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SOIL RUNWAY FRICTION EVALUATION IN SUPPORT OF USAF C-17 TRANSPORT AIRCRAFT OPERATIONS

Thomas J. Yager
Langley Research Center, Hampton, Virginia

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by

Thomas J. Yager
Senior Research Engineer
NASA Langley Research Center

SUMMARY

A three-person NASA Langley test team traveled to Pope Air Force Base, Fayetteville, North Carolina, on March 28-31, 1995, to support U. S. Air Force C-17 transport aircraft takeoff and landing operations on the soil runway 7/25 at Holland landing zone (LZ), Fort Bragg, North Carolina, near Pope AFB. This NASA support was requested by the USAF and McDonnell Douglas flight test engineers at Edwards AFB, California, with funding support from C-17 System Program Office, Wright-Patterson AFB, Ohio. Ground vehicle friction tests were conducted by the NASA team both before and after the C-17 test operations on March 30, 1995. The weather remained good for the duration of testing with no precipitation measured at the test site by a portable NASA rain gauge. The NASA Diagonal-Braked-Vehicle (DBV) and Army "Humvee" test vehicle results indicate an average dry soil runway rolling resistance coefficient of friction of approximately 0.04 and an average Runway Condition Reading (RCR) of 21. Good deceleration measurement agreement was obtained between both ground test vehicles as well as the C-17 test aircraft.

INTRODUCTION

Structural Dynamics Branch personnel at NASA Langley Research Center have been involved in evaluations of aircraft operations on unprepared soil runways since the early 1960's. At the request of the Air Force C-17 flight test office, a NASA literature search on soil runway evaluations was performed and references 1 to 21 were identified. Tests performed at Langley's Aircraft Landing Dynamics Facility to obtain a better understanding of the factors influencing tire/soil interaction and friction performance are described in reference 9. Using the NASA Diagonal-Braked Vehicle and the Instrumented Tire Test Vehicle, extensive tests were performed on the Space Shuttle soil runway landing sites at Dryden Flight Research Center, California, and White Sands Missile Range, New Mexico, in the 1970's to determine tire friction performance under dry conditions (see ref. 15).

TEST EQUIPMENT

USAF C-17 Test Aircraft

The C-17 test aircraft is a wide-body, 4-engine, jet transport shown in a head-on view in figure 1. The landing gear system, shown in figure 2, consists of a dual nose wheel and twelve main gear wheels mounted on four struts. The nose gear tires are 40x16-14, 26 PR bias ply normally inflated to 155 psi. The main gear tires are 50x21.0-20, 30 PR bias ply normally inflated to 160 psi. For the soil runway tests, inflation pressure was set at 114±5 psi for the nose tires and 103±5 psi for the main tires. Reverse thrust was not used for any of the C-17 test operations. Maximum wheel braking was modulated by the antiskid control system.

NASA Diagonal-Braked Vehicle

The diagonal-braked vehicle (DBV) is equipped with a high-performance engine for rapid acceleration to the normal test speed of 60 mph. This vehicle, shown in figure 3, has a specially modified braking system to provide locked-wheel braking on a diagonal wheel pair. With the remaining two freely rotating wheels, this braking configuration permits adequate vehicle stability and directional control when the diagonal wheels are locked at high speed. The diagonal-braked wheels are fitted with American Society for Testing and Materials (ASTM) smooth-tread test tires (specification E-524) inflated to 24 psi. The unbraked wheels are equipped with standard road tires that have a good tread design and are inflated to 32 psi.

The key test parameters monitored by the instrumentation system onboard the DBV are speed, acceleration, and stopping distance from the point of braked-wheel lockup. The longitudinal accelerometer is mounted on the floor inside the vehicle near the center of gravity. Vehicle speed and distance sensors are mounted on the fifth wheel (bicycle wheel attached to rear bumper). Vehicle speed and stopping distance are displayed to the operator by digital counters mounted on the vehicle dashboard. These values of brake application speed and stopping distance are manually recorded by a test observer positioned in the back seat of the vehicle. Figure 3 shows the DBV during a test run on the soil runway at Holland LZ and figure 4 indicates the lack of tire rutting after a DBV stop on this dry, hard-packed, soil runway. A total of 16 runs were made with the DBV at both ends of the runway and in the middle section on both sides of centerline and in both directions. Eleven runs were made in the diagonal braking mode with eight runs from 60 mph to a stop and three runs from 20 mph to a stop. Three DBV runs were conducted using conventional four-wheel braking from 20 mph to a stop for comparison to deceleration data collected using an Army High Mobility Multi-Purpose Wheeled Vehicle (HMMWV) nicknamed the "Hummer" or "Humvee".

Army Humvee Test Vehicle

The Army Humvee vehicle used to obtain deceleration measurements for comparison to NASA DBV data is shown in figure 5. With all the communication equipment in this vehicle, the gross weight was nearly 6000 lb (compared to 5300 lb for DBV). The 36x12.50-16.5 mud grip tires had 20 psi in front tires and 22 psi in rear. Locked four-wheel braking runs at approximately 25 mph down to a stop were made in both touchdown areas and the middle segment of runway 7/25 near the centerline and in both directions.

Portable Decelerometer Meters

Both a manual Tapley meter and an electronic Bowmonk Skidman decelerometer unit (see figure 6) were used to measure ground vehicle stopping performance. The Bowmonk Skidman unit was also operated on board the C-17 aircraft during several of the braking test runs.

The mechanical Tapley meter is a small pendulum-based decelerometer that consists of a dynamically calibrated oil-damped pendulum in a sealed housing. The pendulum is magnetically linked to a lightweight gear mechanism to which is attached a circumferential scale that shows values as a percentage of g, 1g = 32.2 ft/sec^2. A lightweight ratchet retains the maximum scale deflection reached upon completion of a test. The mechanism is enclosed in an aluminum case and the scale is covered with a glass face. The whole assembly is mounted in a cast base plate by means of a fork assembly. Each meter is statically tested and dynamically calibrated before being issued a calibration certificate. When the meter is used in a friction survey, it is placed on the floor of the vehicle. The data have to be visually read and recorded by the operator.

The Bowmonk Skidman is a portable, battery powered, electronic pendulum type decelerometer with an accurate crystal controlled clock. During a vehicle braking test run the accelerometer measures deceleration (g-force or drag factor) developed by the vehicle 400 times per second with an accuracy of better than 2 percent. The output is read by a microprocessor and stored in the 32K byte memory for automatic analysis at the end of the test. At the completion of testing, the average g-force is calculated from the stored results and printed out together with a graph of the g-force as a function of time.

The instrument has a two-line, alphanumeric liquid crystal display. This is used to prompt the user for command entry via the keypad, to confirm bar code input, to indicate results, and to give any error messages. The display can be backlit so that it may be read in poor lighting conditions.

The Skidman contains a miniature dot matrix impact printer capable of printing text in 40 columns and graphics at 240 dots per line. Printout of the tabular results is obtained by pressing the [P] button on the keypad. Graphical printouts, similar to that shown in figures 7 and 8, can be commanded by the user. If required, the instrument can print out all its stored data results. The printout will not fade, and duplicate copies are produced automatically.

With the PC-link, the Skidman can be connected to an IBM compatible computer via an RS232 port. Various software packages are available to analyze the data results on the PC.

The portable Skidman unit weighs 6 lb (2.75 kg) with the following dimensions: 5.5x8.7x3.1 in. (140x220x78 mm).

TEST SITE

The soil runway 7/25 used for these ground vehicle and C-17 transport aircraft tests is called "Holland Landing Zone" (LZ) by Army personnel at Fort Bragg. When the runway was constructed to approximately 100-foot width and 3600-foot length with 150 foot overruns, Georgia clay was trucked in to provide the top 5 in. surface layer. When compacted and dry, minimum California bearing ratio values were 18 with the majority between 30 and 60 (similar to a brick in hardness). The Army routinely uses this runway as a paratrooper drop target zone and many spent M-16 cartridges were found in the area.

TEST RESULTS

The lack of any significant rutting during DBV and Humvee locked-wheel braking test runs on runway 7/25 provides verification of the general hardness of this soil runway surface. In one, small (10 X 30 ft) localized area, some rutting did occur during C-17 aircraft accelerate-stop test runs but it was relatively small compared to the total aircraft runout distance.

From DBV unbraked test runs, the rolling resistance friction coefficient developed on this soil runway in the 070 direction was measured at 0.040 and 0.035 in the 250 heading. Locked-wheel DBV skidding friction coefficient from 60 mph to complete stop averaged 0.6 at high speed and down to 0.8 at low speed. Runway condition readings (RCR) computed from onboard DBV instrumentation, portable Tapley and Skidman decelerometer values resulted in nearly equivalent values. Average DBV RCR was 20, average Tapley meter RCR in DBV measured 22, and average Skidman RCR in DBV was 20. At the low speed of 20 - 25 mph normally used to obtain the RCR values, the data in figure 7 shows good agreement between Humvee and DBV deceleration (four-wheel braking) values (0.59 g's mean). A DBV test run record using diagonal braking from 60 mph to a stop is also shown. For diagonal braking at 20 - 25 mph, the level of deceleration is nearly half the value achieved by four-wheel braking which is in agreement with four-wheel braking deceleration levels.

Figure 8 shows the Skidman deceleration time history records obtained with the unit onboard the C-17 aircraft during most of the landing operations. These deceleration levels, which are tabulated in Table I are in good agreement with values recorded by the C-17 onboard instrumentation setup.

CONCLUDING REMARKS

A test technique for evaluating the friction performance of unprepared soil runways using the NASA Diagonal-Braked-Vehicle and/or a Humvee vehicle equipped with properly calibrated portable decelerometer units has been shown to be successful. Braking deceleration levels measured on runway 7/25 at Holland LZ with these two ground test vehicles as well as the instrumented C-17 test aircraft are considered very good for an unprepared soil runway. It is recommended that future USAF test aircraft use of relatively short unprepared soil runways should be preceded by ground vehicle evaluations to determine suitability. Other soil runways should be included in future testing to further substantiate the test results obtained at Holland LZ.

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Table I.-USAF C-17 Aircraft Skidman Deceleration Data
Pope AFB, NC.(Holland LZ); R/W 25; March 30, 1995

Run #1 - Initial landing - Max braking; Light weight, 355.6K lbs; Pilot, Davis
Record labeled test 12   09:50:58 EST - 14:50:58 Z
Mean decel = 0.48 g's
Peak decel = 0.56 g's
Braking time = 14.10 sec

Run #2 - Second landing - Max Braking; GW = 349.7K lbs; Pilot, Coonce
Record labeled test 13   10:25:36 EST - 15:25:36 Z
Mean decel = 0.59 g's
Peak decel = 0.66 g's
Braking time = 10.92 sec Note: Record started after brakes applied

Run #3 - First accel - stop; GW = 389K lbs; Pilot, Davis
Record labeled test 14   Time of day not noted on record
Mean decel = 0.40 g's
Peak decel = 0.50 g's
Braking time = 11.45 sec

Run #4 - Second accel - stop; GW = 418K lbs; Pilot, Coonce
Record labeled test 15   Time of day not noted on record
Mean decel = 0.44 g's
Peak decel = 0.51 g's
Braking time = 10.42 sec

Run #5 - Third landing - Max braking; GW = 406K lbs; Pilot, Davis
Record labeled test 16   13:36:22 EST - 18:36:22 Z
Mean decel = 0.40 g's
Peak decel = 0.49 g's
Braking time = 15.27 sec

Run #6 - Landing at Pope AFB paved R/W 23 - Normal braking; GW = 400K lbs
Record labeled test 17   Time of day not noted on record
Mean decel = 0.22 g's
Peak decel = 0.29 g's
Braking time = 30.80 sec

General Observations-

-Time of day noted on most records did not agree with time printed on record. Suspect printed time in error.

-Braking deceleration levels considered very good for soil runway. Comparable to dry pavement performance.

-Four(4) wheel maximum braking deceleration measured on both NASA DBV and Army Hum-vee at 20 mph was 0.6 g's.

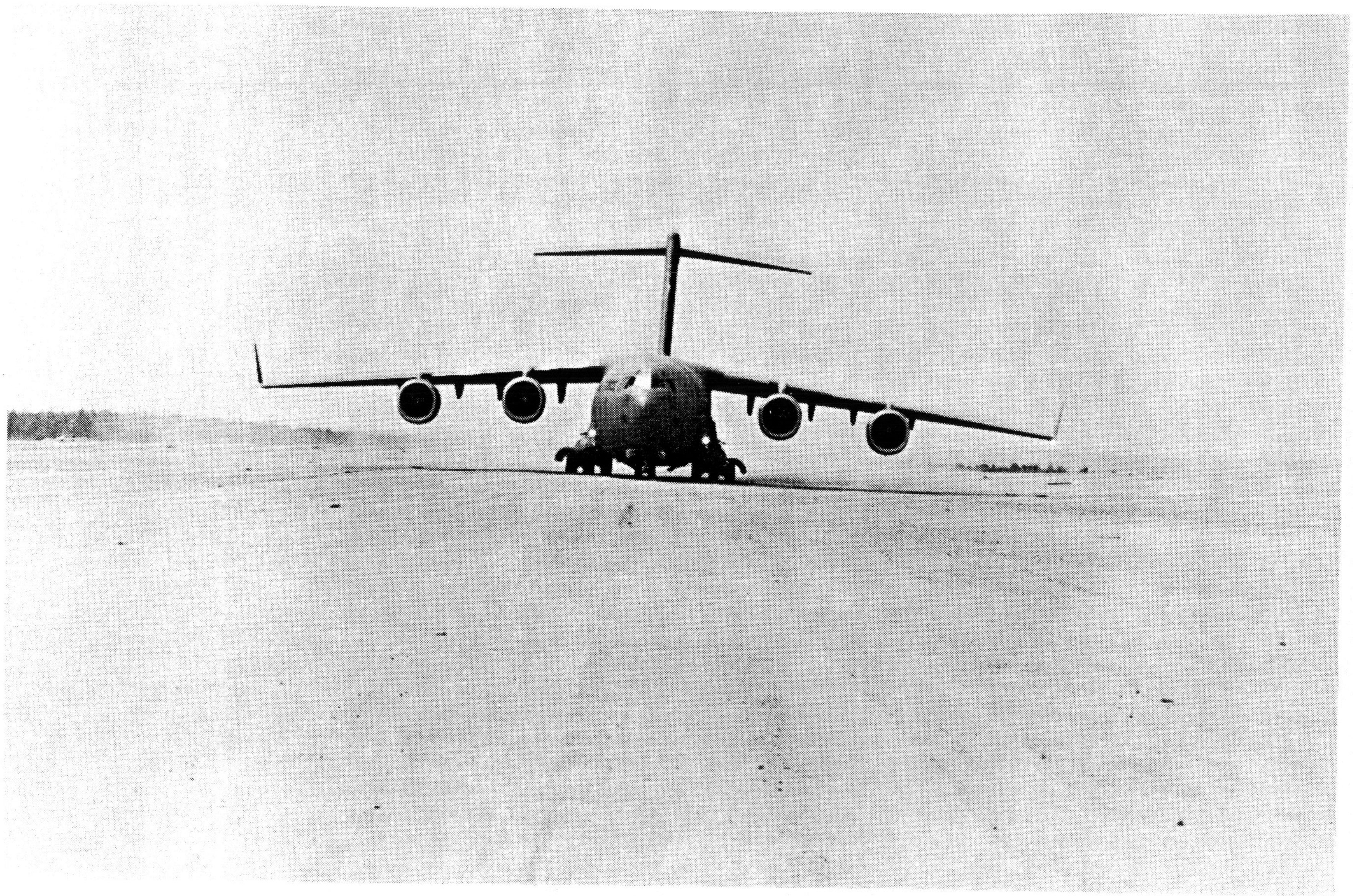


Figure 1.- C-17 transport aircraft operating on soil runway at Holland LZ.

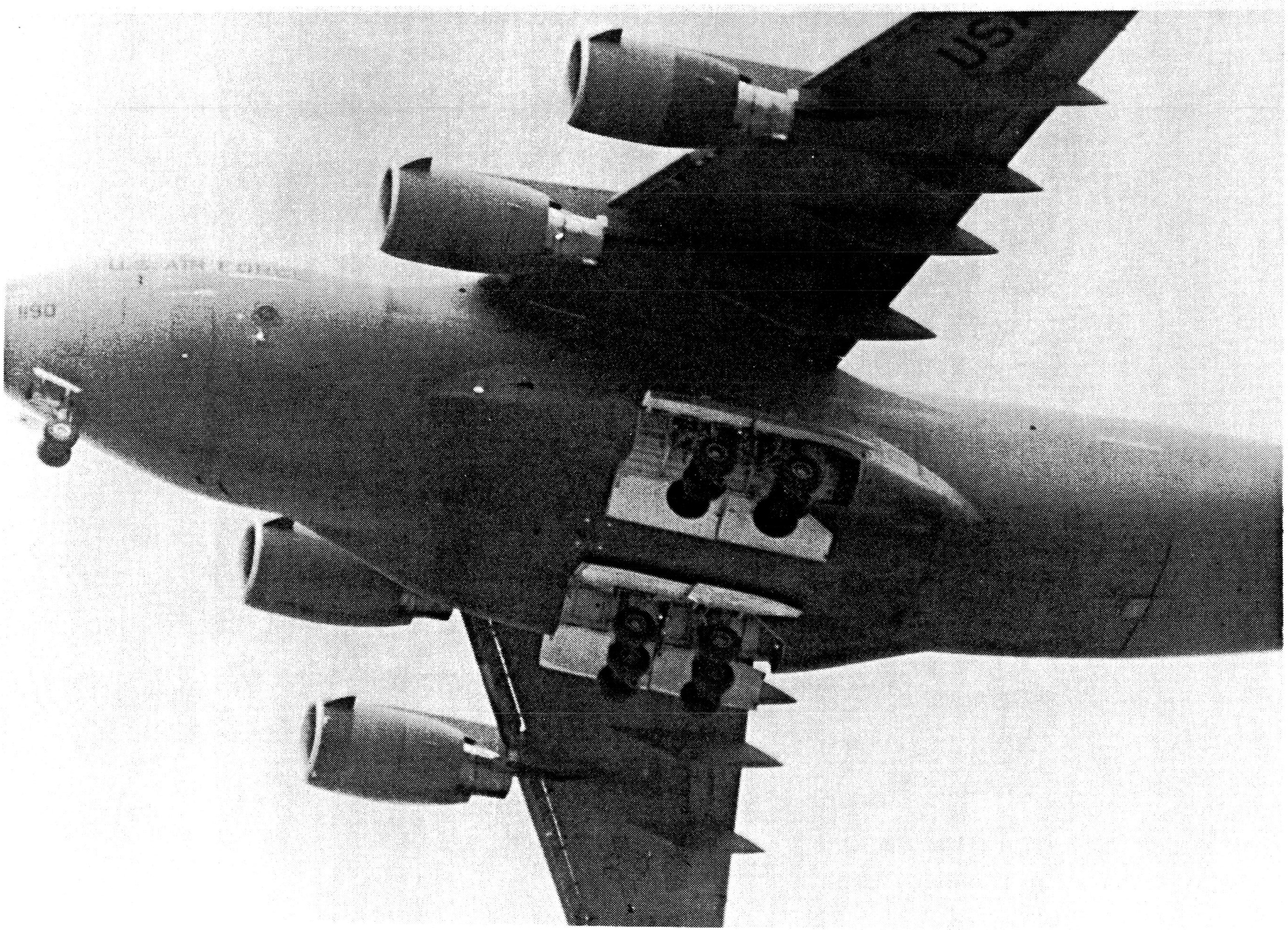


Figure 2.- C-17 transport aircraft undercarriage.

Figure 3.- NASA Diagonal-Braked Vehicle during test run on soil runway at Holland LZ.

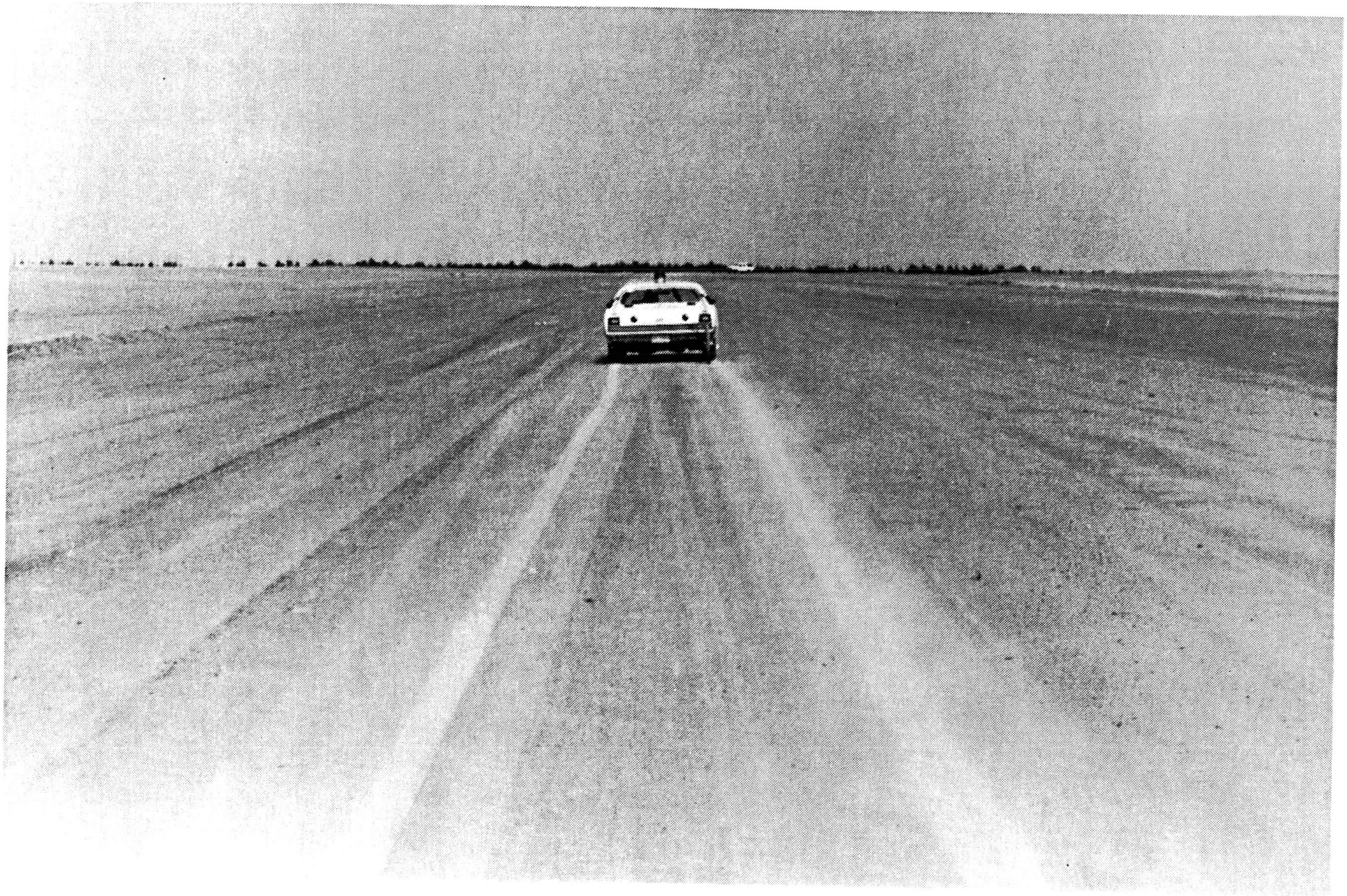


Figure 4.- NASA Diagonal-Braked Vehicle tire track after test run on soil runway.

Figure 5.- Army humvee test vehicle.

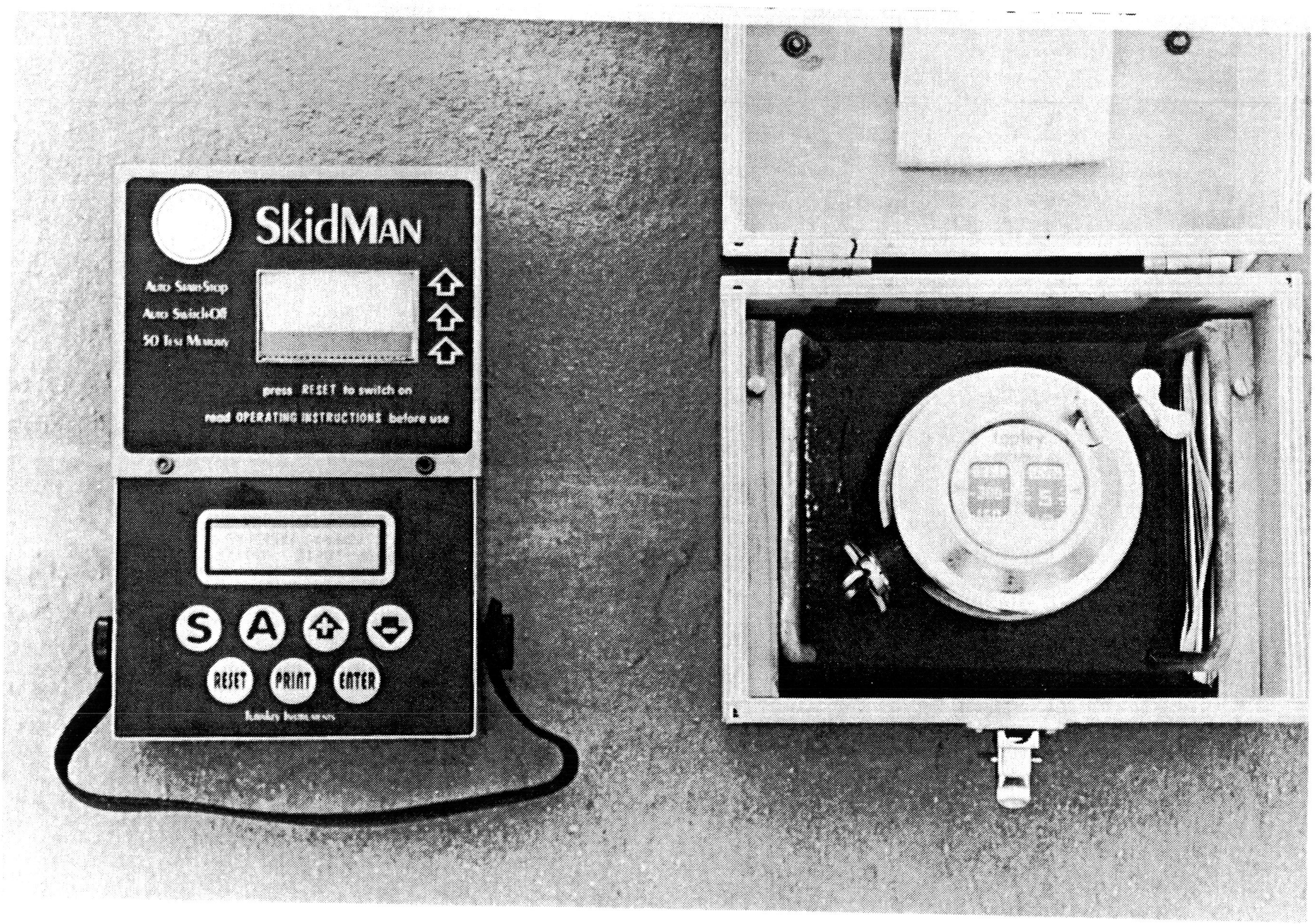


Figure 6.- Portable decelerometer units.

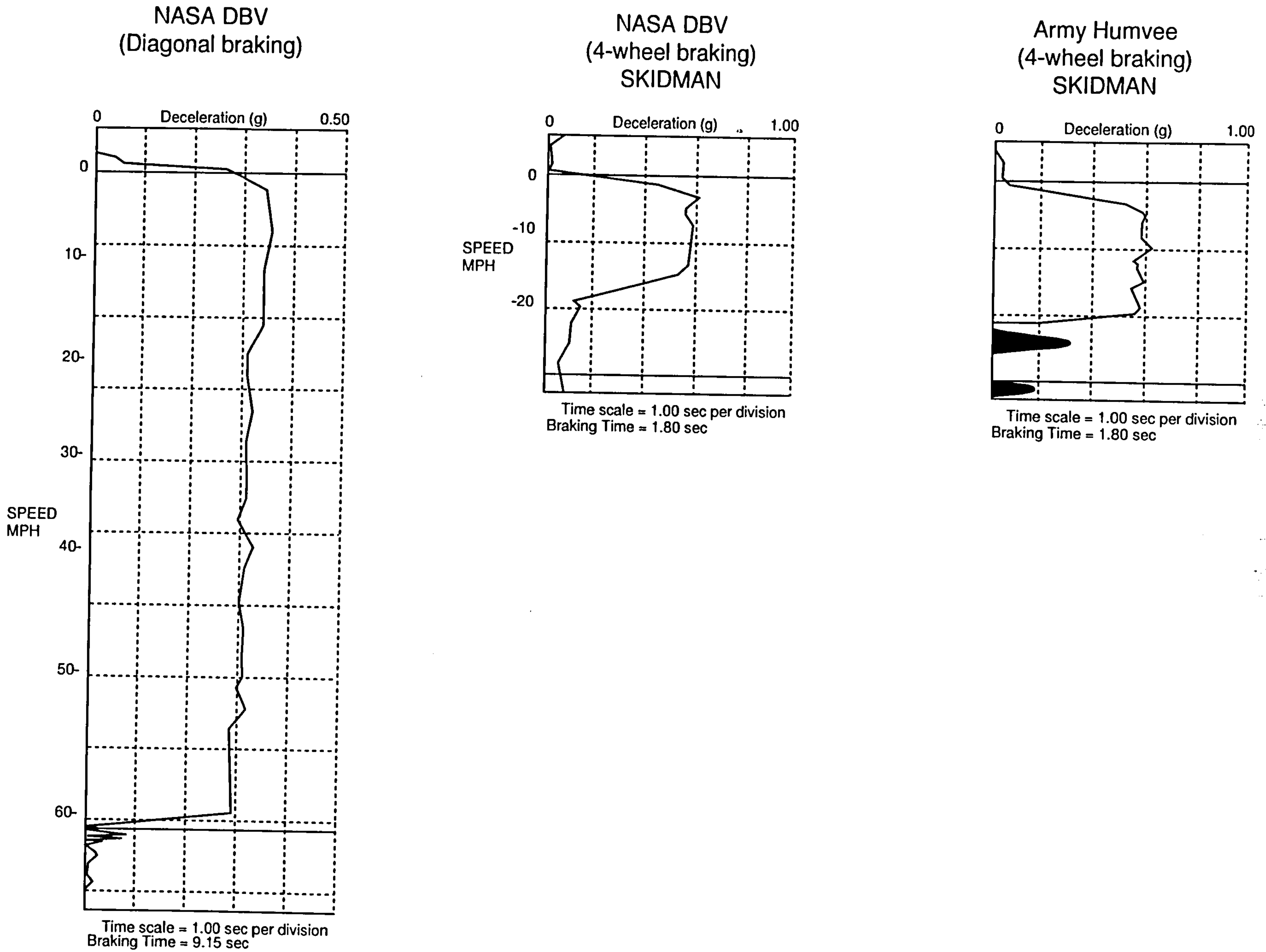
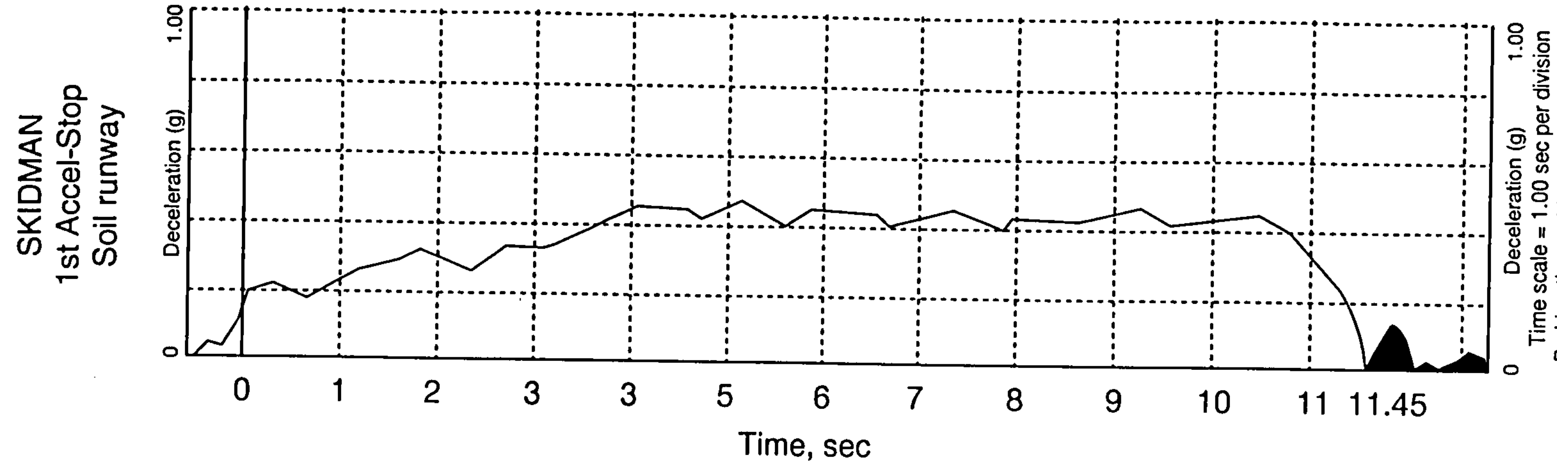


Figure 7. - Comparison of Skidman decelerometer data records obtained with ground test vehicles on soil runway.



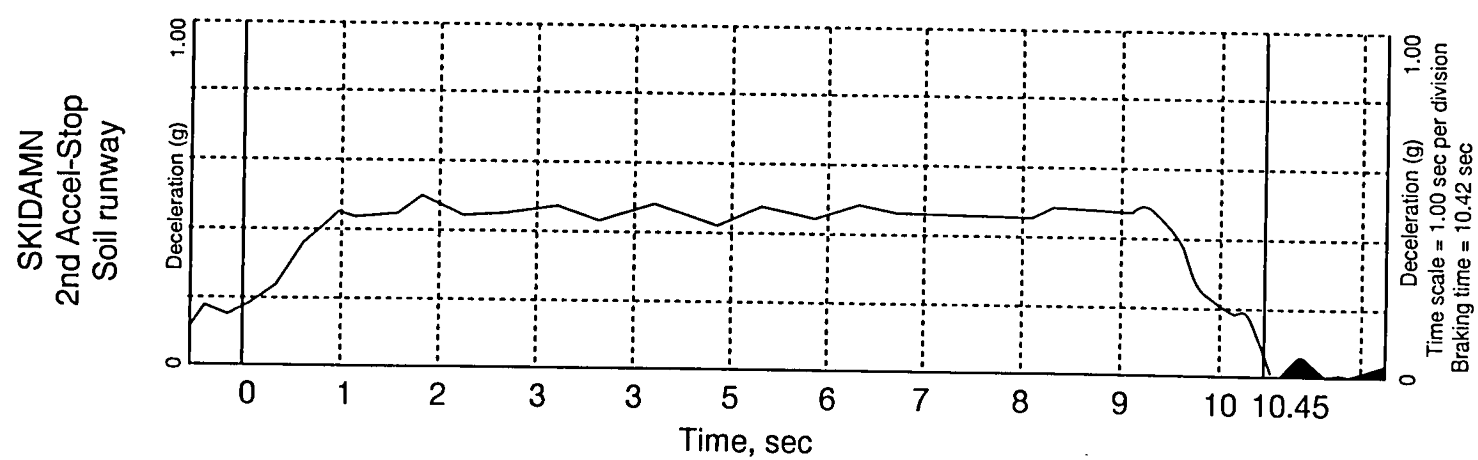


Figure 8. - Comparison of Skidman decelerometer data records obtained with C-17 transport aircraft operating on soil runway and paved runway at Pope Air Force Base.

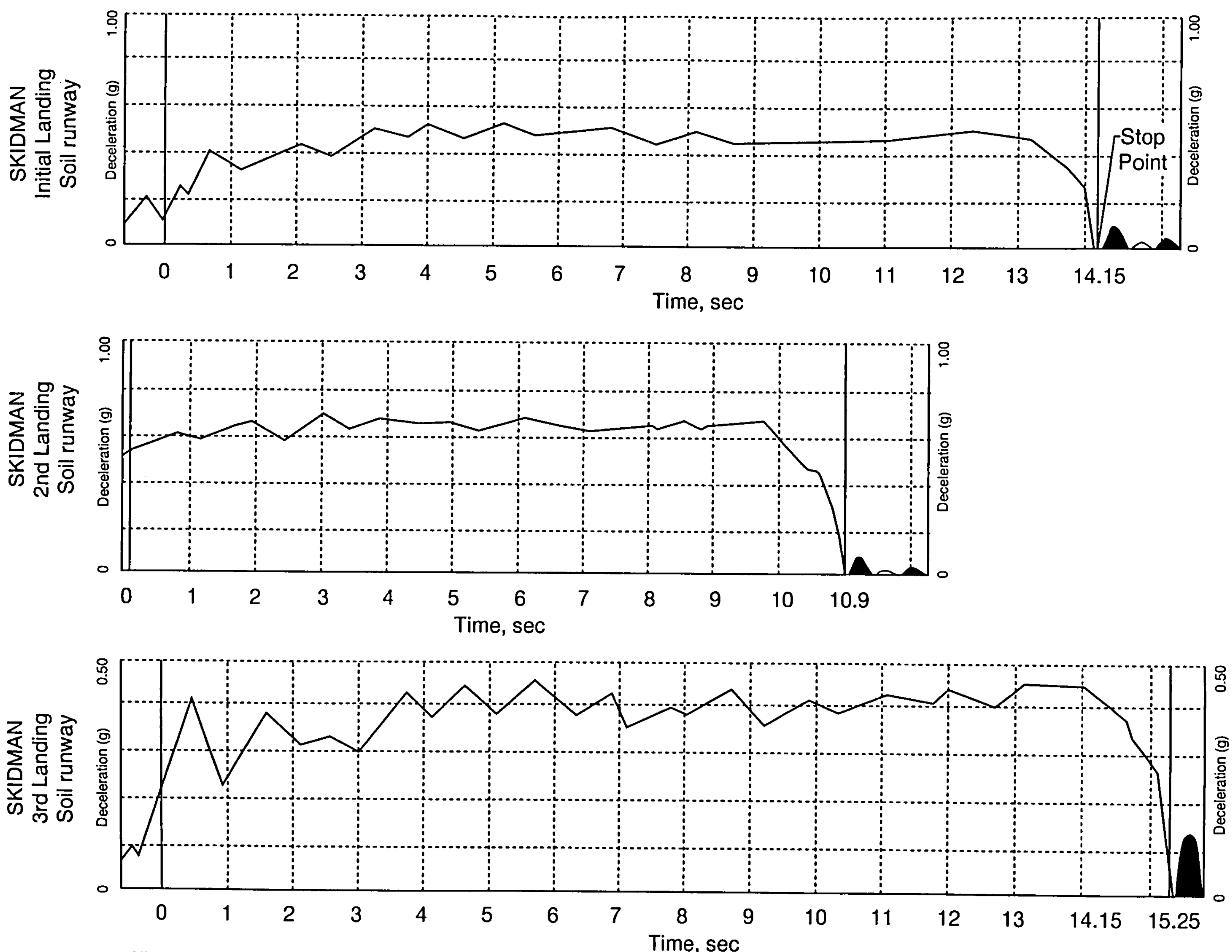


Figure 8. - Continued.

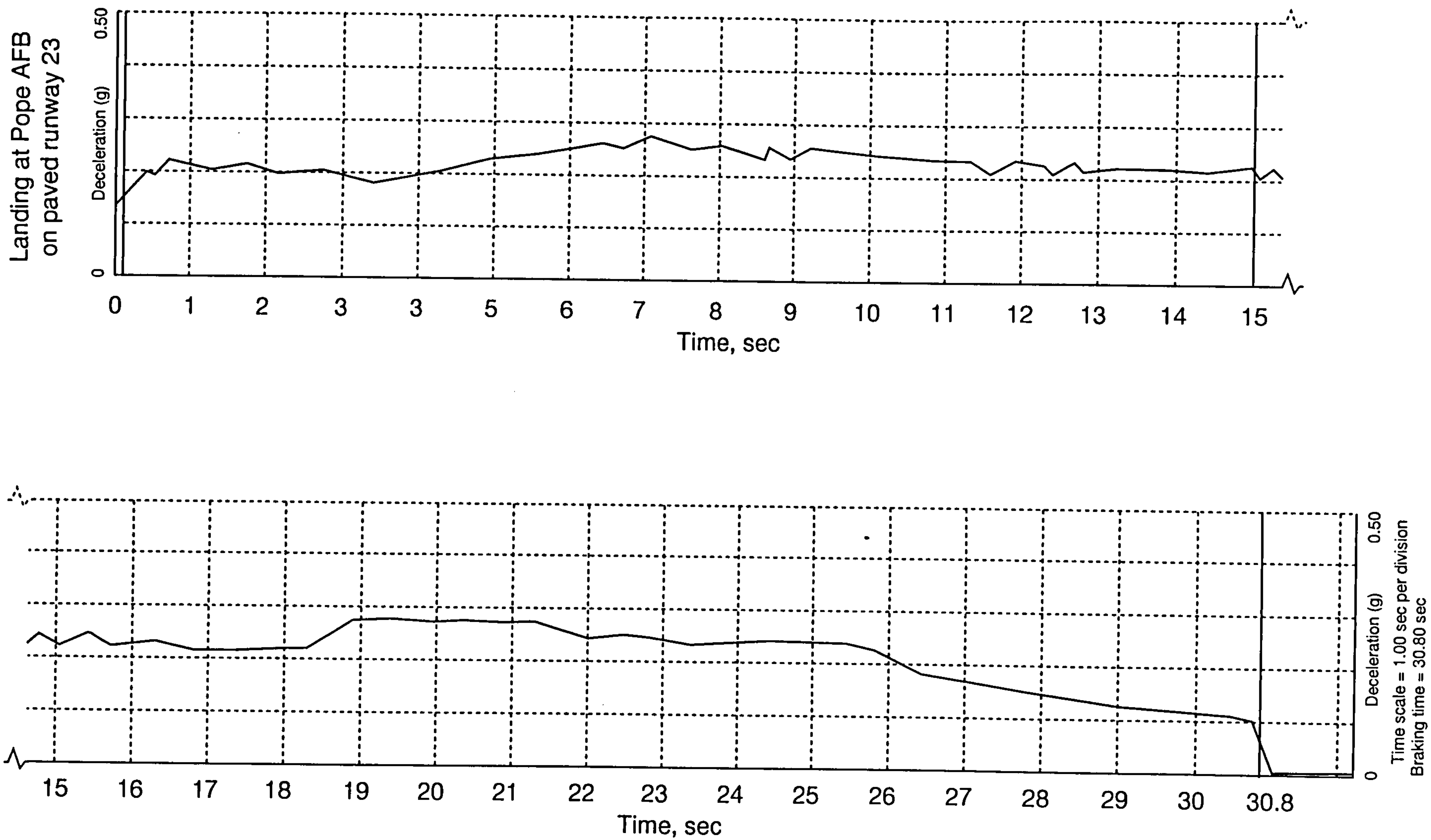


Figure 8. - Concluded.

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13. ABSTRACT *(Maximum 200 words)*

A series of NASA Diagonal-Braked Vehicle (DBV) test runs were performed on the soil runway 7/25 at Holland landing zone, Fort Bragg, North Carolina, near Pope Air Force Base in March 1995 at the request of the Air Force C-17 System Program Office. These ground vehicle test results indicated that the dry runway friction level was suitable for planned C-17 transport aircraft landing and take-off operations at various gross weights. These aircraft operations were successfully carried out. On-board aircraft deceleration measurements were comparable to NASA DBV measurements. Additional tests conducted with an Army High Mobility Multi-Purpose Wheeled Vehicle equipped with a portable decelerometer, showed good agreement with NASA DBV data.

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