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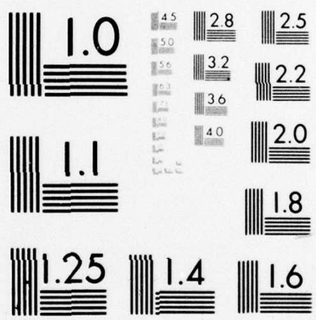

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*DAVIS & HORN

THE INFLUENCE OF LARGE RUNWAY SURFACE ROUGHNESS ON AIRCRAFT RESPONSE

JUN 1978

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An accurate and reliable evaluation of the effective damage produced by military attacks against airfield runways cannot be made until suitable criteria for "effective" damage levels are developed. Obviously, a large crater in a runway will be an effective obstacle. However, from 30 to more than 90 percent of the damaged runway areas associated with each impact point of conventional bombs, cluster bomblets, or tactical nuclear warheads may actually consist of damaged pavement surrounding the crater. Even the craters that are produced by some attacks, such as strafing, mortar, or artillery bombardments, may not be impassable obstacles.

From a defensive standpoint, it is important to know what levels of pavement damage can be tolerated by military aircraft in combat scenarios or how well such damage must be repaired (in terms of surface smoothness) during rapid runway repair operations. The level of pavement damage or runway roughness that will deny use of a runway is therefore an important parameter for both offensive and defensive aspects of warfare. The objective of this study is to develop such criteria for specific combat aircraft.

STUDY CONCEPT

The pilot and the landing gear were selected as the critical components of the aircraft system in this analysis. The failure criterion selected for the pilot was one of maximum tolerable vertical acceleration. It was assumed that aircraft control cannot be maintained during take-off when such accelerations exceed a previously established short-term tolerance limit of 5 g's (1). The failure criterion for the landing gear was a dynamic force exceeding the calculated strength of any critical component in the mechanical linkage of the nose or main gear structures.

A basic element of this investigation was the use of an aircraft simulation computer code, TAXI, originally developed at the Air Force Flight Dynamics Laboratory to compute the acceleration response of aircraft to low-level runway roughness (2). The code was modified to (a) accept the structural and aerodynamic characteristics of a selected fighter aircraft and (b) compute the acceleration response at selected locations on the fuselage and forces within the landing gear system as various idealized types and magnitudes of runway roughness (or pavement damage) were encountered during take-off.

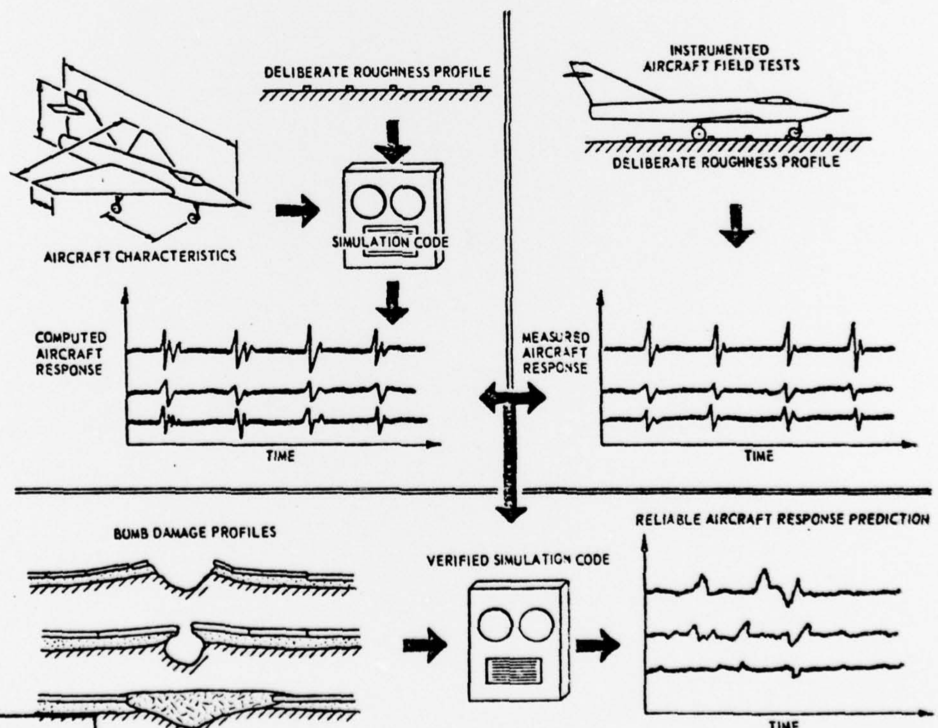


Figure 1. Concept of runway damage study.

It was necessary to verify and "tune" the computer code operation to develop confidence in the results of the TAXI calculations. This was done by comparing the initial output of the code with measurements of aircraft response to low levels of roughness obtained experimentally. Where significant differences existed between the experimental and the calculated results, the computer code was adjusted to match the experimental results. When the code was verified and adjusted, it was then used independently to predict the aircraft response to higher levels of roughness until aircraft failure levels were exceeded. The concept of this approach is illustrated in Figure 1.

RUNWAY DAMAGE DEFINITIONS

An examination of measured profiles of runway damage by various munitions (3-5) revealed four basic types of pavement damage in terms of surface profile distortions. These types, identified as "bumps" and "humps", are shown in Figure 2. A positive bump is a vertical displacement in the pavement profile extending above the normal surface, while a negative bump extends below the normal surface. Similarly, a positive hump is a mound or rise in the pavement, and a negative hump (or slump) is a depression. The boundaries of these basic profile forms are always defined by joints or cracks in concrete pavements. In asphaltic pavements, the boundaries are often less distinct and may be smooth transitions in profile. Since pavement damage intervals can correspond to spacings between impact points of cluster munitions, strafing round impacts, etc., as well as to joint spacings in pavements, the possibility of a resonant response of combat aircraft to a series of bumps was also investigated. Individual and series of bumps or humps were termed "single encounter" or "multi-encounter" problems, respectively.

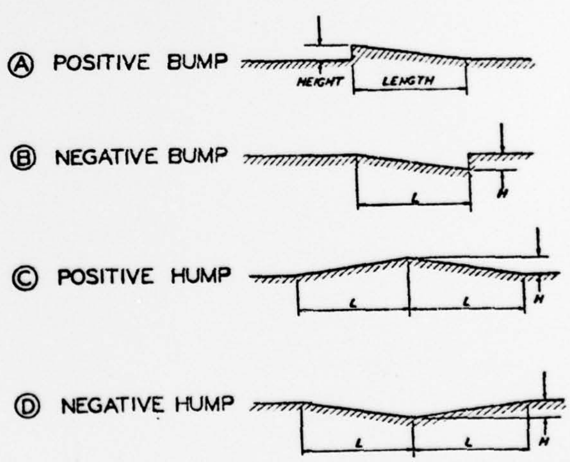


Figure 2. Idealized forms of four major types of runway roughness representing pavement damage.

EXPERIMENTAL PROGRAM

Two phases of field tests were conducted to verify the results of the aircraft response simulation computer code. In Phase 1, response data for a full aircraft/landing gear/pilot system was obtained by taxiing the aircraft across small, artifically-constructed bumps on a runway. Because of the value of the aircraft, it was necessary to restrict the severity of the simulated pavement damage for the Phase 1 tests to low levels of roughness to insure no risk of damage.

Pressure gages, accelerometers, and velocity and displacement transducers were used to monitor the response of the nose and main landing gear components as the aircraft was taxied over the artificial runway bumps. Accelerometers were also mounted on the cockpit floor. Signal conditioning and tape recording equipment was mounted on the wing of the aircraft, with electrical power taken directly from the aircraft power system.

The artificial pavement damage was simulated by plywood strips nailed to the runway surface. The single-encounter bumps ranged in height from one to three centimeters. The multiple-encounter bumps were all one centimeter high and were placed in three groups of 18 bumps each at spacings of 0.35, 1.5 and 3.5 metres. These spacings were determined by initial code calculations to be those most likely to generate a resonant aircraft response. Taxi runs were made over the bumps at speeds of 10, 20, 30 and 40 mph (Figure 3).

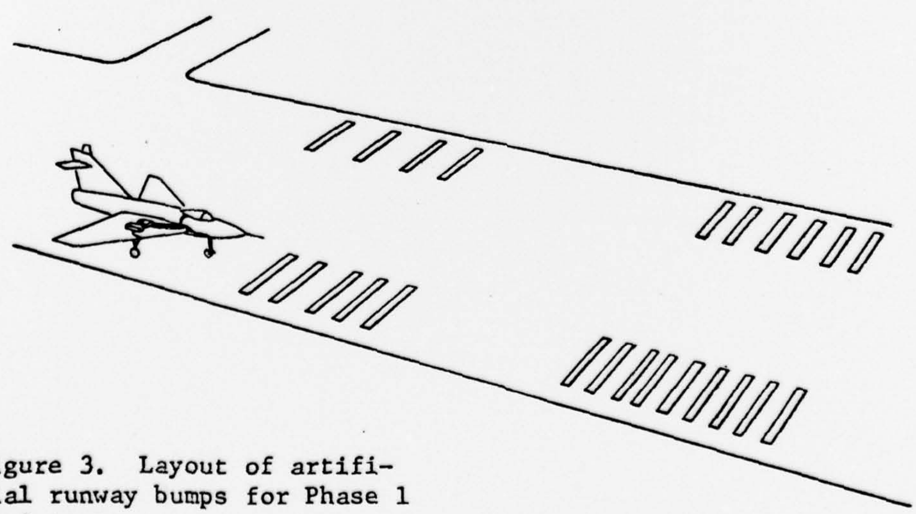


Figure 3. Layout of artificial runway bumps for Phase 1 taxi tests.

Phase 2 of the experimental verification consisted of tests similar to those of Phase 1, except that only the landing gear assembly was tested. A special test carriage was constructed to contain the gear at the back of a dump truck. The carriage permitted the gear to be loaded with a weight equal to the normal aircraft load and towed behind the truck over a series of artificially-constructed bumps, similar to those used in the Phase 1 tests. The Phase 2 tests were identical in nature to those of the Phase 1, except that the bump heights ranged from 1.0 to 7.5 centimeters, and encounter speeds from 10 to 35 mph.

VERIFICATION OF CALCULATIONS

Figure 4 shows typical comparisons of the aircraft response measured in the test programs and the response calculated by the first run of the TAXI code. Although the initial correlations were poor for very low aircraft speeds, the response measured in the full aircraft tests approached within 10 to 30 percent of the first calculated values for speeds greater than 20 mph. The measurements made in the Phase 2 tests (landing gear alone) were not expected to match the calculated values of those measured on the full aircraft, but to simply show the rate of increase in response up to larger bump heights than could be measured on the full aircraft.

After comparisons were made between all measured and calculated response parameters, small adjustments were made to the TAXI program to produce calculated results that were consistent with the measured data.

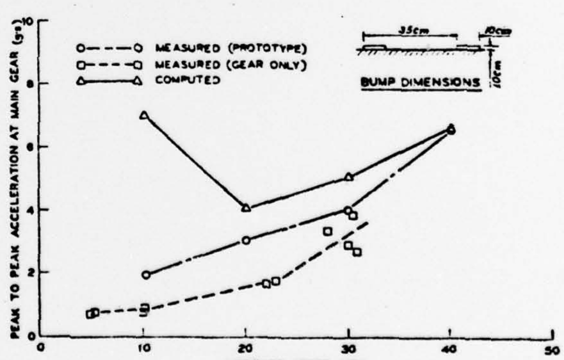


Figure 4. Comparison of measured and calculated main gear accelerations.

RESULTS AND DISCUSSION

When the verification of the TAXI computation results were judged to be satisfactory, the program was run for aircraft speeds ranging from 10 to 160 mph (8.7 to 140 knots) and for bump heights ranging from 1.3 to 15 centimeters (0.5 to 6 inches). Runs were made for each of the four types of characteristic bumps shown in Figure 2. Figure 5 shows the calculated peak acceleration in g's at the pilot station for the positive bump with a pavement slab length of 4 metres (13.12 feet).

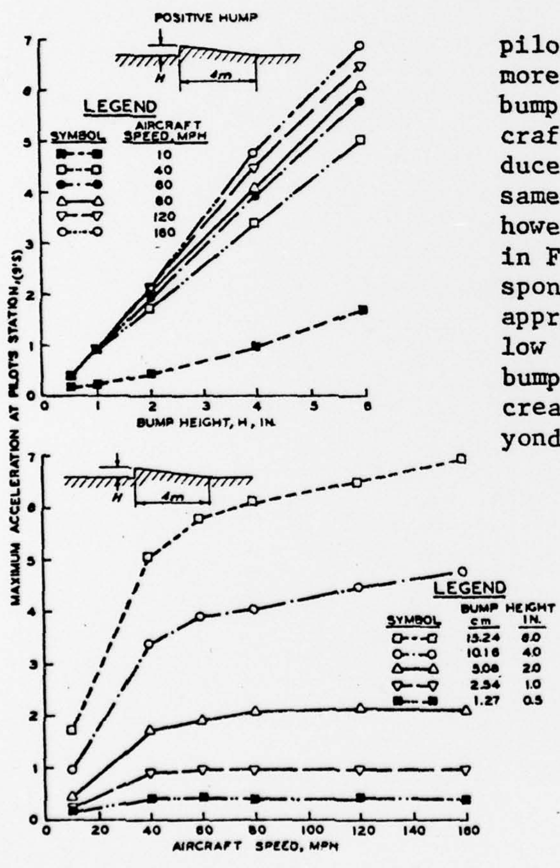


Figure 5. Two types of graphs showing calculated maximum accelerations at pilot station versus speed and bump height.

As might be expected, the pilot station acceleration increases more or less evenly with increasing bump heights, and the higher aircraft speeds generally appear to produce the highest response. When the same data is viewed another way, however, it can clearly be seen in Figure 5 that acceleration response to the smaller bumps approaches its maximum at fairly low speeds. Even for the largest bumps, there is only a small increase in pilot acceleration beyond an encounter speed of 40 mph.

Similar response data for encounters with the other three forms of pavement damage are shown in Figure 6. Figure 6a shows that for a negative bump, the pilot accelerations are similar to those generated by a positive bump up to an encounter speed of about 40 mph. As speed increases, however, the aircraft response drops to much lower levels, with the amount of drop-off increasing with the height (or depth) of the bump. This is due to the aircraft tendency to "fly" across the bump depression as speed increases.

Pilot accelerations generated by positive and negative humps (Figures 6b and 6c) are much less than those produced by positive bumps of equal height at all encounter speeds. The tendency for response to positive humps to peak at about 80 mph is apparently due to the natural frequency of the aircraft/landing gear spring-mass system. As with a negative bump, the aircraft has a tendency to "fly" over a negative hump at higher speeds.

The forces in selected components of the landing gear for large bump sizes and high encounter speeds were also calculated with the adjusted computer code. Figure 7 illustrates the basic mechanical linkages of the nose and main landing gear assemblies, along with force diagrams showing notations for the shear or tensile forces calculated.

Figure 8 shows a typical force graph, with force plotted as a function of bump height (for a positive bump) at different aircraft encounter speeds. From graphs such as this, a bump height was determined for each speed that represented the point at which the force exceeded the limiting strength of the gear component. These failure limits were calculated for each critical component based on an ultimate shear strength of 8 x 10^5 psi for normal aircraft steel.

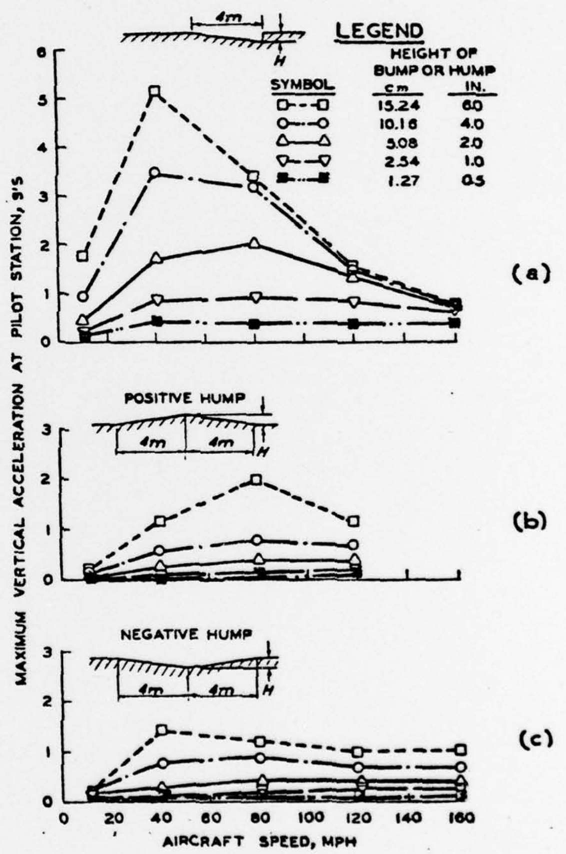
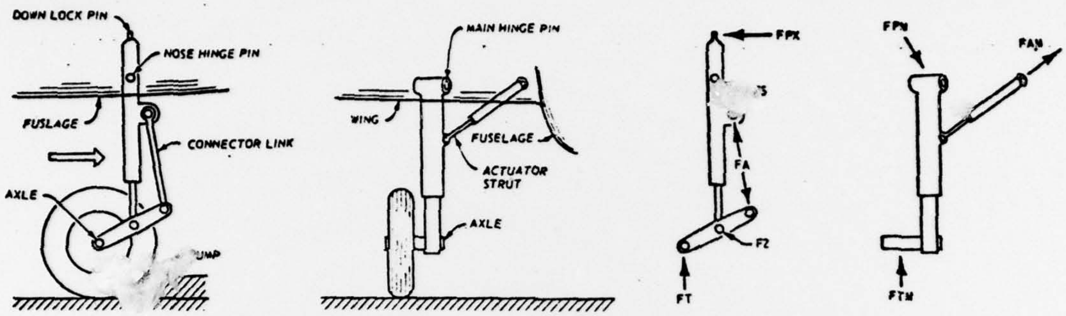


Figure 6. Calculated maximum accelerations at pilot station for different forms of pavement damage.



a. Gear Linkage b. Force Diagrams

Figure 7. Mechanical linkage and force diagrams for nose (left) and main (right) gear assemblies.

Figure 9 shows failure limits, as a function of bump height and aircraft speed, for the weakest components of the landing gear/ pilot system. As mentioned earlier, the criterion for pilot failure was the acceleration level at a frequency of one cycle per second which will begin to produce injury to the pilot, or about 5 g's. Also shown in Figure 9 is the failure limit for the nose gear down-lock pin for a component made of high-strength, chrome-alloy steel. The failure limits for the other gear components would be raised by an equal amount if they are also constructed of such a material.

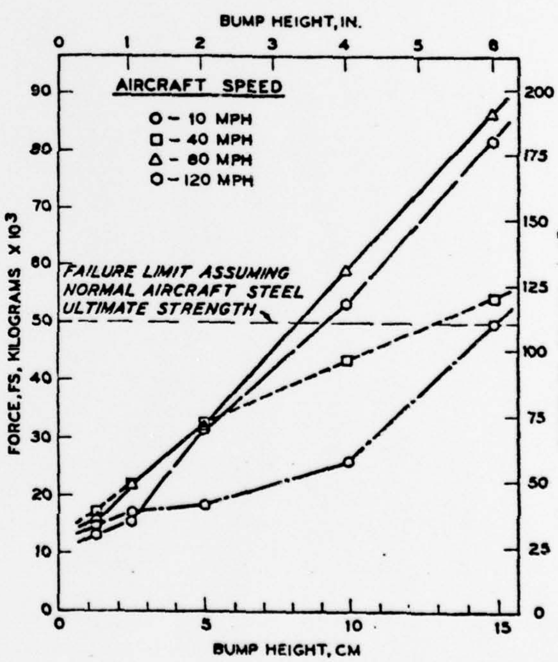


Figure 8. Force on nose gear pivot pin versus bump height and aircraft speed for positive bump.

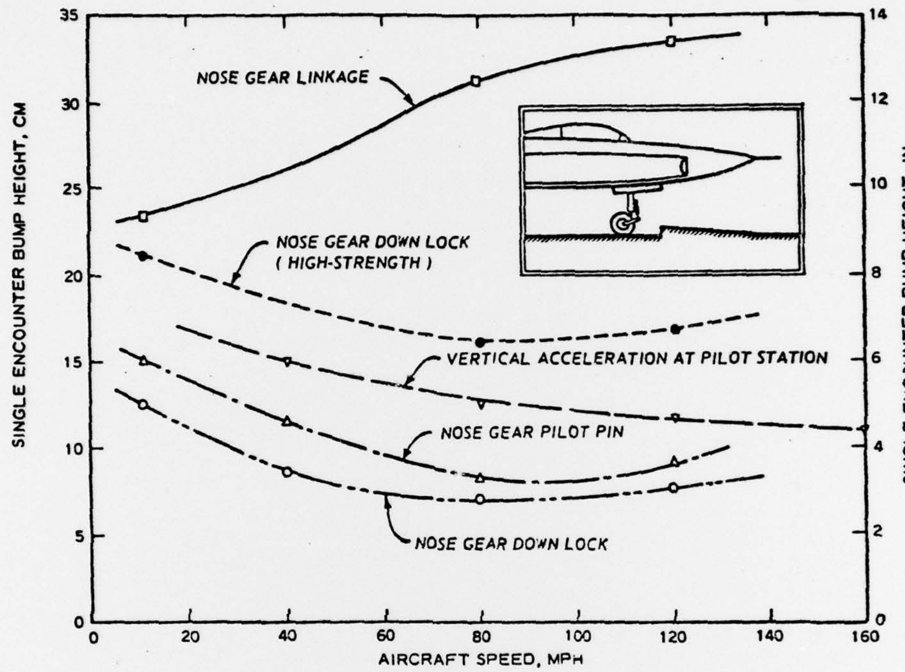


Figure 9. Failure limits of gear components and pilot control as a function of bump height and aircraft speed. Normal aircraft steel strength assumed except as noted.

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