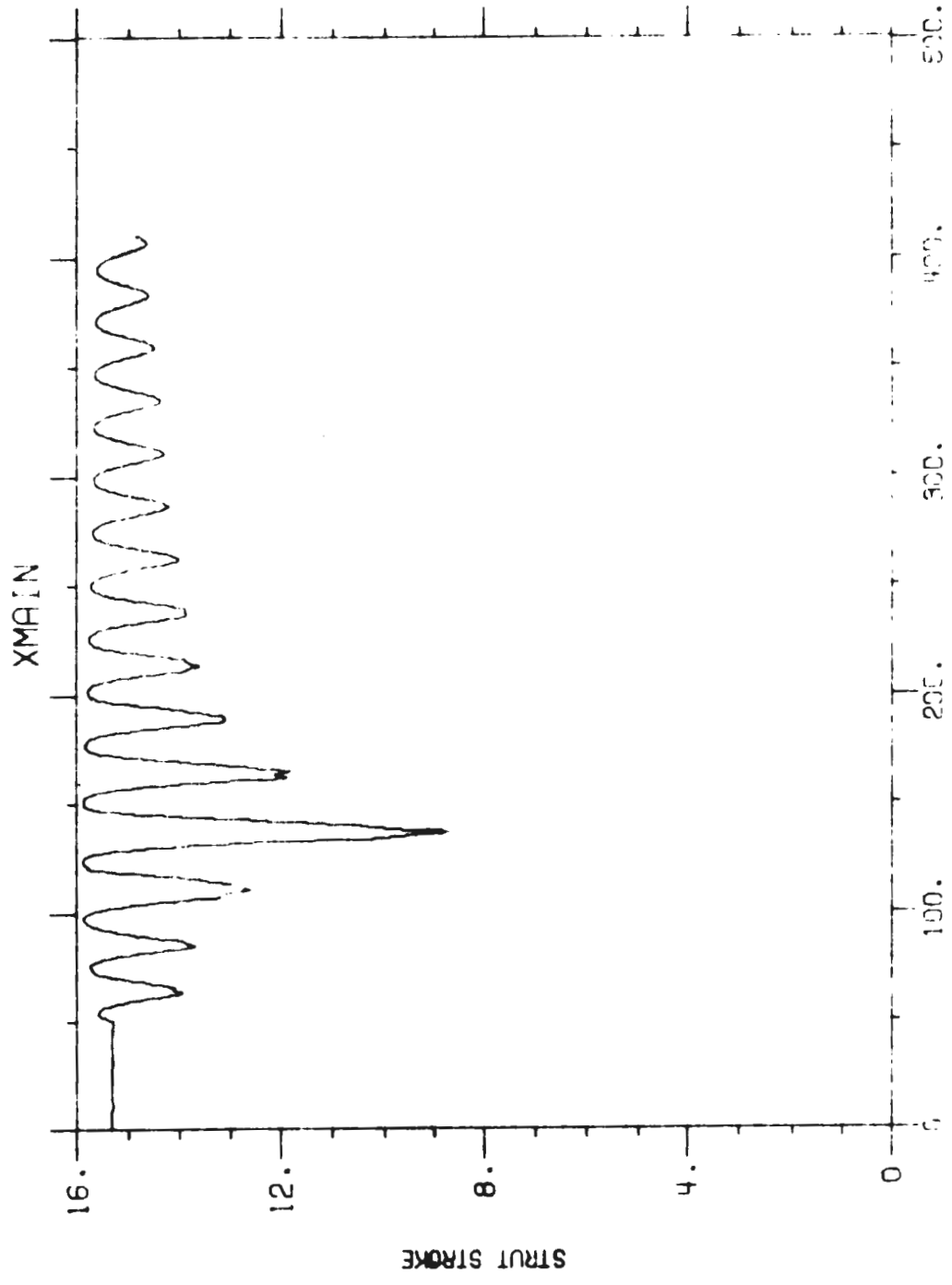


Figure A-4. Take-Off Speed vs Gross Weight

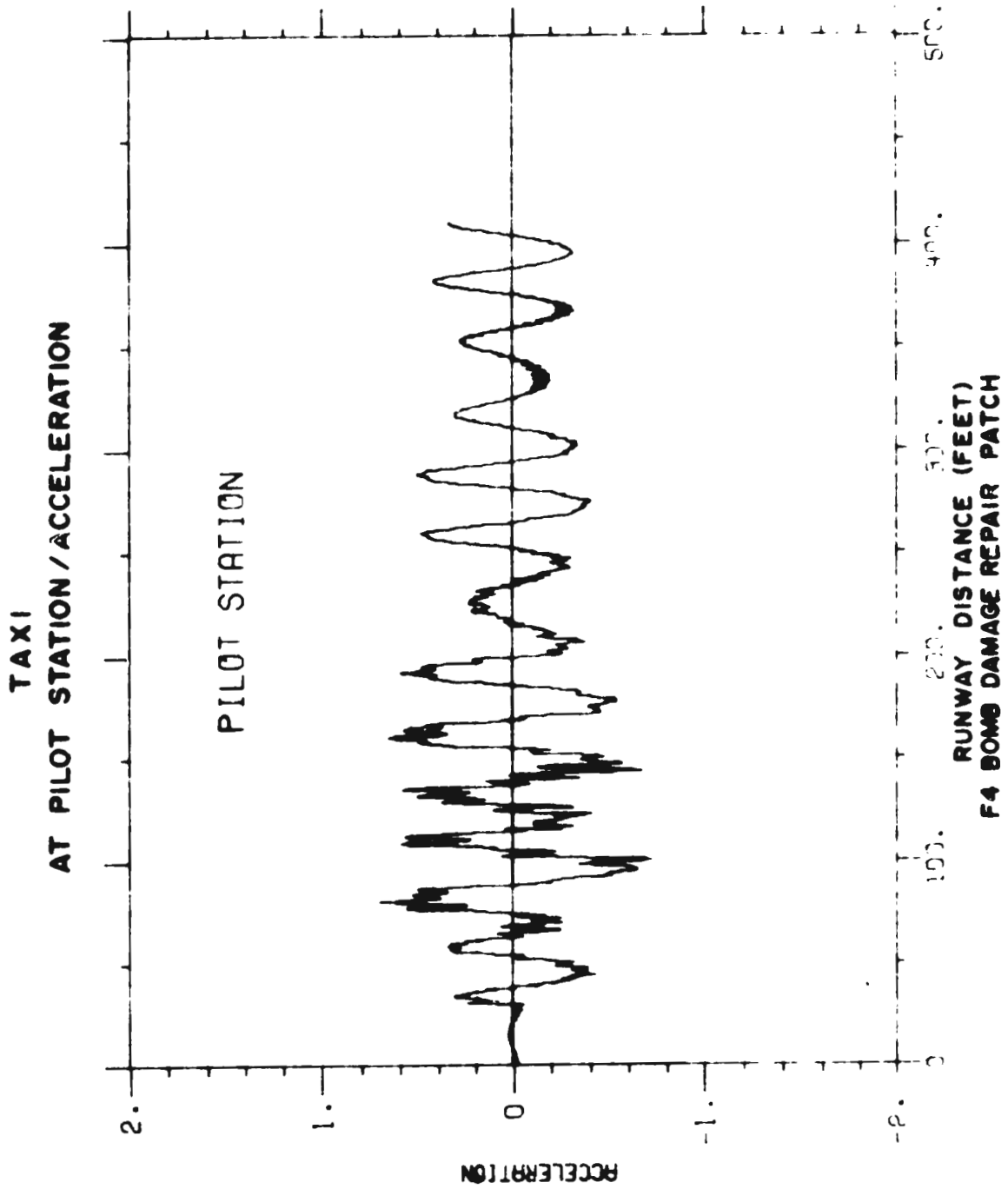
APPENDIX B  
SELECTED TAXI OUTPUT

TAXI  
STRUT STROKE, MAIN GEAR

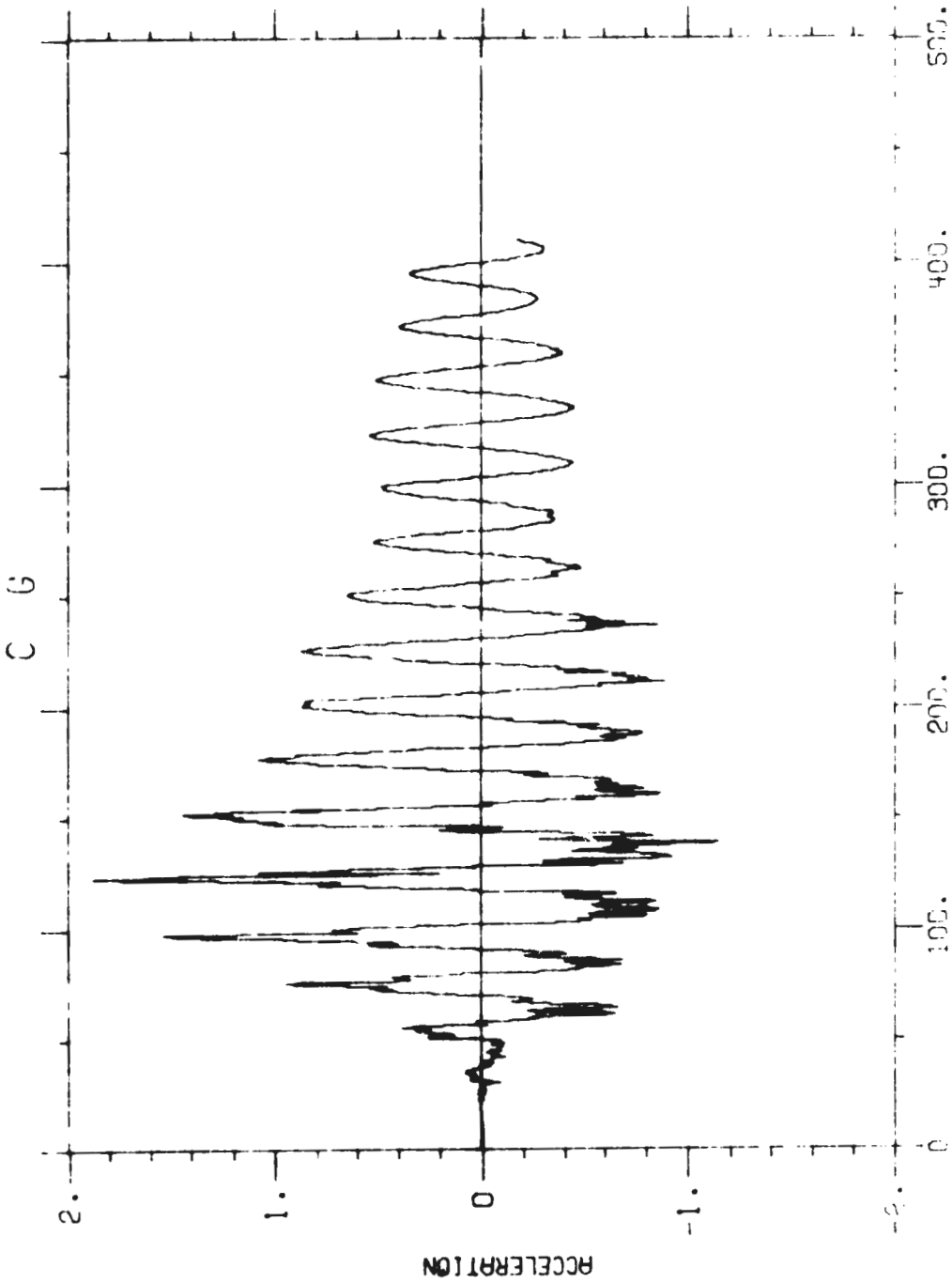


XMAIN

RUNWAY CRACKS (FEET)  
BY BOMB DAMAGE REPAIR TROUGH

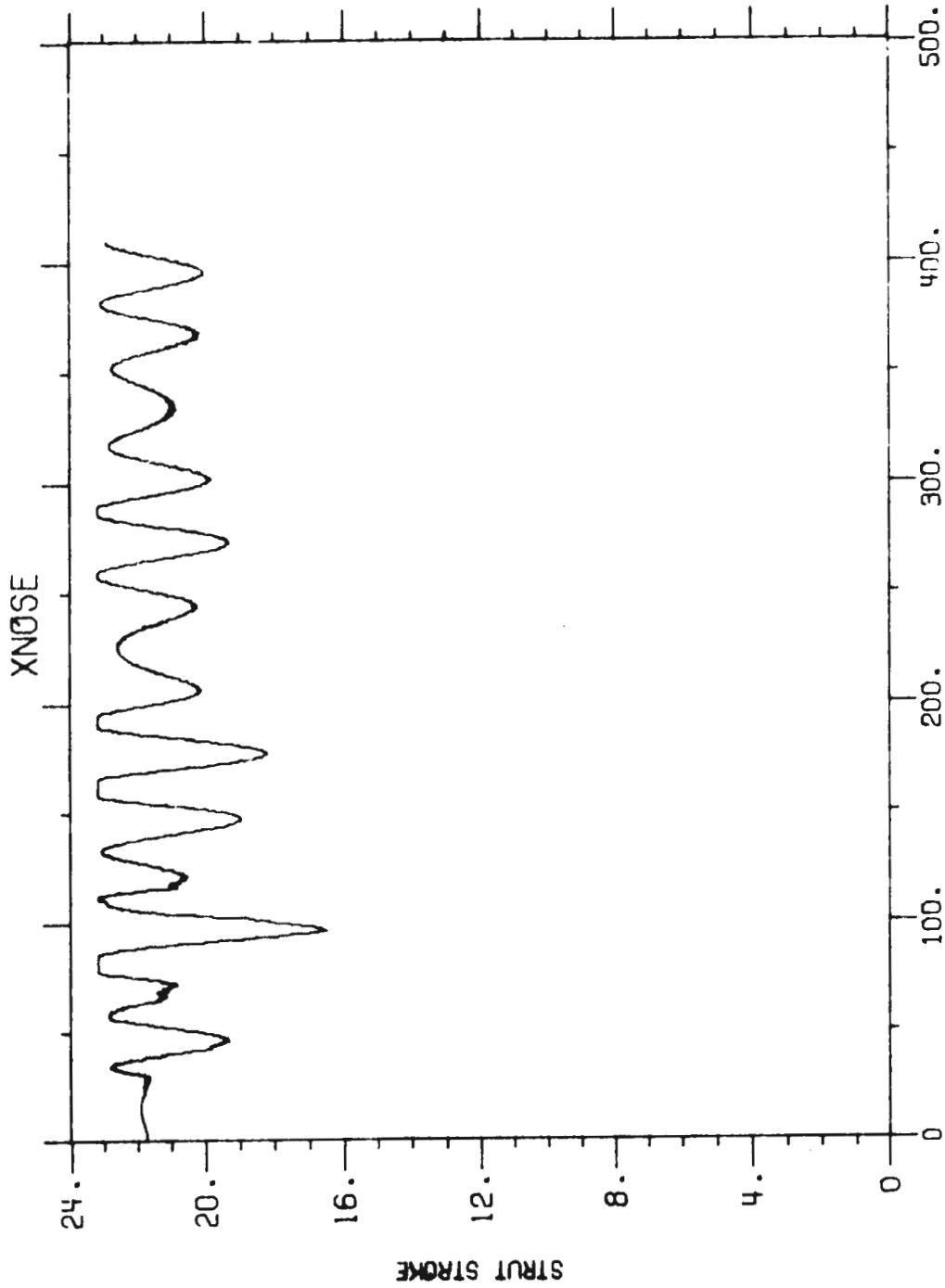


ACCELERATION AT AIRCRAFT CENTER  
OF GRAVITY

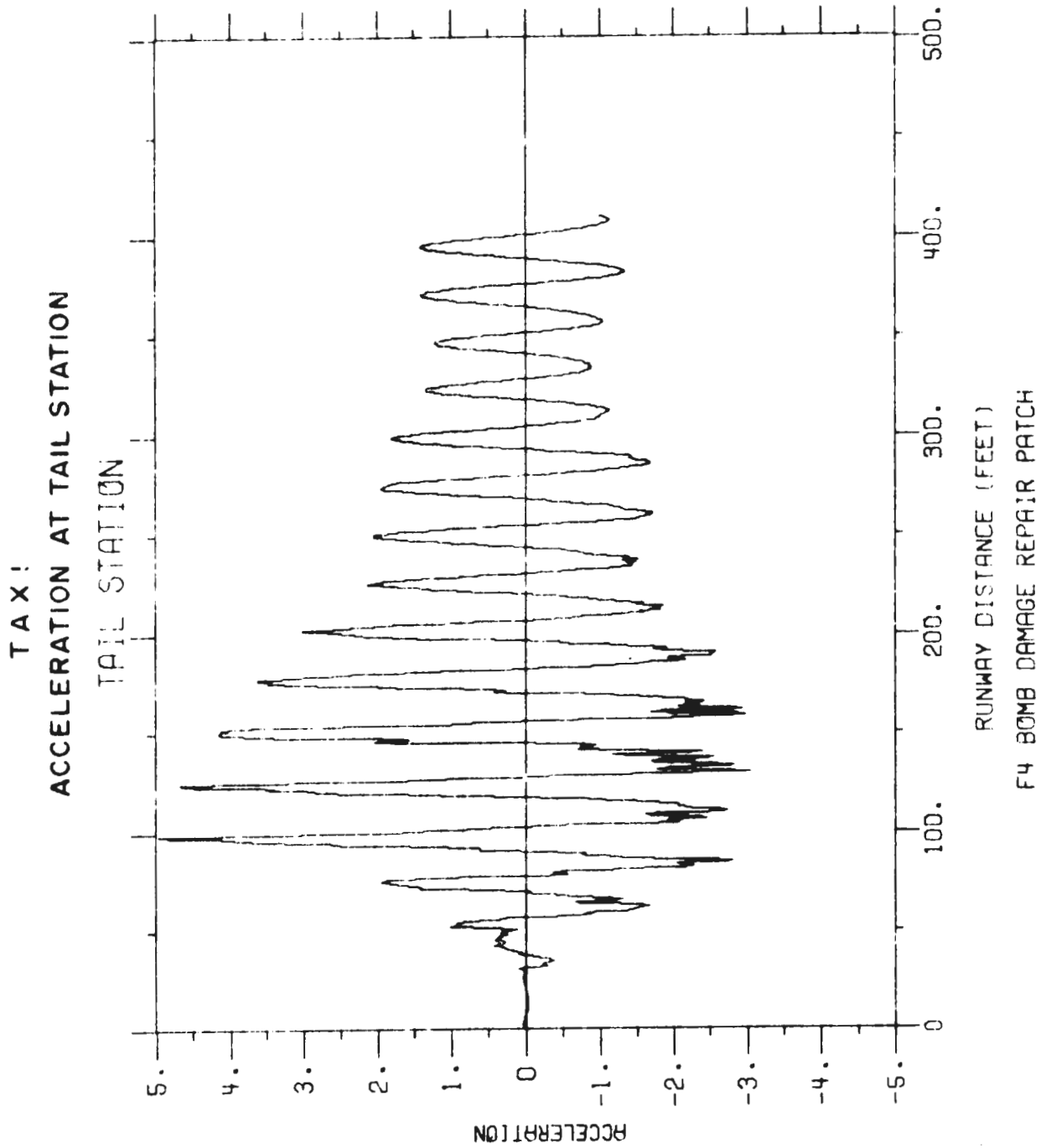


RUNWAY DISTANCE (FEET)  
FOR SOME DAMAGE REPAIR PATCH

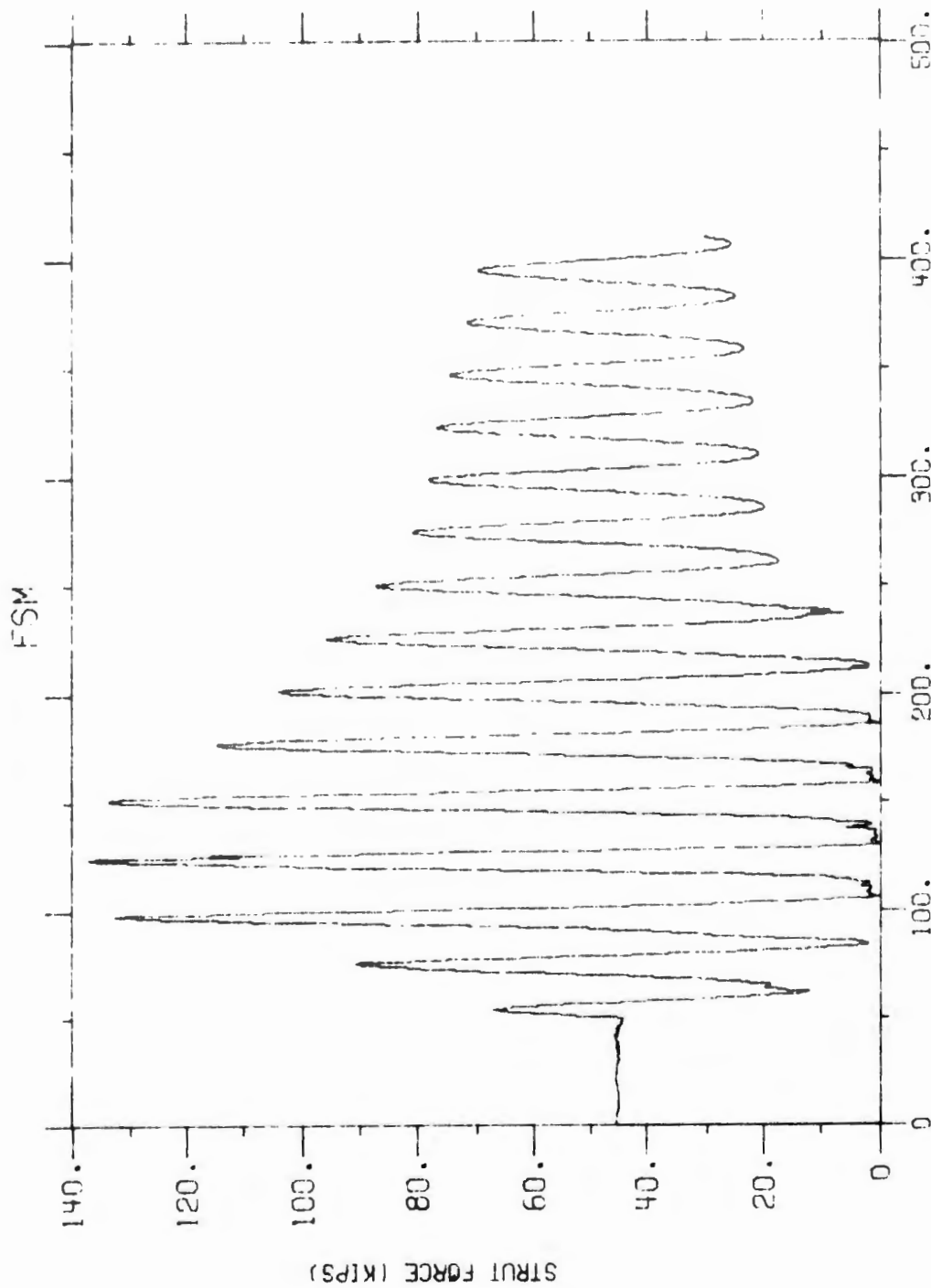
TAXI  
STRUT STROKE, NOSE GEAR



RUNWAY DISTANCE (FEET)  
F4 BOMB DAMAGE REPAIR PATCH

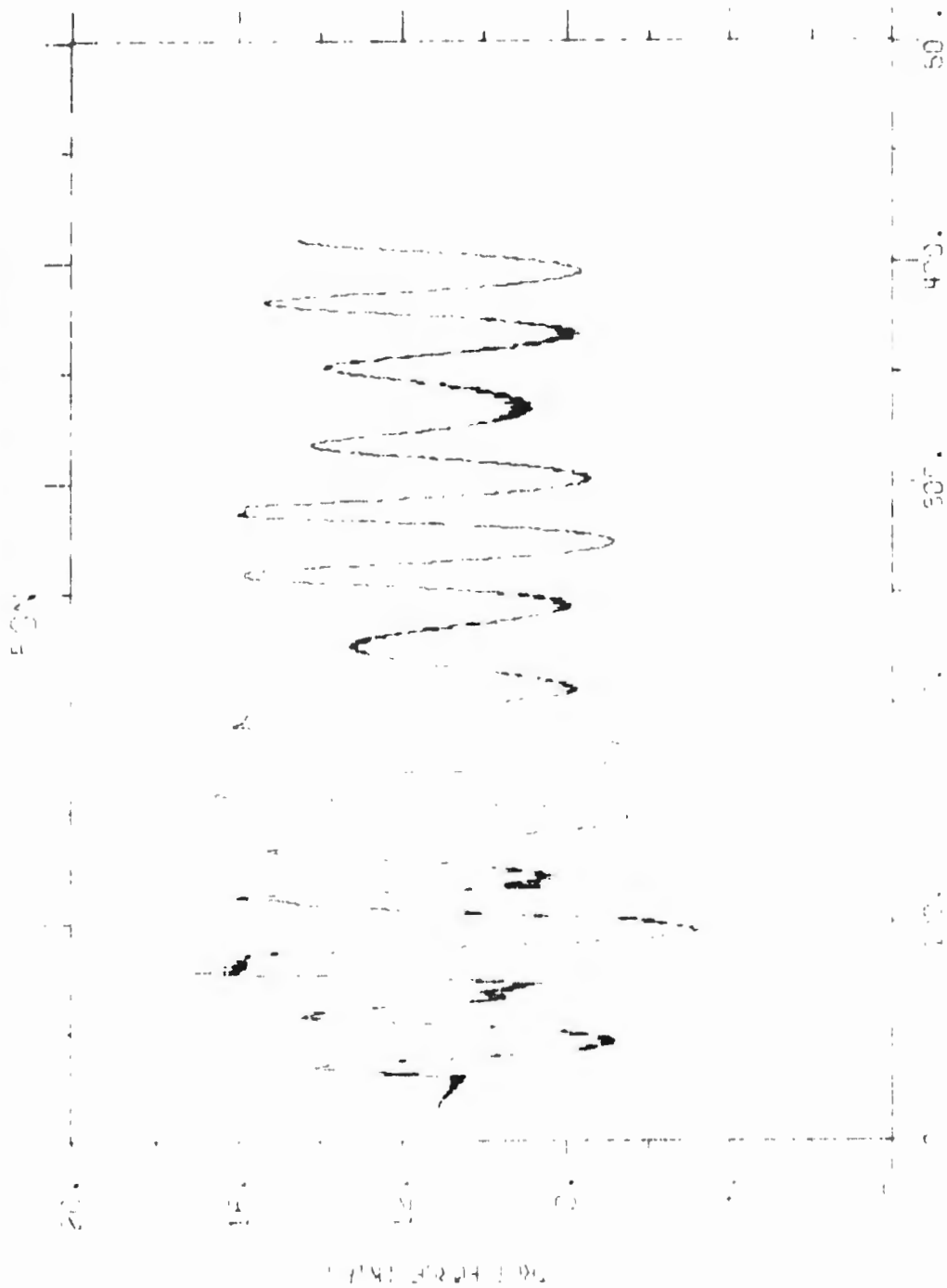


TAXI  
TOTAL FORCE, ALL MAIN GEAR STRUTS



RUNWAY DISTANCE (FEET)  
F4 BOMB DAMAGE REPAIR PATCH

TAXI  
TOTAL FORCE, NOSE GEAR STRUTS



REPAIR PATCH