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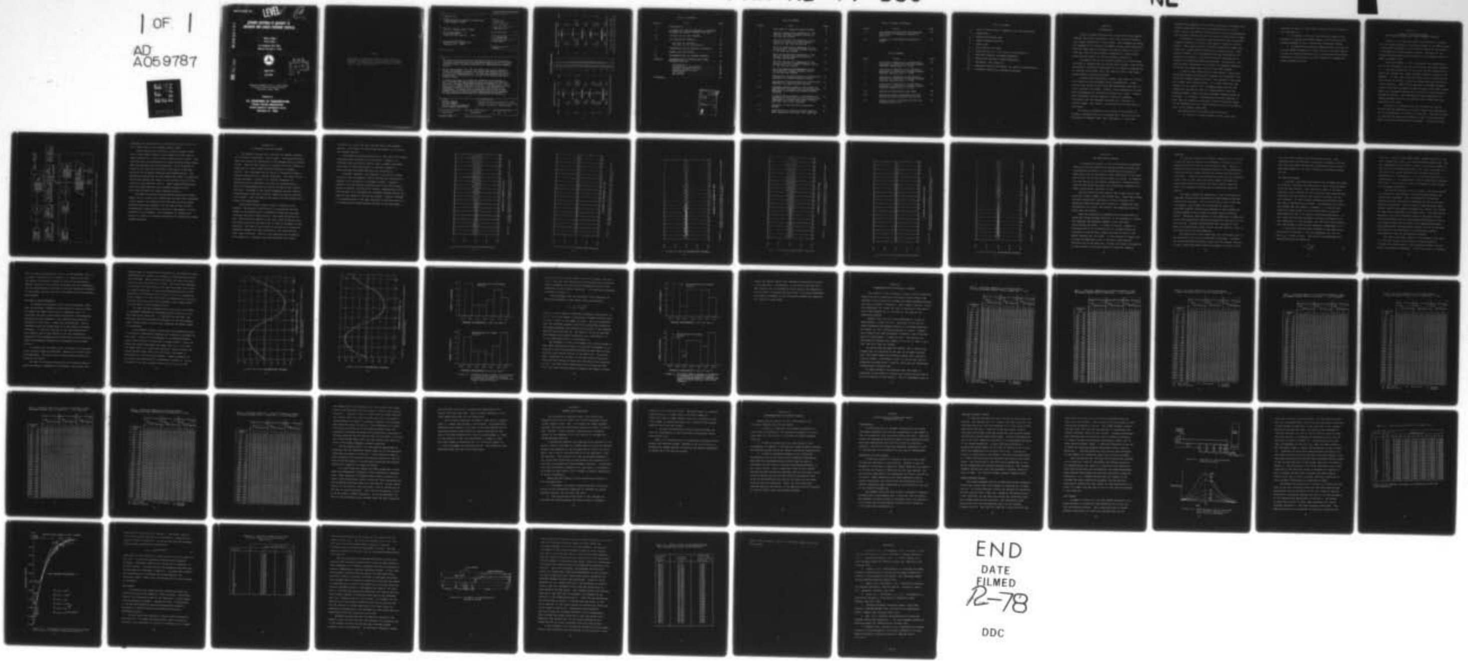

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DYNAMIC RESPONSE OF AIRCRAFT TO UNLOADED AND LOADED PAVEMENT PROFILES

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16. Abstract

The objective of this study was to determine whether or not there exists a significant difference in the simulated dynamic response of an F-4C aircraft traversing either an unloaded (undeflected) or loaded (deflected) pavement profile.

The Air Force computer code, TAXI, was adapted for use on the Clarkson College IBM 360 Model 65 computer from the CDC 6600 computer used by the Air Force Civil Engineering Center. The TAXI code calculates the vertical accelerations at three points on an aircraft as the aircraft traverses a pavement profile.

It appears that there is no significant difference in the response of TAXI to unloaded and loaded pavement profiles at speeds up to 133.3 feet per second. At higher speeds some rejections of the mean do occur, but in light of the continuous acceptance of the test of the distribtion and the predominant acceptance of the test of the mean, these are felt to be insignificant. It appears that the present practice of using unloaded pavement profiles for aircraft dynamic response simulation is acceptable and loaded pavement profiles need not be obtained for this purpose.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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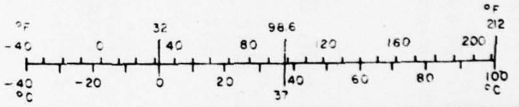
*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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LIST OF SYMBOLS

α - Level of Significance (Probability of False Rejection)

$\bar{X}$ - Sample Mean

u_o - Hypothesized Sample Mean

S - Sample Standard Deviation

n - Sample Size

Z - Test Statistic for Mean

Z_α - Tabulated Value of Z for Level of Significance α

f_i - Observed Frequency (Unloaded Responses)

F_i - Theoretical Frequency (Loaded Responses)

χ^2 - Chi-Square Test Statistic

χ^2_α - Tabulated Value of Chi-Square for Level of Significance α

A,B - Parameters Obtained by Regression Analysis

SECTION I

INTRODUCTION

A major problem encountered by an aircraft during takeoff, landing, and taxiing operations is the high vertical acceleration levels produced by a rough runway. This response can affect the readability of on-board instruments during ground operations. This and other factors influence the overall safety of an aircraft and indicate that pavement roughness is a factor which should not be ignored in airfield pavement evaluation.

To properly control the adverse effects of a rough runway, the areas in question must be located and corrected. Even though a subjective qualitative assessment of the pavement roughness can be obtained from flight crews, the specific area of the runway needing repairs cannot be located.

A method which effectively locates rough areas is to equip an aircraft with low-frequency servo accelerometers. These devices then record the accelerations encountered while the aircraft traverses the runway. However, large expenditures of both time and manpower are required to perform such a test. Furthermore, different aircraft respond to identical pavements differently and the responses generated are a function of aircraft speed. As a result, the practicality of such tests is quite small.

To be able to determine the response of an aircraft to pavement roughness quickly and inexpensively, the Air Force has developed the computer code, TAXI (Reference 1). This code simulates the response of an aircraft to pavement roughness using aircraft characteristics and the pavement profile as input. TAXI's output includes the landing strut forces and displacements and vertical accelerations at three points on the aircraft frame.

At present, the pavement profile used as input to the TAXI program is obtained by using either laser or inertial profilometers. These devices record a series of elevations taken with respect to a local datum to define the pavement profile. This profile, however, is an unloaded profile not deflected by the weight of an aircraft. The profile actually traversed by an aircraft is loaded and therefore deflected. Consequently, the profile being traversed by the aircraft at different speeds are different from those used as input to the TAXI program.

It has not been determined if there exists a significant difference between the simulated response of an aircraft to unloaded and loaded pavement profiles. The purpose of this study was to make such a determination. If it were found that the response of an aircraft to an unloaded pavement profile was essentially the same as that to a loaded profile, then the methods presently used to evaluate pavement roughness would be validated. If, however, a significant difference existed, it would then be necessary to develop a rapid and accurate means for the determination of a loaded pavement profile to be used as input to the computer code, TAXI.

The objectives of this report were as follows:

1. To construct a loaded pavement profile using data

collected at Eglin Air Force Base, Florida during the summer of 1976 (Reference 2).

2. To develop a method of statistically comparing the response to unloaded and loaded pavement profiles which would determine whether or not a significant difference existed.

3. To perform the developed comparison while varying the aircraft speed, direction of travel, and level of significance in order to conclude whether or not a statistically significant difference existed between aircraft response to unloaded and loaded pavement profiles.

SECTION II

A SUMMARY OF PREVIOUS RESEARCH TO DETERMINE UNLOADED AND LOADED PAVEMENT PROFILES

Figure 1 is a flow chart taken from Reference 2 illustrating the steps necessary to determine whether or not there exists a significant difference in the dynamic response of an aircraft to unloaded and loaded pavement profiles. The parts of the complete program which were undertaken in the present study are shown in broken lines.

During the summer of 1976, experiments were conducted to obtain the information upon which this study was based (Reference 2). A detailed description of that work and the methods used to obtain the unloaded and loaded pavement profiles is given in the Appendix. At that time, elevation points along a 2100-foot-long test section of taxiway at Eglin Air Force Base were obtained at 2-foot intervals. These points describe the unloaded pavement profile which would normally be used as input to the TAXI program should the simulated response of an aircraft to this section of taxiway be desired. Data necessary for the computation of a loaded pavement profile to be used as input to TAXI were also obtained at this time.

At each of 23 stations along the taxiway test section, deflections were measured at six points along a line perpendicular to the direction of travel of a load cart. The load cart was a truck with the rear axle modified so that a 25,000 lb single wheel load could be applied to the pavement. The applied load

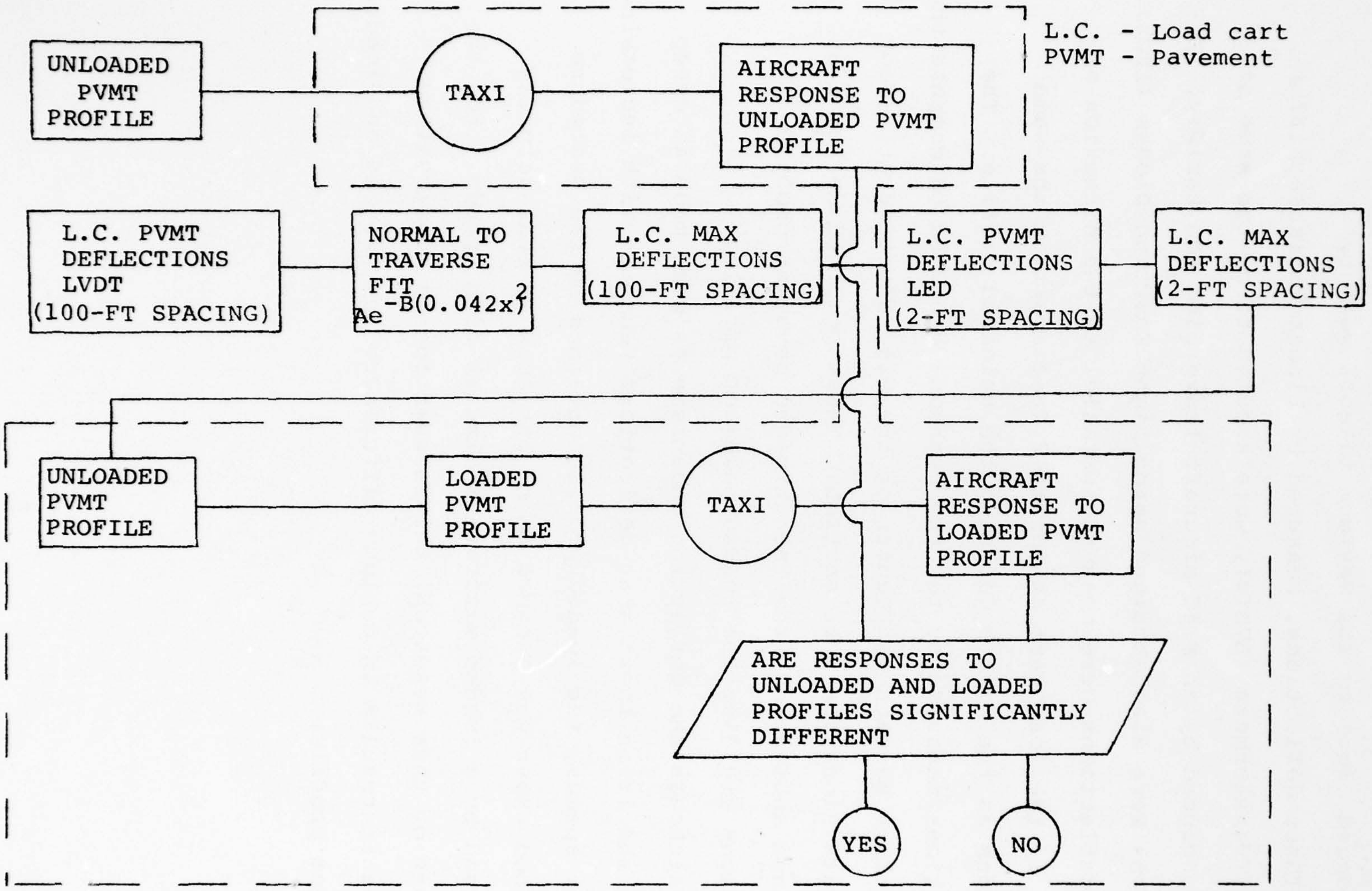

Figure 1. Flow Chart of Complete Research Effort

simulated that which would be applied by the main gear of an F-4C loaded close to its maximum takeoff weight.

These deflections, measured by Linear Variable Differential Transformers (LVDTs), were assumed to be the same as those produced by an F-4C aircraft traversing the taxiway. Deflections were also obtained using Light Emitting Diodes (LEDs). These deflections were measured parallel to the direction of travel of the load cart at points 2 feet apart in the same positions as the points defining the unloaded profile. The deflections measured by the two methods were used to compute the deflections beneath the center of the aircraft tire at 2-foot intervals along the test section. These computed deflections were then subtracted from the unloaded pavement profile elevations yielding the loaded pavement profile.

Although the deflection measurements were made at creep speeds and it is known that deflections decrease with increasing vehicle speeds, the loaded profile obtained by the procedure described above was assumed to be the same as that actually traversed by a loaded aircraft moving at high speeds. For the purposes of this research, this assumption is conservative because it results in maximum differences in unloaded and loaded pavement profiles.

SECTION III

A REVIEW OF THE TAXI PROGRAM

The computer program TAXI simulates the dynamic response of an aircraft traversing a rigid surface. The program does not take into account any deflection of the pavement due to aircraft weight. Input to TAXI consists of aircraft data and a series of elevations at 2-foot intervals which comprise a pavement profile. The programmer has the option of specifying either a constant speed taxi or a takeoff simulation. The output of the program includes a listing of 10 aircraft parameters at specified time (or distance) intervals and Calcomp plots of vertical accelerations and the profile as seen by the aircraft nose gear. Included in the output parameters are the vertical accelerations at the pilot station, center of gravity, and the tail section. Also included in the output are the landing strut forces and displacements.

The profile used as input to TAXI is modifed by the program. The length of the profile is increased by 100 feet (added to the starting end) of pavement so that the nose gear traverses the entire input profile. This modified profile is then normalized with respect to the first input elevation point. The resulting profile has the first 102 feet of pavement at zero elevation. The rest of the points are arrived at by taking the difference between the input elevation at the point and the first input elevation. Finally, the elevations are normalized with respect to a straight line drawn from the first input elevation to a point 280 feet from the end of the pavement profile. The reason for normalizing the profile is to facilitate output plotting.

The resulting normalized profile is that which the program simulates being traversed by the aircraft. Though it is different from the profile used as input, studies have shown that there is little difference in aircraft response to normalized and non-normalized profiles (Reference 2).

Figures 2 through 7 are examples of the output of TAXI plotted to show the general form of the vertical acceleration response of an aircraft to a pavement profile. Figures 2 through 4 are the vertical accelerations at the tail section, center of gravity, and the pilot station, respectively, of an F-4C aircraft as it traverses the unloaded pavement profile at a constant taxi speed of 100 feet per second. Figures 5 through 7 are accelerations at the same positions on the aircraft as it is traversing the loaded pavement profile at the same speed.

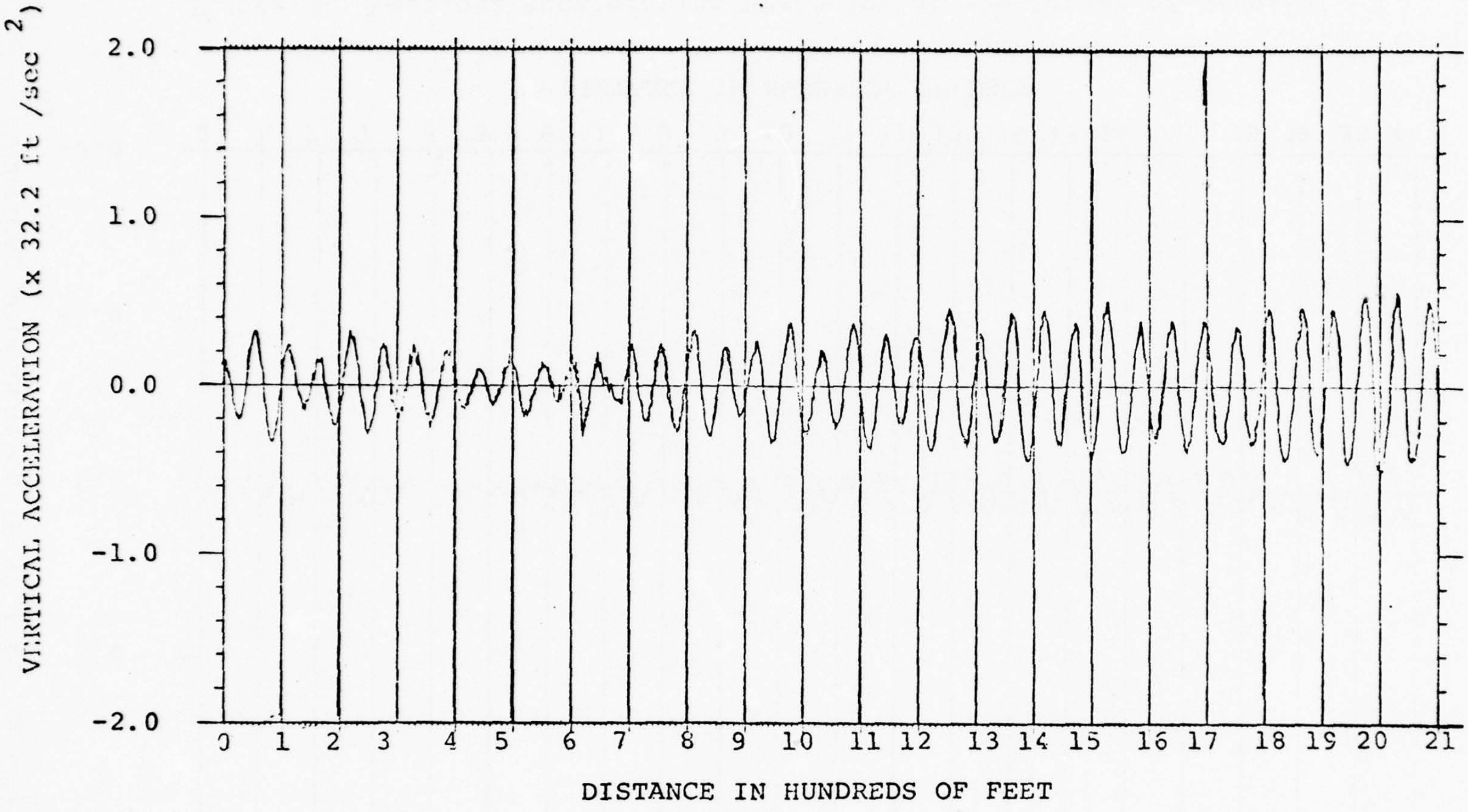

Figure 2. Vertical Acceleration Responses at Tail Section (Unloaded Pavement Profile at 100 Feet Per Second)

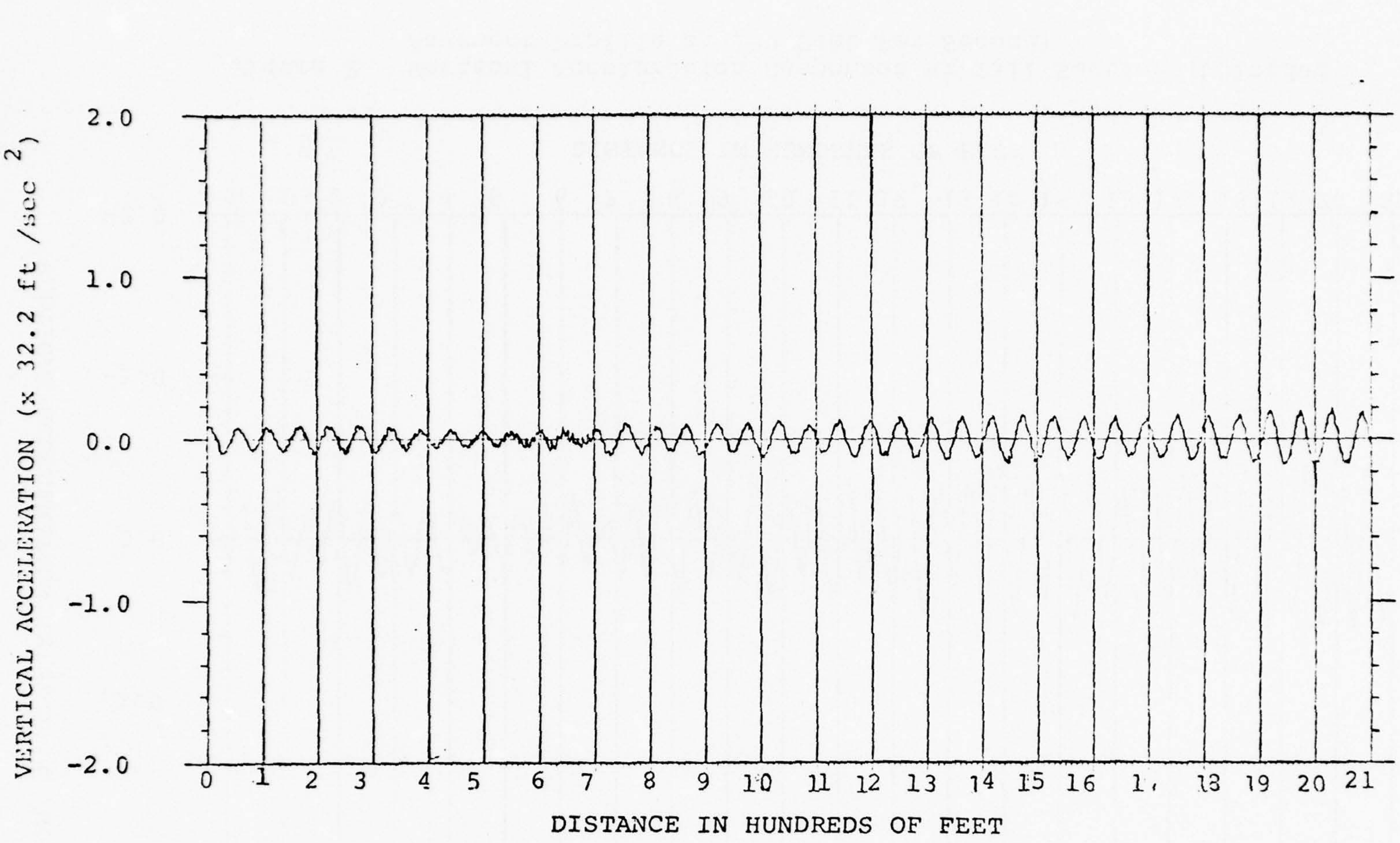

Figure 3. Vertical Acceleration Responses at the Center of Gravity (Unloaded Pavement Profile at 100 Feet Per Second)

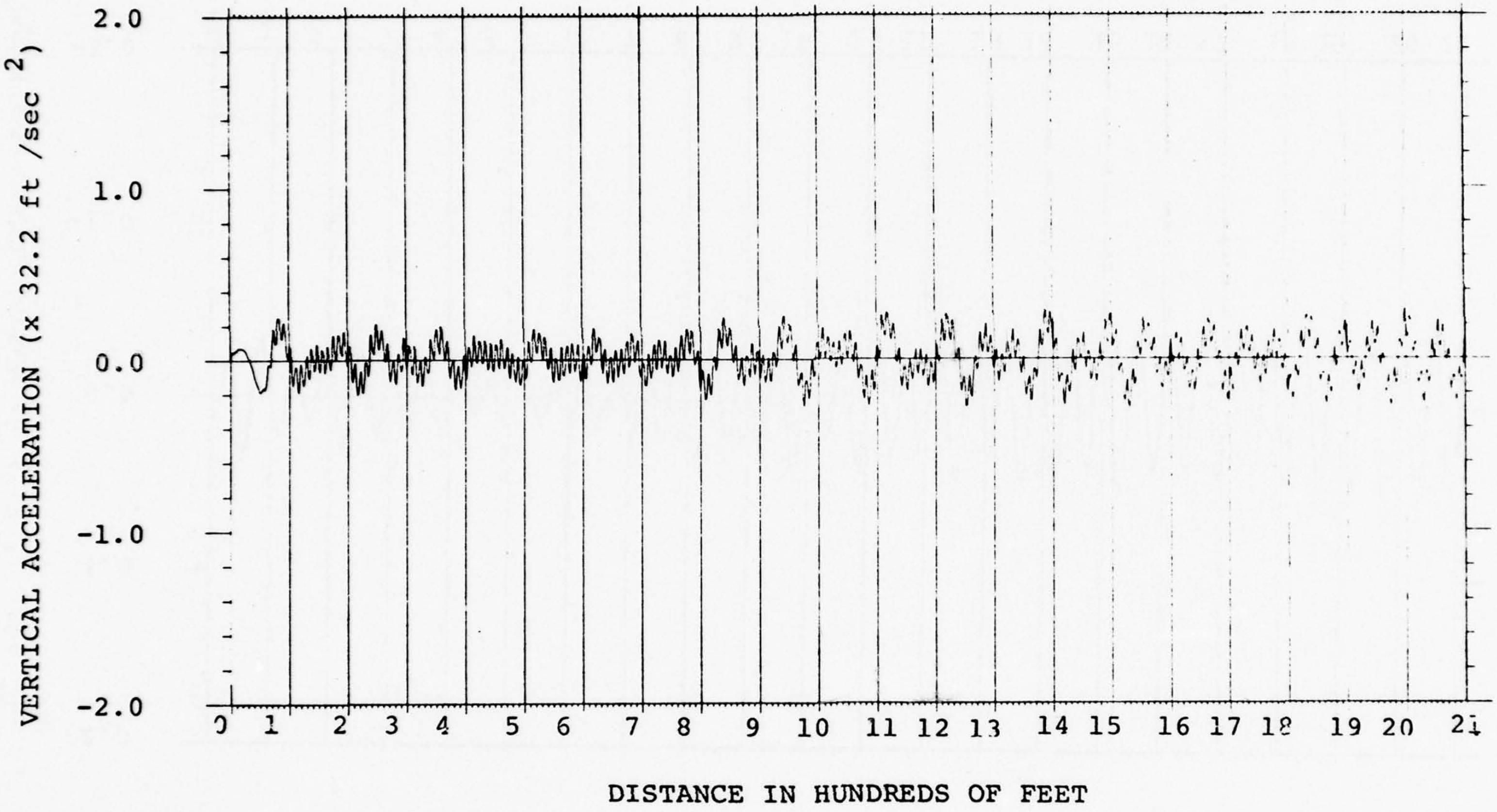

Figure 4. Vertical Acceleration Responses at the Pilot Station (Unloaded Pavement Profile at 100 Feet Per Second)

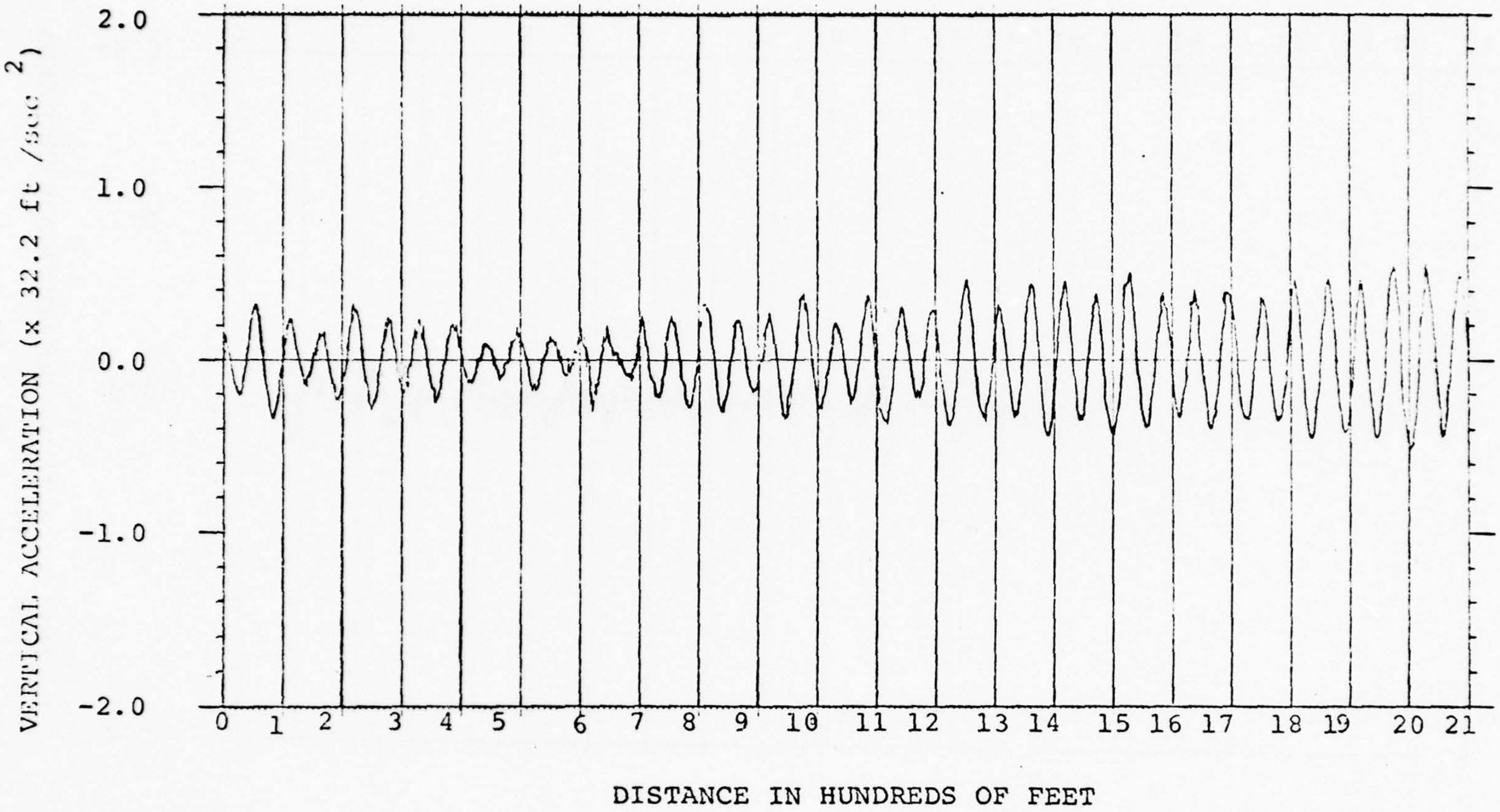

Figure 5. Vertical Acceleration Responses at Tail Section (Loaded) Pavement Profile at 100 Feet Per Second)

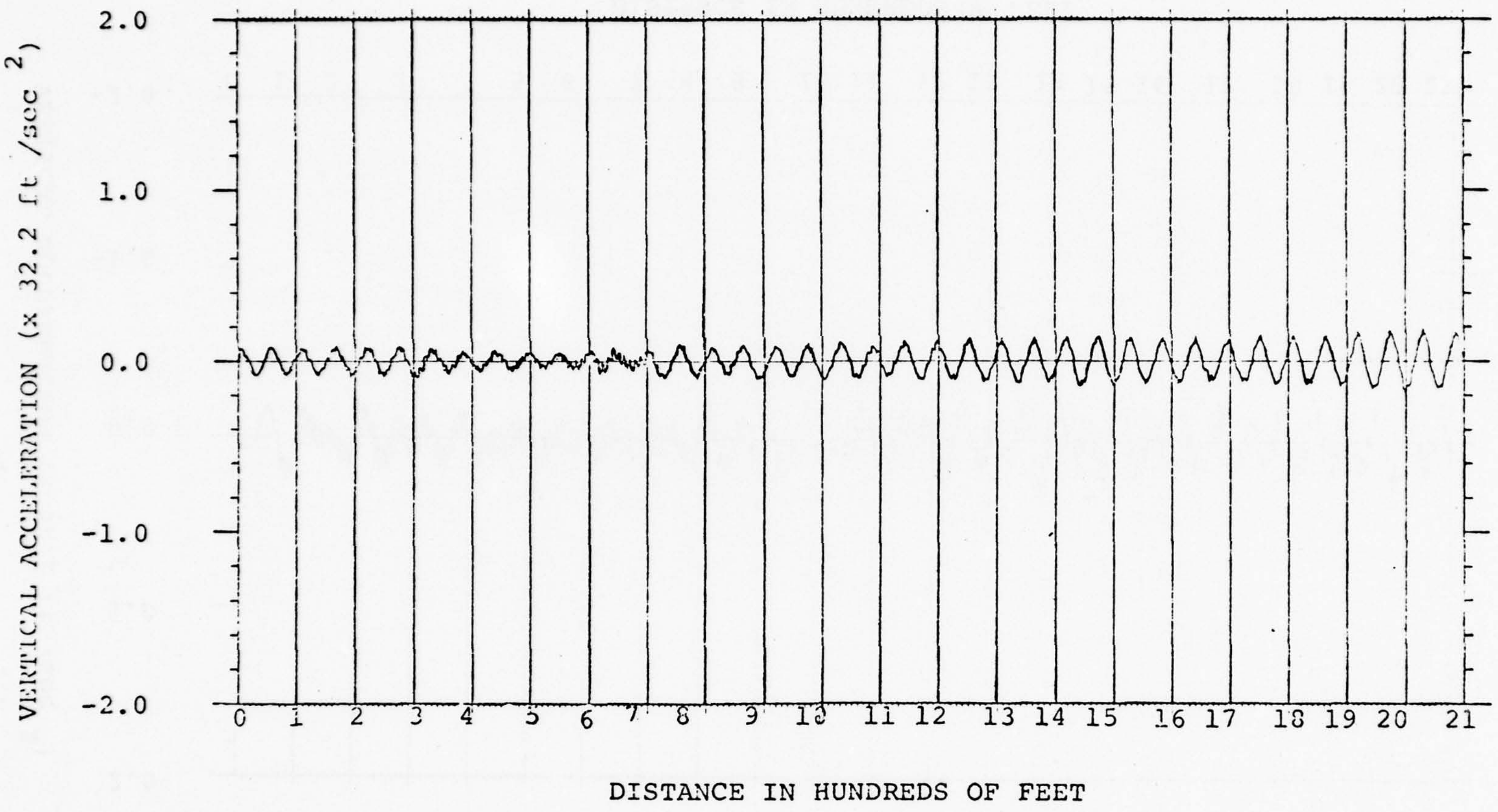

Figure 6. Vertical Acceleration Responses at the Center of Gravity (Loaded Pavement Profile at 100 Feet Per Second)

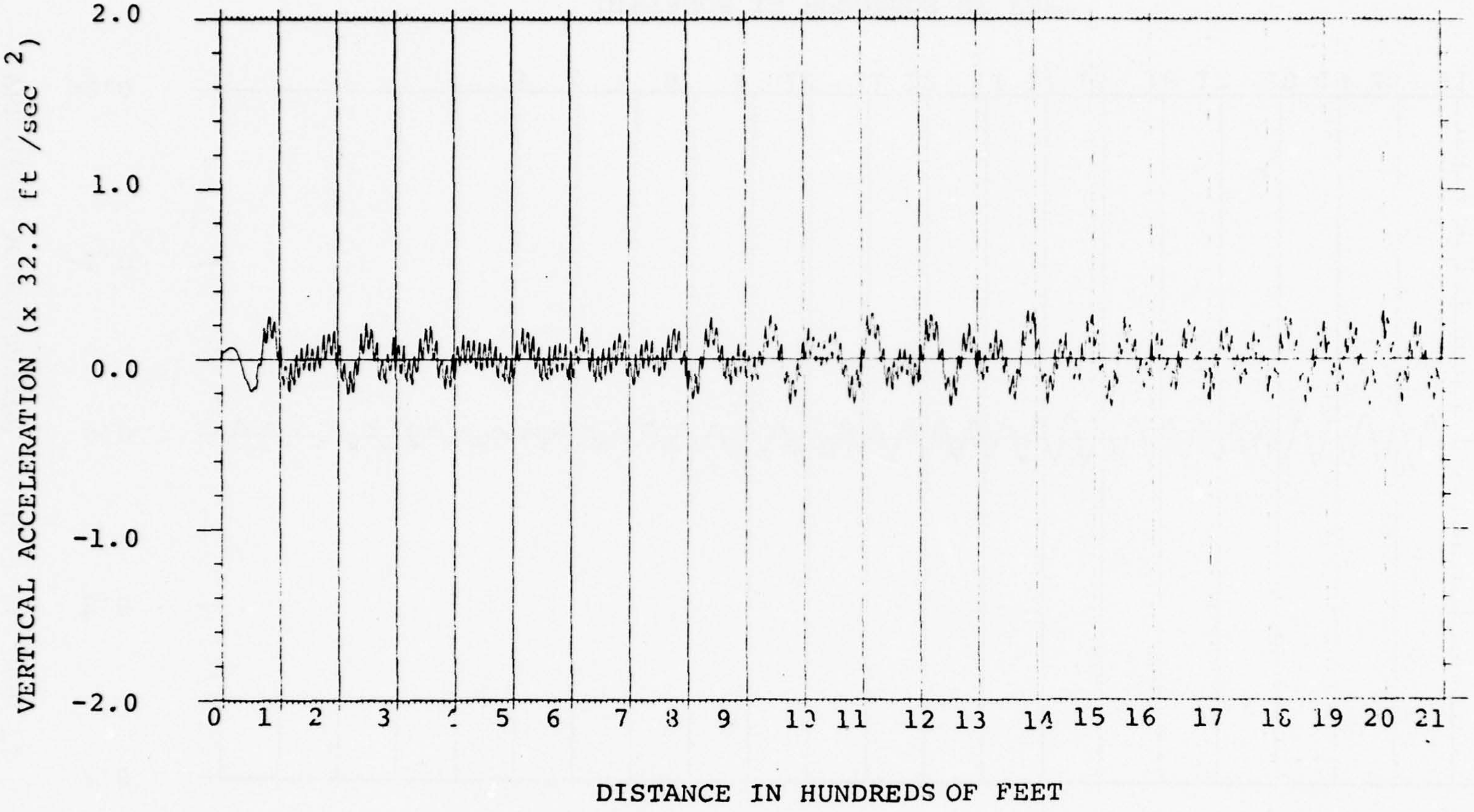

Figure 7. Vertical Acceleration Responses at the Pilot Station (Loaded Pavement Profile at 100 Feet Per Second)

SECTION IV

THE STATISTICAL ANALYSIS

In determining whether or not the acceleration responses resulting from the unloaded and loaded pavement profiles were significantly different, it was decided that the method of comparison would be performed on short subsections of the pavement as well as the test section taken as a whole. By breaking the test section up into smaller subsections, localized areas could be identified over which the acceleration responses were either significantly different or not.

The 2100-foot-long test section was divided into 25 subsections of equal length, each 84 feet long. Since TAXI outputs aircraft acceleration responses at 2-foot intervals, the comparison would be based upon 43 points per subsection; when performed on the entire test section, the comparison would be based upon 1051 points.

Once the acceleration responses were obtained using unloaded and loaded pavement profiles, it was necessary to compare the responses and determine whether or not they were significantly different. In order to do this, a method of comparison had to be developed since no standard method was available to statistically compare two sets of data in the manner required for this study. It was desired to compare the two sets of responses to see if they were significantly different and at the same time, to take into account the position of the aircraft on the test section at which the response occurred.

If the test used were an ordinary comparison of the means of the two sets of acceleration responses, the position of the responses along the section tested would be lost. This is because the mean is the algebraic average of all accelerations along the section tested and does not account for position of occurrence. A test of the distribution would also be inadequate since a test of this type would only compare the number of accelerations which are within the same range of magnitude; again, not accounting for position of occurrence along the section.

For these reasons the comparison of the two acceleration responses obtained from unloaded and loaded pavement profiles consisted of two parts. The first part was a test of the mean of a sample. This sample was constructed by taking the difference between acceleration responses to the unloaded and loaded pavement profiles point for point along the section tested. Therefore, each element in this sample was a comparison of the two acceleration responses generated at that point on the test section. Testing the hypothesis that the mean of this sample is significantly close to zero was then used as a test of the similarity of the two responses.

The second part of the comparison was a Chi-Square test of the distribution of the two acceleration responses. Although the errors mentioned previously would still be present, the use of small subsections would reduce the number of points in each test and tend to reduce and localize those errors. The hypothesis that the unloaded acceleration responses could have come from the loaded acceleration responses was then tested to determine whether or not there existed any difference between the two.

THE TEST OF THE MEAN

Initially, the differences between the unloaded and loaded acceleration responses were obtained on a point for point basis along the test section. This was done at each of the three locations on the aircraft for which vertical accelerations were available; the tail section, the center of gravity, and the pilot station. It was on these acceleration differences that the test of the mean was performed. In performing this test it was assumed that the number of elements, n, in each section tested was large enough so that the distribution could be approximated by that of a normally distributed population. In this study the test was performed on either 43 elements (for each subsection) or 1051 elements (for the entire test section), more than enough to satisfy this assumption (References 3, 4).

A two-tailed test was then performed on the mean of the acceleration differences. The null hypothesis was that the mean, u_o, is equal to zero. The test of this hypothesis was achieved by using the statistic

$$Z = \frac{\bar{X} - u_o}{S/\sqrt{n}} \qquad (1)$$

where $\bar{X}$, S, and n are the sample mean, standard deviation, and size, respectively, and u_o is the hypothesized sample mean. The null hypothesis that the mean is equal to zero was accepted if the value of the computed statistic fell within the range $\pm Z_\alpha$. The value of Z_α can be obtained from standard statistical references (e.g., References 3, 4) for the specified level of significance, α. An acceptance of the null hypothesis indicates that there is no reason to reject the assumption that the mean of the sample equals zero.

The test of the mean is not in itself a sufficient method for testing the significance of the differences between the acceleration responses. This is because the differences obtained from the acceleration responses will not be entirely positive or negative. When the mean is computed using these values, positive and negative elements will cancel; as a result the mean can be expected to be close to zero. It would also be possible to arrive at identical values of the mean from two entirely different sets of acceleration differences so long as the elements cancelled each other in the appropriate manner. These undesirable characteristics prevent the test of the mean to account for the magnitude of the differences between corresponding values of acceleration response.

The test of the mean, though, is an excellent first step in a two step analysis which forms a screening method to determine the significance of the differences between the two sets of acceleration responses. If this first test is rejected;

that is, the null hypothesis, $u_o = 0$, is not accepted, there is no need to further test the section. If, however, the null hypothesis is accepted, a method of testing the differences between the sets of acceleration responses that will compensate for the shortcomings of the test of the mean should be conducted. In this study, the next test was a Chi-Square test of the sample distribution.

THE TEST OF THE DISTRIBUTION

To perform a Chi-Square test of the distribution, there must be available a theoretical distribution to use as a basis to compare the sample being tested. Therefore, prior to performing the test of the sample distribution, the assumption was made that the responses to the loaded profile could be treated as if they were a theoretical distribution. This is reasonable since the loaded profile is that which is actually traversed. In this way, the test of the distribution would then become a test to see whether or not the acceleration responses to the unloaded profile could have come from the theoretical distribution defined by the responses to the loaded profile.

To perform the Chi-Square test, the number of occurrences within certain ranges of magnitude, referred to as cells, must be established. The first step in finding these values is to construct the cells.

For each of the three positions on the aircraft frame at which acceleration responses were available, the highest and lowest values of acceleration obtained over the subsection under consideration by either the unloaded or loaded pavement profile were recorded. These values would become the upper and lower limits of the cells used in the test. The cells were obtained by dividing the region between the upper and lower limits into six equal subregions. It was then determined how many of the accelerations generated out of a total of 43 for a subsection with a length of 84 feet fell within the boundaries of each cell. This was done using first the responses to the loaded profile and then those to the unloaded profile.

In order for the Chi-Square test to be valid, the number of responses generated by the loaded profile occurring in any cell must be at least five. If such were not the case, the deficient cell was combined with whichever of the two adjacent cells (either above or below) that contained the lesser number of occurrences.

As an example, Figures 8 and 9 show two hypothetical sets of simulated acceleration responses for a section of pavement 84 feet long. Figure 8 is the response to an unloaded pavement profile while Figure 9 is that for a loaded profile. Using the method previously described, the upper limit of + 0.32 g and the lower limit of - 0.28 g were obtained. After dividing the region between these limits into six cells, the number of occurrences in each cell were counted. These frequencies of occurrence are represented as histograms in Figure 10. As can be observed, the cell ranging from 0.02 g to 0.12 g in the

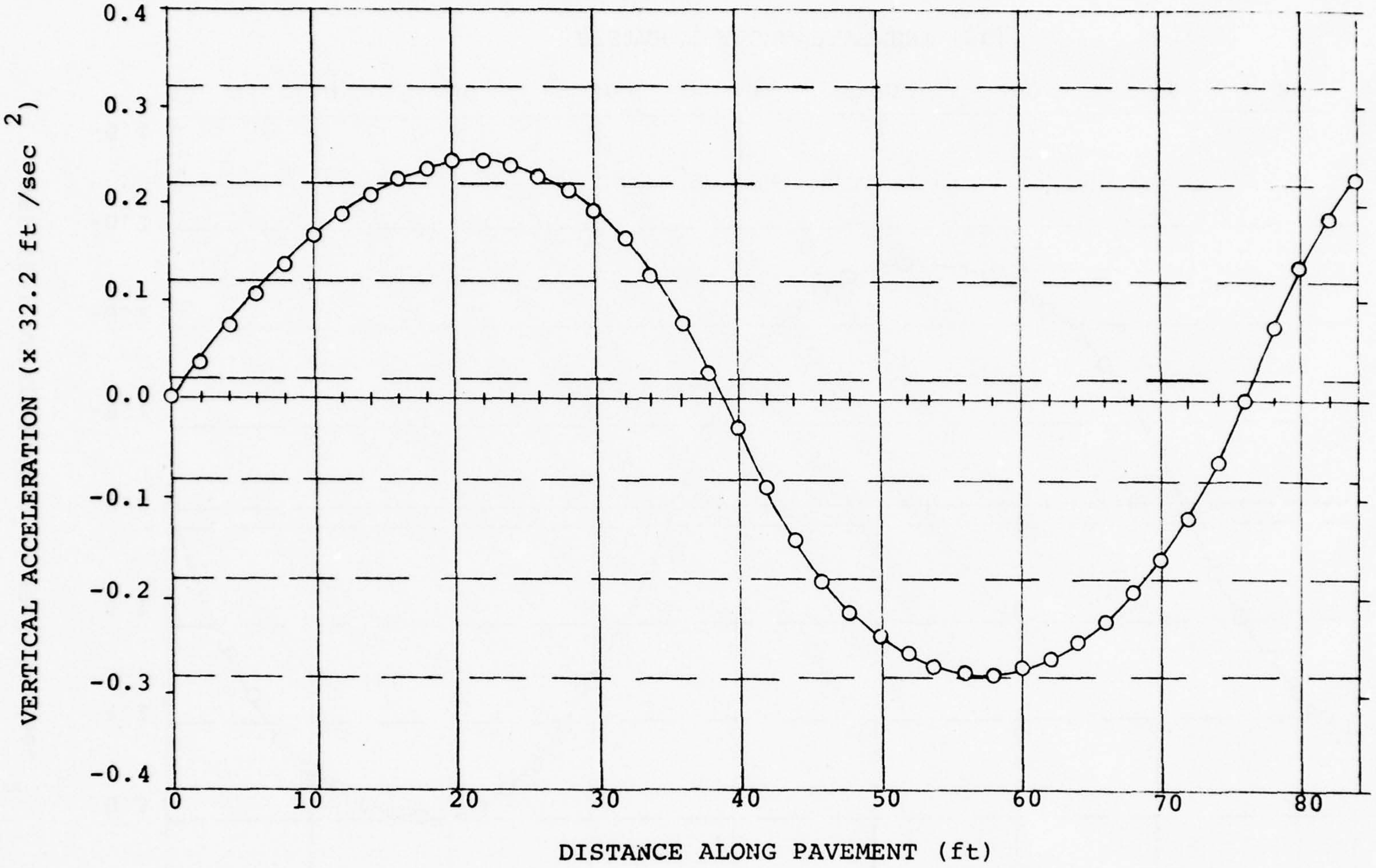

Figure 8. Hypothetical Simulated Vertical Acceleration Response to Unloaded Pavement Profile

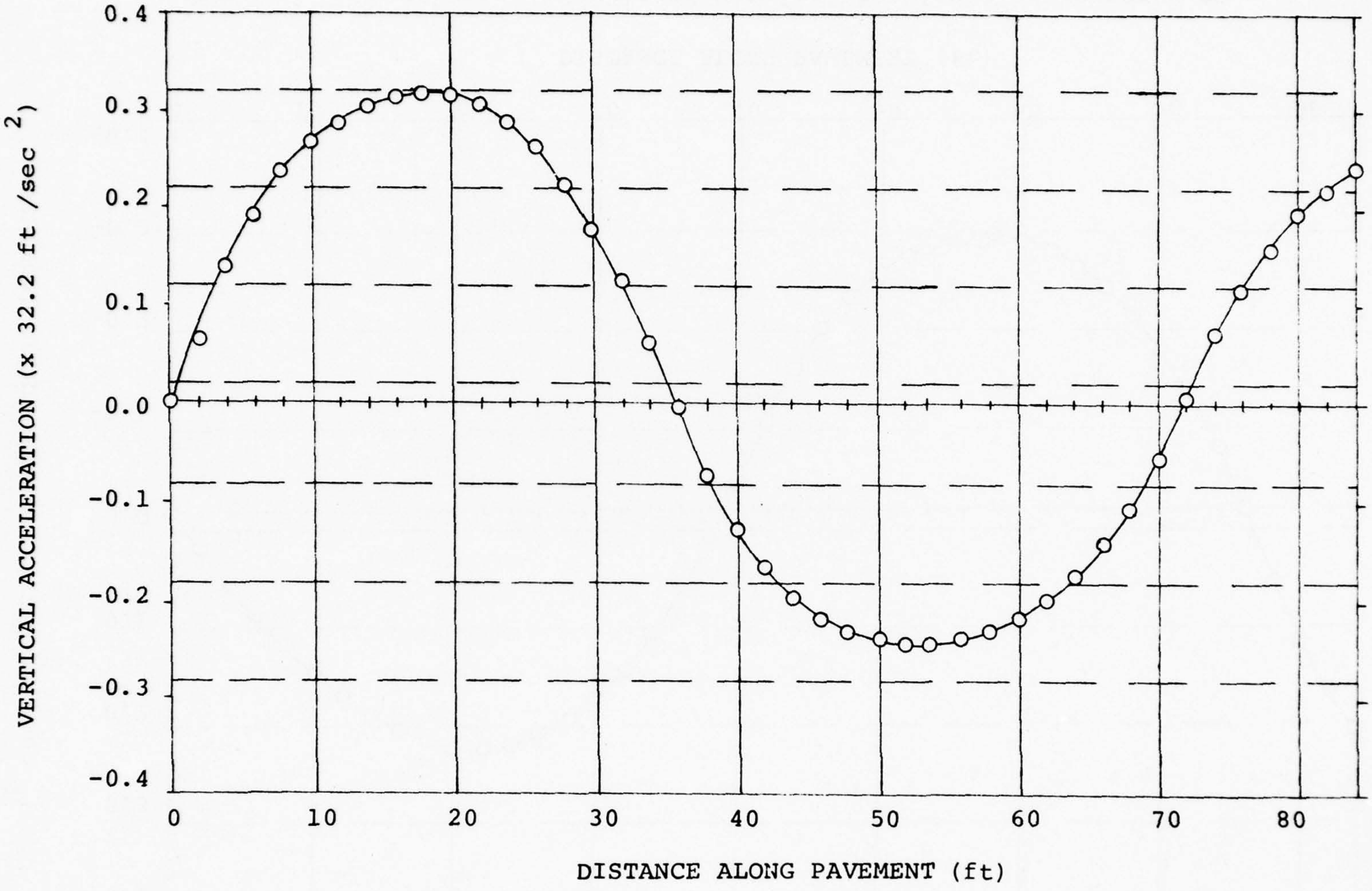

Figure 9. Hypothetical Simulated Vertical Acceleration Response to Loaded Pavement Profile

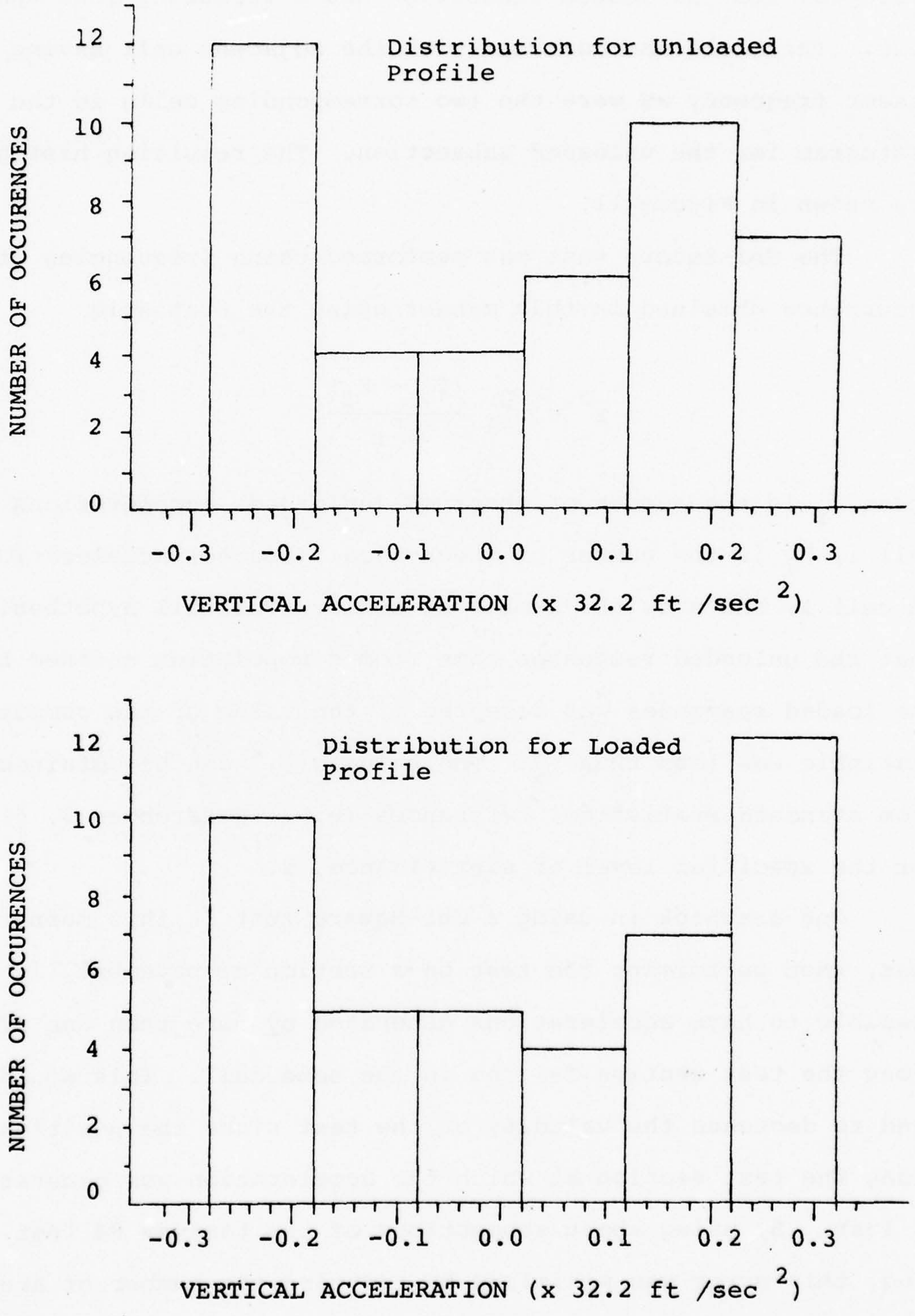

Figure 10. Histogram Showing Number of Occurrences of Hypothetical Simulated Vertical Acceleration Responses to Unloaded and Loaded Pavement Profiles

histogram for the loaded subsection has a frequency less than five. This cell was combined with the adjacent cell having the lesser frequency as were the two corresponding cells in the histogram for the unloaded subsection. The resulting histograms are shown in Figure 11.

The Chi-Square test was performed using frequencies of occurrence obtained in this manner using the statistic

$$\chi^2 = \sum_{i=1}^{n} \frac{(f_i - F_i)^2}{F_i} \tag{2}$$

where f_i is the number of observed (unloaded) accelerations in cell i, F_i is the number of theoretical (loaded) accelerations in cell i, and n is the number of cells. The null hypothesis that the unloaded responses came from a population defined by the loaded responses was accepted if the value of the computed statistic was less than χ^2_α. The value of χ^2_α can be obtained from standard statistical references (e.g., References 3, 4) for the specified level of significance, α.

One drawback in using a Chi-Square test in this manner is that, when performing the test on a section of pavement, it is possible to have accelerations generated by more than one area along the test section falling in the same cell. This would tend to decrease the validity of the test since the position along the test section at which the acceleration was generated is lost. By using short subsections of the taxiway 84 feet long, this error was minimized by reducing the number of areas

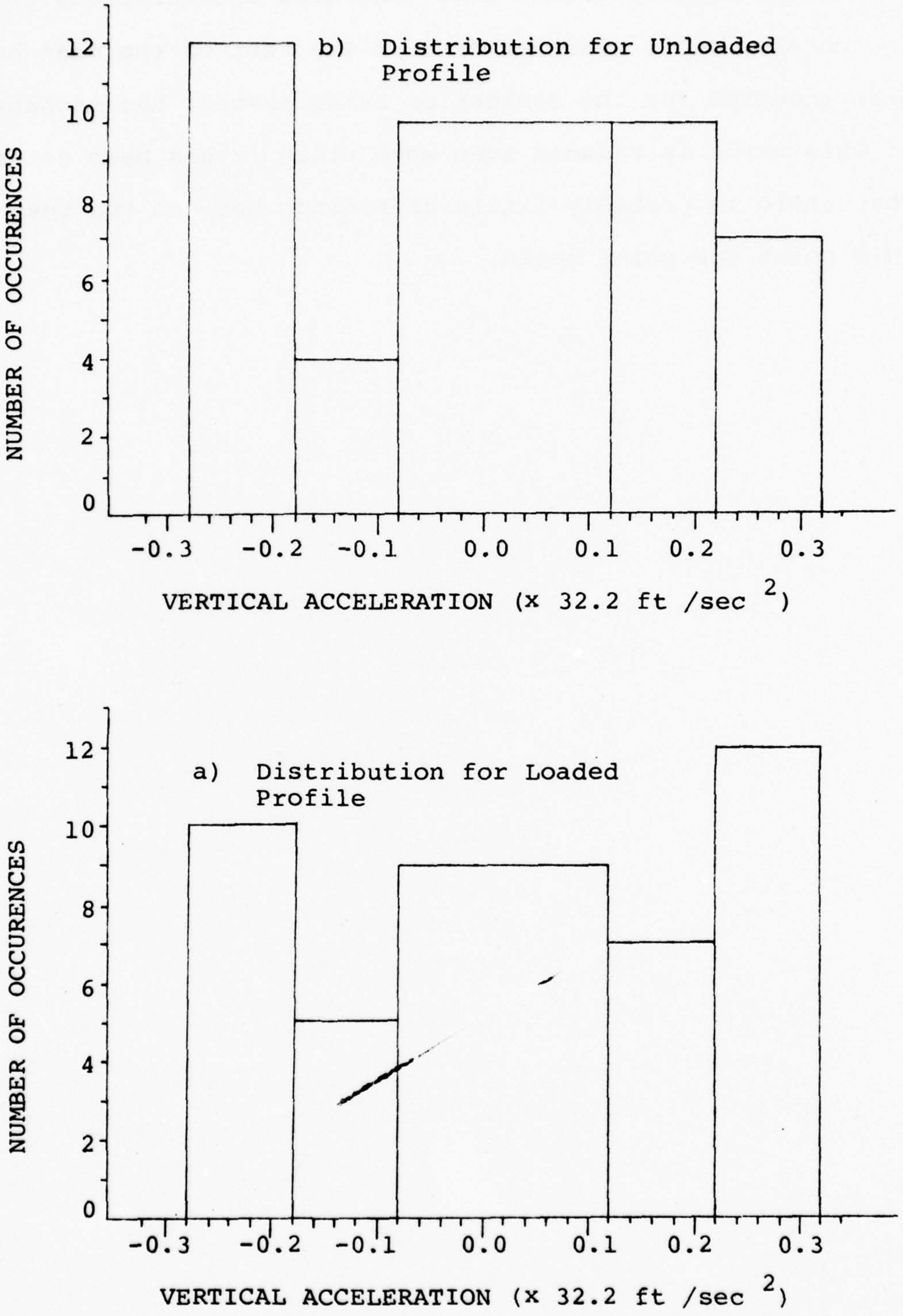

FIGURE 11 HISTOGRAM SHOWING NUMBER OF OCCURENCES OF HYPOTHETICAL SIMULATED VERTICAL ACCELERATION RESPONSES TO UNLOADED AND LOADED PAVEMENT PROFILES (WITH CELLS COMBINED)

within the section tested that generated accelerations falling in the same cell. Furthermore, if the test of the mean has been accepted for the subsection being tested, the probability of this error is reduced even more since it has been determined that there is probably little difference between the responses on a point for point basis.

SECTION V

PRESENTATION AND DISCUSSION OF RESULTS

The results of the statistical analysis used to determine whether or not a significant difference existed between the response of an aircraft to unloaded and loaded pavement profiles are shown in Tables 1 through 4. These tables indicate if the null hypothesis for either the test of the mean or the distribution was accepted (A) or rejected (R) for each of the subsections tested.

Tables 1 and 2 are for tests performed at a level of significance, α, equal to 0.05. The first is for the aircraft traversing the pavement profile in a forward direction, the second is for a reversed direction of travel. Tables 3 and 4 contain the same information as Tables 1 and 2 with the level of significance, α, equal to 0.02. The results are tabulated for constant taxi speeds of 33.3, 66.7, 100.0, 133.3, 166.7 and 200.0 feet per second.

As can be seen by examining Tables 1 and 3, during the forward runs no rejections of the test of the mean occurred until the higher speeds were reached, namely 166.7 and 200.0 feet per second. From Tables 2 and 4 it can be seen that no rejections occurred until a speed of 200.0 feet per second was reached during reversed runs.

At these speeds it was observed that the number of rejections at the center of gravity was usually smaller than at the pilot station or tail section. This is reasonable since it

TABLE 1. STATISTICAL COMPARISON OF ACCELERATION RESPONSES TO LOADED AND UNLOADED PAVEMENT PROFILES (FORWARD RUN; $\alpha = 0.05$)

	Speed = 33.3 ft/sec						Speed = 66.7 ft/sec						Speed = 100 ft/sec					
Subsection (ft)	TS		CG		PS		TS		CG		PS		TS		CG		PS	
	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution
0 - 84	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
84 - 168	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
168 - 252	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
252 - 336	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
336 - 420	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
420 - 504	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
504 - 588	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
588 - 672	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
672 - 756	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
756 - 840	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
840 - 924	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
924 - 1008	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1008 - 1092	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1092 - 1176	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1176 - 1260	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1260 - 1344	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1344 - 1428	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1428 - 1512	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1512 - 1596	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1596 - 1680	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1680 - 1764	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1764 - 1848	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1848 - 1932	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1932 - 2016	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
2016 - 2100	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
0 - 2100	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A

TS - Tail section
CG - Center of gravity
PS - Pilot station
A - Accepted
R - Rejected

TABLE 1. STATISTICAL COMPARISON OF ACCELERATION RESPONSES TO LOADED AND UNLOADED PAVEMENT PROFILES (FORWARD RUN; $\alpha = 0.05$) (CONCLUDED)

	Speed=133.33 ft/sec			Speed=166.67 ft/sec			Speed = 200 ft/sec		
	Mean Distribution			Mean Distribution			Mean Distribution		
Subsection (ft)	TS	CG	PS	TS	CG	PS	TS	CG	PS
0 - 84	A A	A A	A A	A A	A A	A A	A A	A A	A A
84 - 168	A A	A A	A A	A A	A A	A A	A A	A A	A A
168 - 252	A A	A A	A A	A A	A A	A A	A A	A A	A A
252 - 336	A A	A A	A A	A A	A A	A A	A A	A A	R A
336 - 420	A A	A A	A A	A A	A A	A A	R A	R A	R A
420 - 504	A A	A A	A A	A A	A A	A A	A A	A A	A A
504 - 588	A A	A A	A A	R A	A A	A A	A A	A A	A A
588 - 672	A A	A A	A A	A A	A A	A A	R A	A A	A A
672 - 756	A A	A A	A A	A A	A A	R A	A A	R A	R A
756 - 840	A A	A A	A A	A A	A A	A A	A A	A A	A A
840 - 924	A A	A A	A A	A A	A A	A A	R A	R A	R A
924 - 1008	A A	A A	A A	R A	A A	R A	R A	R A	R A
1008 - 1092	A A	A A	A A	A A	A A	A A	A A	A A	A A
1092 - 1176	A A	A A	A A	A A	A A	R A	R A	R A	R A
1176 - 1260	A A	A A	A A	A A	A A	R A	R A	R A	R A
1260 - 1344	A A	A A	A A	A A	A A	A A	A A	A A	A A
1344 - 1428	A A	A A	A A	A A	A A	A A	R A	A A	R A
1428 - 1512	A A	A A	A A	A A	A A	A A	R A	R A	R A
1512 - 1596	A A	A A	A A	A A	A A	A A	R A	A A	A A
1596 - 1680	A A	A A	A A	A A	A A	A A	A A	A A	A A
1680 - 1764	A A	A A	A A	A A	A A	A A	A A	A A	A A
1764 - 1848	A A	A A	A A	A A	A A	A A	A A	A A	A A
1848 - 1932	A A	A A	A A	A A	A A	A A	A A	A A	A A
1932 - 2016	A A	A A	A A	A A	A A	A A	A A	A A	A A
2016 - 2100	A A	A A	A A	A A	A A	A A	A A	A A	A A
0 - 2100	A A	A A	A A	A A	A A	A A	A A	A A	A A

TABLE 2. STATISTICAL COMPARISON OF ACCELERATION RESPONSES TO LOADED AND UNLOADED PAVEMENT PROFILES (REVERSE RUN; α = 0.05)

	Speed = 33.3 ft/sec			Speed = 66.7 ft/sec			Speed = 100 ft/sec		
	Mean / Distribution			Mean / Distribution			Mean / Distribution		
Subsection (ft)	TS	CG	PS	TS	CG	PS	TS	CG	PS
0 - 84	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
84 - 168	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
168 - 252	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
252 - 336	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
336 - 420	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
420 - 504	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
504 - 588	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
588 - 672	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
672 - 756	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
756 - 840	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
840 - 924	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
924 - 1008	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
1008 - 1092	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
1092 - 1176	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
1176 - 1260	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
1260 - 1344	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
1344 - 1428	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
1428 - 1512	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
1512 - 1596	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
1596 - 1680	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
1680 - 1764	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
1764 - 1848	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
1848 - 1932	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
1932 - 2016	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
2016 - 2100	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
0 - 2100	A / R	A / R	A / A	A / A	A / A	A / A	A / A	A / A	A / A

TS - Tail section
CG - Center of gravity
PS - Pilot station
A - Accepted
R - Rejected

TABLE 2. STATISTICAL COMPARISON OF ACCELERATION RESPONSES TO LOADED AND UNLOADED PAVEMENT PROFILES (REVERSE RUN; $\alpha = 0.05$) (CONCLUDED)

Subsection (ft)	Speed=133.33 ft/sec						Speed=166.7 ft/sec						Speed = 200 ft/sec					
	TS		CG		PS		TS		CG		PS		TS		CG		PS	
	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution
0 - 84	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
84 - 168	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
168 - 252	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
252 - 336	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
336 - 420	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
420 - 504	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
504 - 588	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
588 - 672	A	A	A	A	A	A	A	A	A	A	A	A	R	A	A	A	A	A
672 - 756	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
756 - 840	A	A	A	A	A	A	A	A	A	A	A	A	R	A	A	A	A	A
840 - 924	A	A	A	A	A	A	A	A	A	A	A	A	R	A	A	A	A	A
924 - 1008	A	A	A	A	A	A	A	A	A	A	A	A	R	A	A	A	A	A
1008 - 1092	A	A	A	A	A	A	A	A	A	A	A	A	R	A	A	A	A	A
1092 - 1176	A	A	A	A	A	A	A	A	A	A	A	A	R	A	A	A	R	A
1176 - 1260	A	A	A	A	A	A	A	A	A	A	A	A	R	A	A	A	A	A
1260 - 1344	A	A	A	A	A	A	A	A	A	A	A	A	R	A	A	A	A	A
1344 - 1428	A	A	A	A	A	A	A	A	A	A	A	A	R	A	A	A	A	A
1428 - 1512	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1512 - 1596	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1596 - 1680	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1680 - 1764	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1764 - 1848	A	A	A	A	A	A	A	A	A	A	A	A	R	A	R	A	A	A
1848 - 1932	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1932 - 2016	A	A	A	A	A	A	A	A	A	A	A	A	A	A	R	A	A	A
2016 - 2100	A	A	A	A	A	A	A	A	A	A	A	A	R	A	R	A	A	A
0 - 2100	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A

TABLE 3. STATISTICAL COMPARISON OF ACCELERATION RESPONSES TO LOADED AND UNLOADED PAVEMENT PROFILES (FORWARD RUN; α = 0.02)

Subsection (ft)	Speed = 33.3 ft/sec						Speed = 66.7 ft/sec						Speed = 100 ft/sec					
	TS		CG		PS		TS		CG		PS		TS		CG		PS	
	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution
0 - 84	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
84 - 168	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
168 - 252	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
252 - 336	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
336 - 420	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
420 - 504	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
504 - 588	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
588 - 672	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
672 - 756	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
756 - 840	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
840 - 924	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
924 - 1008	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1008 - 1092	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1092 - 1176	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1176 - 1260	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1260 - 1344	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1344 - 1428	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1428 - 1512	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1512 - 1596	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1596 - 1680	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1680 - 1764	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1764 - 1848	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1848 - 1932	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1932 - 2016	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
2016 - 2100	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
0 - 2100	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A

TS - Tail section
CG - Center of gravity
PS - Pilot station
A - Accepted
R - Rejected

TABLE 3. STATISTICAL COMPARISON OF ACCELERATION RESPONSES TO LOADED AND UNLOADED PAVEMENT PROFILES (FORWARD RUN; $\alpha = 0.02$) (CONCLUDED)

Subsection (ft)	Speed=133.33 ft/sec			Speed=166.67 ft/sec			Speed = 200 ft/sec		
	Mean / Distribution			Mean / Distribution			Mean / Distribution		
	TS	CG	PS	TS	CG	PS	TS	CG	PS
0 - 84	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
84 - 168	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
168 - 252	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
252 - 336	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
336 - 420	A / A	A / A	A / A	A / A	A / A	A / A	R / A	A / A	R / A
420 - 504	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
504 - 588	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
588 - 672	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
672 - 756	A / A	A / A	A / A	A / A	A / A	R / A	A / A	A / A	R / A
756 - 840	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
840 - 924	A / A	A / A	A / A	A / A	A / A	A / A	R / A	R / A	A / A
924 - 1008	A / A	A / A	A / A	R / A	A / A	A / A	R / A	R / A	R / A
1008 - 1092	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
1092 - 1176	A / A	A / A	A / A	A / A	A / A	R / A	R / A	A / A	R / A
1176 - 1260	A / A	A / A	A / A	A / A	A / A	R / A	R / A	A / A	A / A
1260 - 1344	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
1344 - 1428	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
1428 - 1512	A / A	A / A	A / A	A / A	A / A	A / A	R / A	R / A	R / A
1512 - 1596	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
1596 - 1680	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
1680 - 1764	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
1764 - 1848	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
1848 - 1932	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
1932 - 2016	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
2016 - 2100	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A
0 - 2100	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A	A / A

TABLE 4. STATISTICAL COMPARISON OF ACCELERATION RESPONSES TO LOADED AND UNLOADED PAVEMENT PROFILES (REVERSE RUN; $\alpha = 0.02$)

Subsection (ft)	Speed = 33.3 ft/sec						Speed = 66.7 ft/sec						Speed = 100 ft/sec					
	TS		CG		Ps		TS		CG		Ps		TS		CG		PS	
	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution
0 - 84	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
84 - 168	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
168 - 252	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
252 - 336	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
336 - 420	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
420 - 504	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
504 - 588	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
588 - 672	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
672 - 756	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
756 - 840	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
840 - 924	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
924 - 1008	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1008 - 1092	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1092 - 1176	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1176 - 1260	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1260 - 1344	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1344 - 1428	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1428 - 1512	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1512 - 1596	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1596 - 1680	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1680 - 1764	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1764 - 1848	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1848 - 1932	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1932 - 2016	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
2016 - 2100	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
0 - 2100	A	R	A	R	A	A	A	A	A	A	A	A	A	A	A	A	A	A

TS - Tail section
CG - Center of gravity
PS - Pilot station
A - Accepted
R - Rejected

TABLE 4. STATISTICAL COMPARISON OF ACCELERATION RESPONSES TO LOADED AND UNLOADED PAVEMENT PROFILES (REVERSE RUN; $\alpha = 0.02$) (CONCLUDED)

Subsection (ft)	Speed=133.33 ft/sec						Speed=166.67 ft/sec						Speed = 200 ft/sec					
	TS		CG		PS		TS		CG		PS		TS		CG		PS	
	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution	Mean	Distribution
0 - 84	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
84 - 168	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
168 - 252	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
252 - 336	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
336 - 420	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
420 - 504	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
504 - 588	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
588 - 672	A	A	A	A	A	A	A	A	A	A	A	A	R	A	A	A	A	A
672 - 756	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
756 - 840	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
840 - 924	A	A	A	A	A	A	A	A	A	A	A	A	R	A	A	A	A	A
924 - 1008	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1008 - 1092	A	A	A	A	A	A	A	A	A	A	A	A	R	A	A	A	A	A
1092 - 1176	A	A	A	A	A	A	A	A	A	A	A	A	R	A	A	A	A	A
1176 - 1260	A	A	A	A	A	A	A	A	A	A	A	A	R	A	A	A	A	A
1260 - 1344	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1344 - 1428	A	A	A	A	A	A	A	A	A	A	A	A	R	A	A	A	A	A
1428 - 1512	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1512 - 1596	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1596 - 1680	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1680 - 1764	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1764 - 1848	A	A	A	A	A	A	A	A	A	A	A	A	R	A	A	A	A	A
1848 - 1932	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
1932 - 2016	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
2016 - 2100	A	A	A	A	A	A	A	A	A	A	A	A	R	A	R	A	A	A
0 - 2100	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A

was observed that the extremities of the aircraft experienced greater accelerations than the center of gravity (See Figures 2 through 7). Because of this, it would seem to follow that the tail section and pilot station would experience even greater accelerations as a result of pavement roughness at high speeds than would the center of gravity. The differences in accelerations due to deflection of the loaded pavement would also increase as the speed increased thus causing more rejections at the pilot station and tail section than at the center of gravity. Yet in the extreme case, 200.0 feet per second, only about one third of the tests performed received rejections.

The Chi-Square test of the distribution experienced no rejections for any subsection tested under any of the specified conditions for speed or direction. It was observed, however, that rejections of the entire test section occurred at the tail section and the center of gravity when traversing the reversed profile at a speed of 33.3 feet per second.

It is felt that the reasons for these rejections is that these two comparisons consisted of 1051 acceleration responses each. Short sections of pavement profile were not used; as a result, the acceleration values in each cell were generated from many different positions along the test section. As was stated earlier in this report, this can cause a loss in reliability of the test of the distribution. This loss in reliability is felt to be the cause of these rejections. As can be observed, the test of the distribution was accepted under the same conditions that the test section was rejected when subsections with a length of 84 feet were used. Thus it seems reasonable to conclude these rejections are not significant.

It can also be seen that a change in the level of significance, α, caused some changes in the results. No changes were observed in the results of the test of the distribution for all conditions tested; about 40 percent fewer rejections of the test of the mean occurred for a level of significance, α, equal to 0.02 than for a level of significance, α, equal to 0.05. The total number of rejections for $\alpha = 0.02$ was 27 while for $\alpha = 0.05$, the number of rejections was 46. The effects of this difference were not felt to be significant.

SECTION VI

SUMMARY AND CONCLUSIONS

The acceleration responses used in this study were simulated using the Air Force Civil and Environmental Office (CEEDO) computer code, TAXI, on unloaded and loaded pavement profiles obtained from information gathered at Eglin Air Force Base, Florida. These simulated responses were considered typical of the response of an F-4C aircraft to unloaded and loaded pavement profiles.

A statistical analysis was prepared which consisted of two parts; a test of the mean of a sample made up of the differences between the responses to the two profiles on a point for point basis, and a test of the distribution of the responses to the two profiles. This analysis was used to determine whether or not significant differences existed between the response of an aircraft to unloaded and loaded pavement profiles. It was found that when performing a comparison of this type it is necessary to divide the test section into a number of smaller subsections to attain reliability.

Based upon the results of this statistical analysis, it can be stated that:

1. Throughout the range of speeds analyzed, the distribution of the acceleration responses to unloaded and loaded pavement profiles are virtually the same.

2. Some significant differences in the responses to unloaded and loaded pavement profiles do occur at speeds in

excess of 133.3 feet per second. The differences in responses observed were not a major part of the total number of comparisons made at these speeds; less than 33 percent of the total number of comparisons made were rejected at the highest speed of 200.0 feet per second.

3. No major differences in results were seen when the level of significance of the statistical analysis was varied from 0.05 to 0.02.

Thus it is concluded that no significant differences exist between the simulated dynamic response of an F-4C aircraft to unloaded and loaded pavement profiles during taxiing operations at speeds up to 200 feet per second.

SECTION VII

RECOMMENDATIONS FOR FURTHER RESEARCH

Based upon the results of this investigation, the following research should be performed:

1. A study to investigate the possible existence of significant differences in the generated response of aircraft other than an F-4C aircraft to unloaded and loaded pavement profiles.

2. A study to investigate the significance of the differences in response to unloaded and loaded pavement profiles as generated by TAXI using the takeoff simulation specification.

3. A study to determine whether or not significant differences exist in the acceleration responses generated by TAXI when the unloaded pavement profile used as input is obtained by either laser or inertial profilometer methods, or by a level survey. Such a comparison could be done readily because the same statistical analyses used in the present study could be applied and the unloaded profile obtained by level survey on the 2100-foot test section at Eglin Air Force Base could be used for comparison. Thus, the only field data required would be the profile on the same test section obtained by inertial and/or laser profilometer methods.

APPENDIX

DETERMINATION OF UNLOADED AND LOADED PAVEMENT PROFILES

INTRODUCTION

The determination of unloaded (undeflected) and loaded (deflected) pavement profiles was accomplished in the summer of 1976 in conjunction with the United States Air Force - American Society of Engineering Education Summer Faculty Research Program which was sponsored by the Air Force Office of Scientific Research. This work is described elsewhere (Reference 2) and is included here as an appendix for the sake of completeness.

DESCRIPTION OF TEST SECTION

A 2100-foot section of taxiway at Eglin Air Force Base, Florida was selected as a test section. Because it was not possible to close down a taxiway or runway which was long enough to satisfy the minimum of 2000 feet for the test section, the test section consisted of two subsections of 1700 ft and 400 ft in length. These subsections were then combined to form a single (fictitious) test section and the elevations of the 400-foot subsection were referenced to the elevation at the end of the 1700-foot subsection.

The pavement along the test section consisted of asphaltic concrete with a sand asphalt base. Along the line of profile, the asphaltic concrete varied in thickness from 1 5/8 inches to 5 1/2 inches and the sand asphalt base was from 5 inches to 7 1/4 inches thick (Reference 5).

UNLOADED PAVEMENT PROFILE

A 2100-foot straight line was laid off on the taxiway and painted. The taxiway runs in a general east-west direction and distances along the line were measured from a zero point at the west end of the line. Starting at the zero point, 25-foot intervals were marked along the subsections with painted arrows and 100-foot stations were established. Station 17N marked the end of the first subsection and Station 17S delineated the start of the second subsection. A bench mark was selected on a compass pad located about 50 feet west of Station 0 and a local datum was established as elevation 100.0 feet. Starting at Station 0, elevations to the nearest 0.001 foot were determined at 2-foot intervals along the 2100-foot test section by a level survey. The elevations at the 1051 points determined in this manner established the unloaded pavement profile. The unloaded pavement profile data were then punched on computer cards for input to TAXI - the aircraft dynamic response computer code.

LOADED PAVEMENT PROFILE

The loaded pavement profile is described by the elevations of the test section when the pavement is traversed by a loaded vehicle. The loaded pavement profile was obtained by traversing the test section with a load cart, measuring the deflections at 2-foot intervals (at the same 1051 points the elevations along the unloaded profile were measured), and subtracting these deflections from the corresponding point on the unloaded pavement profile. The load cart used was a truck with the rear axle modified so that a 25,115-pound single-wheel load was applied to the pavement. The aircraft tire was inflated to the operational pressure of 250 psi. The loaded pavement profile obtained using the load cart was expected to approximate the profile typically "seen" by the aircraft. Pavement deflections were measured with two different types of measuring devices: (1) linear variable differential transformers (LVDTs) and (2) light emitting diodes (LEDs). A detailed discussion on the use of LVDTs for measuring pavement deflections can be found in Reference 7. The LED system has only recently been developed for the CEEDO and a technical report has not been published.

Both the LED and the LVDT data were obtained and recorded in the field by a team of researchers from Purdue University. The method used by the authors in calculating the deflection from LVDT and LED data was developed by the Purdue Researchers. When obtained from Purdue the LVDT data consisted of absolute deflections (i.e. pavement deflections with respect to the unloaded and hence undeflected pavement) and the LED data consisted of deflections with respect to LVDT deflections at a point 2.5 inches from the edge of the F-4 aircraft tire mounted on the load cart.

LVDT SYSTEM

As shown in Figure A-1, the LVDT system consisted of six gages mounted on a cantilever beam supported at a point outside the deflection basin. This system was used to measure pavement deflections in a direction perpendicular to the

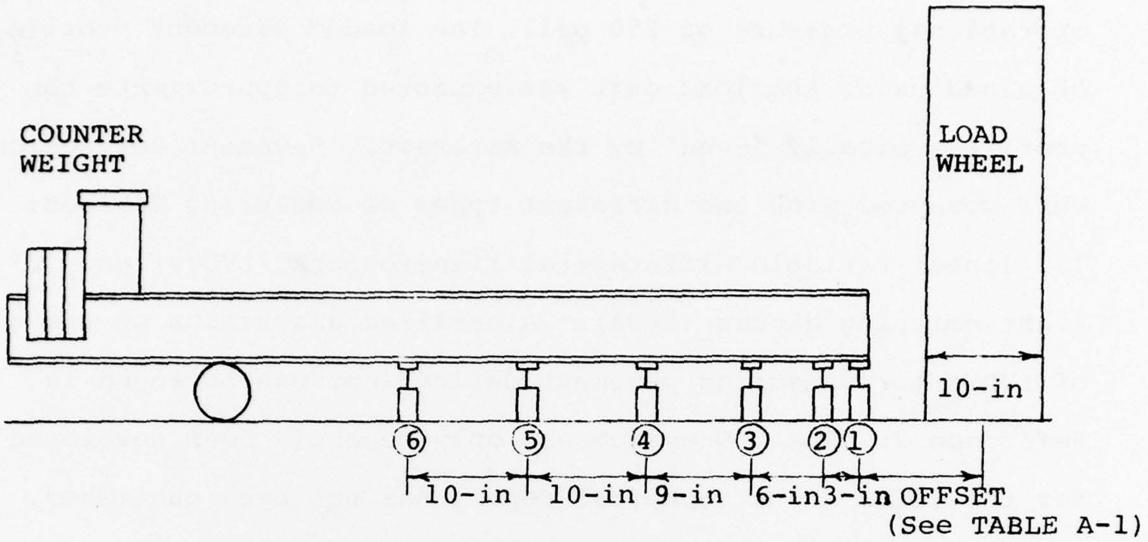

Figure A-1. Schematic of LVDT Deflection Measuring System.

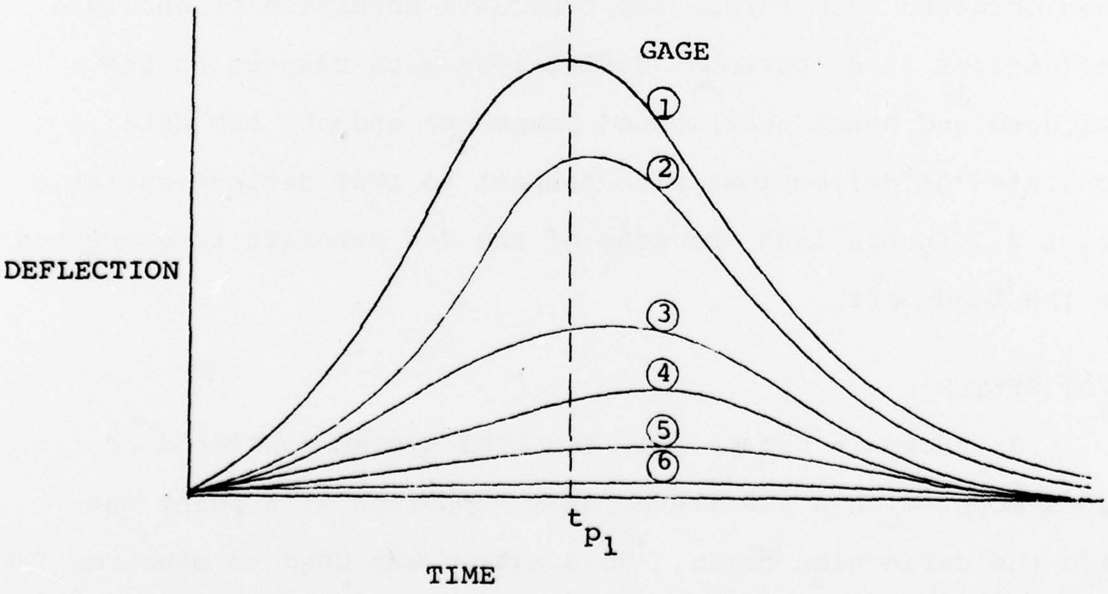

Figure A-2. Time-Deflection Record From LVDT Gages as Wheel Approaches and Moves Past the LVDT Beam.

direction of travel of the load cart. As the load cart moved past the stationary beam, each of the six LVDT gages experienced voltage changes proportional to the magnitude of the pavement deflection beneath each gage. Deflections were measured at 100-foot intervals (at each of the 23 stations) over the 2100-foot test section. A schematic of deflection versus time for each gage is shown in Figure A-2. The deflections for each gage corresponding to the time (t_{p_1}) when the gage closest to the load wheel (gage 1) reached its maximum are given in Table A-1. Inspection of this table indicates that the position of the center of the F-4 tire on the load cart with respect to the LVDT beam varied and the minimum offset distance from the center of the 10-inch-wide tire to the closest gage was 8.5 inches at Station 2. The variation in the offset distance is due to the inability of the load cart driver to maneuver the vehicle so that it passed the LVDT beam at exactly the same relative distance for each of the 23 stations (100-foot intervals) at which pavement deflections were measured by LVDTs.

To predict the deflections at a point 2.5 inches from the edge of the tire (the point where the LED system measured the deflections) and at the center of the tire (point of maximum deflection), regression analysis was used to fit various models to the measured LVDT deflections at Station 2. The models selected were similar to those used previously for similar purposes (Reference 7) and those currently being used. The models selected are illustrated in Figure A-3 along with the

TABLE A-1. DEFLECTIONS MEASURED BY LVDT GAGES[a] (in)

Station	Offset (in)	LVDT Gage No.					
		1	2	3	4	5	6
0	14.5	0.0369	0.0294	0.0170	0.0079	0.0031	0.0011
1	12.0	0.0341	0.0268	0.0170	0.0077	0.0030	0.0008
2	8.5	0.0487	0.0379	0.0238	0.0109	0.0030	0.0008
3	15.0	0.0339	0.0267	0.0159	0.0067	0.0025	0.0007
4	10.0	0.0429	0.0311	0.0204	0.0099	0.0041	0.0014
5	10.25	0.0144	0.0131	0.0096	0.0055	0.0027	0.0010
6	12.0	0.0288	0.0238	0.0148	0.0072	0.0031	0.0013
7	10.25	0.0237	0.0197	0.0127	0.0063	0.0027	0.0027
8	9.5	0.0303	0.0237	0.0149	0.0065	0.0024	0.0009
9	10.5	0.0259	0.0197	0.0120	0.0053	0.0022	0.0009
10	10.0	0.0283	0.0210	0.0124	0.0049	0.0020	0.0007
11	9.0	0.0208	0.0172	0.0105	0.0057	0.0028	0.0014
12	11.0	0.0216	0.0176	0.0093	0.0048	0.0023	0.0009
13	10.0	0.0150	0.0120	0.0076	0.0024	0.0013	0.0007
14	10.0	0.0146	0.0119	0.0078	0.0043	0.0022	0.0010
15	9.5	0.0131	0.0117	0.0078	0.0043	0.0022	0.0010
16	8.75	0.0149	0.0110	0.0084	0.0035	0.0014	0.0005
17N	9.0	0.0172	0.0146	0.0100	0.0060	0.0031	0.0014
17S	8.6	0.0149	0.0135	0.0098	0.0061	0.0031	0.0014
18	11.0	0.0150	0.0119	0.0083	0.0049	0.0024	0.0010
19	11.5	0.0181	0.0145	0.0080	0.0039	0.0023	0.0011
20	9.75	0.0249	0.0169	0.0094	0.0040	0.0014	0.0008
21	8.9	0.0284	0.0212	0.0141	0.0075	0.0035	0.0012

[a] Offset is the distance from gage 1 to centerline of the tire (see Figure A-1).

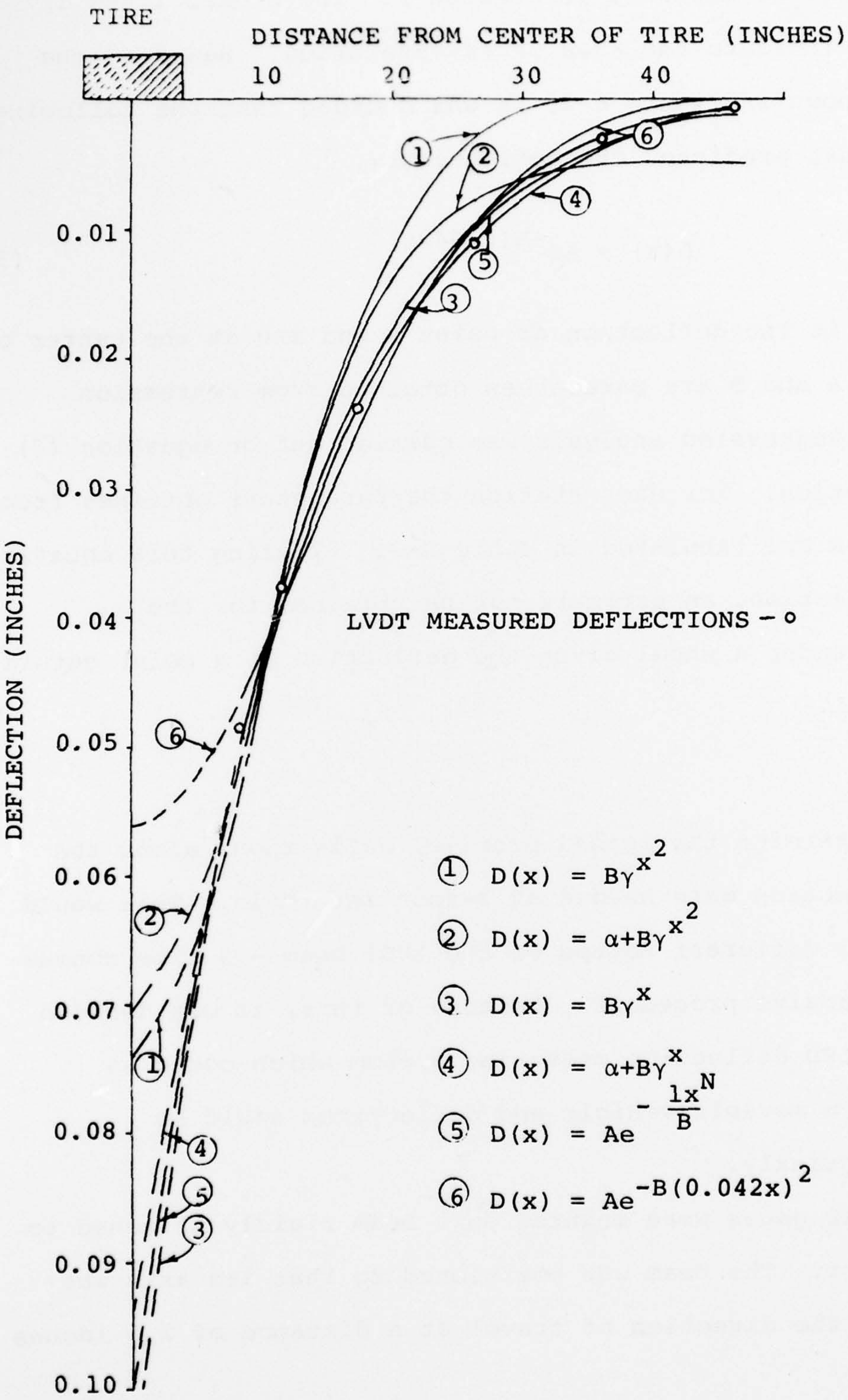

Figure A-3. LVDT Measured Deflections and Predicted Deflections for Regression Models at Station 2.

LVDT deflections measured at Station 2. The broken lines in the Figure indicate the area of extrapolation. Based on the analysis shown in Figure A-3, it was decided that the following equation best predicted the deflections:

$$D(x) = Ae^{-B(0.042x)^2} \tag{3}$$

where D(x) is the deflection at point x and x=0 at the center of the tire. A and B are parameters obtained from regression analyses. Regression analysis was carried out on equation (3) at each station. For each station the parameters obtained from the analyses are tabulated in Table A-2. By using this equation for extrapolation, an estimate can be obtained for the deflection under a wheel given the deflection at a point outside of the wheel.

LED SYSTEM

To determine the loaded profile, deflections along the 2100-foot section were needed at 2-foot intervals. This would require 1051 different setups of the LVDT beam - a time consuming and expensive procedure. Because of this, it was decided to use the LED deflection measuring system which could be attached to a movable vehicle and deflections could be determined quickly.

Six LED gages were mounted on a beam rigidly attached to the load cart. The beam was positioned so that its axis was parallel to the direction of travel at a distance of 2.5 inches

TABLE A-2. Regression Model Coefficients for Each Station from LVDT Measured Deflections

	$D(x) = Ae^{-B(0.042\,x)^2}$	
Station	A	B
0	0.054	1.112
1	0.044	1.161
2	0.056	1.478
3	0.052	1.114
4	0.050	1.309
5	0.016	0.755
6	0.037	1.068
7	0.028	1.106
8	0.036	1.378
9	0.033	1.396
10	0.036	1.607
11	0.024	1.171
12	0.208	1.379
13	0.019	1.439
14	0.016	0.998
15	0.015	0.907
16	0.016	1.230
17N	0.019	0.871
17S	0.016	0.756
18	0.017	0.858
19	0.024	1.285
20	0.033	1.955
21	0.031	1.224

from the outside edge of the load tire (7.5 inches from the center of the tire). The load cart traveled the entire 2100-foot test section and measurements related to pavement deflection were recorded at 0.25-second intervals. The LED apparatus mounted on the load cart is illustrated schematically in Figure A-4.

The LED system did not measure deflections directly but required that the actual deflection be known at some reference. This reference is an external reference and must be obtained by another independent or external measuring system. In this case, the external reference was provided by the LVDT deflections which were taken at 100-foot intervals as described previously. The procedure used to determine deflections using the LED system as suggested by the Purdue researchers was as follows: With the external reference known, a LED reading was taken at the same point. The load cart was driven along the test section and the LED recorded changes in deflection from that at the reference point at a sampling rate of 4 per second. For example, if the deflection at the external reference point was 0.100 inch and the LED reading at another point was -0.015 inch, then, by subtracting algebraically, the deflection at the second point as determined by the LED system was 0.115 inch.

Although elapsed time was not directly recorded on the magnetic tape used for recording LED readings, the sampling rate (4 per second) at which the LED data was recorded allowed elapsed time to be determined. As previously mentioned, arrows

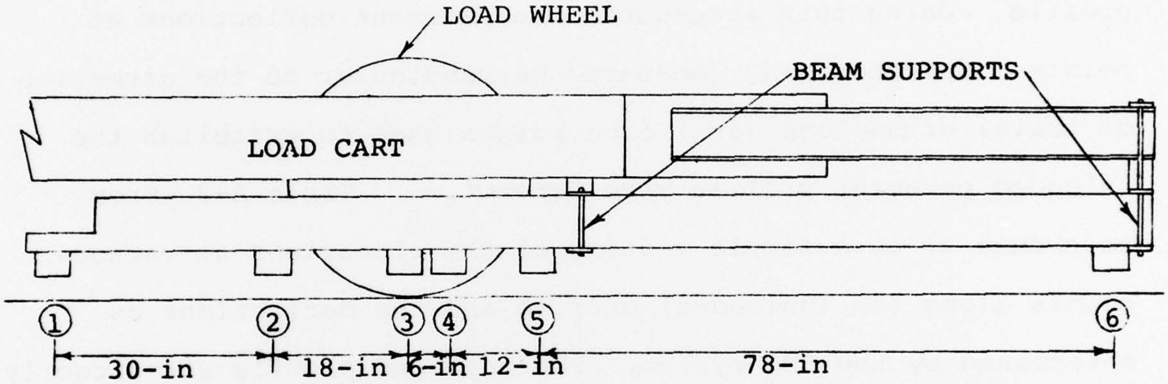

Figure A-4. Schematic of LED Deflection Measuring System were painted on the profile line at 25-foot intervals and as the load cart traveled over each arrow, an event marker was triggered manually on one of the tape channels. By counting the number of LED readings between successive event signals, the time it took the load cart to travel 25-feet was obtained. Thus the average velocity of the load cart over that particular 25-foot segment of the profile was known. With this information, individual LED readings could be coordinated with points on the profile. Using this procedure, the pavement deflections at points 7.5 inches away (measured perpendicular to the direction of travel of the load cart) from points used to establish the unloaded pavement profile were determined. Table A-3 (From Reference 2) is a sample listing of the elevations at various points along the (unloaded) profile and the deflections as determined by the LED system. The unloaded profile was directly inputted to the TAXI code to determine the response of the aircraft to the undeflected profile. Since the LED deflections are deflections at points 7.5 inches from the center of the tire, Equation (3) was first applied to estimate the deflection at the center of the tire. Subtracting this estimated deflection from the unloaded elevation at the corresponding point yielded the loaded elevation at that particular point. Repeating this process for all 1051 points determined the loaded profile at 2-foot increments along the test section.

It was assumed in the statistical analyses that the loaded profile calculated for the tire mounted on the load cart is the

TABLE A-3. SAMPLE LISTING OF UNLOADED PROFILES AND PAVEMENT DEFLECTIONS (FROM REFERENCE 2)

Distance Along Profile (ft)	Unloaded Elevation (ft)	Deflection 7.5 in from Center of the Tire (in)
286.0	97.031	0.060
288.0	97.017	0.061
290.0	97.002	0.061
292.0	96.986	0.061
294.0	96.968	0.061
296.0	96.952	0.061
298.0	96.933	0.061
300.0	96.928	0.061
302.0	96.916	0.061
304.0	96.897	0.078
306.0	96.881	0.078
308.0	96.858	0.078
310.0	96.849	0.078
312.0	96.839	0.071
314.0	96.831	0.071
316.0	96.826	0.071
318.0	96.818	0.072
320.0	96.803	0.060
322.0	96.786	0.060
324.0	96.776	0.060
326.0	96.764	0.060
328.0	96.742	0.060
330.0	96.726	0.060
332.0	96.717	0.060
334.0	96.702	0.060
336.0	96.694	0.075
338.0	96.683	0.075
340.0	96.674	0.075
342.0	96.663	0.075
344.0	96.650	0.075
346.0	96.641	0.062
348.0	96.628	0.049
350.0	96.626	0.050

same as that typically "seen" by a similarly loaded tire on an F-4 aircraft.

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