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LANDING PERFORMANCE OF AN AIR-CUSHION LANDING SYSTEM INSTALLED ON A 1/10-SCALE DYNAMIC MODEL OF THE C-8 BUFFALO AIRPLANE

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SUMMARY

An experimental study was conducted to evaluate the landing behavior of a 1/10-scale dynamic model of the C-8 Buffalo airplane equipped with an air-cushion landing system (ACLS) on a variety of surfaces including both calm and rough water and a smooth hard surface. Taxi runs were made on the hard surface over several obstacles. Landings were made with the model at various pitch and roll attitudes and vertical velocities and at one nominal horizontal velocity. Data from the landings include time histories of the trunk and air-cushion pressures and accelerations at selected locations on the model.

The investigation indicated that for calm-water landings the maximum normal accelerations were about 3g to 4g for a nominal vertical velocity of 1.21 m/s (3.96 ft/sec). The characteristic behavior of the model was to trim down to a nearly level attitude during the first impact, pitch up about 10°, come back to a near 0° attitude, and run smoothly along the calm-water surface. The model behavior for all landings in rough water was considered satisfactory; however, due to the random nature of contact with the waves, many more tests would be required to establish definite trends. The maximum normal acceleration for rough water was about 5.5g. Hard-surface landings were generally rather smooth. There was a small bounce after initial impact followed by some small oscillations. The maximum acceleration was about 3g.

Taxi runs across a simulated tree stump and a ditch caused no difficulty for the most part. Taxiing at low speeds up a 45° ramp initiated a divergent pitch and heave oscillation which was not observed at higher speeds.

INTRODUCTION

Ground loads transmitted through conventional landing gears play a major role in the design of the airframe inasmuch as those loads are concentrated at discrete points on the aircraft structure. Similarly, pavement design (runway, taxiway, ramps, etc.) is based upon the loadings in the tire-pavement interface. With the current trend of larger and heavier aircraft, efforts to maintain acceptable loadings both in the airframe and on the ground have resulted in a multiplicity of gears. The expense in volume and weight for such systems, which serve no useful purpose once when the aircraft is airborne, is high. Furthermore, the demands being placed upon the runway surface are becoming excessive. One approach to these problems, currently under consideration, is to replace the conventional gear with an air-cushion landing system (ACLS) as illustrated in figure 1. This system consists of a large flexible understructure generally referred to as a trunk, which is attached to the bottom of the fuselage and forms an elongated doughnut shape when inflated. During operation of the system the trunk is inflated by a continuous airflow from an independent onboard source. A peripheral jet flow is produced through a large number of holes arranged in a regular pattern at the base of the trunk close to the ground tangent. The escaping air serves as an air bearing and also creates a pressure within the doughnut cavity (cushion) when the aircraft is in close proximity to the ground. Thus, during ground operation the weight of the aircraft is supported on a cushion of air over an effective bearing area approximately equal to that formed by the trunk. Typical ground bearing pressures (model scale) are on the order of 0.7 to 1.4 kPa gage (0.1 to 0.2 psig). In addition to reduced runway loads, the air cushion offers excellent cross wind performance, attractive amphibious capabilities, and simple retraction and storage mechanisms, all at a potential system-weight saving. In view of these features, considerable attention has been given to establishing the feasibility of such a landing system, particularly in terms of the landing impact behavior and ground handling performance.

Reference 1 discusses some results of full-scale flight and ground tests conducted on a lightweight amphibian airplane equipped with an air-cushion landing system and how these results might be applied to larger aircraft. These tests, which included operations on a variety of surfaces, both prepared and unprepared, established that the landing system was feasible and efforts are currently underway to adapt an ACLS to the C-8 Buffalo, a larger airplane having a broader ground performance envelope. Some theories on the operation of an ACLS are presented in references 2 and 3. The analytical estimation of the transient response of the ACLS to landing situations is most difficult because of the complex mechanism of energy absorption.

The purpose of this paper is to demonstrate the performance of an air-cushion landing system and present the results of an experimental study to evaluate the landing behavior of an ACLS installed in a 1/10-scale dynamic model of the C-8 airplane on a variety of surfaces including both calm and rough water and a smooth hard surface. Taxi runs were made on the hard surface over several obstacles. Landings were made at a nominal scaled horizontal velocity of the airplane and with the model at various pitch and roll attitudes and vertical velocities. Data from the landings include time histories of the trunk and air-cushion pressures and accelerations at selected locations on the model.

Values are given in both SI and U.S. Customary Units. The measurements and calculations were made in U.S. Customary Units.

APPARATUS AND TEST PROCEDURE

Model Scaling

Complete dynamic similarity between a scale model and a full-scale prototype can be achieved only by maintaining geometric similarity, the ratio of inertia forces to viscous forces, and the ratio of inertia forces to gravity forces. Froude scale relationships were used for the ACLS model in order to maintain the highly dominant inertia- to gravity-force ratio, thus the inertia- to viscous-force ratio is compromised. The effect of this compromise cannot be predicted (it is not a simple Reynolds number correction) since there are some compressibility effects in the trunk system and the air cushion. Furthermore, due to practical limitations, several full-scale ACLS characteristics were not strictly scaled in the model tests; namely, atmospheric pressure in which the test was conducted, the total air-supply-fan pressure-flow characteristics, and the elastic trunk characteristics.

The scale relationships for the dynamic model of this investigation are presented in table I. The physical dimensions of the model and the ACLS were accurately scaled; however, the accuracy of the scaling of the operating parameters is not known. The magnitude of pertinent parameters is given in table II for the 1/10-scale model together with the corresponding values for the full-scale C-8 Buffalo airplane. It will be noted in the table that gage pressures were used rather than absolute pressures, since the tests were primarily concerned with flow rather than compression phenomena.

Model Description

The aircraft model used in this investigation was a 1/10-scale dynamic model of the C-8 Buffalo with an attached ACLS (see fig. 2). The model was constructed principally of fiberglass and plastic with hardwood and balsa wood bulkheads and foam-plastic or wood reinforcements where required. Two trunk configurations were examined (1) a short trunk (shown on the model in fig. 3) and (2) a long trunk (shown in fig. 4) which was used for the major portion of the investigation since it permitted a greater range of test parameters. Details and locations of the ACLS trunks are presented in figure 5. The trunks were constructed of a lightweight, flexible inelastic material. Air for the ACLS was supplied by two centrifugal fans connected to the trunk by suitable ducting. The fans were driven by an onboard electric motor. The ACLS mass flow of air was 9.68 m^3/min

($342 \text{ ft}^3/\text{min}$) out of ground effect and $8.75 \text{ m}^3/\text{min}$ ($309 \text{ ft}^3/\text{min}$) in ground effect and it was controlled by adjusting the fan motor speed and the number of holes in the trunk (discharge area). The trunk and cushion pressures were monitored by pressure transducers installed in the model as shown in figure 5.

Test Surfaces

The model was landed on calm and rough water and also on a smooth hard surface. The rough water simulated a sea state 3 condition with waves (model scale) 15 cm (6 in.) high by 305 cm (120 in.) crest to crest. Taxi tests on the hard surface were made over several different obstacles. The obstacles (see fig. 6) consisted of a simulated stump which was 4.45 cm (1.75 in.) high (50 percent of trunk height), a ramp 6.35 cm (2.5 in.) high (72 percent of trunk height) with 45° sloped edge, and a ditch 9.14 cm (3.6 in.) deep and 30.5 cm (12 in.) wide across the top (31 percent of trunk length) with 45° sloped sides.

Launch Apparatus

The launch apparatus consisted of a compressed-gas (nitrogen) powered catapult with a carriage shown in figure 3 mounted on the catapult guide rails. The carriage was attached to an endless cable which was actuated by an accelerating piston and stopped by a decelerating piston. The model velocity was controlled by the gas pressure in the accelerating piston.

Instrumentation

Model instrumentation consisted of three pressure transducers and four accelerometers mounted at the strategic locations defined in figure 5. One strain-gage-type pressure transducer monitored the trunk pressure and the other two monitored the pressure in the air cushion (cavity). Each pressure transducer had a range of ± 3.45 kPa ($\pm 0.5 \text{ lb/in}^2$). The four strain-gage-type accelerometers each had a range of $\pm 5g$. Three measured normal acceleration at the nose, near the center of gravity, and in the port nacelle and the fourth, mounted near the center of gravity, measured longitudinal acceleration. A trailing cable supported by an overhead guide wire was used to transmit the signals from the model to the conditioning and recording equipment. The trailing cable contained only three circuits for transmitting accelerometer data, therefore, the three accelerometers that measured normal acceleration were used for the water landings, so that pitching and rolling accelerations could be determined. For the hard-surface landings the circuit to the accelerometer measuring normal acceleration in the nacelle was connected to the one measuring longitudinal acceleration since, in these tests, longitudinal acceleration appeared to be of more interest than roll acceleration.

Test Procedure

The testing technique involved launching the model in free flight at a preselected attitude and at a vertical velocity determined by drop height and monitoring the outputs from the onboard instruments as the model landed. Pitch attitudes for the water landings were varied from 0° to 6° with no roll generally although several tests were conducted with the model at 3° and 6° roll angles. For the water landings the nominal horizontal velocity (model scale) was 11.8 m/s (38.6 ft/sec) and the nominal vertical velocity was 1.2 m/s (3.9 ft/sec). For the hard-surface landings, the pitch attitude was varied between 3.5° and 13° with no roll except for two cases which incorporated 3° and 6° roll angles, the nominal horizontal velocity was 11.8 m/s (38.6 ft/sec), and the nominal vertical velocities ranged from 0.6 to 1.2 m/s (2 to 3.9 ft/sec). Taxi tests on a hard surface with various obstacles were made at several horizontal velocities from 2.9 to 11.4 m/s (9.6 to 33.3 ft/sec).

The power supply to the fan motor was regulated prior to launch so as to obtain the specified trunk pressure in the ACLS. Nominal trunk pressure (model scale) was 1.5 kPa gage (0.22 psig) out of ground effect and 1.6 kPa gage (0.24 psig) in ground effect. The nominal cushion gage pressure was zero out of ground effect and 0.8 kPa gage (0.12 psig) in ground effect. The launch carriage and model were accelerated and the model left the launch carriage at the predetermined speed and landing attitude. The control surfaces were set so that the attitude did not change appreciably during the brief free flight from catapult release to surface contact. Throughout each test the outputs from the onboard instruments were recorded on magnetic tape.

The overhead guide wire which supported the instrument cable also supported the power lead-in wires for the ACLS fan motor. The limited length of these wires made it necessary to shut off the power to the ACLS fan motor shortly after the initial landing impact so that the model could be stopped without damage at the end of the guide wire.

RESULTS AND DISCUSSION

A summary of the pertinent data from the landing tests is presented in table III for the water landings and in table IV for the hard-surface landings. Time-history plots of accelerations and pressures are also presented for representative test runs in figures 7 to 13. These tables and figures are used in the following sections to aid in describing the behavior of the model during landings on calm and rough water, on hard smooth surfaces, and during taxi tests over several obstacles. All values are model scale unless otherwise indicated. A motion-picture film supplement (L-1138) shows landing tests of the 1/10-scale dynamic model made on water and on a hard surface. A request card form and a description of the film will be found at the back of this paper.

Water Landings

Calm water.- Typical results of landing in calm water are presented in the time histories of figures 7 to 9 to illustrate the effect of pitch angle, roll angle, and trunk length on the model behavior. The normal accelerations for all conditions were the greatest at initial impact (approximately 4g at the nose and 3g near the center of gravity), subsequently dropping to about -0.5g as the model almost cleared the water, and then peaking to roughly 1g as the model settled back on the water surface. The time histories for trunk and cushion pressures are shown to have shapes similar to the acceleration curves. The trunk pressure essentially doubled during the initial impact. Figure 7 shows that the normal accelerations and the trunk and cushion pressures are essentially unaffected by small changes in the pitch attitude. For the tests described by this figure, the power supply to the air fan was shut down shortly after the second impact as denoted by the trunk pressure which drops below the nominal value of 1.5 kPa gage (0.22 psig).

As shown in figure 8, the maximum trunk pressure developed during calm water landings was 3.2, 3.3, and 3.7 kPa gage (0.46, 0.48, and 0.54 psig) at roll angles of 0°, 3°, and 6°, respectively. As can be seen from table III the maximum developed cushion pressure for the same conditions ranged from about 1.7 to 2.3 kPa gage (0.25 to 0.34 psig) and increased as the pitch attitude increased. As shown by movie film, in all cases the model trimmed down to a nearly level attitude during the first impact and then pitched up to between 6° and 10° and almost cleared the water although the back edge of the trunk usually remained in contact. Shortly after the second impact occurred the model trimmed down to approximately 0°.

Landing in calm water at roll angles as great as 6° caused no adverse effects on the model behavior. When the model was landed at 3° roll, it came to a wing-level condition soon after contacting the water. Similar behavior was noted when the model landed at 6° roll although the model traveled a longer distance in the water before it became level. The wing floats in the photograph of figure 3 did not contact the water during the landing runouts. As observed from figure 8, there were only small differences in accelerations or pressures for the various roll angles tested and accelerations near the center of gravity were about the same as those which occurred at the nose. Typically the maximum acceleration was about 3g and occurred on the initial impact with subsequent impacts producing acceleration levels less than 1g. The pressure peaks which occur on landing follow the shape and duration of the acceleration curves very closely.

The very limited tests which were conducted with the short trunk indicated that for the conditions tested it performed as well as the longer trunk. Figure 9 shows a comparison of the short-trunk and long-trunk acceleration and pressure time histories. The acceleration curves are very similar for the two trunks throughout the landing run. The difference in trunk pressures in this test may be attributed to the inadvertent shut down of the ACLS power supply about one-third of a second earlier for the short trunk than for the long trunk.

Rough water.- The model behavior for all landings in rough water was considered satisfactory. However, due to the random nature of contact with the waves, many more tests would be required to establish definite trends. Figure 10 presents some typical time histories of accelerations and pressures for three different pitch attitudes (0^{o} roll) for the model landing into oncoming waves 15 cm (6 in.) high by 305 cm (120 in.) crest to crest. The maximum acceleration was about 5.5g as recorded by the nose accelerometer and occurred when the model impacted on the forward slope of the wave. However, the model landed more frequently on the wave crest where the maximum acceleration recorded at the nose was between 3.5g and 4.5g. The accelerometer at the center of gravity showed a maximum initial impact of about 4g and appeared to be generally independent of the location on the wave where the first contact was made. After the initial impact the peaks tend to show a random variation. It will be noted in figure 10 that the largest acceleration values occur for the landing at 4^{o} pitch attitude which is felt to be the result of the point of initial wave contact and not a function of pitch attitude. During this particular landing the model made initial contact on the forward slope and penetrated rather deeply into the wave, then the model came clear of the water and skipped over two wave crests before making a second impact which occurred after the ACLS power had been shut down. Both rough-water landings at 5^{o} and 6^{o} pitch attitude made initial water contact on the wave crest. The 5^{o} landing skipped over one wave crest whereas the 6^{o} landing contacted each subsequent wave crest. During rough-water landings, the maximum developed trunk pressure was about 3.9 kPa gage (0.57 psig) and the maximum cushion pressure was about 2.7 kPa gage (0.39 psig) (see table III).

Hard-Surface Landings

The ACLS landing on a smooth hard surface resulted in one or two small bounces followed by several small oscillations. Some typical acceleration and pressure time histories are presented in figure 11 for three landing pitch attitudes. The figure shows that the longitudinal acceleration generally never exceeded 0.25g for most of the landings except for pitch attitudes of 12^{o} when the maximum acceleration was about 0.5g. The maximum normal accelerations generally ranged between 2g and 3g at the nose (see table IV) and between 1.5g and 2.5g near the center of gravity. Note that for the 12^{o} pitch attitude the normal acceleration at the nose goes negative for a short interval. This is attributed to the pitch down or rotation to a nearly level attitude after the initial surface contact. This pitch-down rotation associated with the high pitch angle also explains the lengthy duration of the initial impact acceleration. At the lower pitch angles the model impacts the surface and then rebounds with very little trim change involved.

A comparison of initial-impact accelerations recorded on the hard surface (table IV) and on rough water (table III) for comparable model landing attitudes shows that those on the hard surface are roughly half those encountered in the rough water. Similarly, the initial-impact peak pressures in the trunk and cushion were considerably lower during the hard-surface landings than the corresponding peak pressures developed on rough water. As shown in table IV, the maximum developed trunk pressure for hard-surface landings was about 3.3 kPa gage (0.48 psig) and the maximum cushion pressure was about 2.0 kPa gage (0.29 psig). For these high pressures the model had an average pitch angle (6°) and a high vertical landing speed.

Obstacles

Stump.- Several taxi runs were made across the simulated tree stump (50 percent as high as the trunk) (see fig. 6(a)) at nominal speeds of 3.2, 6.3, and 11.1 m/s (10.5, 20.6, and 36.4 ft/sec). There was no discernible effect on the acceleration or pressure traces; consequently, no time histories are presented for the tree-stump negotiation. A static pull force of 20 N (4.5 lbf) was required to move the front of the trunk across the stump, and a force of 40 N (9 lbf) was required to pull the rear of the trunk across.

Ramp.- A static pull force of 35.6 N (8 lbf) was required to pull the model up the ramp (72 percent as high as the trunk) shown in figure 6(b). Typical acceleration time histories recorded during taxi runs across the ramp at various horizontal velocities are shown in figure 12. The sketches of the model in the figure show its approximate location with respect to the ramp and the corresponding acceleration time histories. When the model encountered the ramp at 3.1 m/s (10.2 ft/sec) it started a divergent pitching and heave oscillation at a frequency of about 3 Hz which produced normal accelerations of about ±1g at the nose and near the center of gravity. At this velocity the model came to rest prior to departing the ramp. When the speed was increased to 6.7 m/s (22.0 ft/sec) the model developed a moderate but damped pitching oscillation upon both encountering and departing the ramp. The figure shows that the intensity of the pitching oscillation when leaving the ramp was such that the normal accelerations ranged between 2.5g and -1g.

Figure 12(c) shows the acceleration response at a horizontal speed of 11.4 m/s (37.3 ft/sec). At this speed the model experienced little pitching oscillation both upon encountering and departing the ramp as it appeared to float over the obstacle. Also included in figure 12(c) is the measured longitudinal acceleration of the model as it traversed the ramp. This time history is typical of all three horizontal velocities in that the longitudinal-acceleration limit extended to about 0.25g when the model encountered the ramp with no detectable acceleration when the ramp was departed. These tests indicate that a ramp of the size evaluated may be negotiated without difficulty at the higher taxi speeds while the lower taxi speeds may cause some heave or pitch stability problem.

Ditch.- A static pull force of 33.4 N (7.5 lbf) was required to pull the model across the 0.3-m-wide (1-ft) ditch (31 percent of the trunk length) shown in figure 6(c). Typical acceleration time histories recorded during taxi runs across the ditch at various horizontal speeds are presented in figure 13. The sketches of the model in the figure show its approximate location relative to the ditch and the corresponding acceleration time history. At a speed of 2.9 m/s (9.6 ft/sec) the model experienced a pitching oscillation which produced normal accelerations generally within the level of ±0.5g. The maximum longitudinal accelerations shown in figure 13(a) were about 0.15g when the model crossed the ditch and were about the same for all horizontal velocities tested. At approximately 6.8 m/s (22.3 ft/sec) the maximum normal accelerations increased to about 1.5g. There was some heave instability, which produced normal accelerations of about 1g before the model encountered the ditch; however, crossing the ditch in such a condition had a minimal effect on the taxi run. When the model crossed the ditch at 11.1 m/sec (36.4 ft/sec) the maximum normal acceleration was about 1g (see fig. 13(c)). It appeared that crossing the ditch at this higher speed had the least effect on the model and there was no noticeable trim change during this crossing.

CONCLUDING REMARKS

A landing investigation was conducted with a 1/10-scale dynamic model of a C-8 Buffalo airplane equipped with an air-cushion landing system (ACLS). The landing-impact accelerations, trunk and air-cushion pressures, and landing behavior of the model were determined. Landings were made at one nominal scaled horizontal velocity of the airplane and with the model at various pitch and roll attitudes and vertical velocities.

The investigation indicated for landings in calm water, the maximum normal accelerations experienced by the model were about 3g to 4g, and landings with roll angles as high as 6° made no appreciable differences in the acceleration values. The characteristic behavior of the model was to trim down to a nearly level attitude during the first impact and then pitch up, as much as 10°, and sometimes clear the water. The model then normally returned to a near 0° attitude and ran smoothly along the water surface.

The model behavior for all landings in rough water was considered satisfactory. However, due to the random nature of contact with the waves, many more tests would be required to establish definite trends. The maximum normal acceleration was about 5.5g.

Hard-surface landings were generally rather smooth. There was a small bounce after initial impact followed by small oscillations. A maximum normal acceleration of about 3g developed.

Taxi runs across a simulated tree stump and ditch generally caused no difficulty. There was a divergent pitch and heave oscillation initiated when the model went up a ramp at low speed, however, at the higher speeds this oscillation became less pronounced.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., June 15, 1973.

REFERENCES

1. Earl, T. D.: The Potential of an Air Cushion Landing Gear in Civil Air Transport. Can. Aeronaut. & Space J., vol. 14, no. 9, Nov. 1968, pp. 355-364.

2. Digges, Kennerly H.: Theory of an Air Cushion Landing System for Aircraft. AFFDL-TR-71-50, U.S. Air Force, June 1971. (Available from DDC as AD 728 647.)

3. Han, Lit S.: Air Cushion Pressure During Stiff-Operation for Air Cushion Landing System. Pt. I. Theory. AFFDL-TR-71-4, Pt. I, U.S. Air Force, May 1971. (Available from DDC as AD 726 606.)

TABLE I.- SCALE RELATIONSHIPS

[λ = Scale of model = 1/10]

Quantity	Full-scale value	Scale factor	Model value
Length	l	λ	λl
Force	F	λ^3	$\lambda^3 F$
Moment of inertia	I	λ^5	$\lambda^5 I$
Mass	m	λ^3	$\lambda^3 m$
Time	t	$\sqrt{\lambda}$	$\sqrt{\lambda} t$
Speed	V	$\sqrt{\lambda}$	$\sqrt{\lambda} V$
Linear acceleration	a	1	a
Pressure (initial) gage	p gage	λ	λp gage
Density	ρ	1	ρ
Viscosity	μ	1	μ

TABLE II.- PERTINENT DIMENSIONS AND TEST PARAMETERS WHICH WERE USED IN THE INVESTIGATION OF AN AIR-CUSHION LANDING SYSTEM INSTALLED ON A 1/10-SCALE DYNAMIC MODEL OF THE C-8 BUFFALO AIRPLANE

Parameter	1/10-scale model	C-8 Buffalo airplane
Mass, kg (lbm)	17.9 (39.5)	17 735 (39 100)
Overall length, m (in.)	2.41 (94.75)	24.07 (947.5)
Wing span, m (in.)	2.93 (115.20)	29.26 (1152.0)
Center of gravity, m (in.):		
Distance from nose	0.82 (32.25)	8.2 (322.5)
Distance from fuselage bottom	0.18 (7.00)	1.8 (70.0)
Moments of inertia, kg-m^2 (slug-ft^2):		
Yaw	5.76 (4.25)	6.16×10^5 (4.55×10^5)
Pitch	3.67 (2.71)	3.81×10^5 (2.81×10^5)
Roll	3.00 (2.21)	3.04×10^5 (2.24×10^5)
Trunk pressure, kPa gage (psig):		
Out of ground effect	1.51 (0.22)	15.1 (2.2)
In ground effect	1.64 (0.24)	16.4 (2.4)
Air-cushion pressure, kPa gage (psig):		
Out of ground effect	0 (0)	0 (0)
In ground effect	0.82 (0.12)	8.2 (1.2)
Nominal landing speeds, m/s (ft/sec):		
Horizontal	11.77 (38.6)	37.2 (122)
Vertical (water)	1.21 (3.96)	3.81 (12.5)
Vertical (hard surface)	0.6 to 1.2 (2 to 3.9)	1.9 to 3.8 (6.3 to 12.4)
Wave size, cm (in.):		
Height	15 (6)	150 (60)
Crest to crest	305 (120)	3050 (1200)

TABLE III.- SUMMARY OF RESULTS OF WATER LANDINGS WITH AN AIR-CUSHION LANDING SYSTEM INSTALLED ON A 1/10-SCALE DYNAMIC MODEL OF THE C-8 BUFFALO AIRPLANE

[All values are model scale]

Landing attitude, deg		Water condition	Landing speed				Maximum normal accelerations, g units			Maximum trunk pressure at impact		Maximum air-cushion pressure at impact			
			Horizontal		Vertical							Forward		Aft	
Pitch	Roll		m/s	ft/sec	m/s	ft/sec	Nose	c.g.	Nacelle	kPa gage	psig	kPa gage	psig	kPa gage	psig
0	0	Calm	11.6	38.1	1.2	4.0	3.42	2.96	---	---	---	1.7	0.24	2.0	0.29
0	0		11.4	37.6	1.2	4.0	3.55	2.76	3.33	3.1	0.45	1.9	.27	1.9	.27
0	0		11.2	36.7	1.3	4.1	3.62	2.82	3.36	3.2	.47	1.9	.28	1.9	.28
0	0		11.3	37.0	1.3	4.3	3.60	2.77	3.30	3.2	.47	2.0	.28	1.9	.28
0	0		11.3	37.0	1.4	4.4	3.64	2.82	3.06	3.1	.46	1.9	.27	1.8	.26
0	0		11.4	37.4	1.5	4.8	4.24	3.02	3.54	3.3	.48	2.0	.29	1.9	.28
2	0		10.8	35.4	1.1	3.8	3.88	2.98	3.26	3.2	.46	2.0	.29	1.9	.28
3	0		11.2	36.8	1.3	4.4	3.58	2.84	3.44	3.3	.48	2.3	.34	2.1	.31
3	0		11.7	38.4	1.2	4.1	3.49	2.73	3.22	3.3	.48	2.2	.32	2.1	.30
4	3		11.0	36.0	1.2	3.9	2.99	2.90	3.20	3.7	.54	2.1	.31	2.0	.30
4	6		11.1	36.4	1.2	4.1	2.75	2.56	2.74	3.7	.54	---	---	1.9	.27
4	0	Waves[a]	11.6	38.2	1.3	4.3	5.40	4.24	4.14	3.8	.54	2.5	.36	2.4	.34
4	0		11.4	37.4	1.4	4.5	4.96	---	4.40	3.9	.56	2.6	.38	2.5	.37
4	3		11.2	36.7	1.1	3.7	3.68	2.35	3.00	3.0	.44	1.7	.24	1.6	.24
4	6		11.2	36.8	1.2	4.1	4.33	2.89	3.34	3.9	.57	---	---	1.9	.27
5	0		11.6	38.2	1.2	3.9	4.84	3.72	4.65	3.8	.54	2.7	.39	2.6	.38
5.5	0		11.6	38.2	1.1	3.5	4.70	2.62	---	3.3	.49	1.8	.26	1.5	.21
6	0		11.7	38.4	1.1	3.5	3.47	3.00	3.41	3.3	.47	2.5	.36	2.3	.34

[a]Landings were made into oncoming waves which simulated sea state 3 (15 cm (6 in.) high by 305 cm (120 in.) crest to crest).

TABLE IV.- SUMMARY OF RESULTS OF HARD-SURFACE LANDINGS WITH AN AIR-CUSHION LANDING SYSTEM INSTALLED ON A 1/10-SCALE DYNAMIC MODEL OF THE C-8 BUFFALO AIRPLANE

[All values are model scale]

Landing attitude, deg		Landing speed				Maximum accelerations, g units			Maximum impact pressure			
		Horizonal		Vertical					Trunk		Air cushion (aft transducer)	
Pitch	Roll	m/s	ft/sec	m/s	ft/sec	Normal nose	Normal c.g.	Longit. c.g.	kPa gage	psig	kPa gage	psig
3.5	0	11.3	37.0	1.0	3.4	2.86	2.69	0.08	3.2	0.47	2.0	0.29
4	0	11.3	37.0	1.0	3.5	2.80	2.53	.12	3.0	.43	1.7	.25
4	3	11.4	37.4	1.1	3.7	2.80	2.18	.06	2.8	.41	1.6	.23
4	0	11.2	36.8	.9	2.9	1.65	1.54	.06	2.5	.36	1.2	.18
4	0	11.3	37.0	.8	2.7	1.78	1.92	.06	2.7	.40	1.4	.20
5	0	10.7	35.1	.7	2.2	1.61	1.35	.12	2.2	.32	.8	.11
5	0	11.2	36.8	1.0	3.1	2.29	2.32	.06	3.0	.44	1.7	.25
5	6	11.4	37.2	1.2	3.9	2.31	2.18	.08	2.7	.40	1.5	.22
6	0	11.3	36.9	1.3	4.4	3.31	2.88	.19	3.2	.47	2.0	.29
6	0	10.8	35.6	1.4	4.5	3.18	2.86	.25	3.3	.48	1.9	.28
6	0	11.3	36.9	.9	2.9	1.88	1.68	.16	2.5	.36	1.4	.20
6	0	11.1	36.4	.8	2.5	1.96	1.78	.16	2.5	.36	1.4	.20
6	0	11.2	36.8	.6	2.0	1.35	1.33	.02	2.3	.34	1.2	.17
8	0	11.4	37.3	1.4	4.4	2.71	2.66	.16	3.0	.44	1.9	.28
9	0	11.5	37.7	.9	3.0	1.80	1.49	.16	2.1	.31	1.1	.16
9	0	11.8	38.8	1.2	4.1	2.69	2.48	.19	2.9	.42	1.7	.24
12	0	11.5	37.7	1.2	3.9	2.53	2.08	.50	2.4	.35	1.3	.19
12.5	0	11.5	37.8	1.1	3.6	2.51	1.92	.41	2.4	.35	1.5	.22
13	0	11.2	36.6	1.4	4.6	3.00	2.33	.49	2.3	.34	1.2	.18

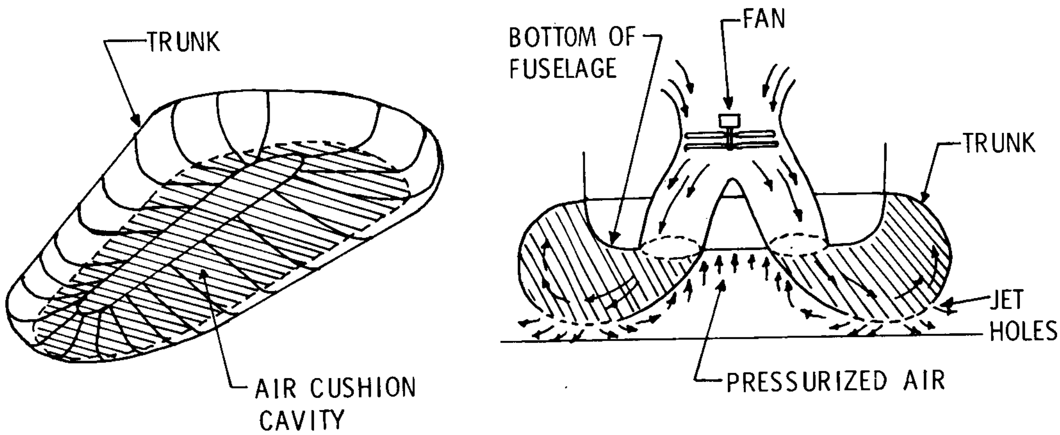

Figure 1.- Basic principles of operation of the air-cushion landing system (ACLS).

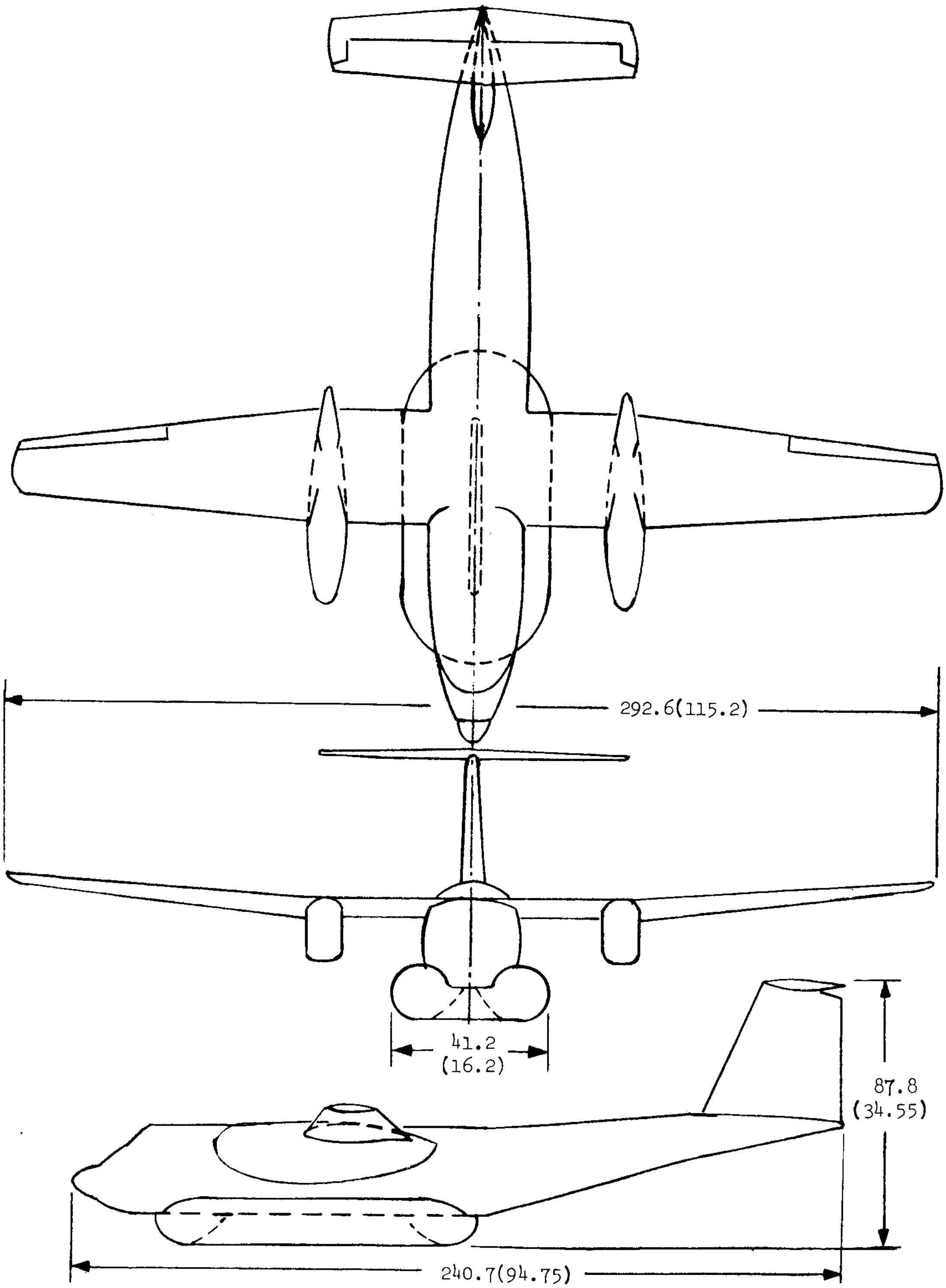

Figure 2.- General arrangement of the ACLS test vehicle. Dimensions are model scale, cm (in.).

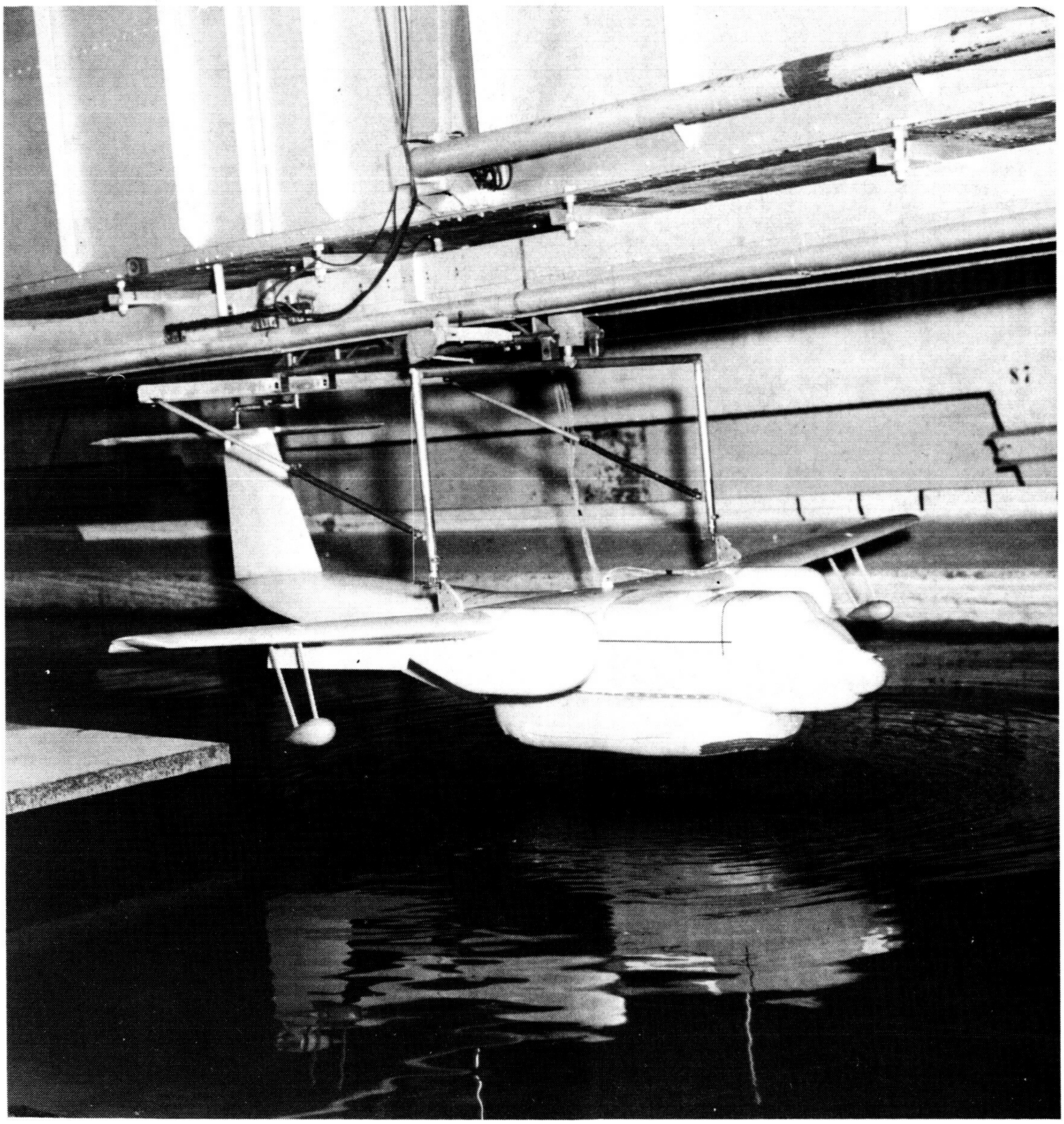

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Figure 3.- Model with short trunk on the catapult ready for a water landing.

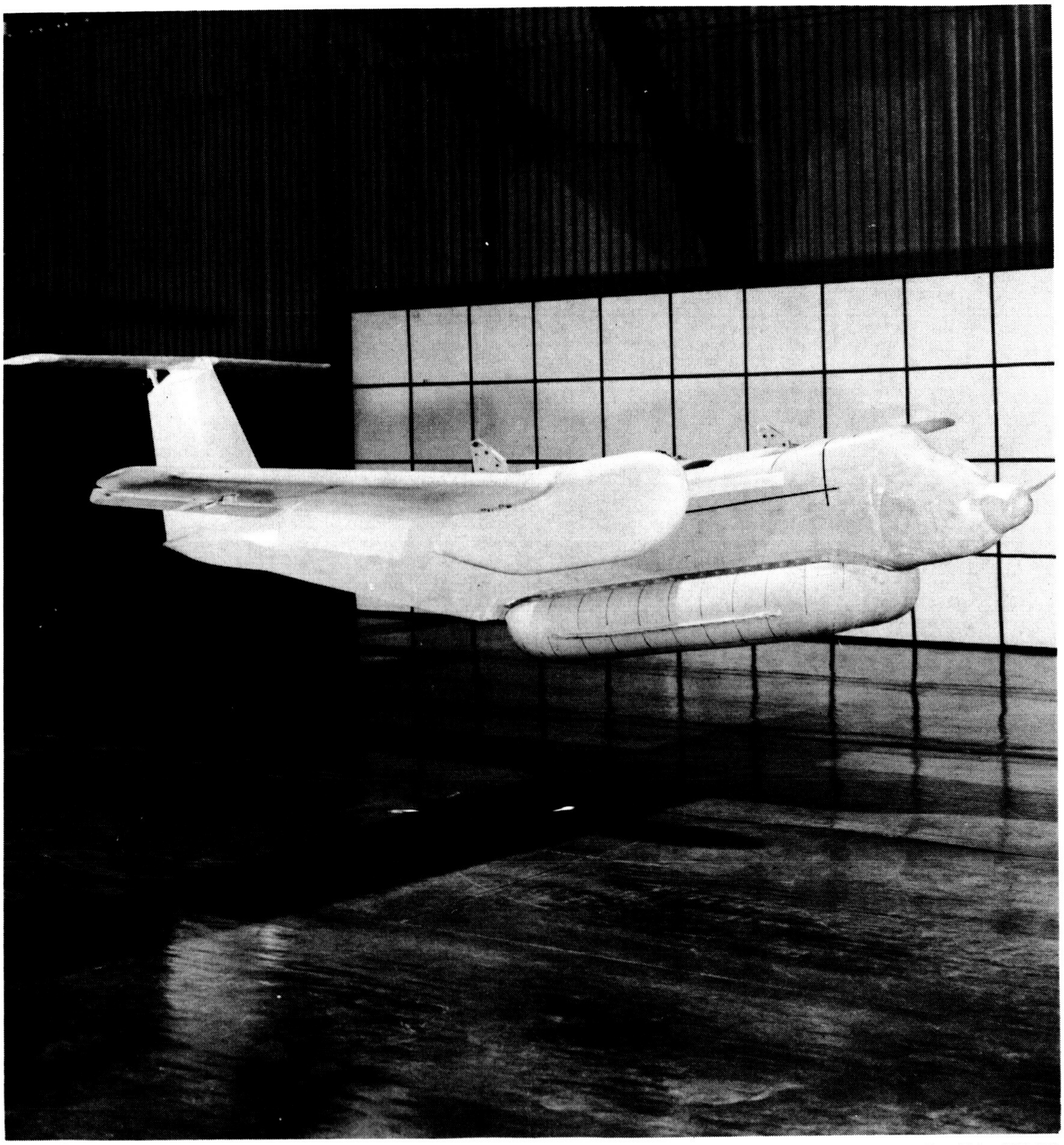

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Figure 4.- Model with long trunk over the hard-surface landing area.

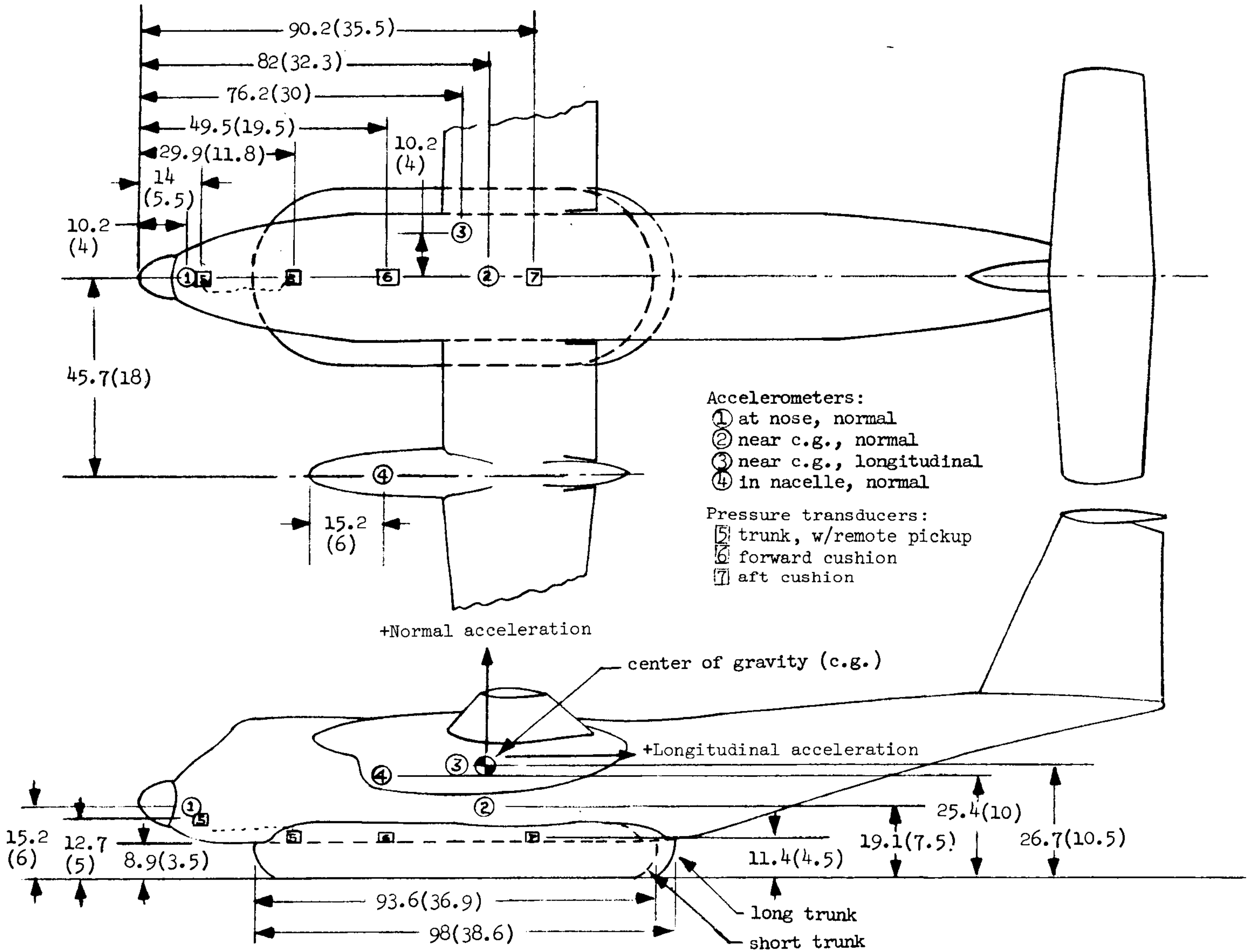
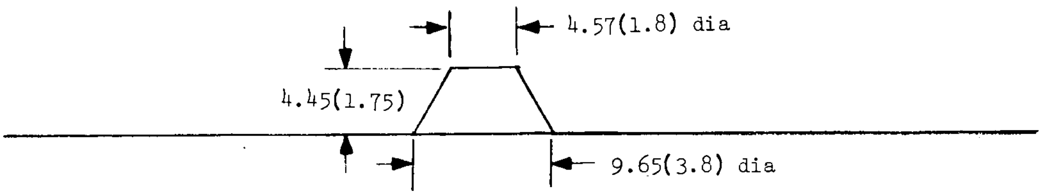
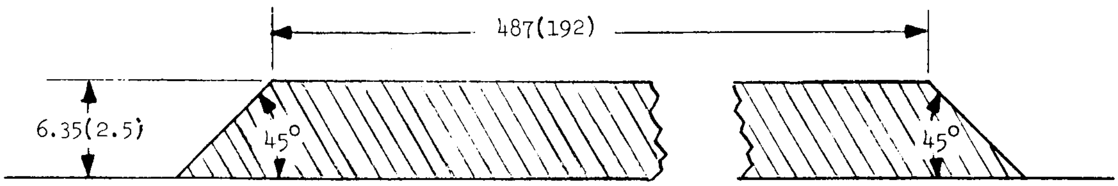


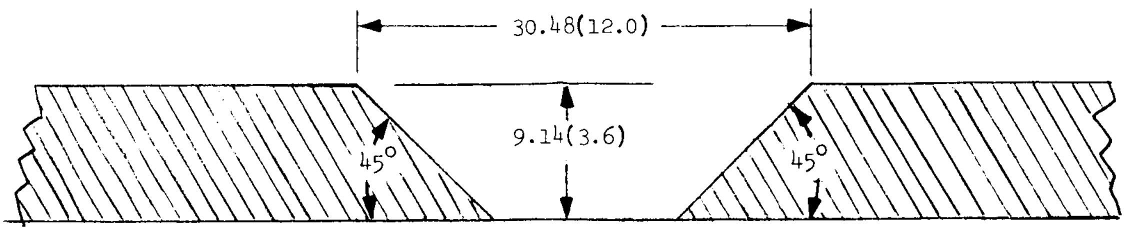
Figure 5.- Instrumentation and landing-system trunk location on the 1/10-scale model. Dimensions are model scale, cm (in.).



(a) Tree stump.



(b) Ramp, 243.8 (96) wide.



(c) Ditch, 243.8 (96) wide.

Figure 6.- Obstacles used in taxi tests. Dimensions are in cm (in.).

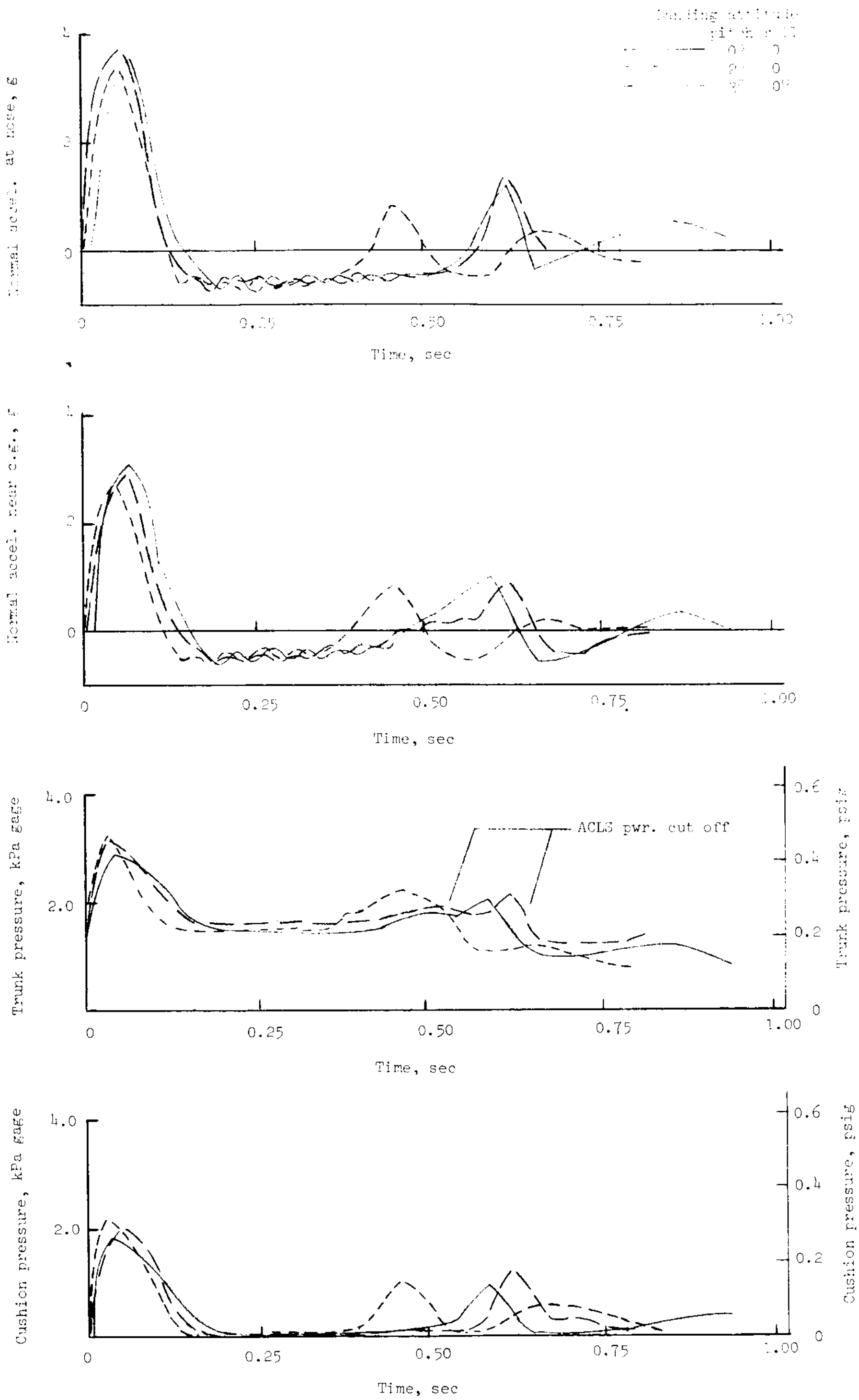


Figure 7.- Landings in calm water at various pitch attitudes. Nominal landing speeds – horizontal, 11.8 m/s (36.8 ft/sec); vertical, 1.2 m/s (3.9 ft/sec). All values are model scale.

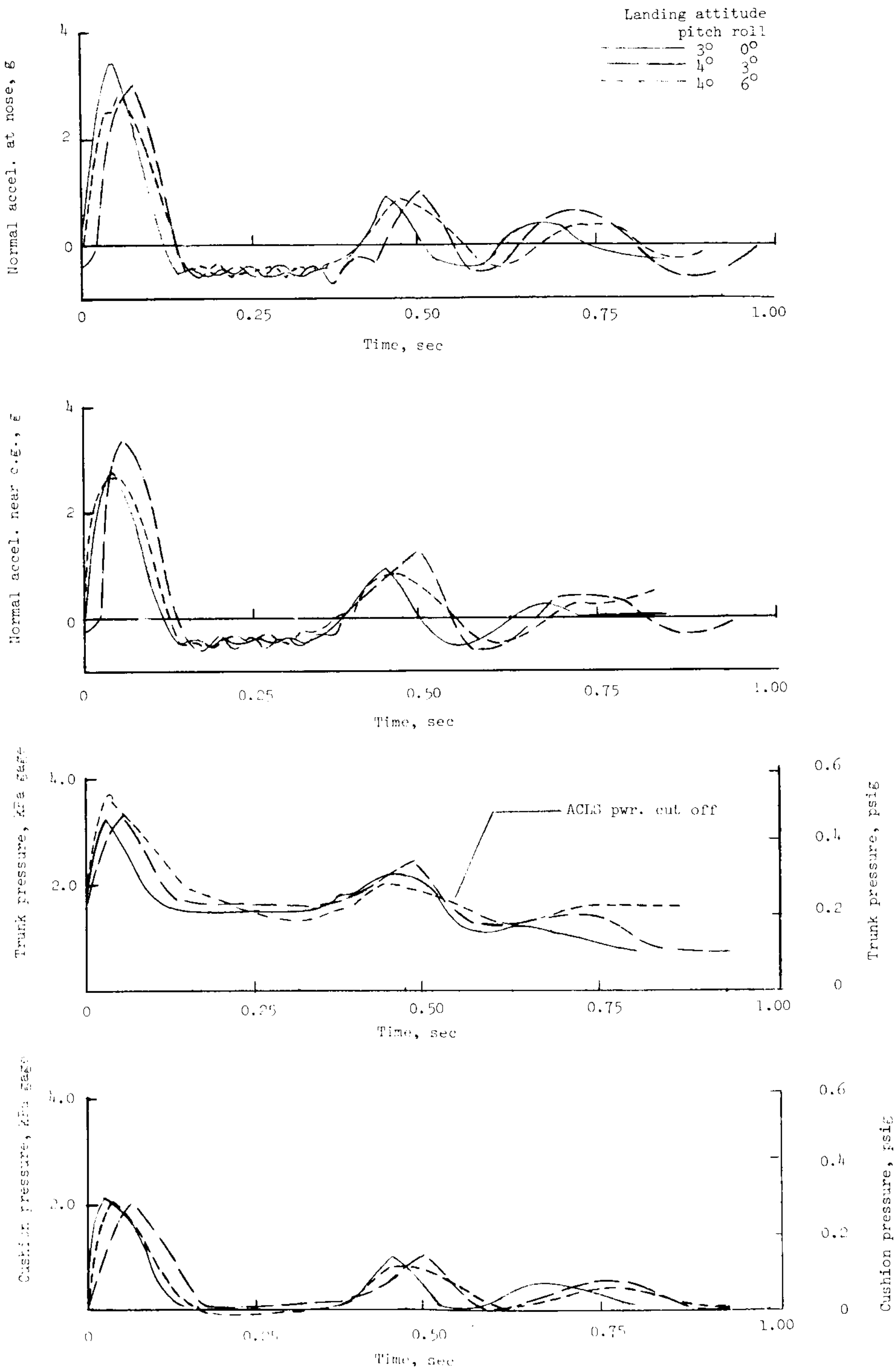


Figure 8.- Landings in calm water at various roll angles. Nominal landing speeds – horizontal, 11.8 m/s (36.8 ft/sec); vertical, 1.2 m/s (3.9 ft/sec). All values are model scale.

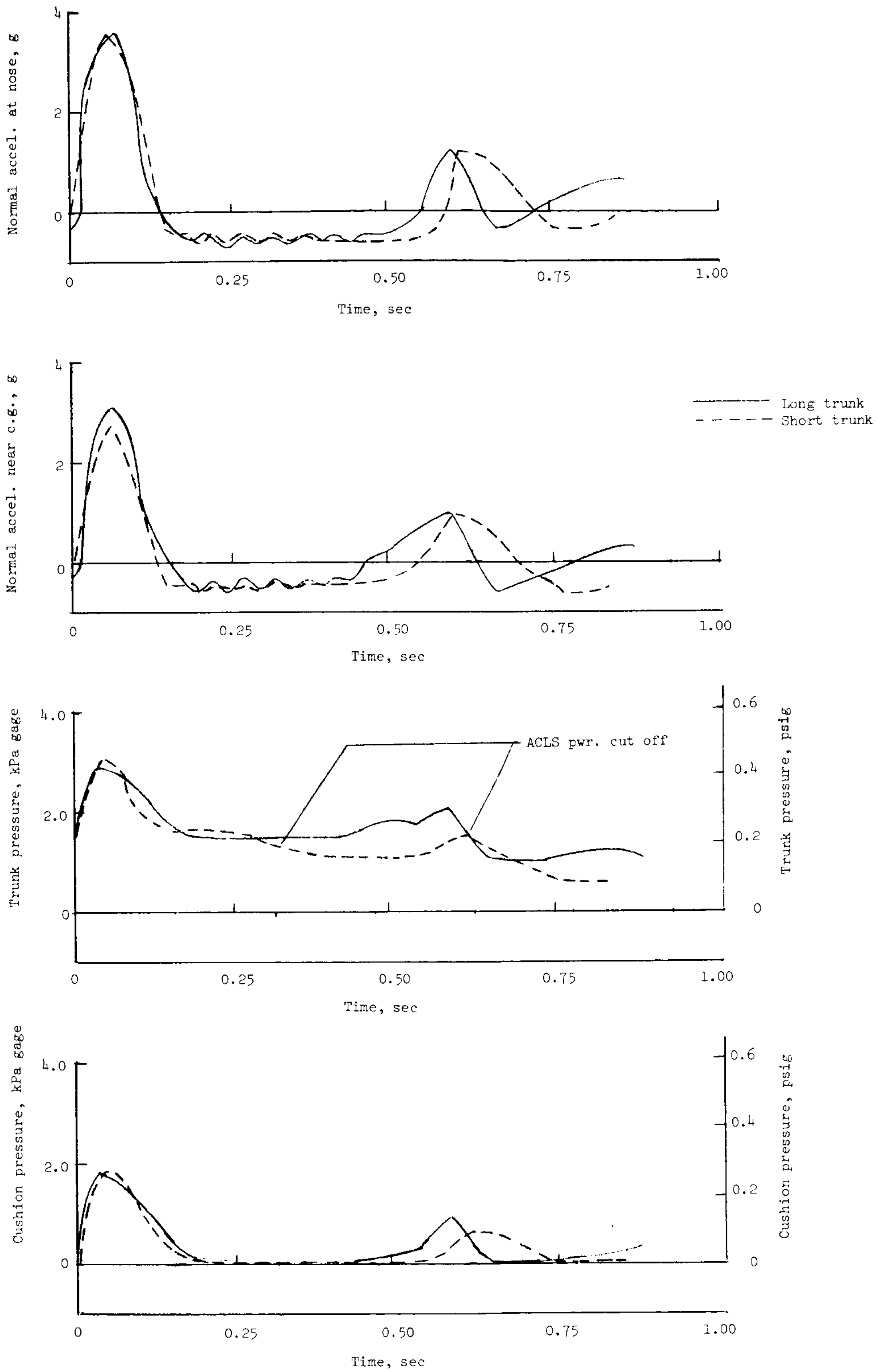


Figure 9.- Landings in calm water with both the short and the long trunk. Landing attitude – pitch, 0°; roll, 0°. Nominal landing speeds – horizontal, 11.8 m/s (36.8 ft/sec); vertical, 1.2 m/s (3.9 ft/sec). All values are model scale.

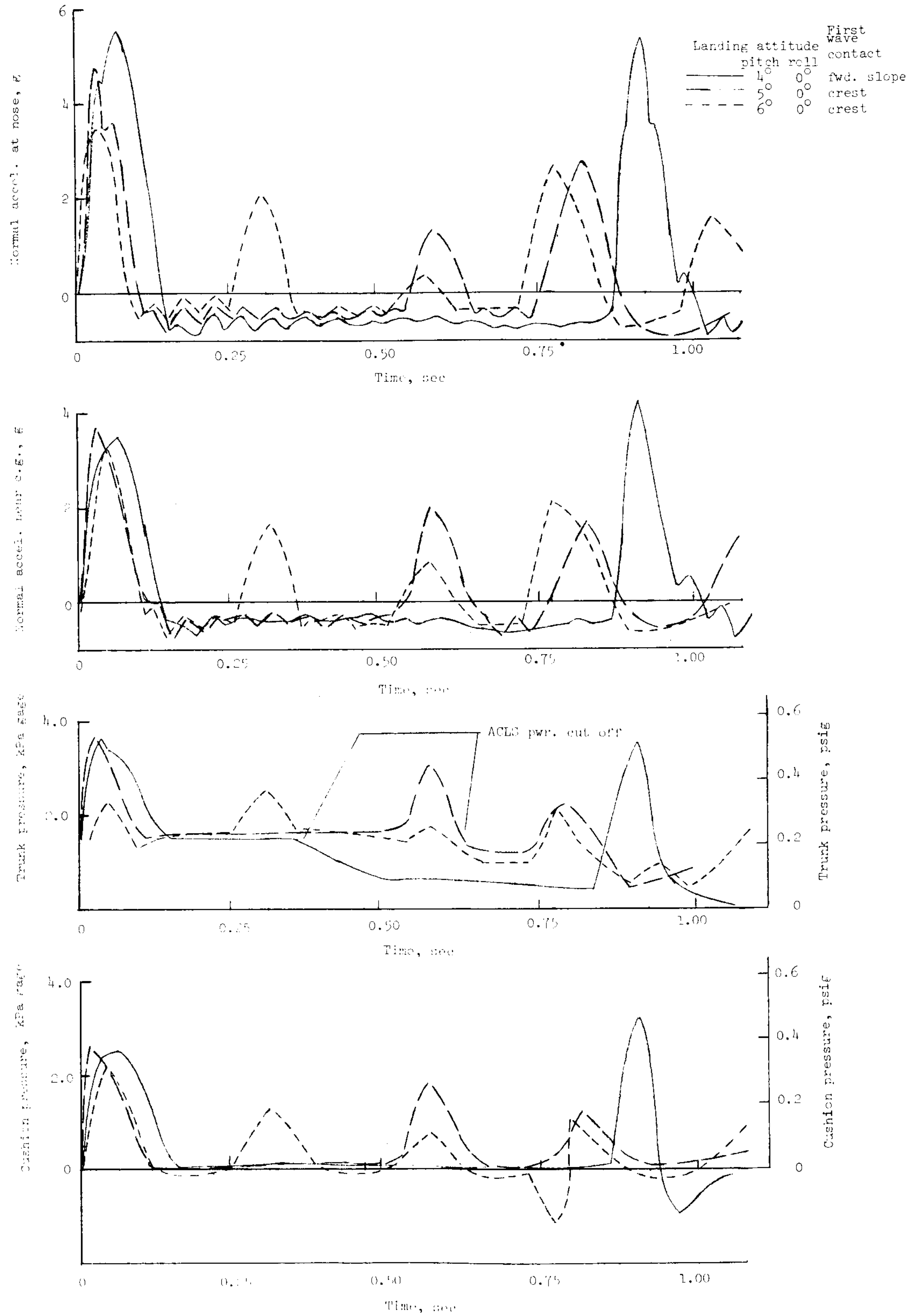


Figure 10.- Landings in waves 15 cm (6 in.) high by 305 cm (120 in.) crest to crest at various pitch attitudes and various initial contact points along the waves. Nominal landing speeds – horizontal, 11.8 m/s (36.8 ft/sec); vertical, 1.2 m/s (3.9 ft/sec). All values are model scale.

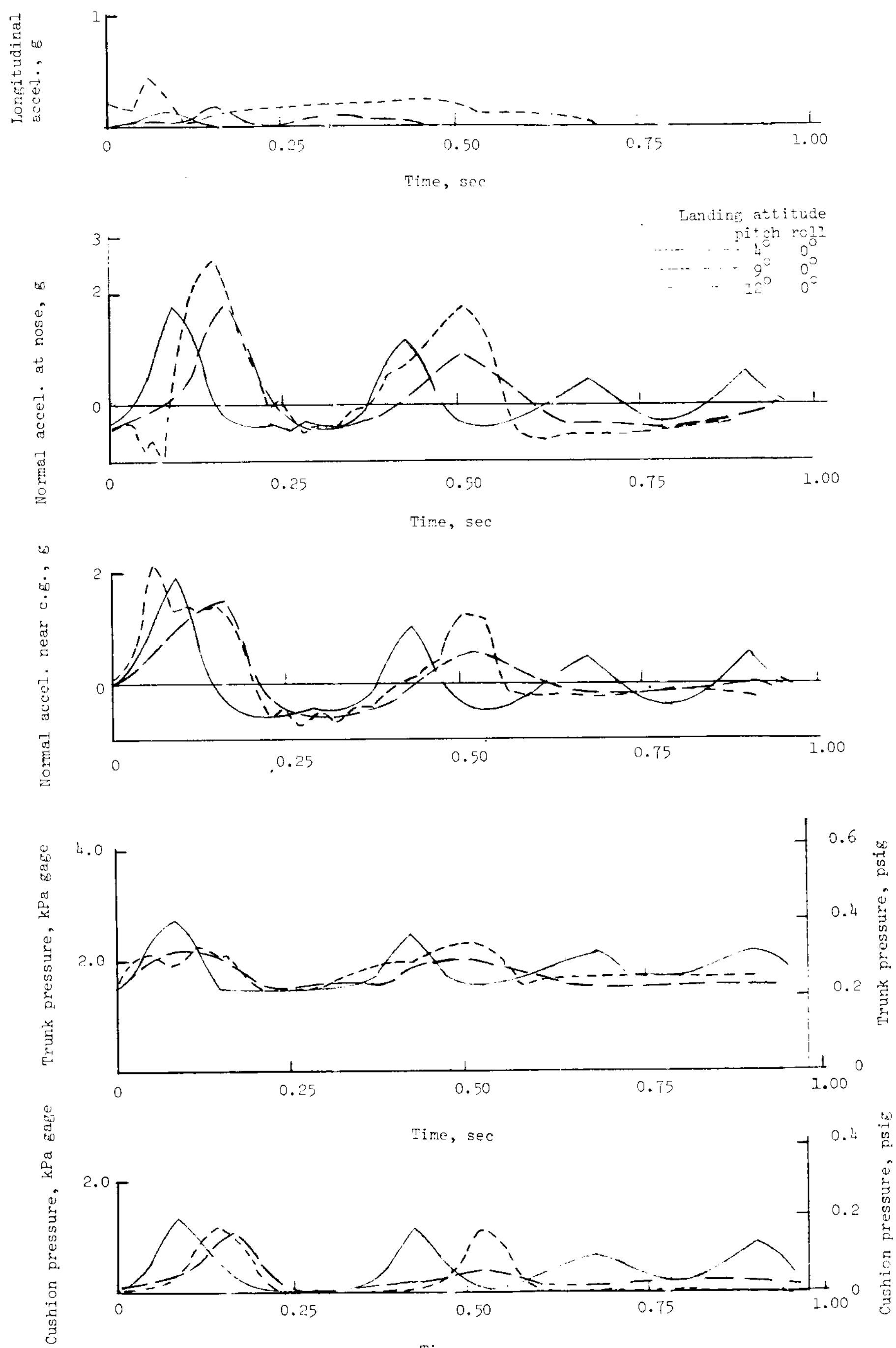
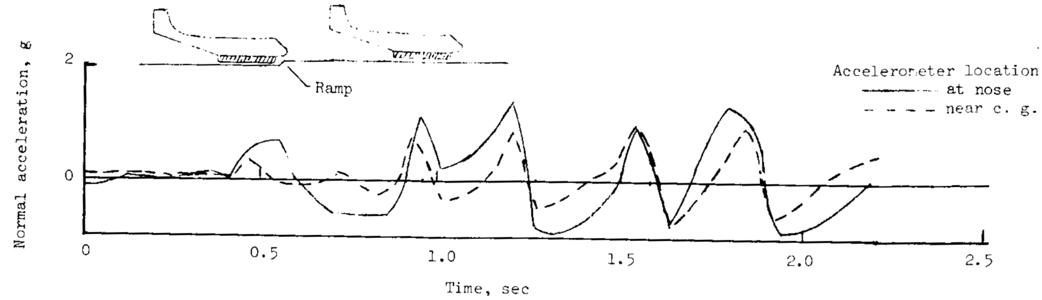
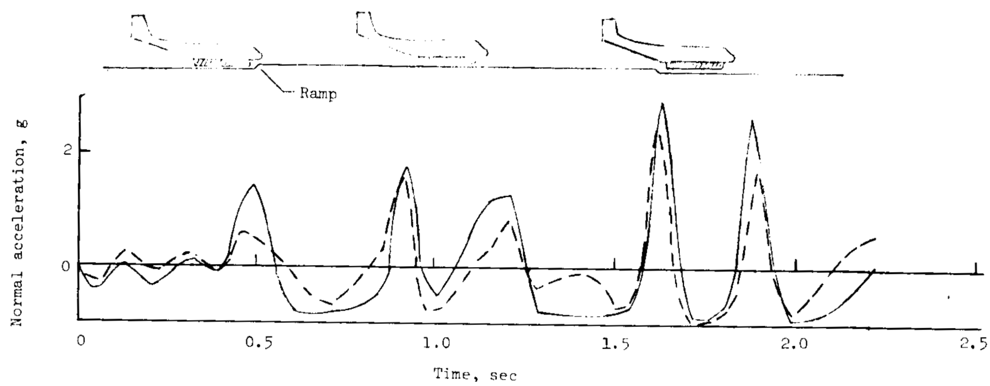


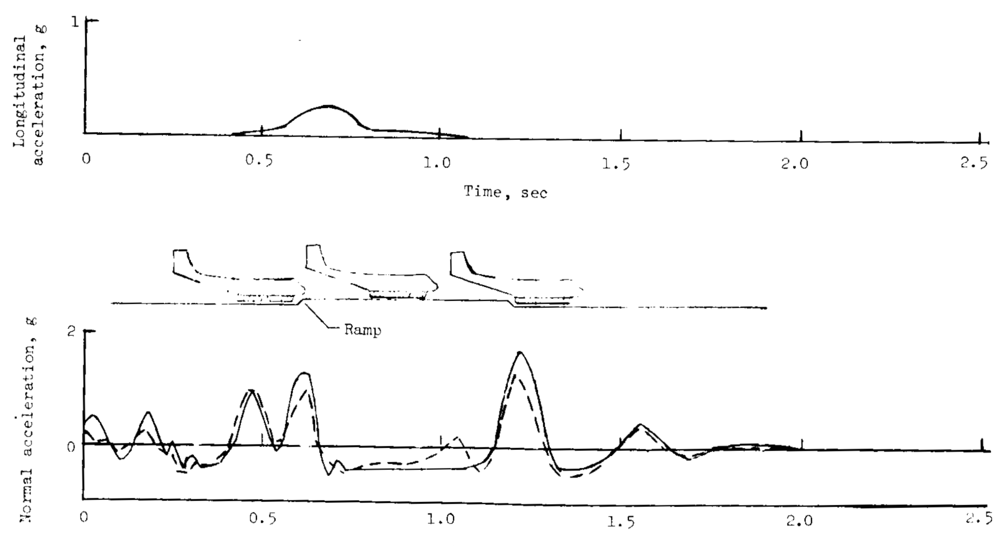
Figure 11.- Hard-surface landings at various pitch attitudes. Nominal landing speeds – horizontal, 11.8 m/s (36.8 ft/sec); vertical, 1.2 m/s (3.9 ft/sec). All values are model scale.



(a) Horizontal velocity 3.1 m/s (10.2 ft/sec).

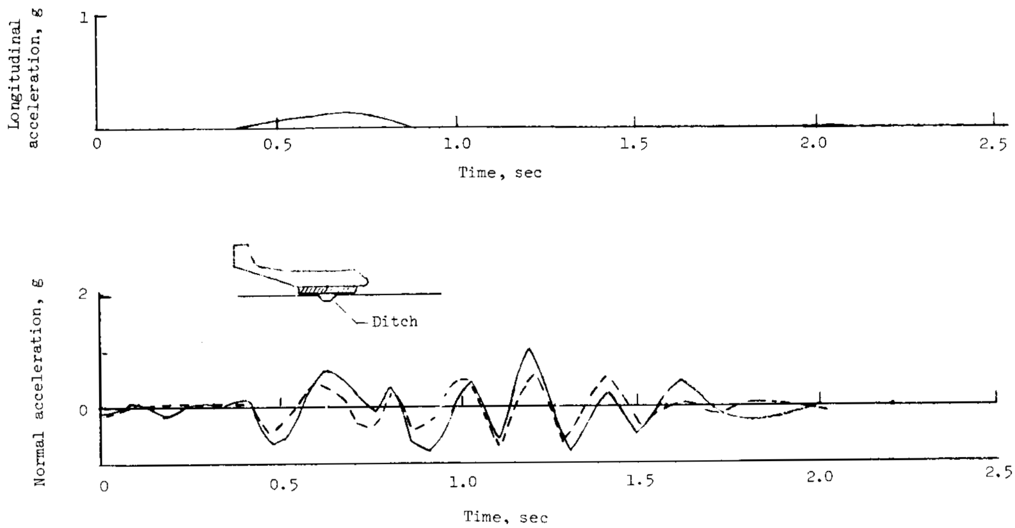


(b) Horizontal velocity 6.7 m/s (22.0 ft/sec).

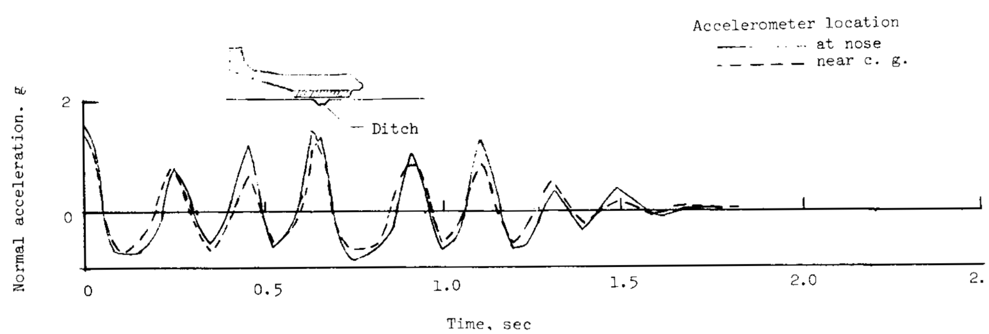


(c) Horizontal velocity 11.4 m/s (33.3 ft/sec).

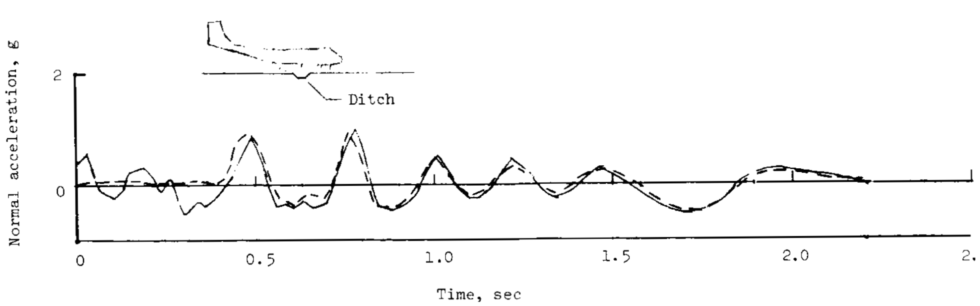
Figure 12.- Accelerations encountered while negotiating a 45^{o} ramp 6.35 cm (2.5 in.) high. All values are model scale.



(a) Horizontal velocity 2.9 m/s (9.6 ft/sec).



(b) Horizontal velocity 6.8 m/s (22.3 ft/sec).



(c) Horizontal velocity 11.1 m/s (36.4 ft/sec).

Figure 13.- Accelerations encountered when crossing a ditch with sides sloped 45°, 30.48 cm (12.0 in.) wide at the top, and 9.14 cm (3.6 in.) deep. All values are model scale.

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