AIRCRAFT GROUND-FLOTATION INVESTIGATION

PART XI — DATA REPORT ON TEST SECTION 10

W. BRABSTON and W. HILL, JR.

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The investigation described herein constitutes one phase of studies conducted during 1964 and 1965 at the U. S. Army Engineer Waterways Experiment Station (WES) under U. S. Air Force Project No. 410-A, MIL P. No. 65-4-177, "Development of Landing Gear Design Criteria for the CX-H5B Aircraft." (The CX-H5B is now designated C-5A.) This program was sponsored and directed by the Landing Gear Group, Air Force Flight Dynamics Laboratory, Research and Technology Division, Mr. R. W. Parker, Project Engineer.

These tests were conducted by personnel of the WES Flexible Pavement Branch, Soils Division, under the general supervision of Messrs. W. J. Turnbull, A. A. Maxwell, and R. G. Ahlvin, and the direct supervision of Mr. D. R. Brown. Other personnel actively engaged in this study were Messrs. C. R. Burns, D. W. Lass, W. N. Brabston, B. R. Ulery, Jr., and W. J. Hill, Jr. This report was prepared by Messrs. Brabston and Hill.

Directors of WES during the conduct of this investigation and preparation of this report were Col. Alex G. Sutton, Jr., CE, and Col. John R. Oswalt, Jr., CE. Technical Director was Mr. J. B. Tiffany.

Publication of this technical documentary report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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ABSTRACT

This data report describes work undertaken as part of an overall program to develop ground-flotation criteria for the C-5A aircraft. A test section was constructed to a width adequate for two test lanes. Each lane was divided into two items having different subgrade CBR values and different traffic surfaces. Item 1 was surfaced with modified T11 aluminum landing mat and item 2 with M6 steel landing mat. Both traffic lanes were subjected to traffic of a single-wheel load assembly consisting of one 56x16, 32-ply aircraft tire inflated to 250 psi. A 50,000-lb load was used on one lane and a 75,000-lb load on the other lane.

The information reported herein includes layout of the test lanes, characteristics and print dimensions of the load assembly tires, and data collected on soil strengths, surface deformations and deflections, and drawbar pull. The traffic-coverage level is given at which each test item was considered failed.
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SUMMARY

Tests on Section 10 are one phase of a comprehensive research pro-
gram to develop ground-flotation criteria for heavy cargo-type aircraft.
Section 10 was laid out to accommodate two test lanes, lanes 23A and 23B,
each of which was divided into two items having different subgrade CBR
values and different traffic surfaces (figure 9). Item 1 was surfaced with
modified Till aluminum landing mat and item 2 with MS steel landing mat.
Both lanes were subjected to traffic of a single-wheel load assembly con-
sisting of one 56x16, 32-ply aircraft tire inflated to 85 psi. A 50,000-
lb load was used on lane 23A and a 75,000-lb load was used on lane 23B.
Figure 11 gives pertinent tire-print dimensions and tire characteristics.

The lanes were trafficked to failure in accordance with criteria
designated in Part I of this report. Data were recorded throughout testing
to give a behavior history of each item. Using the test criteria men-
tioned above, it was possible to directly compare the effects of traffick-
ing with different loads on a single-wheel assembly. Basic performance
data are summarized in the following paragraphs.

Lane 23A

Item 1

The item was considered failed due to roughness at 32 coverages.
The rated CBR of the item was 3.0.

Item 2

The item was considered failed due to roughness at 2 coverages.
The rated CBR of the item was 3.8.

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Item 1

The item was considered failed due to roughness at 4 coverages. The rated CRR of the item was 3.5.

Item 2

The item was considered failed due to roughness after 2 passes of the load vehicle. The rated CRR of the item was 3.9.
The investigation reported herein is one phase of a comprehensive research program being conducted at the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., as part of U. S. Air Force Project No. 430-A, MLPK No. AS-4-127, to develop ground-flotation criteria for the C-5A, a heavy cargo-type aircraft. Specifically, the tests reported herein were conducted to compare the trafficking effect on landing mat surfaces of a single-wheel landing-gear assembly carrying different test loads.

Prosecution of this investigation consisted of constructing two similar traffic lanes and subjecting them to traffic of a single-wheel tracking assembly with test loads of 50,000 and 70,000 lb.

This report presents a description of the test section and wheel assembly, and gives results of traffic. Equipment used, types of data and method of recording them, and general test criteria are summarized in this part; more complete explanations and illustrations appear in Part I of this report.
SECTION II: DESCRIPTION OF TEST SECTION AND LOAD VEHICLE

Description of Test Section

Test Section 10 (figure 9) was constructed within a test area in order to allow control of the subgrade CBR (California Bearing Ratio) in the test items. In construction of the test section, an 85- by 36-ft area was excavated to a depth of 2 ft, and then backfilled in five compacted lifts with a heavy clay soil (basalt; classified as CH according to the Unified Soil Classification System, M3-S6D-3H). The fill material used was a local clay with a plastic limit of 27, liquid limit of 38, and plasticity index of 31. Gradation and classification data for the subgrade material are given in Part 1.

Two traffic lanes, each divided into two items, were constructed in the test section. Different subgrade strengths were obtained in the items (figure 9) by controlling the water content and compaction effort. Item 1 was surfaced with modified 321 aluminum loading mat and item 2 with MS steel loading mat (figure 10). The loading mats used are described and illustrated in Part 1.

Load Vehicle

The load vehicle used for trafficking Section 10 is shown in figure 2. Load cart construction, details of linkage between the load compartment and prime mover, and method of applying load are explained in Part 1. For trafficking lanes 6A and 6B, a single-wheel assembly was used with 90,000- and 75,000-lb loads, respectively. A 36x16, 32-ply aircraft tire with a 250-psi tire inflation pressure was used on both lanes. Tire-print data and pavement tire characteristics are given in figure 11.
SECTION III: APPLICATION OF TRAFFIC, FAILURE CRITERIA, AND DATA COLLECTED

Application of Traffic

The load vehicle was operated to produce uniform traffic coverage on the test lanes. The load cart was driven forward and backward along the same track, then shifted laterally and the forward-backward operation repeated. In this manner, two coverages of traffic were applied to the test lane as the vehicle progressed from one side of the lane to the other. Figure 1 is representative of the general method of applying uniform coverage to the test lanes.

Figure 1. Application of traffic on Test Section 10

Failure Criteria and Data Collected

Failure criteria used in this investigation and descriptive terms used in presentation and discussion of data in all parts of this report are presented in Part I. A general outline of types of data collected is given in the following paragraphs. Details on apparatus and procedure for obtaining specific measurements are given in Part I.

CBR, water content, and dry density

CBR, water content, and dry density of the subgrade were measured for each test item prior to application of traffic, at intermediate coverage levels, and at failure. After traffic was concluded on an item, a measure of subgrade strength termed "rated CBR" was determined. Rated CBR is generally the average CBR value obtained from all the determinations made in the top 22 in. of soil during the test life of an item. In

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certain instances, extreme or irregular values may be ignored if the analyst decide that they are not properly representative.

**Surface roughness, or differential deformation**

Surface roughness, or differential deformation, measurements were made using a 10-ft straightedge at various traffic-coverage levels on all items. Dishing effects of individual mat panels were recorded.

**Deformations**

Deformations, defined as permanent cumulative surface changes in cross section or profile of an item, were charted by means of level readings at pertinent traffic-coverage levels.

**Deflection**

Deflection of the test surface under an individual static load of the tracking assembly was measured at various traffic-coverage levels. Level readings on the item surface on each side of the load wheel and on a pin and cap device directly beneath the load wheel provided deflection data. All net deflection was for practical purposes recoverable, i.e., total deflection equaled elastic (spring-back) deflection. The pin and cap device for measuring deflection directly beneath load wheels was applied to the subgrade through a hole (existing or cut) in the mat.

**Rolling resistance**

Rolling resistance, or drawbar pull, measurements were performed with the load vehicle over each test item at designated coverage levels. Three types of drawbar measurements were taken: (a) maximum force required to overcome static inertia and commence forward movement of the load cart, termed "initial DBF"; (b) average force required to maintain a constant speed once the load vehicle is in motion, termed "rolling DBF"; and (c) maximum force obtained during the constant speed run, termed "peak DBF."

**Mat breaks**

Mat breaks were inspected, classified by type, and recorded at various coverage levels.
SECTION IV: BEHAVIOR OF ITEMS UNDER TRAFFIC AND TEST RESULTS

Lane 23A

Behavior of items under traffic

Item 1. Figure 3 shows item 1 prior to traffic. During the first 2 coverages, a large number of center-line rivets sheared. Traffic was continued to 32 coverages at which time the item was considered failed due to roughness (figure 4). The rated CBR for the item was 3.0.

Item 2. Figure 5 shows item 2 prior to traffic. The item deformed rapidly under traffic and at 2 coverages was considered failed due to roughness (figure 6). The rated CBR for the item was 3.0.

Test results

Results of trafficking lane 23A are summarized in table 1. Soil test data are given in table 2. Table 1 contains drawbar pull values for the load vehicle operated over an asphalt-paved strip for comparison with drawbar pull values recorded on the test lane.

Item 1. Item 1 was considered failed due to roughness at 32 coverages. A large number of center-line rivet failures occurred with trafficking. The following information was obtained from traffic tests on item 1.

a. Roughness. Table 1 shows differential deformation measurements at 2 and 32 coverages. At failure the average transverse, diagonal, and longitudinal differential deformations were 3.09, 2.40, and 1.03 in., respectively. Dishing of individual mat panels averaged 0.36 in. at failure.

b. Deformations. Figure 12 shows average cross-section deformations at 2 and 32 coverages for each of two typical mat runs. Figure 13 shows a profile plot of the item at the same coverage levels. Severe transverse differential deformations are evident and were the principal roughness factor contributing to failure.

c. Deflection. Average elastic mat deflections under static load of the load wheel assembly for three positions of the assembly relative to mat end joints are plotted in figure 14. Deflection at 32 coverages was greatest for each position. Elastic soil deflection at failure was 1.6 in.

d. Rolling resistance. Drawbar pull values recorded at 2 and 32 coverages are shown in table 1. No significant change in drawbar value occurred with trafficking.

e. Mat breaks. The number and type of mat breaks resulting from
Traffic lanes宜’re given in Table 1. A large number of center-line rivet failures were recorded at failure.

Item 2. Item 2 was considered failed due to roughness at 2 coverages. The following information was obtained from traffic tests on item 2.

a. Roughness. Table 1 shows differential deformations at 2 coverages. Average values at failure were 1.22, 2.00, and 1.81 in. for transverse, diagonal, and longitudinal measurements, respectively. Dishing of individual mat panels was slight and averaged 0.10 in. at failure.

b. Deformations. Average cross-section deformations at 2 coverages for two typical mat runs are plotted in figure 22. A very significant factor in cross-section deformations was the mat uplift along both sides of the lane. Figure 13 shows the longitudinal irregularities that contributed to early failure of the item.

c. Deflection. Average elastic mat deformations under static load of the wheel assembly are plotted in figure 14 for three positions of the assembly relative to mat end joints.

d. Rolling resistance. Drawbar pull values measured at 2 coverages are shown in Table 1.

e. Mat breaks. No mat breaks were observed after the item failed. The NO mat conformed to the shape of the deformed subgrade without breaking.

Lane 23B

Behavior of items under traffic

Item 1. Figure 3 shows item 1 prior to traffic. The mat surface deformed and many rivet failures occurred with initial coverages. The item was considered failed due to roughness at 4 coverages with the primary failure factor being excessive transverse differential deformations (Figure 7). The rated GES for the item was 5.0.

Item 2. Figure 5 shows item 2 prior to traffic. The subgrade was severely deformed with the first pass of the load vehicle. The item was considered failed due to roughness after 2 passes (Figure 8). The rated GES for the item was 1.9.

Test results

Results of traffickng lane 23B are summarized in Table 1. Soil test data are given in Table 2. Table 1 contains drawbar pull values for the load vehicle operated over an asphalt-paved strip for comparison.
with drawbar pull values recorded on the test lane.

Item 1. Item 1 was considered failed due to roughness at ¼ cover-
age. A large number of center-line rivet failures occurred with traffic-
ing. The following information was obtained from traffic tests on item 1.

a. Roughness. Table 1 shows the differential deformations that
existed at failure of the item. The principal roughness factor
was transverse differential deformation which averaged 3.47 in.
at failure. Diagonal and longitudinal differential deformations
averaged 3.49 and 1.03 in., respectively. Dishing of individual
mat panels was slight, averaging 0.25 in. at failure.

b. Deformations. Figure 12 shows average cross-section deformations
at ¼ coverages for two typical mat runs. Mat uplift at the lane
edges contributed to the cross-section deformation. No profile
deformation data were obtained on this item.

c. Deflection. Average elastic mat deflections under static load of
the wheel assembly for three positions of the assembly relative
to mat end joints are plotted in figure 14. Only small dif-
fferences in deflection occurred for the different positions.

d. Rolling resistance. Drawbar pull values at ¼ coverages are shown
in Table 1.

e. Mat breaks. The number and type of mat breaks resulting from
traffic are shown in Table 1. Center-line rivet failures far
exceeded other types of mat breaks.

Item 2. Item 2 was considered failed due to roughness after 2
passes of the load vehicle.

a. Roughness. Table 1 shows maximum and average values of trans-
verse differential deformation at 2 passes. The average measure-
ment was 8.37 in. No measurements were made of longitudinal and
diagonal differential deformations.

b. Deformations, deflection, and rolling resistance. No measure-
ments were made of cross-section and profile deformations, de-
fections, or rolling resistance.

c. Mat breaks. No breaks occurred in the No mat with trafficking.
### SECTION VII: PRINCIPAL FINDINGS

From the foregoing discussion, the principal findings relating test load, wheel assembly, tire inflation pressure, surface type, subgrade CBR, and traffic coverages are as follows:

<table>
<thead>
<tr>
<th>Load, Wheel Assembly, and Tire Pressure</th>
<th>Type of Surface</th>
<th>Rated CBR</th>
<th>Coverages at Failure</th>
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<tr>
<td>50,000-lb load; single-wheel assembly; 56x16, 32-ply tire with 250-psi inflation pressure</td>
<td>Modified TIl aluminum mat</td>
<td>3.0</td>
<td>32</td>
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<td>M8 steel landing mat</td>
<td>3.8</td>
<td>2</td>
</tr>
<tr>
<td>75,000-lb load; single-wheel assembly; 56x16, 32-ply tire with 250-psi inflation pressure</td>
<td>Modified TIl aluminum mat</td>
<td>3.5</td>
<td>4</td>
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<td>M8 steel landing mat</td>
<td>3.9</td>
<td>2 passes</td>
</tr>
<tr>
<td>Test Item</td>
<td>Coverage</td>
<td>Depth (in.)</td>
<td>No. of Tested Sections</td>
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<td>----------</td>
<td>------------</td>
<td>------------------------</td>
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<tr>
<td>Lane 2PA</td>
<td>2</td>
<td>7</td>
<td>92</td>
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<tr>
<td>Modified T3</td>
<td>2</td>
<td>8</td>
<td>92</td>
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<tr>
<td>MS steel</td>
<td>2</td>
<td>1.8</td>
<td>92</td>
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<tr>
<td>Asphalt test</td>
<td>2</td>
<td>7.1</td>
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<th>Test Item</th>
<th>Coverage</th>
<th>Depth (in.)</th>
<th>No. of Tested Sections</th>
<th>Longitudinal</th>
<th>Transverse</th>
<th>Diagonal</th>
<th>Shear</th>
<th>Tension</th>
<th>Bending</th>
<th>Permanent</th>
<th>Elastic</th>
<th>Total Deflection</th>
<th>Remarks</th>
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<td>1</td>
<td>58.4</td>
<td>95</td>
<td>1.13 1.02 1.03 0.97 1.00 1.01 0.29 0.25 12.1 8.9 6.1</td>
<td>2.7 2.7 2.9</td>
<td>Failed due to roughness at 1 covers.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modified T3</td>
<td>2</td>
<td>0.9</td>
<td>95</td>
<td>3.00 6.97</td>
<td>Failed due to roughness at 1 covers.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>MS steel</td>
<td>2</td>
<td>3.9</td>
<td>95</td>
<td>2.9</td>
<td>Failed due to roughness at 2 covers.</td>
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<td>Asphalt test</td>
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<td>95</td>
<td>2.9</td>
<td>Failed due to roughness at 2 covers.</td>
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</table>

Note: A single-axle assembly with a 56.16, 35-psi tire inflated to 250 psi was used for testing lanes 2PA and 2PB. The test loads were 50 and 75 kips for lanes 2PA and 2PB, respectively. * These types are defined and illustrated in Part I.
<table>
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<td><strong>Modified Till</strong></td>
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Figure 2. Test load vehicle

Figure 3. Lanes 23A and 23B, Item 1, prior to traffic

II

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Figure 4. Lane 23A, item 1. Transverse straightedge shows roughness at 32 coverages (failure)

Figure 5. Lanes 23A and 23B, item 2, prior to traffic
Figure 6. Lane 23A, Item 2. Transverse straightedge shows roughness at 2 coverages (failure)

Figure 7. Lane 23B, Item 1. Transverse straightedge shows roughness at 4 coverages (failure)
Figure 8. Lane 258, Item 2. Transverse straightedge shows roughness at 2 passes (failure)
LAYOUT OF TEST SECTION 10
AND SUMMARY OF TEST RESULTS
56 X 16, 32-PLY TIRES
250-PSI INFLATION PRESSURE
TIRE-PRINT DIMENSIONS AND TIRE CHARACTERISTICS
56 x 16, 32-PLY TIRES
TEST SECTION 10
LANES 23A AND 23B

Figure 11
Figure 14

AVERAGE DEFLECTIONS
TEST SECTION 10
LANES 23A AND 23B

Legend:
- ■ Number of coverages
- Measured data
- Extrapolated data
Aircraft Ground-Flotation Investigation
Part XI Data Report on Test Section 10

Final Technical Report
Brabston, W. N.
Hill, W. J., Jr.

September 1966

This data report describes the results of work undertaken as part of an overall program to develop ground-flotation criteria for the C-5A aircraft.
Aircraft Ground Flotation  
Rolling Resistance  
Remote Area Airfields  
Support Area Airfields  
Forward Area Airfields  
Vehicle Mobility

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