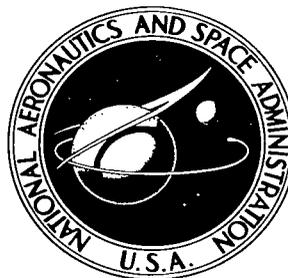


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OF VARIOUS SKID MATERIALS ON
DISSIMILAR LAKEBED SURFACES DURING
THE SLIDEOUT OF THE X-15 AIRPLANE**

*by Ronald J. Wilson
Flight Research Center
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SUMMARY

An investigation was made to determine the coefficients of friction and the wear characteristics for X-15 landing-gear skids of various materials. Data are presented for skids made of 4130 steel, with and without cermet coating, and Inconel X for several lakebed-surface conditions. The mean coefficient of friction on a dry-hard surface was found to be 0.30 for 4130 steel skids, 0.36 for 4130 steel skids with cermet coating, and 0.35 for Inconel X skids. The mean coefficient of friction for the cermet-coated skids on a soft surface was 0.46; for Inconel X skids on a damp surface the mean value was 0.25. Flight data are compared with experimental ground-tow test data on natural and simulated lakebed surfaces. Also included is the variation of skid wear with slideout distance.

INTRODUCTION

Landing gear that use skids instead of wheels have been used on a number of flight vehicles and have been proposed for some future vehicles. Some of the advantages of this type of gear are its simplicity, reliability, the ability to withstand aerodynamic heating, minimum space and weight requirements, and the ability to sustain high landing speeds. The X-15 research airplane utilizes a landing gear of this type. Some aspects of operating with skid gear on the X-15 are reported in references 1 to 6.

Coefficients of friction and wear characteristics for skids of various materials have been studied by several investigators. The results of experimental ground-tow tests on simulated and natural lakebeds at velocities up to 82.5 knots are reported in references 7 to 9. Flight tests of operational skids, fabricated from structural steels, on hard lakebed surfaces were made in the investigations of references 3 and 10. Optimum friction coefficients for landing skids are discussed in reference 11. Additional information is required, however, on coefficients of friction and wear at high speeds on hard, soft, and damp lakebed surfaces. In order to obtain information of this type during high-speed slideout, an X-15 airplane was instrumented by the NASA Flight Research Center, Edwards, Calif., to measure pertinent quantities during landing. Twelve tests were conducted with skids of various materials

and for several different lakebed surface conditions. This paper presents the results of the investigation.

TEST VEHICLE AND EQUIPMENT

The X-15 airplane (fig. 1) used as the test vehicle in this investigation is a rocket-powered aircraft capable of attaining a Mach number of 6 and altitudes in excess of 300,000 feet. The airplane is described fully in references 12 and 13.



Figure 1.— X-15 airplane.

E-7905

Gear system.— The X-15 landing-gear system, discussed in detail in reference 3, consists of a non-steerable, full-castering (360°) nose gear located well forward of the airplane center of gravity and a skid-type main gear located under the tail, well aft of the center of gravity.

The main-gear legs are Inconel X struts attached to the fuselage by trunnion fittings (fig. 2) and through bellcrank arms to high-pressure shock struts inside the fuselage. The two skids are universally mounted to the struts to allow for pitching and rolling motion, but are restrained in yaw for parallel alignment. The drag braces are attached to the fuselage by semi-universal fittings and are similarly connected to the skids ahead of the

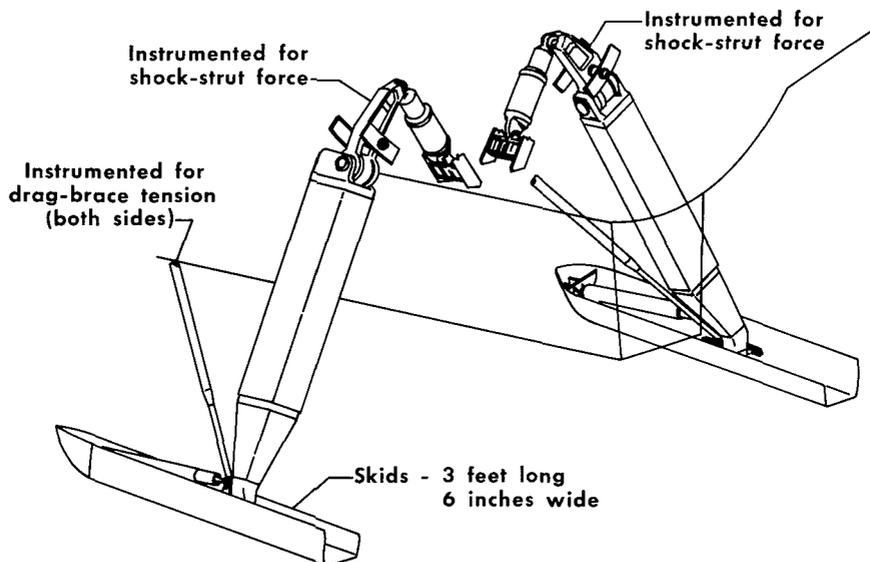
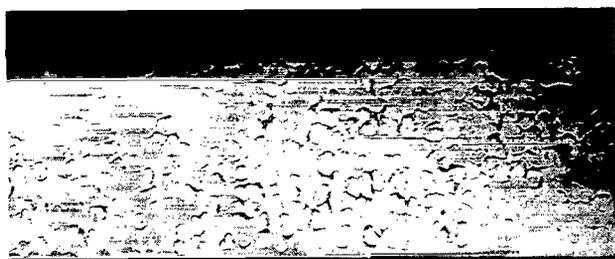


Figure 2.— X-15 main landing gear and instrumentation.

strut-attachment pin. Bungees connect the leading edge of the skid to the main-landing-gear leg to insure a nose-up attitude of the skids before touch-down.

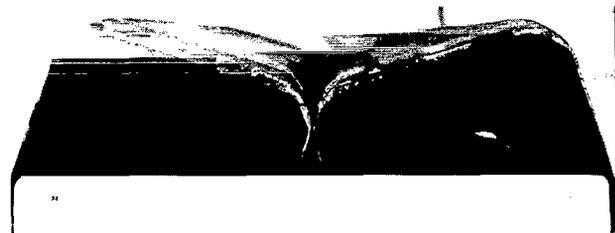
Landing-gear skids.— Three skid materials were used in this investigation. The first set of skids, which is standard equipment on the X-15 airplane, was fabricated from 4130 steel. The second set was of 4130 steel with a cermet coating that was originally developed for the X-20 nose-gear skid. The third set was fabricated from Inconel X.

The skids were 6 inches wide and 3 feet long, with contact surfaces approximately 4.8 inches wide and 30.6 inches long. The wearing surfaces were approximately 0.150-inch thick for the 4130 steel skids, 0.40-inch thick for the cermet-coated skids, and 0.150-inch thick for the Inconel X skids.



(a) Bottom view.

E-10822



(b) End view of both skids.

E-10820

Figure 3.— Cermet-coated skid.

The landing conditions for the tests discussed herein are summarized in table I. As shown, the landing weights for the X-15 ranged from 14,500 pounds to 15,855 pounds. The true ground speed varied from 164 knots to 221 knots. The maximum slideout distance was 8968 feet, and the minimum distance was 3520 feet. The maximum wind velocity across the lakebed was approximately 10 knots.

All the landings of this study except one were made on the hard, smooth lakebed of Rogers Dry Lake, at Edwards, Calif.; one landing was made on the soft surface of Cuddeback Dry Lake, near Edwards.

Lakebed-surface conditions were variable and presented a range of hardness values dependent on weather conditions, location, and soil characteristics.

The cermet-coating process (figs. 3(a) and 3(b)) consisted of: (1) copper-brazing $\frac{3}{16}$ -inch screened tungsten carbide chips to the skid surface after precoating the surface with flux (the chips were applied to the surface by hand); (2) flame-spraying a 0.020-inch- to 0.040-inch-thick matrix of tungsten (35 percent), chrome, nickel, and boron (65 percent) on top of the copper-brazed carbide chips, then fusing and grit blasting; and (3) flame-spraying with a copper-nickel matrix. The cermet coating was then ground to a nominal thickness of 0.20 inch.

TEST LANDING CONDITIONS

Surface-hardness values were not obtained directly for all of the surface conditions. Hardness values, expressed in terms of California Bearing Ratio (CBR)¹, were obtained from reference 9 for dry-hard surface conditions. The values for tests 1 to 9 and 11 averaged 76, with a high of 94 and a low of 59. A CBR of 30 or greater is considered satisfactory for operations of heavy jet-transport aircraft.

TABLE I
SUMMARY OF TEST CONDITIONS

Test	Type of skid	Lakebed surface condition	Landing weight, lb	Distance from main-gear to nose-gear touchdown, ft	Time of nose-gear impact, sec	Slideout distance, ft	Wind velocity, knots	Velocity at touchdown (indicated airspeed), knots	Velocity at touchdown (true ground speed), knots
1	4130	Dry-hard	14,700	312	0.7	7920	8	207	207
2	4130	Dry-hard	14,500	304	.8	----	Calm	198	196
3	4130	Dry-hard	14,600	218	.54	----	10	---	196
4	4130	Dry-hard	14,950	294	.74	8170	Calm	198	204
5	4130	Dry-hard	15,150	205	.60	4488	2	160	164
6	Cermet	Dry-hard	14,920	252	.72	5702	Calm	181	175
7	Cermet	Dry-hard	15,100	253	.61	4805	3	184	208
8	Cermet	Dry-hard	15,100	310	.83	5204	Calm	184	193
9	Cermet	Dry-hard	14,750	320	.89	5808	Calm	184	187
10	Cermet	Dry-soft	14,920	271.6	.76	3520	5	184	181
11	Inconel X	Dry-hard	15,798	287.8	.712	6056	Calm	178	205
12	Inconel X	Damp-hard	15,855	365	.715	8968	Calm	192	221

Surface CBR values were not determined for the soft surface of Cuddeback Lake, used in test 10, because of the remote location of the lake. A CBR of 16 to 23 was estimated on the basis of ground tests that provided the same coefficient of friction for the same skid material. No estimates of surface hardness were made for the damp surface condition of test 12.

Ball tests were conducted to compare surface-hardness values of the natural lakebed surfaces with those of the simulated lakebed surface of reference 7. A 17.9-pound steel ball, 5 inches in diameter, was dropped onto the lakebed from a height of 6 feet. The diameters of the indentations left by the ball on the hard lakebed surface ranged from 2.25 inches to 2.50 inches. On the soft lakebed surface, indentation diameters were from 4.0 inches to 4.50 inches. The ball tests on the simulated lakebed of reference 7 resulted in diameters of 3.0 inches.

INSTRUMENTATION AND DATA REDUCTION

Airspeed, shock-strut force, and drag-brace tension load were measured during the approach, touchdown, and slideout phases of the landings. Airspeed data were obtained from the X-15 flow-direction sensor in the nose of the

¹California Bearing Ratio is defined as the ratio of the bearing strength of the soil surface in question to a standard high-quality compacted crushed-stone surface. This standard has a bearing strength of 1000 lb/sq in. at a depth of 0.10 inch.

aircraft and static pressure pickups on the aircraft fuselage. Strain gages mounted on each of the main-gear bellcrank arms and drag braces (fig. 2) were arranged to measure the normal skid and drag loads.

The measured quantities were recorded on standard oscillographs, synchronized at 0.1-second intervals to a common timer. The natural frequency and damping ratio of the recording galvanometers were 20 cps and 0.64, respectively. Recordings were accurate within ± 2 percent of full-scale readings.

The true ground speed at touchdown was calculated by dividing the measured distance between the main-gear and nose-gear touchdown points on the lakebed by the time interval between main-gear and nose-gear touchdown (as obtained from oscillograph records). The true ground speed during slideout was determined by correcting the true airspeed, obtained from onboard recording, for the differential between the airspeed and the ground speed at touchdown. The data are accurate to within ± 1 knot.

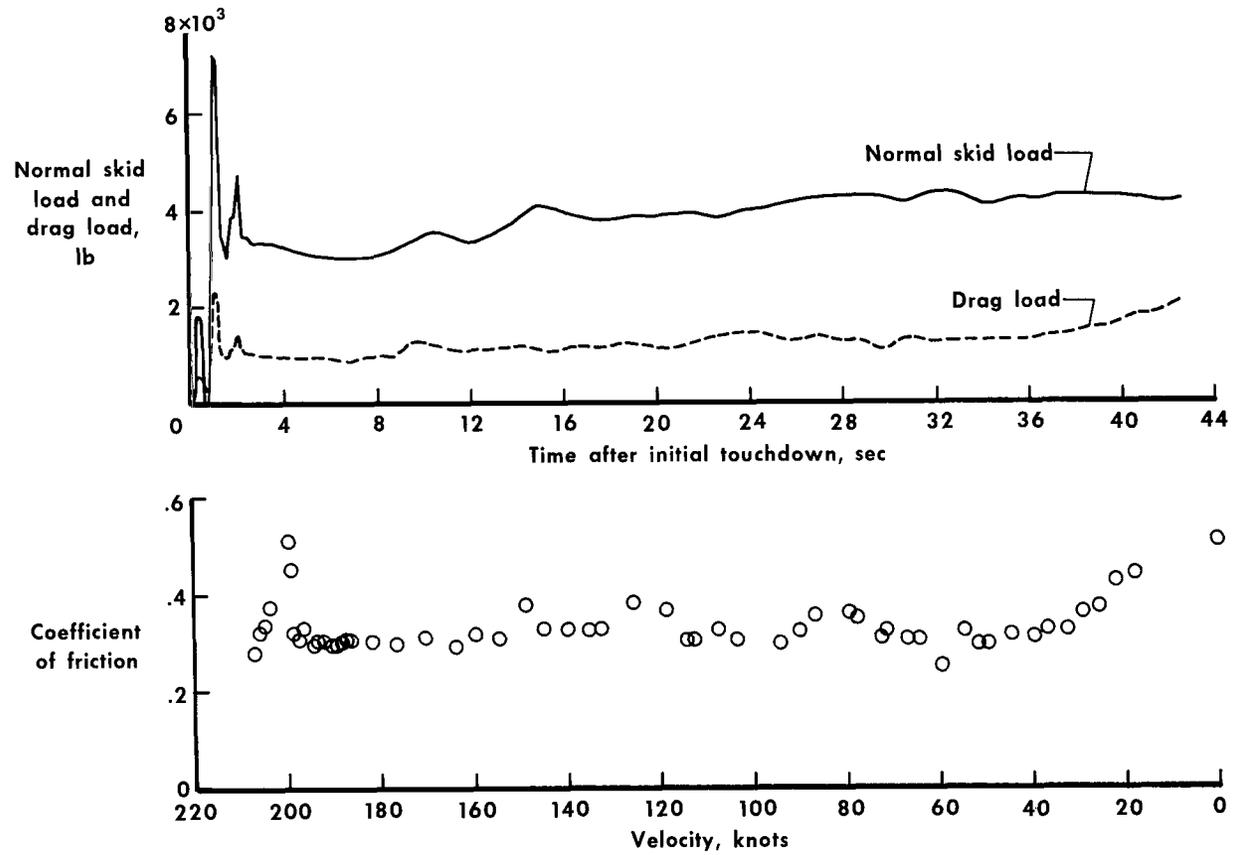
Landing-gear loads, which are normal skid and drag loads, were determined from data recorded for each main-gear skid during the slideout. The strain gages on the left and the right main drag braces were calibrated to give the drag-brace tension loads resulting from the drag loads on the skids. From the geometry of the main-gear system, the drag-brace tension loads were used to calculate the drag reaction between the skids and the ground. No interaction exists between the drag-brace load and the main-gear shock strut, since pivot points at the fuselage for the drag brace and the landing-gear leg fall on a line that is essentially parallel to the longitudinal centerline of the fuselage.

The strain gages on the main-gear bellcrank arm were calibrated to give the axial load on the shock-strut cylinders. Since only slight pitching, vertical, and rolling motions were experienced during the slideout, the main-gear shock-strut reaction to the vertical load of the skid was regarded as being equal to the strut airspring force; that is, the airplane was essentially riding on the airspring force of the shock struts. A calibration on the main-gear system correlated the effect of the vertical force of the skid on the shock-strut-cylinder reaction and shock-strut displacement.

TEST RESULTS

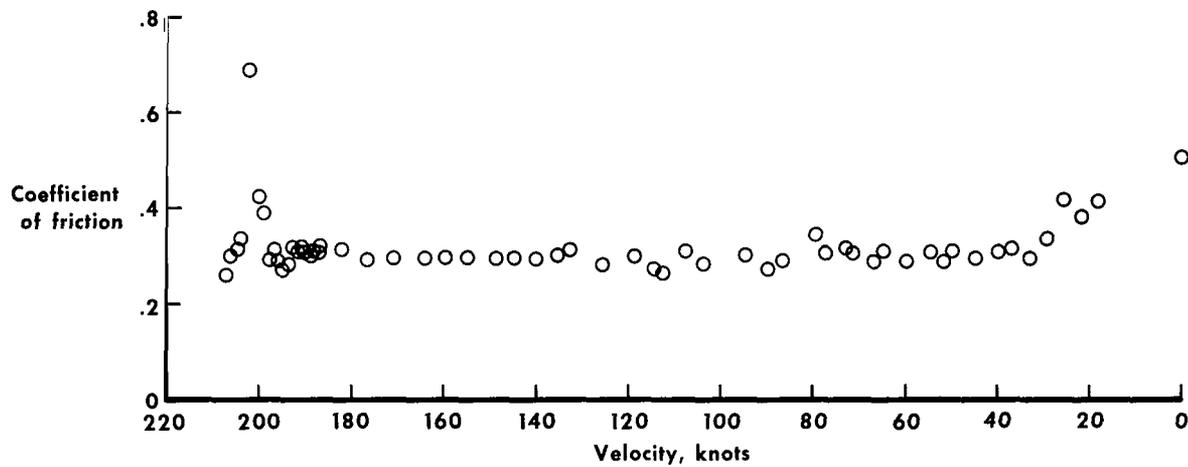
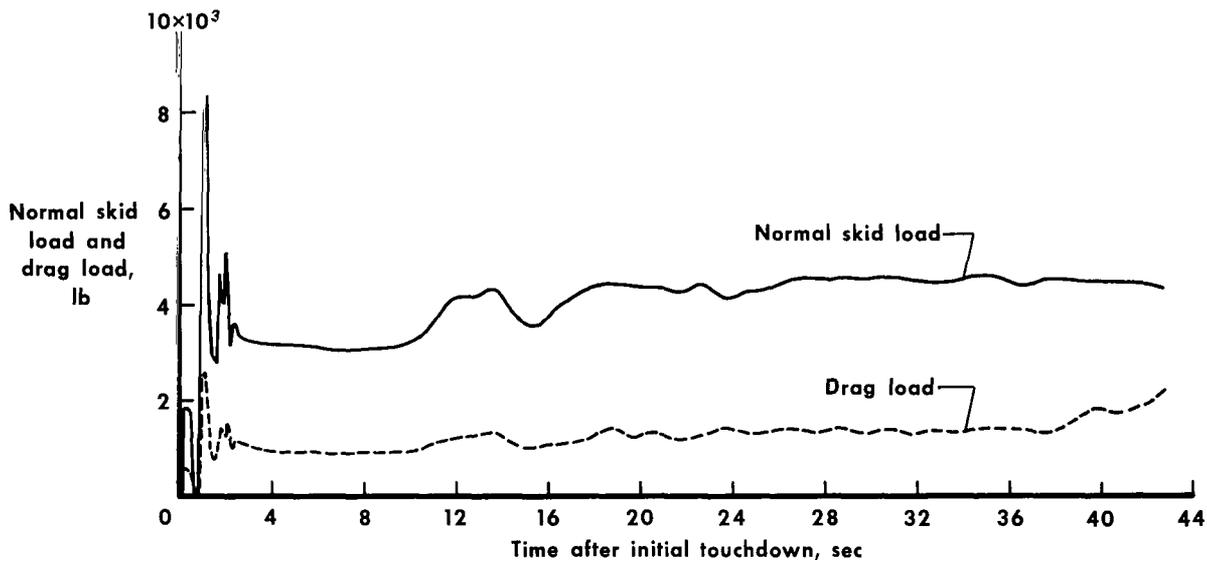
Twelve tests were conducted with skids of various materials and for several different lakebed-surface conditions (table I).

Tests 1 to 5 were made with the 4130-steel skids on a dry-hard surface, which was smooth except for a few indications of previous aircraft use. The typical variation of skid loads with time and of coefficients of friction with forward speed during slideout on these tests is shown in the data of figures 4(a) and 4(b). During landing impact, the initial values of the coefficients of friction were somewhat similar in magnitude to the values obtained during wheel spin-up on conventional landing gear. These high values were not



(a) Left main gear.

Figure 4.— Drag characteristics of main gear on test 1. 4130 steel skids; dry-hard lakebed.



(b) Right main gear.

Figure 4.— Concluded.

analyzed because of the transient conditions of impact, rebound, and maximum loading. For this paper, the coefficients of friction were evaluated during the stabilized portion of the slideout.¹ During this period, the coefficient of friction decreased to a relatively constant value. At approximately 50 knots, it began to increase to its maximum value (impending static friction) at the end of slideout.

Tests 6 to 9 were also conducted on a dry-hard lakebed, but with cermet-coated skids. Landing-loads data were not obtained on test 7 because of a loss of instrumentation during flight. Typical data from these tests are presented in figures 5(a) and 5(b).

Test 10 was conducted with the cermet-coated skids on a soft lakebed surface that was relatively rough and wavy. The variation of landing loads with time and coefficient of friction with forward speed during slideout is shown in figures 6(a) and 6(b). The drag loads could not be obtained until 2 seconds after touchdown because of indistinguishable oscillograph traces. A second gap in the data occurred at 13.4 seconds after touchdown as a result of contact with a graded road. Because of surface irregularities, the measured loads fluctuated considerably more than during the previous tests.

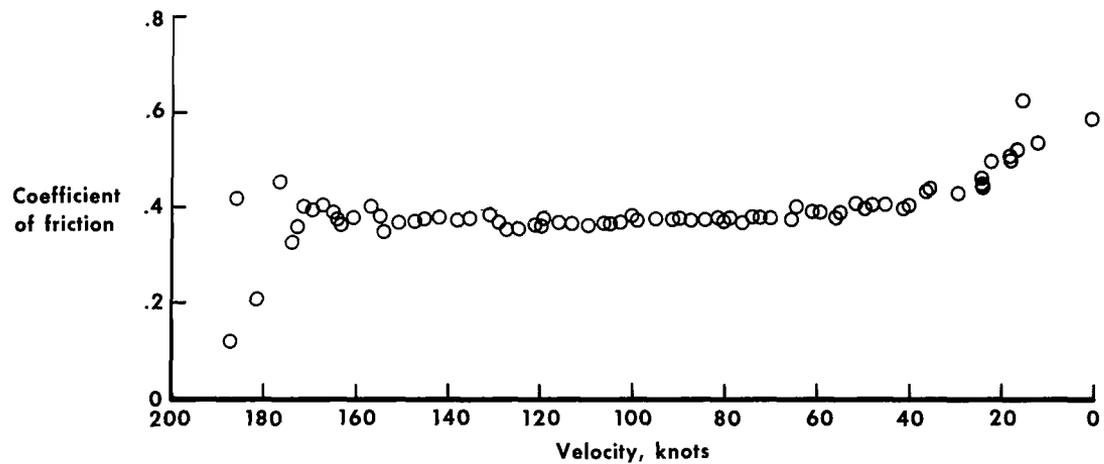
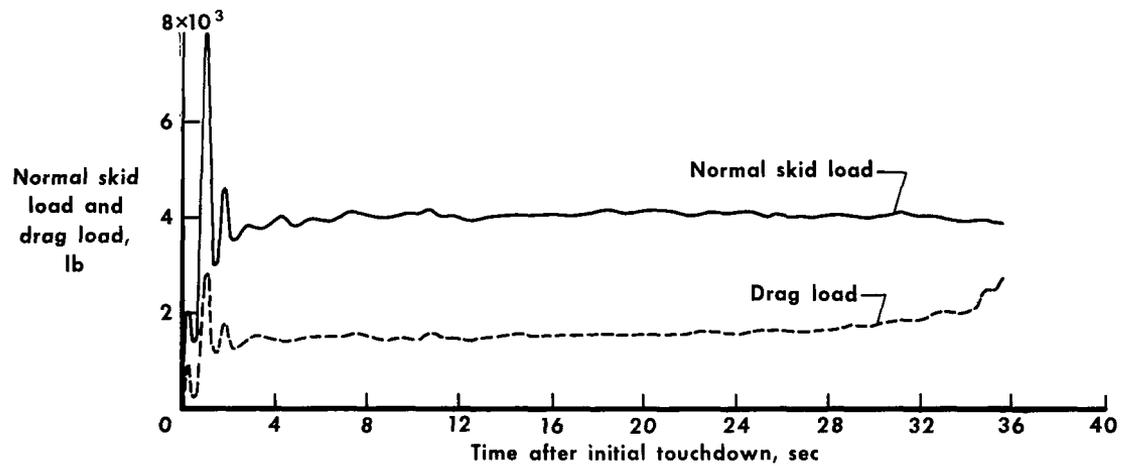
Tests 11 and 12 were made on dry-hard and damp-hard lakebeds, respectively, using Inconel X skids. Data from the tests are presented in figures 7(a) and 7(b) and 8(a) and 8(b).

Table II summarizes pertinent quantities resulting from each slideout.

TABLE II
SUMMARY OF TEST CONDITIONS AND MEASURED DATA

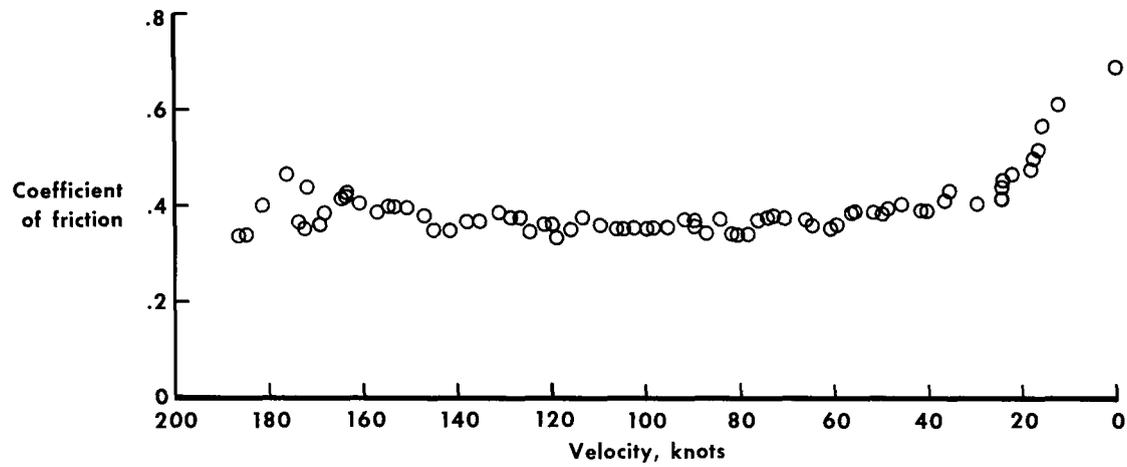
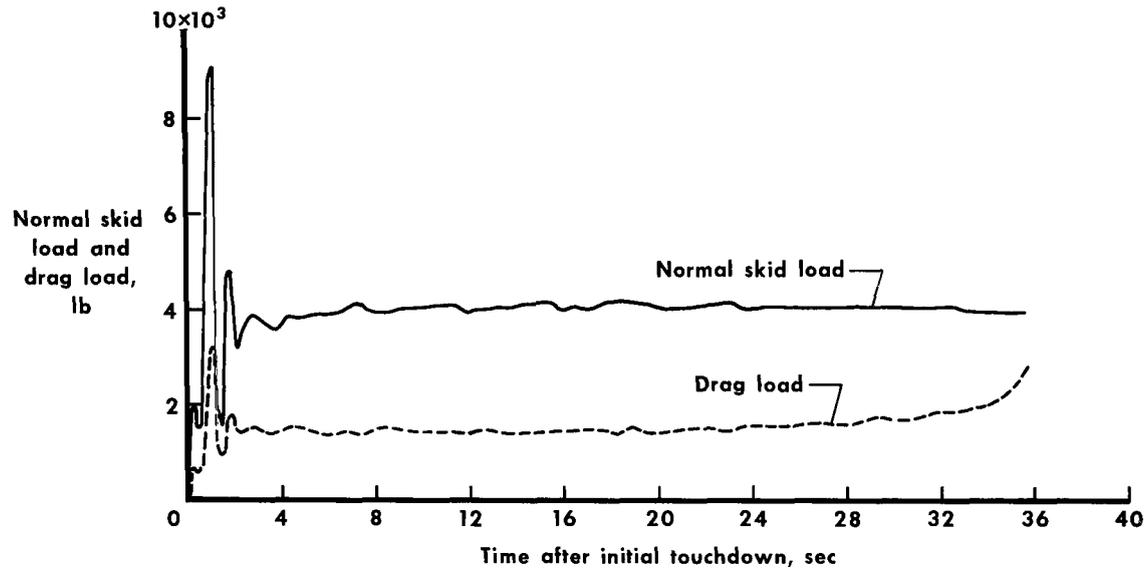
Test	Type of skid	Lakebed surface condition	Estimated CBR	Mean coefficient of friction	Mean absolute deviation of coefficient of friction	Range of coefficient of friction		Skid mean bearing pressure, lb/sq in.
						Low	High	
1	4130	Dry-hard	59 to 94	0.31	0.01	0.25	0.36	26.5
2	4130	Dry-hard	59 to 94	.29	.02	.25	.33	30.7
3	4130	Dry-hard	59 to 94	.28	.02	.22	.34	31.2
4	4130	Dry-hard	59 to 94	.32	.02	.18	.38	25.7
5	4130	Dry-hard	59 to 94	.32	.02	.19	.37	28.3
6	Cermet	Dry-hard	59 to 94	.37	.02	.33	.47	25.5
7	Cermet	Dry-hard	59 to 94	----	----	----	----	----
8	Cermet	Dry-hard	59 to 94	.36	.03	.29	.45	27.8
9	Cermet	Dry-hard	59 to 94	.38	.02	.34	.45	27.4
10	Cermet	Dry-soft	16 to 23	.46	.04	.35	.64	25.7
11	Inconel X	Dry-hard	59 to 94	.35	.03	.18	.46	30.6
12	Inconel X	Damp-hard	-----	.25	.07	.06	.47	26.4

¹Stabilized slideout was considered to be the period between 2 seconds after impact and 6 seconds before termination of slideout, at which time impending static friction started to increase the coefficient of friction.



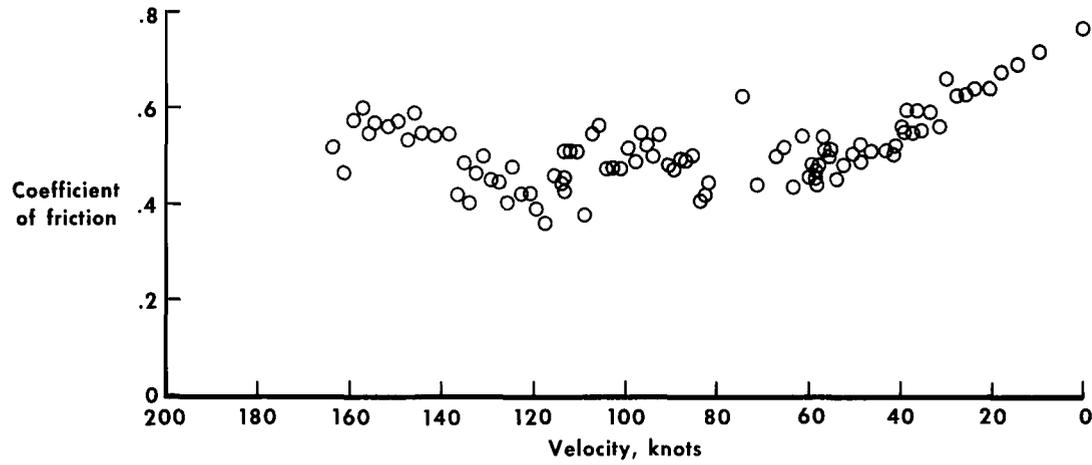
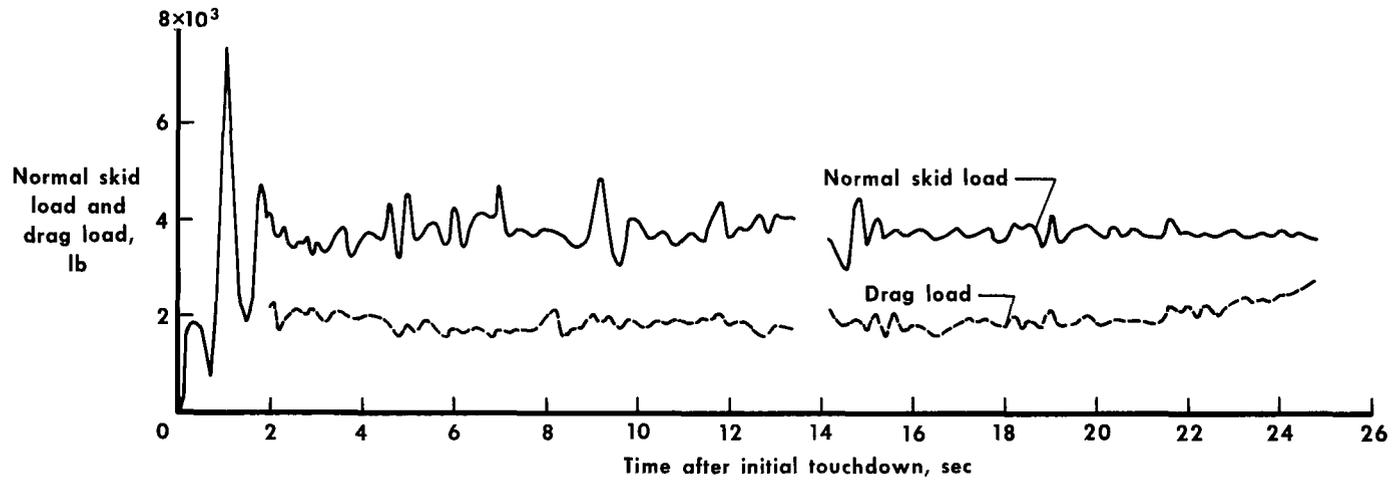
(a) Left main gear.

Figure 5.— Drag characteristics of main gear on test 9. Cermet-coated skids; dry-hard lakebed.



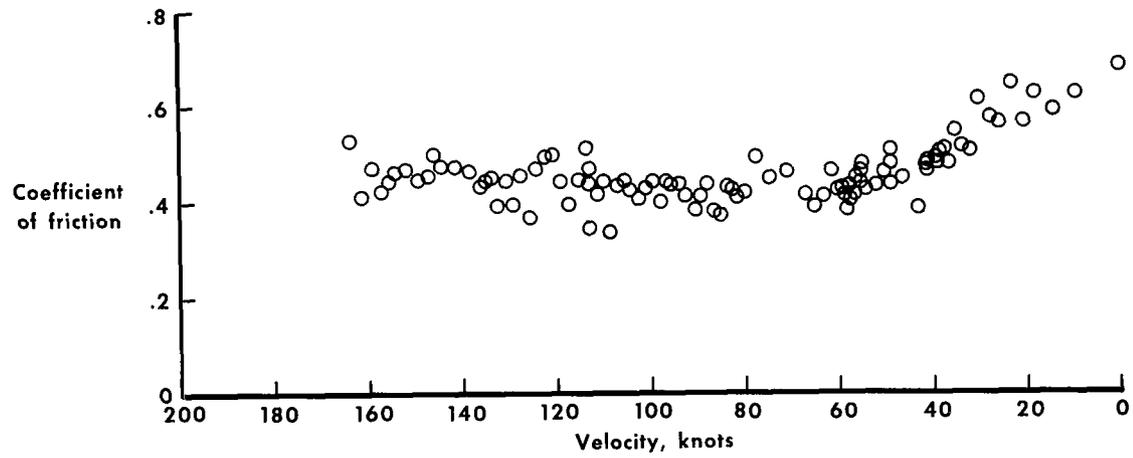
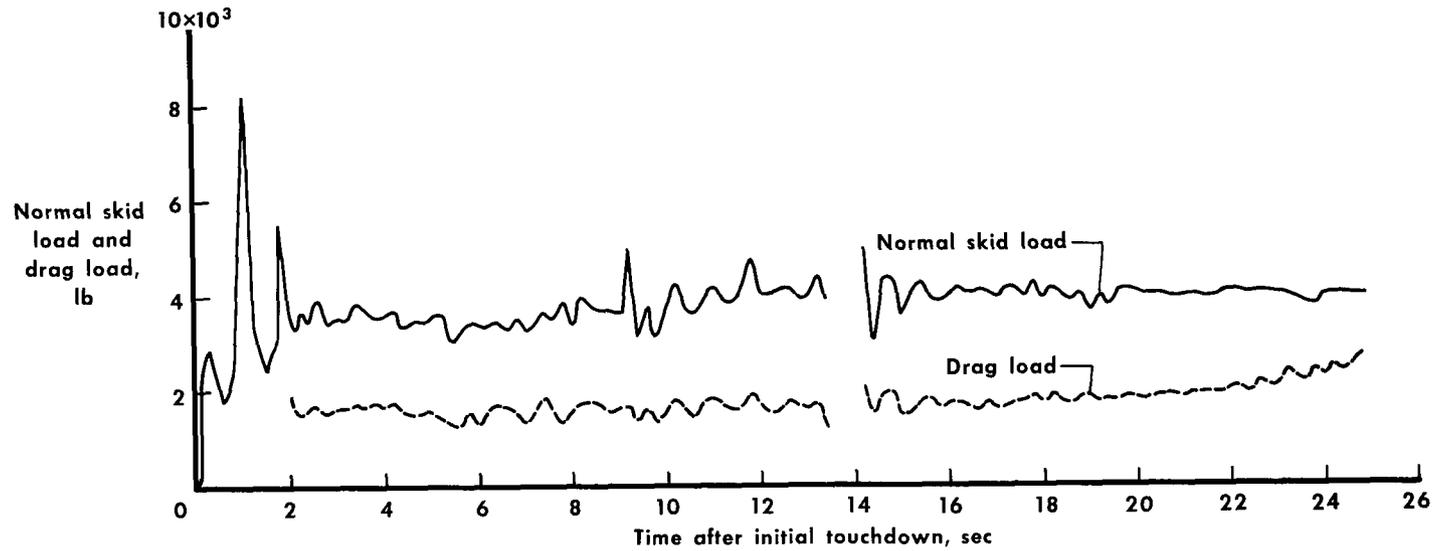
(b) Right main gear.

Figure 5.— Concluded.



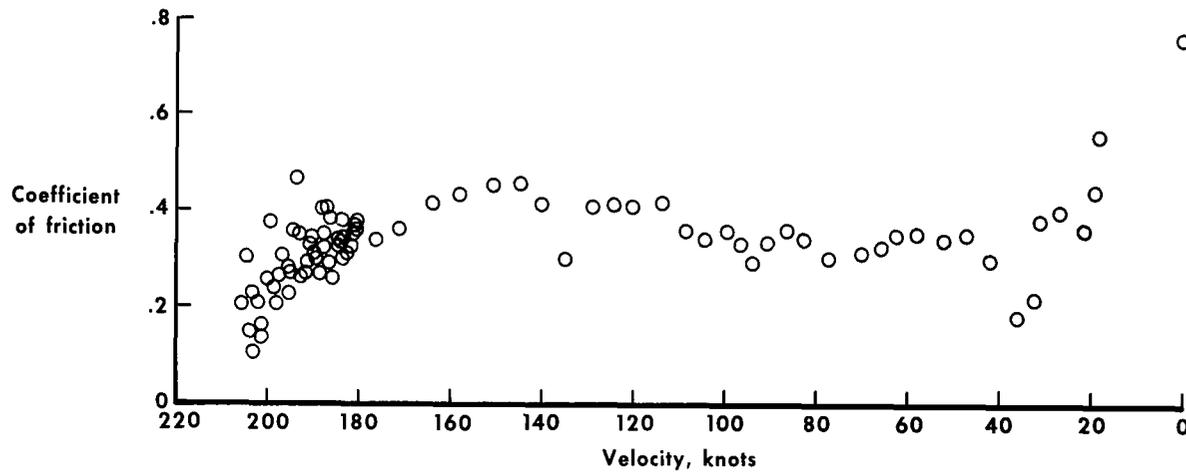
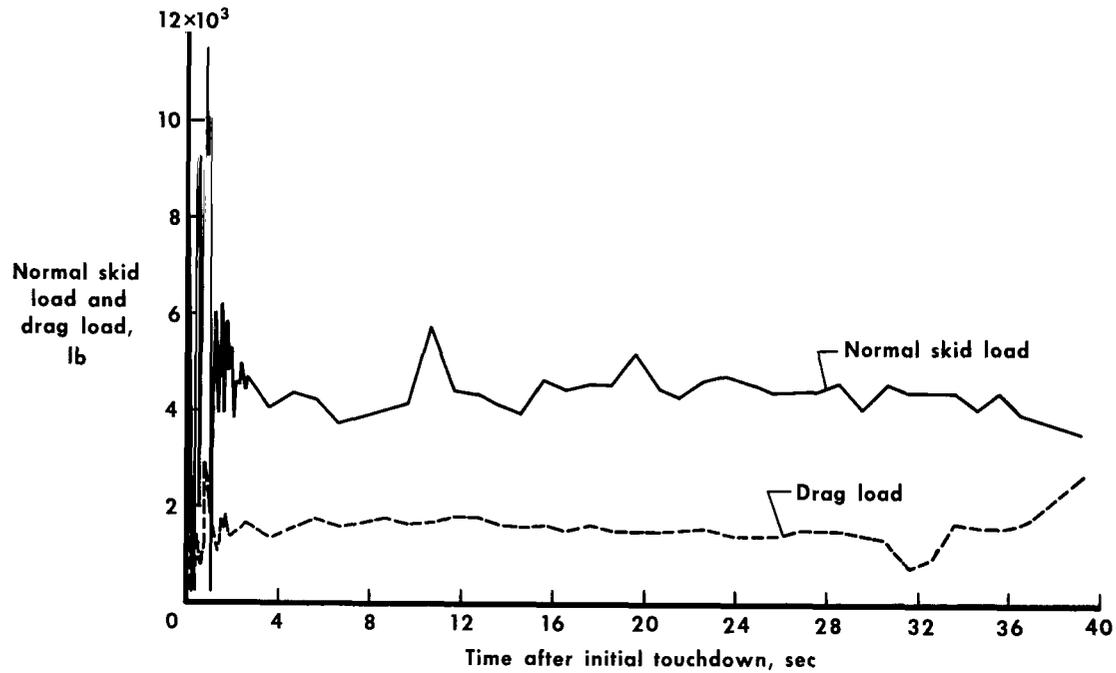
(a) Left main gear.

Figure 6.— Drag characteristics of main gear on test 10. Cermet-coated skids; dry-soft lakebed.



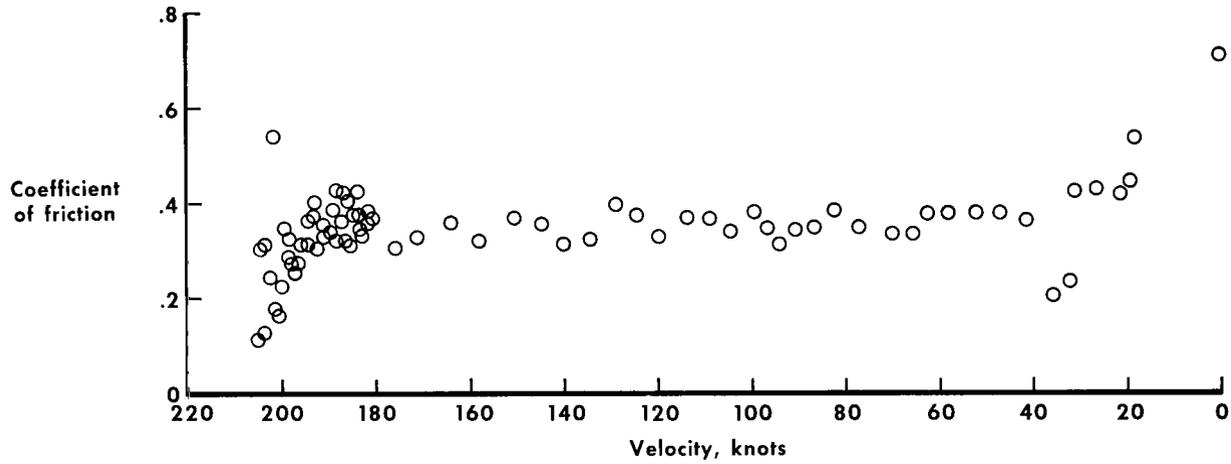
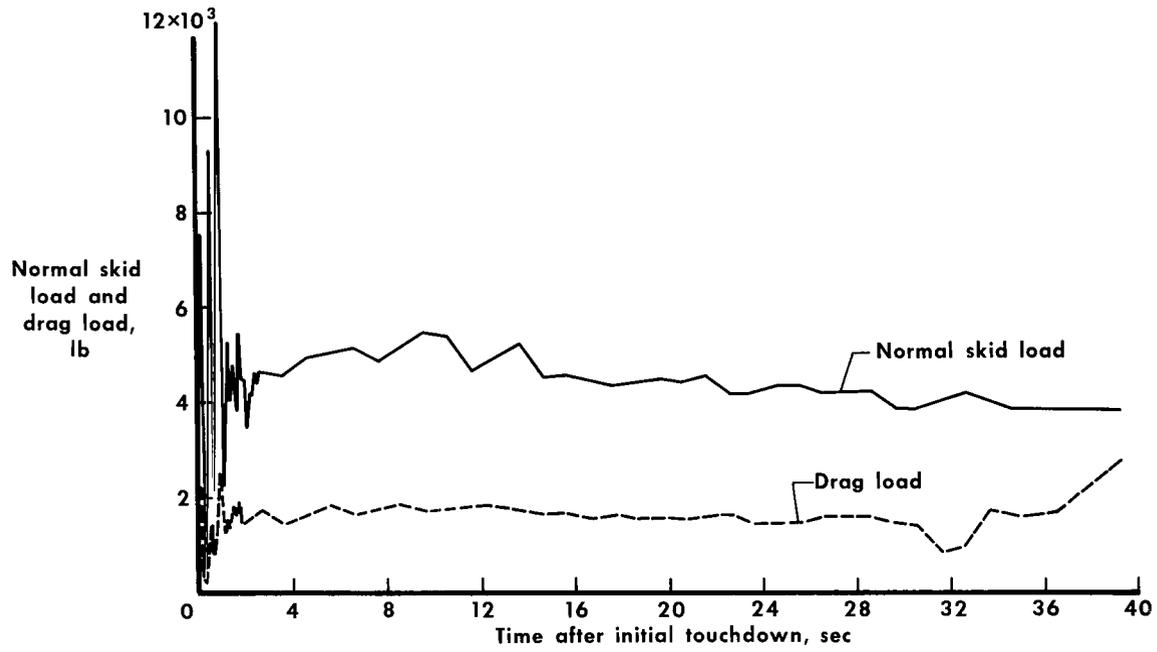
(b) Right main gear.

Figure 6.— Concluded.

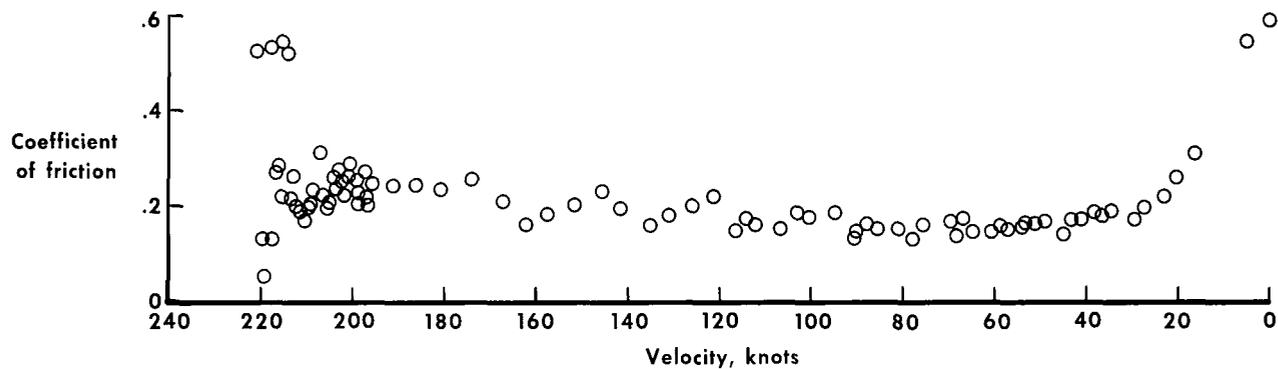
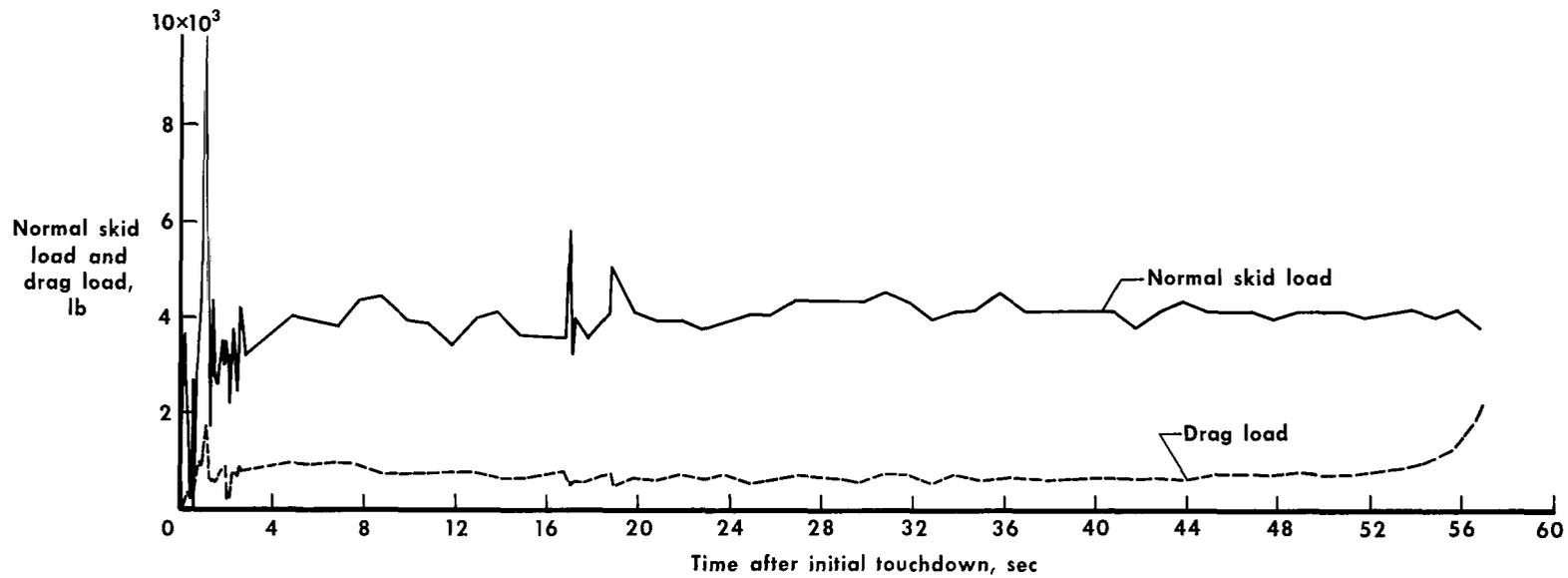


(a) Left main gear.

Figure 7.— Drag characteristics of main gear on test 11. Inconel X skids; dry-hard lakebed.

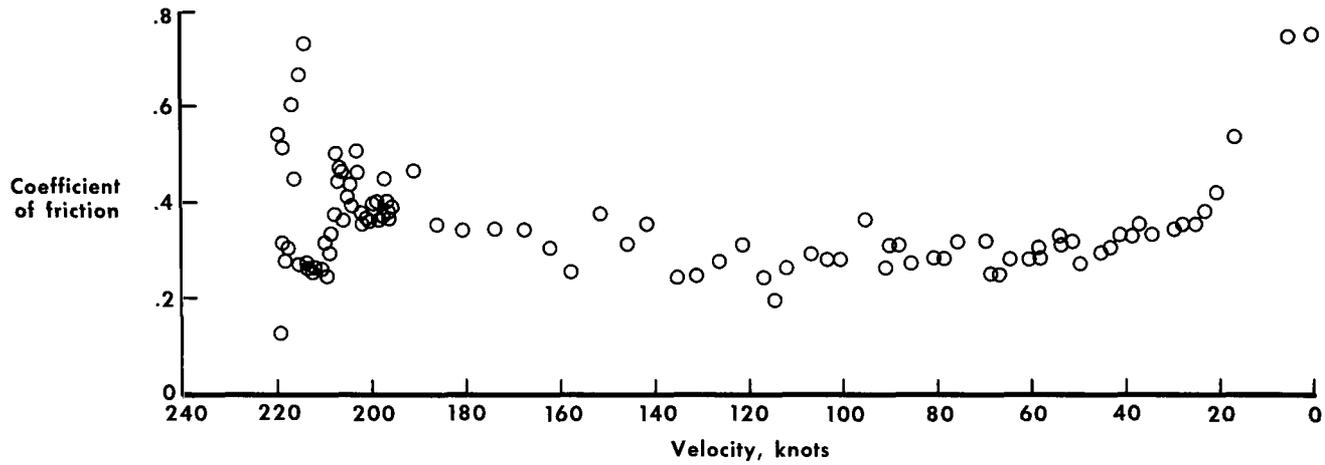
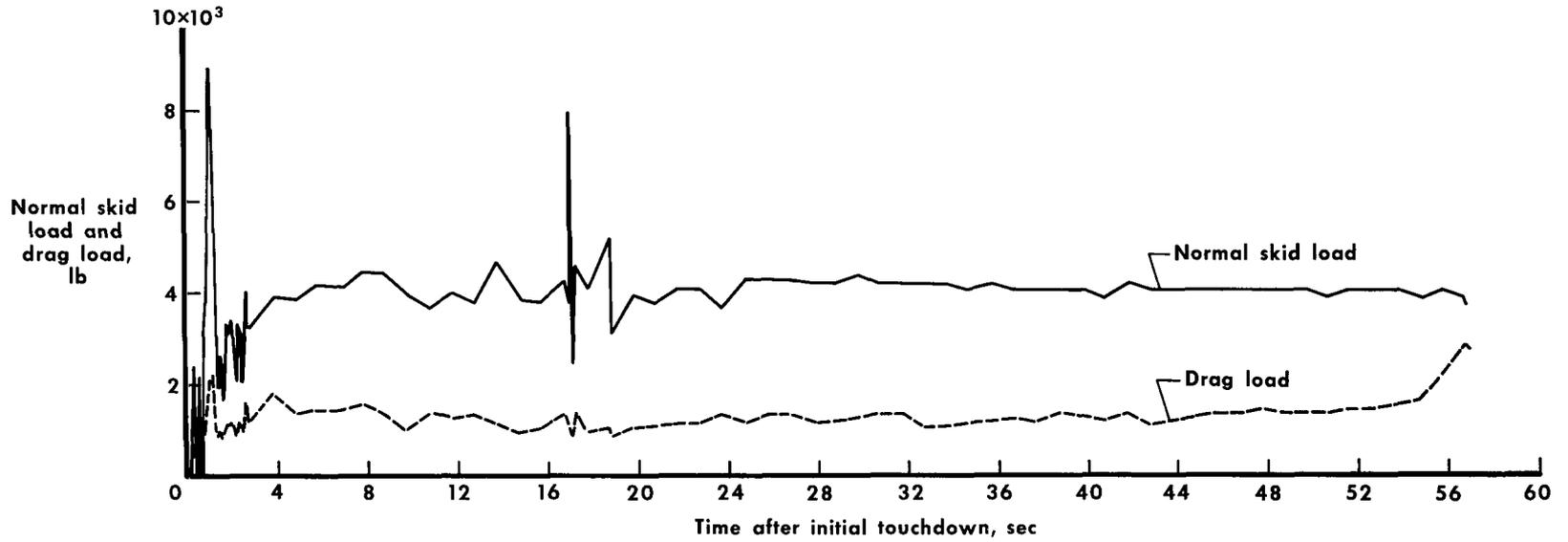


(b) Right main gear.
 Figure 7.- Concluded.



(a) Left main gear.

Figure 8.— Drag characteristics of main gear on test 12. Inconel X skids; damp-hard lakebed.



(b) Right main gear.
 Figure 8.- Concluded.

Included are the mean coefficient of friction $\bar{\mu}$ and the mean absolute deviation (ref. 14) of the friction coefficient, expressed by

$$\frac{1}{N} \sum f_i (\mu_i - \bar{\mu})$$

where

$(\mu_i - \bar{\mu})$ = absolute deviation from the mean coefficient of friction of a data value μ_i

f_i = the number of occurrences of the associated value μ_i

N = total number of data points considered

DISCUSSION OF RESULTS

Coefficient of Friction

The process of a skid sliding on a relatively soft surface such as a lake-bed involves shearing and ploughing, two of the principal factors which produce the resistance that determines the coefficient of friction. The shearing term is essentially independent of skid pressure, whereas the ploughing term is a function of skid penetration, which, in turn, is a function of skid shape, load distribution, and pressure (ref. 8). For this analysis, the values of drag force and normal load on each skid were determined from data recorded for each main-gear skid during landing impact and slideout.

Effect of surface hardness.— The effect of surface hardness on the shearing and ploughing terms of the sliding coefficient of friction is shown in figures 9 to 11.

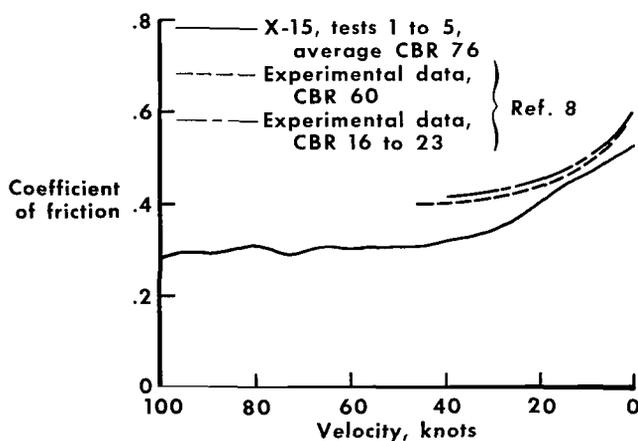
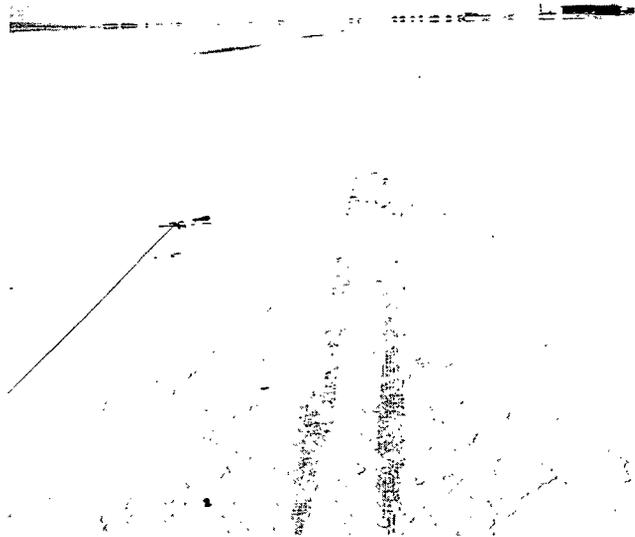


Figure 9.— Variation of coefficient of friction with true ground speed for X-15 flight data and experimental data. 4130 steel skids.

Figure 9 compares the average of the coefficients of friction for tests 1 to 5 with the experimental ground-tow tests of reference 8 at low velocities. The five recorded slideouts were made on a surface with an average CBR of 76. The experimental data of reference 8, using the same type of skid, apply to a surface with a CBR of 60 and 16 to 23. The coefficients of friction from flight tests (0.30) are considerably lower than those from experiments (0.40) at velocities above 40 knots. Since the surface was generally harder, the lower values from flight data could be expected.

Figure 10 shows, photographically, that skid penetration in the area of landing impact and slideout, with a CBR of 59 to 94, was slight, with little breakthrough of the surface (maximum vertical load occurred during nose-gear impact).



E-5233
Figure 10.— Landing impact and slideout area. Rogers Dry Lake.

Figure 11 compares the average coefficients of friction for the cermet-coated skids during tests 6, 8, and 9 on a hard surface (estimated CBR of 59 to 94) and during test 10 on a soft surface (estimated CBR of 16 to 23). This comparison illustrates the effect of surface hardness and skid ploughing on the measured coefficients of friction. The increase in the values of the mean coefficients of friction (0.36 to 0.46) can be attributed to the ploughing of the skid into the softer surface, inasmuch as the skid bearing pressures are approximately equal.

(Additional tests may indicate that the ploughing factor of skids is

partially dependent on bearing pressure, i.e., a skid of the same size, shape, and load distribution, on the same lakebed would produce different values of friction coefficients with varying bearing pressure or skid penetration.)

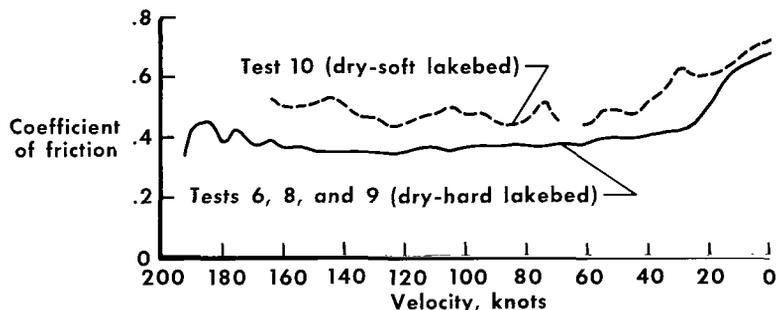


Figure 11.— Variation of coefficient of friction with true ground speed. Cermet-coated skids.

As in tests 1 to 5, the skid penetration of the cermet-coated skids in tests 6, 8, and 9 was slight, with little breakthrough of the surface; however, a series of grooves left by the exposed tungsten carbide chips could be observed. On the dry-soft surface of test 10, the penetration of the skids at the time of nose-gear impact was approximately 2.5 inches to 2.75 inches (fig. 12), as compared to the insignificant penetration of tests 1 to 6, 8, and 9. During the stabilized portion of the slideout on the dry-soft surface, the penetration was approximately 0.10 inch to 0.15 inch, except at impact with surface irregularities. The skids broke through the surface, leaving a

compacted-powder residue along the skid track that could be removed to a depth of approximately 0.20 inch before a firm surface was reached.



E-11308

Figure 12.— Landing impact and slideout area on Cuddeback Dry Lake.

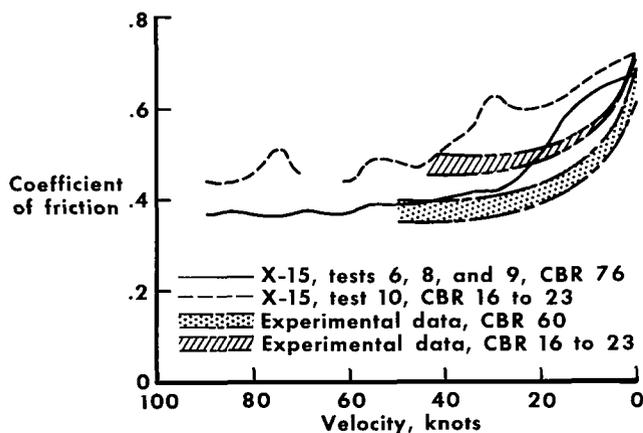


Figure 13.— Variation of coefficient of friction with true ground speed for recorded X-15 flight data and experimental data. Cermets-coated skids.

Figure 13 compares the recorded flight data from tests 6 and 8 to 10 with the experimental data of reference 8, in which the same type of skid was used but with a thinner cermet coating. The recorded flight data agree closely with the experimental results above 40 knots, assuming that the experimental data remain constant at high speeds. The irregularity of the curve (see fig. 11 also) for test 10 is due primarily to the roughness of the different lakebed surface. Although the lakebed surface for the ground-tow tests of reference 8 was not identical to the lakebed surface for flight tests 6 and 8 to 10, the hard and soft surfaces do yield similar results. These results show that the ploughing effect results in the coefficient of friction being partially dependent on the skid bearing pressure.

Effect of material.— The effect of various skid materials on the coefficient of friction during slideout on natural and simulated lakebed surfaces (ref. 7) is shown in figure 14. This figure compares the average coefficients of friction as a function of forward velocity for skids of 4130 steel, 4130 steel with cermet coating, and Inconel X on the same landing site, and for a 1020 steel skid, with a contact area of 4 inches by 24 inches, on a simulated lakebed. Coefficients of friction for the 4130 steel skid and for the 1020 steel skid on a simulated lakebed agree well at velocities above 70 knots. The skid bearing pressure was 26.8 lb/sq in. for the 4130 steel skid and 22.4 lb/sq in. for the 1020 steel skid.

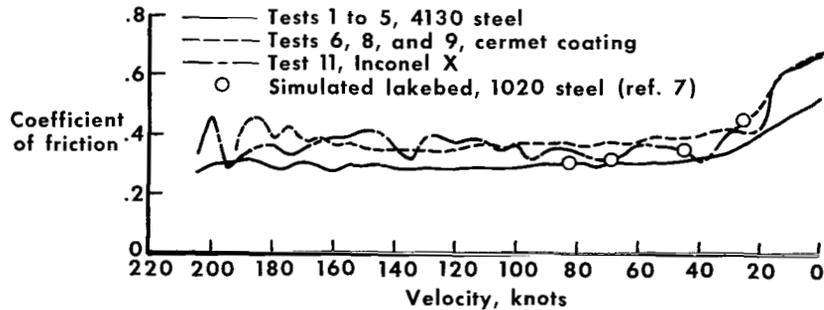
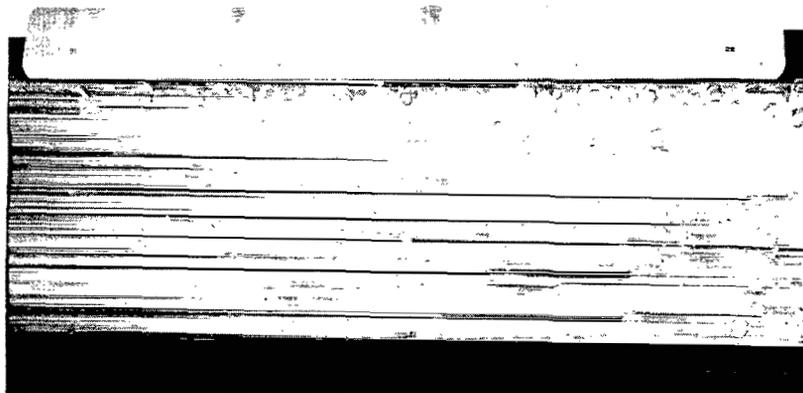


Figure 14.— Effect of various skid materials on the coefficient of friction. Dry-hard runways.

Figure 14 also illustrates the rise in the mean coefficient of friction for the cermet-coated skids (0.36) over that for 4130 steel skids (0.30). This increase is attributed to the soft copper-nickel matrix and the exposed tungsten carbide chips, which resulted in an increased ploughing component. Figure 15 shows a bottom view of the cermet-coated skid, revealing the exposed tungsten carbide chips and the sheared copper-nickel matrix.



E-10825

Figure 15.— Bottom view of cermet-coated skid after first slideout.

The results of test 11 in which an Inconel X skid was used are also shown in figure 14. The reason for the increase in the mean coefficient of friction for the Inconel X skid over that for the 4130 steel skid has not been established.

Effect of moisture.— The effect of moisture on the coefficient of friction is shown in the results from tests 11 and 12. The same Inconel X skids and the same landing location were used in the two tests; however, on test 12 the lakebed surface was damp, because of a recent rainfall. Figure 16 presents the average values for the two landings. The drop in the mean value (0.35 for test 11 and 0.25 for test 12) between the two flights is attributed to the dampness of the lakebed surface. Skid penetration for test 11 was slight,

with some surface breakthrough during the initial phase of the slideout. Skid penetration for test 12 was also slight; however, the skid tracks were compacted and left a relatively slick surface because of the moisture content of the lakebed material.

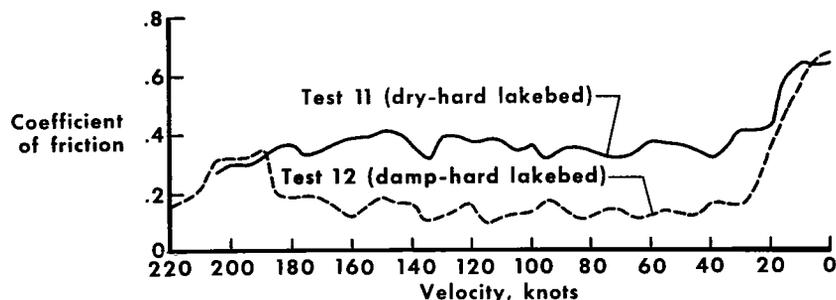


Figure 16.— Effect of a damp surface on coefficient of friction. Inconel X skids.

The effect of a damp surface on a skid-type landing is shown also in the slideout distance recorded on test 12. Although there is some correlation between the X-15 slideout distance and touchdown velocity, the longest slideout of 8968 feet for a touchdown velocity of 221 knots was experienced on this test. A slideout of 7228 feet was recorded for the highest touchdown velocity of 238 knots (ref. 5).

The results of test 12--the lower coefficient of friction and the resulting slideout distance--indicate the effect of a damp surface on a skid-type landing.

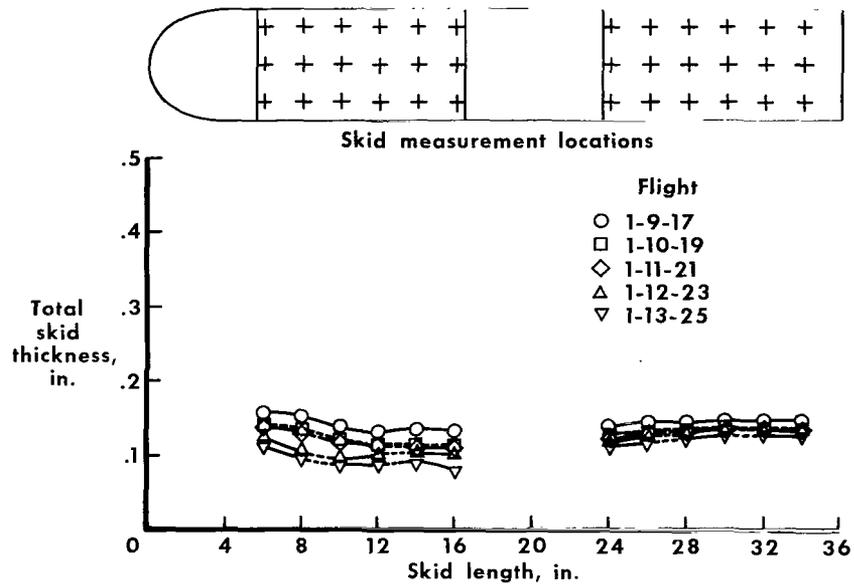
Skid Wear

Skid wear is caused by the shearing of surface irregularities from the skid surface and the separation of the irregularities from the skid material by the surface over which it is sliding. The amount of skid wear depends on the speed of sliding, the strength and hardness of the skid material, the strength of the surface material, and the sliding distance.

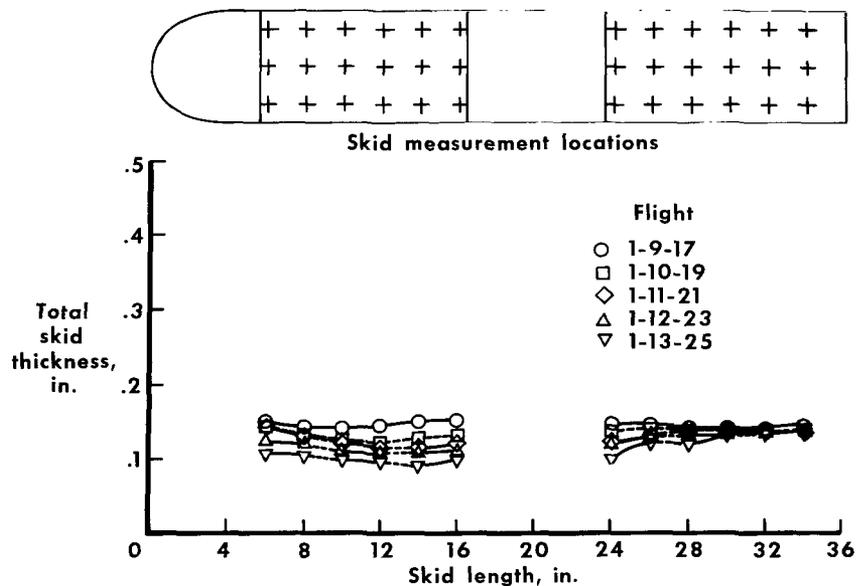
The thickness of the X-15 skids was measured after each flight to determine the usefulness of the skid for the succeeding flight. Skids were rejected when the minimum thickness (generally near the point of attachment of the main strut) was 0.06 inch or less. Because of deep grooves in the skids, the thickness was taken as the average of several measurements. The weight of the material removed during each slideout was determined by multiplying the volume removed by the specific weight of the material. The skids were not weighed after each flight because of the difficulty of removal and reinstallation.

Wear data for the 4130 steel skids were obtained from previous X-15 flights, rather than from the flights of this investigation, because it was not possible to phase a new set of skids into the program at the time the drag-brace instrumentation was installed. Data from five flights, numbers 1-9-17

to 1-13-25 (see ref. 5), are presented. Skid life for this type of skid is about five landings. The sketches in figures 17(a) and 17(b) show the approximate positions at which thickness was measured on the 4130 steel skids after each landing. Below the sketches are plots of the average total skid thickness as a function of longitudinal position.



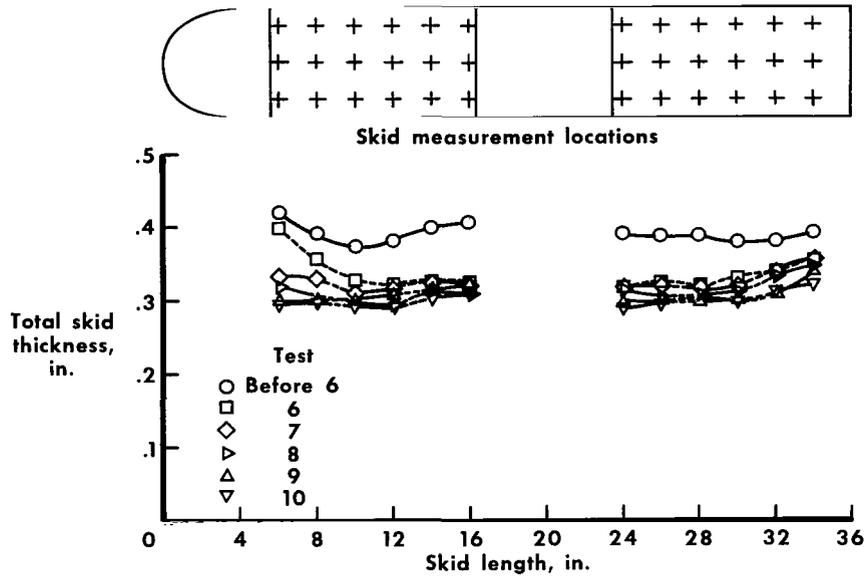
(a) Left main gear.



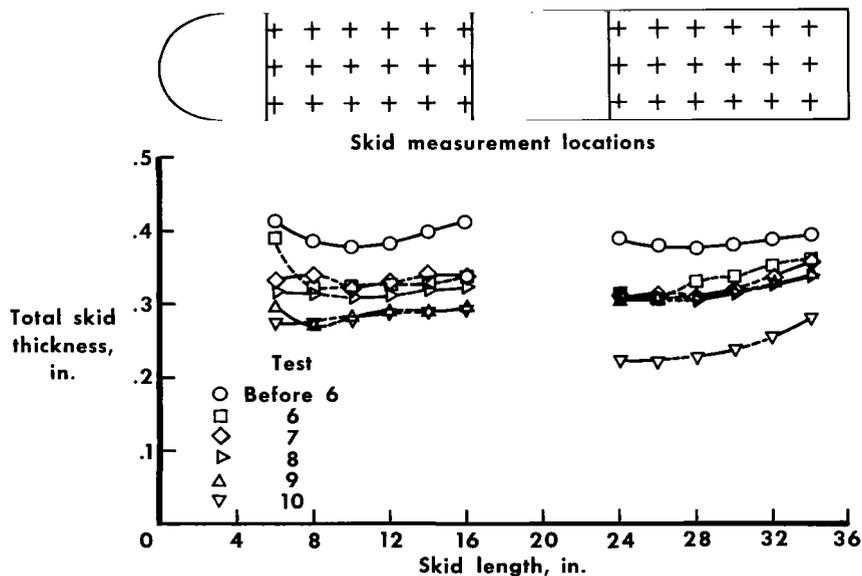
(b) Right main gear.

Figure 17.— Variation of total skid thickness of the main gear with skid length for five X-15 flights. 4130 steel skids.

Figures 18(a) and 18(b) present similar information on the cermet-coated skids. Considerable wear occurred during the first landing because of the soft outer layer of copper-nickel. Less wear occurred during later landings as the tungsten carbide chips were uncovered. Some amount of material flow, or transfer, was noted, which made measurements difficult to interpret. The heat



(a) Left main gear.



(b) Right main gear.

Figure 18.— Variation of total skid thickness of the main gear with skid length for tests 6 to 10. Cermet-coated skids.

generated by the slideout and the physical characteristics of the copper-nickel matrix are believed to be responsible for this transfer of material.

The wear of coated and uncoated skids on a natural lakebed surface is compared in figure 19 in terms of pounds of material removed as a function of sliding distance. The data for the 4130 steel skids showed an increasing amount of skid wear as the sliding distance increased beyond 6400 feet. The data for the cermet skids revealed a considerable amount of wear for the first slideout of 5702 feet, which was expected because of the soft copper-nickel matrix. The remaining landings showed a reduced amount of wear, similar to the experience with the 4130 steel skid. This reduction in wear is a result of the increasing proportion of contact with the hard carbide chips and work-hardening of the copper-nickel matrix.

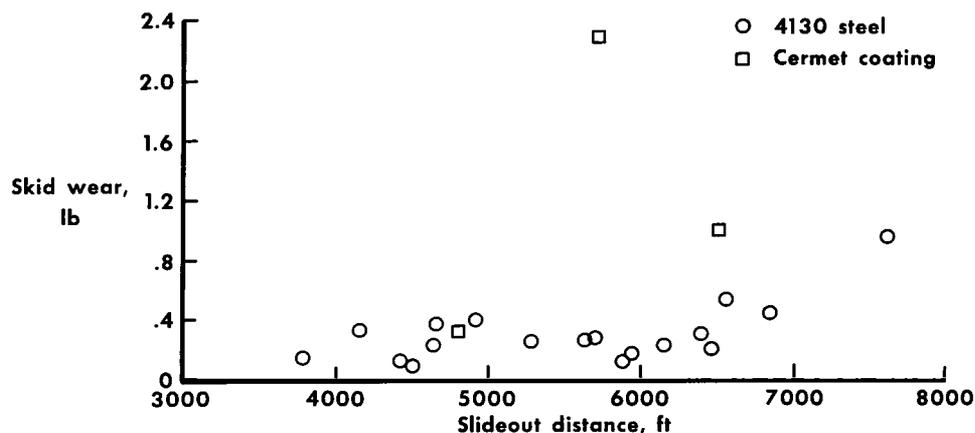


Figure 19.— Variation of wear for 4130 steel and cermet-coated skids on a lakebed surface for various slideout distances.

Wear characteristics of the Inconel X skids were not determined because of the difficulty of measuring the chemically milled areas inside the skid. However, preliminary data indicate wear resistance superior to that of 4130 steel, with or without a cermet coating.

CONCLUSIONS

Results of an investigation to determine the coefficients of friction and the wear characteristics for X-15 landing-gear skids of various materials showed that:

1. The mean coefficient of friction determined from flight data for the 4130 steel skids was 0.30. Comparison of flight data and ground-tow tests on the same lakebed resulted in lower values of friction coefficients for the X-15. The results also tend to agree with ground-tow tests on a simulated lakebed for velocities exceeding 70 knots.

2. The mean coefficient of friction for the cermet-coated skids on a dry-hard surface was 0.36. The ploughing action of skids and its effect on the measured coefficient of friction is illustrated by the increase of measured values to 0.46 on a dry-soft surface.

3. The moisture content of the lakebed surface has a marked effect on the coefficient of friction. The mean coefficient of friction of the Inconel X skids was 0.35 on a dry lakebed surface and 0.25 on a damp lakebed surface.

4. The wear experienced by the 4130 steel skids tended to be constant up to a slideout distance of 6400 feet, with increased wear during greater slideout distances.

Flight Research Center,
National Aeronautics and Space Administration,
Edwards, Calif., December 3, 1965.

REFERENCES

1. Houbolt, John C.; and Batterson, Sidney A.: Some Landing Studies Pertinent to Glider-Reentry Vehicles. NASA TN D-448, 1960.
2. McKay, James M.; and Kordes, Eldon E.: Landing Loads and Dynamics of the X-15 Airplane. NASA TM X-639, 1962.
3. McKay, James M.; and Scott, Betty J.: Landing-Gear Behavior During Touchdown and Runout for 17 Landings of the X-15 Research Airplane. NASA TM X-518, 1961.
4. McKay, James M.: Measurements Obtained During the First Landing of the North American X-15 Research Airplane. NASA TM X-207, 1959.
5. Noll, Richard B.; Jarvis, Calvin R.; Pembo, Chris; Lock, Wilton P.; and Scott, Betty J.: Aerodynamic and Control-System Contributions to the X-15 Airplane Landing-Gear Loads. NASA TN D-2090, 1963.
6. Noll, Richard B.; and Halasey, Robert L.: Theoretical Investigation of the Slideout Dynamics of a Vehicle Equipped With a Tricycle Skid-Type Landing-Gear System. NASA TN D-1828, 1963.
7. Dreher, Robert C.; and Batterson, Sidney A.: Coefficients of Friction and Wear Characteristics for Skids Made of Various Metals on Concrete, Asphalt, and Lakebed Surfaces. NASA TN D-999, 1962.
8. Tebben, Gerald D.: An Investigation of the Coefficients of Friction and Wear Properties of Cermet Material Proposed for the X-20A Nose Gear Skid. FTC-TDR-63-20, U. S. Air Force, Dec. 1963.

9. Tebben, Gerald D.: An Investigation of the Coefficients of Friction and Wear Property of Wire Brush Skids Constructed With René 41 Bristles. FTC-TDR-64-11, U.S. Air Force, Aug. 1964.
10. Walker, H.; Deutschman, J.; and van Summern, J.: Pitch Landing Condition. Nose Gear Loads. Rep. No. 52-941-010, Bell Aircraft Corp., Apr. 1953 (rev. July 1954).
11. Blanchard, Ulysse J.: Landing Characteristics of a Winged Reentry Vehicle With All-Skid Landing Gear Having Yielding-Metal Shock Absorbers. NASA TN D-1496, 1962.
12. Tremant, Robert A.: Operational Experiences and Characteristics of the X-15 Flight Control System. NASA TN D-1402, 1962.
13. Yancey, Roxanah B.: Flight Measurements of Stability and Control Derivatives of the X-15 Research Airplane to a Mach Number of 6.02 and an Angle of Attack of 25°. NASA TN D-2532, 1964.
14. Kenney, J. F.; and Keeping, E.S.: Mathematics of Statistics. Part One. Third ed., D. Van Nostrand Co., Inc., 1954, p. 76.

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