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VERIFICATION OF TAKEOFF PERFORMANCE PREDICTIONS FOR THE XB-70 AIRPLANE

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INTRODUCTION

Considerable effort has been expended in the last few years in predicting the takeoff characteristics of large aircraft and, in particular, large supersonic-cruise aircraft such as the supersonic transport (refs. 1 to 4). Particular characteristics of interest include heavy takeoff weights, low-aspect-ratio wings, slender, flexible fuselages with relatively high pitch and yaw moments of inertias, and moderately high thrust-to-weight ratios. The flight research program with the XB-70 airplane provided means for obtaining actual full-scale takeoff performance data on an airplane in this category.

This paper presents standardized takeoff performance data for the XB-70 airplane and compares these data with simple predictions based on aerodynamic and engine estimates. Included are the effects of atmospheric variation and other pertinent variables on XB-70 takeoff performance. Although experimentation with various techniques for rotating the aircraft to lift-off attitudes was limited, the effect of the pilot techniques used are discussed and compared.

The data presented in this paper were obtained from takeoffs of the XB-70 airplane during a flight program conducted jointly at Edwards Air Force Base, Calif., by the U.S. Air Force, North American Rockwell Corp., and the NASA Flight Research Center.

SYMBOLS

The units used for physical quantities in this paper are given in U.S. Customary Units and parenthetically in the International System of Units (SI).

a_n	normal acceleration, g
a_x	aircraft acceleration tangent to runway, ft/sec^2 (m/sec^2)
$\overline{a_{x_{C_L}}}$	average longitudinal acceleration for constant lift coefficient during ground roll, ft/sec^2 (m/sec^2)
C_D	drag coefficient

C_L	aerodynamic lift coefficient
$C_{L_{LOF_s}}$	standardized lift coefficient for lift-off (eq. (A3))
D	drag, lb (N)
F	thrust of aircraft, lb (N)
F_g	gross thrust of aircraft, lb (N)
F_n	net thrust of aircraft, lb (N)
f	frequency of occurrence
g	acceleration due to gravity, ft/sec^2 (m/sec^2)
h	height above runway, ft (m)
h_a	air-phase height, 35 ft (10.7 m) above lift-off point
h_p	pressure altitude, ft (m)
h_V	specific kinetic-energy increase of aircraft gained during air phase, $\frac{(V_a)^2 - (V_{LOF})^2}{2g}$, ft (m)
L	lift, lb (N)
S	wing area, ft^2 (m^2)
S_a	horizontal distance traveled by aircraft from lift-off to air-phase height of 35 ft (10.7 m), ft (m)
S_g	ground roll distance (distance traveled by aircraft from brake release to lift-off), ft (m)
$S_{g_{C_L}}$	ground roll distance corrected to a constant C_L at lift-off, ft (m)
S_{g_c}	ground roll distance corrected to a condition of zero wind, zero runway slope, and constant lift coefficient at lift-off, ft (m)
$S_{g_{s(V)}}$	ground roll distance standardized for relating distance to aircraft velocity, ft (m)
$S_{g_{s(W)}}$	ground roll distance standardized for relating distance to aircraft weight, ft (m)

S_{g_w}	ground roll test distance referenced to zero wind, ft (m)
$S_{r_{s(V)}}$	ground roll distance traveled by aircraft from brake release to initiation of rotation, standardized for relating distance to aircraft velocity, ft (m)
S_0	horizontal distance from brake release, ft (m)
T	ambient temperature, °F (°C)
t	time, sec
t_a	time at air-phase height, sec
V	aircraft velocity, knots
V_a	aircraft velocity at air-phase height, knots
V_i	indicated velocity, knots
V_{i_a}	indicated velocity at air-phase height, knots
$V_{LOF_{C_{L_s}}}$	aircraft lift-off velocity standardized to a constant lift coefficient (eq. (A3)), knots
V_w	wind velocity, knots
W	aircraft weight, lb (kg)
α	aircraft angle of attack, deg
Δ	algebraic change in value of reference variable
δ_e	average elevon deflection of aircraft, deg
θ	aircraft pitch attitude, deg
μ	coefficient of rolling friction
ρ	ambient density, slugs/ft^3 (kg/m^3)
σ	ratio of measured ambient density to standard value

Subscripts:

LOF	lift-off of aircraft
r	initiation of rotation

s standardized value

t test value

A bar over a quantity denotes the average value of that quantity.

AIRPLANE DESCRIPTION

The XB-70 airplane (fig. 1) was a delta-wing airplane designed for long-range supersonic cruise. Its maximum gross weight exceeded 500,000 pounds (227,000 kilograms). Of the two XB-70 airplanes built, the only significant difference in configuration was in the wing dihedral; the first airplane (XB-70-1) had 0° dihedral, and the second airplane (XB-70-2) had 5° dihedral. Specific configuration details are included in reference 5.

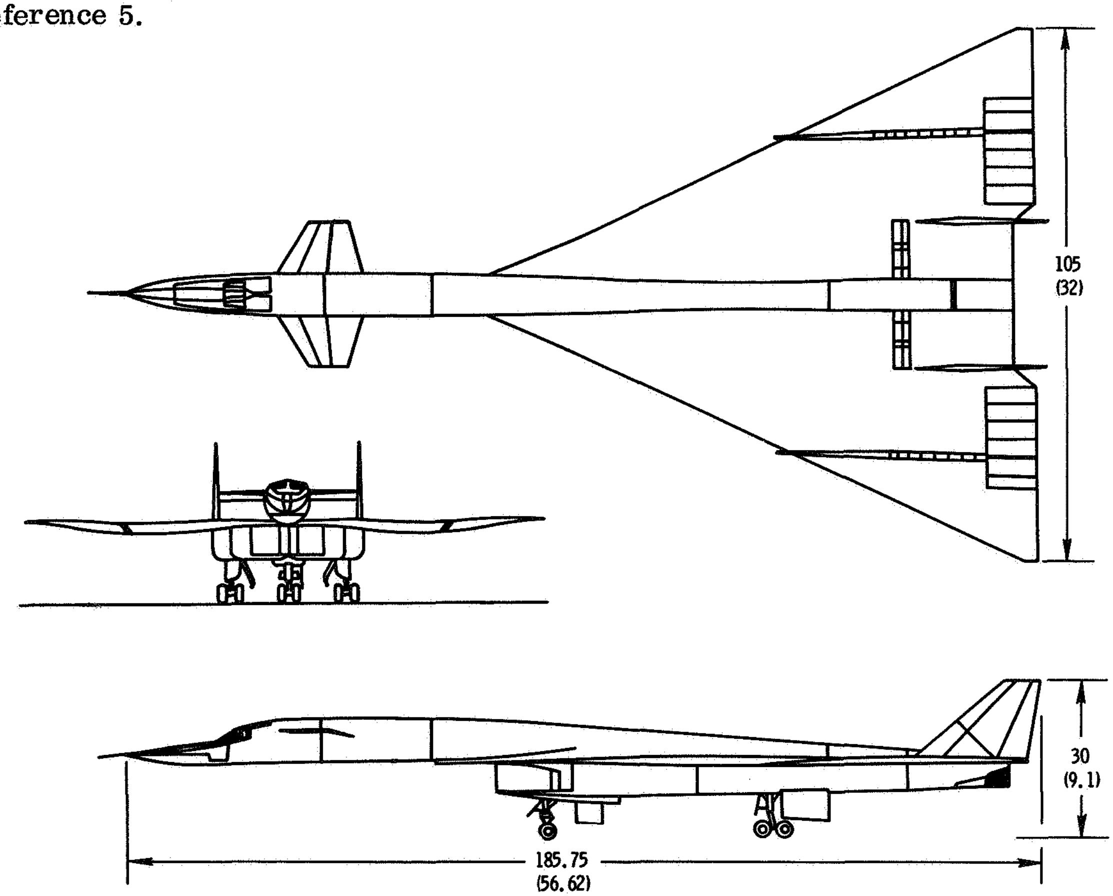


Figure 1. Three-view drawing of the XB-70 airplane. Dimensions in feet (meters).

Each aircraft had a canard surface and segmented trailing-edge elevons, with six segments to a side. During takeoff and landing, canard incidence was set at 0°, and the canard flaps were deflected to the 20° position. The foldable wing tips were undeflected during takeoff and landing.

The airplane's propulsion system consisted of six YJ93-GE-3 engines with sea-level, static-thrust ratings of approximately 30,000 pounds (130,000 newtons).

The landing gear was a conventional tricycle arrangement with four wheels on each main gear and two on the nose gear. A detailed description of the landing gear is presented in reference 6.

Wing loading varied from 68 lb/ft^2 to 85 lb/ft^2 (332 kg/m^2 to 415 kg/m^2). The center of gravity varied from 20.8 percent to 24.5 percent of the mean aerodynamic chord. The maximum trailing-edge-up elevon deflection used for rotation was 12° of the 20° or 25° available.

TEST PROCEDURES

Takeoffs were made in both directions from the main, 15,000-foot (4600-meter), concrete runway at Edwards Air Force Base, Calif. This runway has a mean elevation of 2291 feet (698.3 meters) and a grade of 0.14 percent. Dry runway conditions prevailed during all the tests. No abnormal takeoff tests, such as abused takeoffs, were made.

In the normal takeoff procedure the six engines were set to minimum afterburner power before brake release. The brakes were then released, the throttles were advanced to maximum afterburner power (usually within 10 seconds or less from brake release), and the airplane was allowed to accelerate to a nominal speed of 20 knots below the intended lift-off speed as determined from the pilot's aircraft manual. The airplane was rotated by elevon control to about 10° pitch attitude, which the pilot established by sighting the upper surface of the fuselage nose on the horizon. This attitude was held until lift-off.

Although little experimentation with XB-70 takeoff was accomplished, a few of the rotations were initiated at a speed approximately 30 knots lower than the intended lift-off speed. Also, significant variations in rotation procedures occurred because of pilot technique.

MEASUREMENTS AND ANALYSIS

Data were obtained from three sources: space-positioning data from an Askania cinetheodolite tracking system (ref. 7), meteorological information from the Air Weather Service at Edwards Air Force Base, and the remainder of the data from the XB-70 onboard recording system (ref. 5). Velocity and acceleration were calculated from the space-positioning data. For the 4-frame-per-second tracking data, two-station solutions and a seven-point smoothing procedure were used.

The primary parameters recorded by the XB-70 data system and used in the analysis in this report included angle of attack, elevon position, pressure altitude, indicated airspeed, and fuel quantity (for weight determination). Angle of attack was measured by a vane mounted on the nose boom of the airplane.

The estimated accuracies of all the pertinent quantities used in evaluating takeoff performance are presented in the tabulation on the next page.

Quantity	Accuracy
Position	±2 ft (±0.6 m)
Velocity	±1 knot
Acceleration	±0.1 ft/sec^2 (±0.03 m/sec^2)
Angle of attack	±0.5°
Elevon position	±1°
Thrust	±5000 lb (±22,000 N)
Weight	±500 lb (±230 kg)
Temperature	±1° F (±0.6° C)
Pressure	±2 lb/ft^2 (±100 N/m^2)

Evaluation of takeoff performance requires that the data for each takeoff be corrected to standard conditions. Therefore, the data were corrected to sea-level, standard-day, no wind conditions for standard weights and lift coefficients. Procedures for making these corrections are described in appendix A. Table 1 presents the test and standardized values of takeoff distances and velocities, as well as pertinent quantities used to standardize each takeoff analyzed.

Ground roll performance was evaluated at the initiation of rotation (lift-off of the nosewheel) and at the lift-off of the last wheel to become airborne. Distance values were referenced from brake release. Air-phase performance was evaluated at the time the aft bogie was 35 feet (10.7 meters) above the takeoff point. Distances were projected from lift-off directed along the runway.

RESULTS AND DISCUSSION

General Takeoff Characteristics

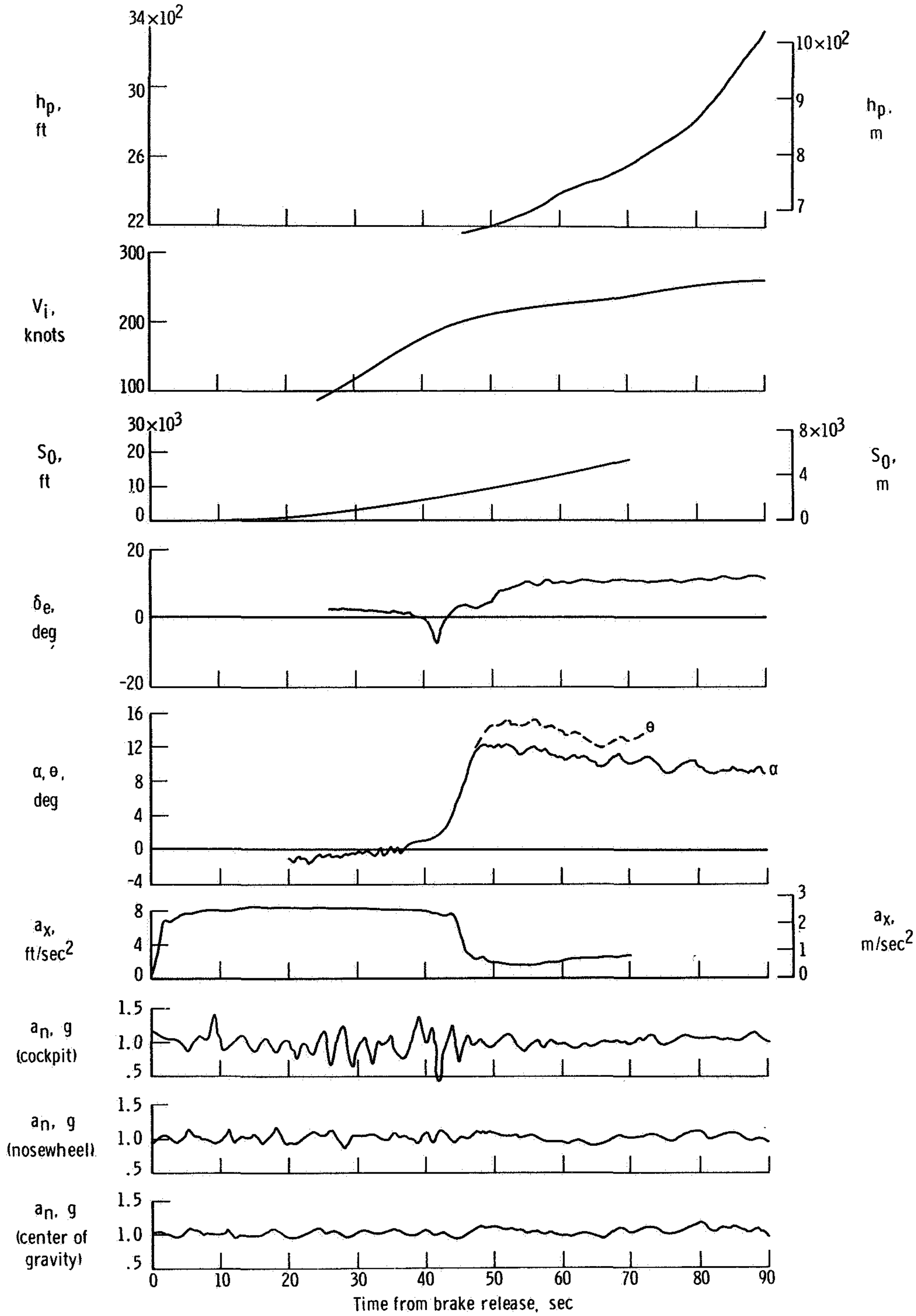
Time histories of two XB-70 takeoffs are shown in figure 2. Figure 2(a) is representative of the normal takeoff procedure in which the pilot initiated rotation approximately 20 knots lower than the intended lift-off speed. Figure 2(b) is representative of the few takeoffs in which rotation was initiated approximately 30 knots lower than the intended lift-off speed. From these figures, it can be seen that the longitudinal acceleration increased to near its maximum value during the first 10 seconds, as the pilot advanced all engines to maximum afterburner, and remained essentially constant after this time until the initiation of rotation. During rotation, the acceleration decreased markedly. This reduction resulted mainly from the large increase in drag due to lift associated with the nose-high attitude of the airplane.

Marginal air-phase performance with all engines operating (from lift-off to 35 ft (10.7 m)) was indicated by the low values of longitudinal acceleration at lift-off. Because of the low excess thrust of the XB-70 airplane during the air phase, initial climb angles typically ranged from 1° to 2°. As a result, negative values of longitudinal acceleration sometimes occurred; an example is shown in figure 2(b) 78 seconds after brake release.

Although it was not specifically a problem in these tests, the extremely rough ride in the cockpit, as indicated by the normal-acceleration trace in figure 2(a), could cause some concern for the pilot's ability to perform the takeoff, especially for takeoffs from rough runways. Although the variation in vertical acceleration at the center of gravity

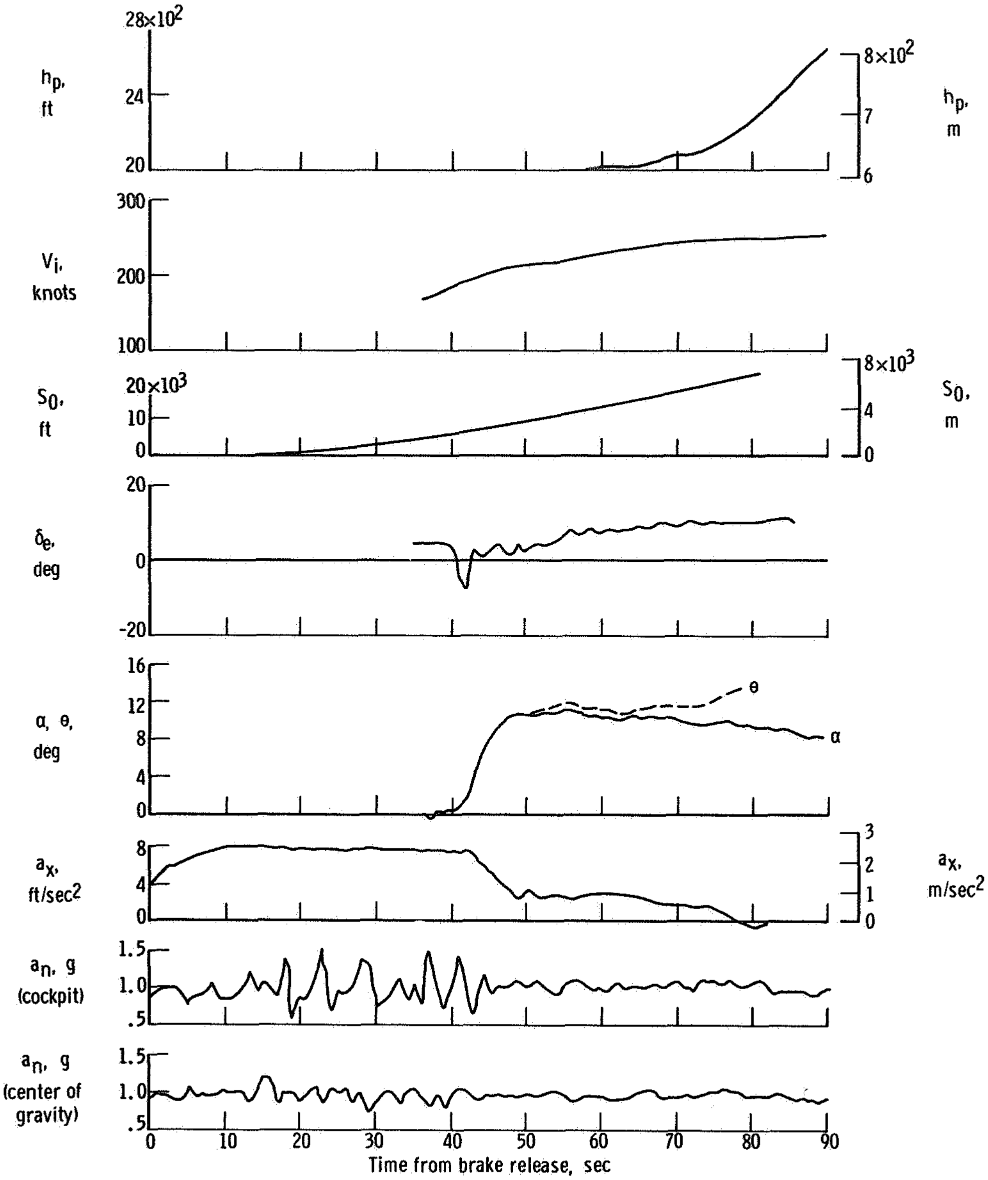
TABLE 1. – QUANTITIES FOR EVALUATION OF XB-70 TAKEOFF PERFORMANCE

Takeoff test conditions							Atmospheric conditions					Takeoff performance																
Flight	Takeoff heading, deg	$\frac{F_g}{W_t}$	W_t, lb	W_t, kg	W_s, lb	W_s, kg	T, °F	T, °C	σ	V_w, knots	Wind direction, deg	S_{g_t}, ft	S_{g_t}, m	S_{g_c}, ft	S_{g_c}, m	$S_{g_{s(W)}}$, ft	$S_{g_{s(W)}}$, m	$S_{g_{s(V)}}$, ft	$S_{g_{s(V)}}$, m	V_{LOF_t}, knots	V_{LOF_s}, knots	S_{a_t}, ft	S_{a_t}, m	S_{a_s}, ft	S_{a_s}, m	h_v, ft	h_v, m	V_{a_t}, knots
1-2	222	0.345	406.1×10^3	184.2×10^3	440×10^3	199.6×10^3	49	9.4	0.861	01	360	6,780	2066.5	7,640	2328.7	5080	1548.4	5620	1713.0	200	192	1350	411.5	947	288.6	99	30.2	204
1-3	222	.355	416.4	188.9	440	199.6	75	23.9	.894	05	235	6,790	2069.6	7,420	2261.6	5660	1725.2	6000	1828.8	200	195	2000	609.6	1479	450.8	252	76.8	210
1-4	222	.365	428.9	194.5	440	199.6	57	13.9	.922	09	200	7,349	2240.0	7,000	2133.6	5790	1764.8	6590	2008.6	208	209	1870	570.0	1633	497.8	222	67.7	222
1-6	42	.334	466.1	211.4	440	199.6	54	12.2	.933	03	060	7,170	2185.4	7,880	2401.8	6740	2054.4	5430	1655.1	206	194	2010	612.6	1412	430.4	213	64.9	220
1-7	42	.324	494.0	224.1	520	235.9	51	10.6	.940	08	110	8,230	2508.5	7,900	2407.9	7080	2158.0	8250	2514.6	216	214	2000	609.6	2128	648.6	190	57.9	233
1-8	222	.312	503.6	228.4	520	235.9	53	11.7	.924	20	240	7,680	2340.9	8,680	2645.7	7450	2270.8	7120	2170.2	201	197	1600	487.7	1540	469.4	112	34.1	213
1-9	222	.313	503.7	228.5	520	235.9	50	10.0	.930	05	240	7,990	2435.4	8,820	2688.3	7670	2337.8	7490	2283.0	203	200	1700	518.2	1668	508.4	118	36.0	223
1-10	42	.297	501.1	227.3	520	235.9	78	25.6	.888	12	280	10,400	3169.9	9,800	2987.0	7390	2252.5	8630	2630.4	227	218	2400	731.5	1720	524.2	142	43.3	330
1-11	42	.301	510.7	231.6	520	235.9	66	18.9	.910	04	010	9,760	2974.8	9,460	2883.4	7820	2383.5	8400	2560.3	222	214	----	------	----	------	---	-----	---
1-12	222	.304	515.1	233.6	520	235.9	56	13.3	.921	07	045	8,230	2508.5	9,340	2846.8	7860	2395.7	7180	2188.5	205	198	2270	691.9	1950	594.4	175	53.3	211
1-13	42	.306	519.1	235.5	520	235.9	50	10.0	.928	Calm	---	9,740	2968.8	9,190	2801.1	7870	2429.3	8490	2587.8	226	217	----	------	----	------	---	-----	---
1-14	42	.301	517.9	234.9	520	235.9	56	13.3	.923	08	220	9,880	3011.4	9,440	2877.3	7930	2417.1	8400	2560.3	224	216	2290	698.0	1731	527.6	149	45.4	224
1-15	42	.301	518.4	235.1	520	235.9	58	14.4	.922	05	220	9,220	2810.3	9,260	2822.4	7820	2383.5	7880	2401.8	219	210	4210	1283.2	3419	1042.1	534	162.8	243
1-16	42	.300	517.7	234.8	520	235.9	80	26.7	.884	Calm	---	10,030	3057.1	10,320	3145.5	8260	2517.6	8140	2481.1	220	207	3920	1194.8	2548	776.6	274	83.5	234
1-17	222	.303	514.5	233.4	520	235.9	60	15.6	.913	16	220	8,000	2438.4	9,550	2910.8	7910	2411.0	6880	2097.0	200	192	2210	673.6	1808	551.1	168	51.2	214
1-18	42	.298	519.7	235.7	520	235.9	63	17.2	.919	Calm	---	8,590	2618.2	9,340	2846.8	7750	2362.2	7210	2197.6	211	202	2450	746.8	1848	563.3	135	41.1	218
1-19	42	.304	518.2	235.1	520	235.9	57	13.9	.926	06	250	10,500	3203.4	9,230	2813.3	7990	2435.4	9100	2773.7	233	225	2490	759.0	2016	614.5	205	62.5	240
1-20	42	.303	520.1	235.9	520	235.9	55	12.8	.926	08	250	9,240	2816.4	8,890	2709.7	7850	2392.7	8960	2731.0	220	212	2870	874.8	2314	705.3	238	72.5	232
1-21	222	.305	509.9	231.3	520	235.9	62	16.7	.914	10	280	8,500	2590.8	9,460	2883.4	7830	2386.6	7440	2267.7	207	200	2170	661.4	1837	560.5	179	54.6	219
1-23	42	.321	504.7	228.9	520	235.9	44	6.7	.955	Calm	---	8,270	2520.7	8,300	2529.8	7330	2234.2	8180	2493.3	216	215	2490	759.0	2384	726.6	294	89.6	232
1-24	42	.321	506.6	229.8	520	235.9	43	6.1	.951	Calm	---	8,180	2493.3	8,080	2462.8	7460	2273.8	8020	2444.5	214	212	1466	------	1459	444.7	91	27.7	219
1-26	42	.323	508.8	230.8	520	235.9	37	2.8	.959	11	050	7,560	2304.3	8,100	2468.9	7670	2337.8	7530	2295.1	205	203	1540	469.4	1668	508.4	124	37.8	218
1-27	42	.325	512.1	232.3	520	235.9	35	1.7	.971	Calm	---	8,380	2554.2	7,790	2374.4	7530	2295.1	8420	2566.4	220	219	2180	664.5	2681	817.2	250	76.2	233
1-29	42	.317	510.6	231.6	520	235.9	44	6.7	.948	Calm	---	7,740	2359.2	8,140	2481.1	7460	2273.8	7420	2261.6	209	206	1700	518.2	1579	481.3	111	33.8	215
1-30	42	.327	505.4	229.3	520	235.9	39	3.9	.969	Calm	---	7,760	2365.2	7,600	2316.5	7370	2246.4	7950	2414.0	212	212	1760	536.4	1794	546.8	185	56.4	220
1-32	42	.345	457.7	207.6	440	199.6	54	12.2	.930	01	170	7,820	2383.5	7,830	2386.6	6790	2069.6	6190	1886.7	214	203	2420	737.6	1874	571.1	267	81.4	227
1-33	42	.351	457.3	207.4	440	199.6	45	7.2	.948	Calm	---	6,780	2066.5	7,440	2267.7	6750	2057.4	6750	2057.4	202	194	1380	420.6	1027	313.0	141	43.0	210
1-34	222	.310	505.6	229.3	520	235.9	54	12.2	.969	07	265	7,180	2188.5	8,240	2511.6	7380	2249.4	7380	2249.4	197	197	1400	426.7	1325	403.9	73	22.3	207
1-35	42	.314	521.6	236.6	520	235.9	37	2.8	.964	02	335	7,570	2307.3	8,680	2645.7	7960	2426.2	7960	2426.2	204	200	1890	576.1	1524	464.5	106	32.3	208
1-36	42	.305	523.6	237.5	520	235.9	46	7.8	.954	10	090	7,560	2304.3	8,980	2737.1	8160	2487.2	6840	2084.8	198	192	2340	713.2	2161	658.7	177	53.9	215
1-37	222	.294	513.3	232.8	520	235.9	66	18.9	.905	10	240	8,450	2575.6	10,360	3157.7	8350	2545.1	7220	2200.7	199	191	2340	713.2	1650	502.9	109	33.2	215
1-38	42	.312	516.0	234.0	520	235.9	52	11.1	.955	15	090	7,700	2347.0	8,900	2712.7	8140	2481.1	7250	2209.8	199	196	1930	588.3	1798	548.0	99	30.2	212
1-39	42	.307	515.7	233.9	520	235.9	56	13.3	.940	13	060	7,580	2310.4	9,190	2801.1	8090	2465.8	6890	2100.1	196	191	2420	737.6	2164	659.6	167	50.9	217
1-40	42	.301	514.5	233.4	520	235.9	62	16.7	.916	Calm	---	9,140	2785.9	9,540	2907.8	7940	2420.1	7880	2401.8	215	207	2310	704.1	1891	576.4	184	56.1	224
1-45	222	.287	521.4	236.5	520	235.9	72	22.2	.892	08	260	9,100	2773.7	10,910	3325.4	8330	2539.0	7090	2161.0	205	194	2510	765.0	1419	432.5	88	26.8	217
1-47	42	.296	520.8	236.2	520	235.9	71	21.7	.912	15	065	8,930	2721.9	10,030	3057.1	8320	2535.9	7510	2289.0	207	198	2380	725.4	1914	583.4	188	57.3	231
1-59	222	.306	500.4	226.9	520	235.9	49	9.4	.939	12	290	8,460	2578.6	8,283	2524.6	7061	2152.2	7837	2388.7	219	216	1495	455.7	1310	399.3	116	35.4	225
2-4	42	.297	494.0	224.1	480	217.7	86	30.0	.872	08	210	10,070	3069.3	10,774	3283.9	7730	2356.1	6880	2097.0	223	206	2270	691.9	897	273.4	55	16.8	222
2-5	42	.311	491.4	222.9	480	217.7	66	18.9	.899	12	060	8,160	2487.2	9,454	2881.6	7550	2301.2	6290	1917.2	210	197	2065	629.4	1365	416.1	148	45.1	224
2-6	42	.303	507.2	230.1	520	235.9	67	19.4	.905	03	065	8,680	2645.7	9,427	2873.3	7670	2337.8	7530	2295.1	210	202	2150	655.3	1714	522.4	152	46.3	220
2-7	222	.291	507.4	230.2	520	235.9	81	27.2	.881	08	035	10,100	3078.5	10,159	3096.5	7590	2313.4	8040	2450.6	222	210	2680	816.9	1780	542.5	114	34.7	223
2-8	42	.287	500.2	226.9	520	235.9	90	32.2	.868	Calm	---	10,420	3176.0	10,442	3182.7	7460	2273.8	8150	2484.1	222	210	4090	1246.6	2808	855.9	263	80.2	234
2-10	42	.308	512.4	232.4	520	235.9	65	18.3	.934	Calm	---	8,630	2630.4	9,080	2767.6	7850	2392.7	7800	2377.4	211	206	3640	1109.5	3002	915.0	287	87.5	226
2-11	42	.296	507.8	230.3	520	235.9	74	23.3	.897	02	190	9,910	3020.6	9,950	3032.8	7760	2365.2	8250	2514.6	220	211	2940	896.1	2087	636.1	171	52.1	227
2-12	42	.312	522.3	236.9	520	235.9	37	2.8	.966	02	044	8,010	2441.4	8,590	2618.2	8050	2453.6	7550	2301.2	208	204	3190	972.3	3044	927.8	297	90.5	225
2-13	42	.313	520.9	236.3	520	235.9	41	5.0	.958	Calm	---	7,880	2401.8	8,770	2673.1	7870	2398.8	7360	2243.3	208	204	2600	792.5	2289	697.7	214	65.2	220
2-15	42	.307	529.1	240.0	520	235.9	44	6.7	.950	03	175	8,570	2612.1	9,060	2761.5	8320	2535.9	7620	2322.6	212	206	4620	1408.2	3813	1162.0	432	131.7	233
2-16	42	.304	530.6	240.7	520	235.9	44	6.7	.940	Calm	---	9,580	2920.0	9,680	2950.5	8690	2648.7	8270	2520.7	219	210	3740	1140.0	2979	908.0	334	101.8	236
2-17	42	.316	531.5	241.1	520	235.9	30	-1.1	.981	Calm	---	7,910	2411.0	8,390	2557.3	8390	2557.3	7540	2298.2	209	204	3910	1191.8	3756	1144.8	391	119.2	229
2-18	42	.319	520.5	236.1	520	235.9	34	1.1	.974	Calm	---	8,170	2490.2	8,340	2542.0	8150	2484.1	7980	2432.3	211	208	4070	1240.5	3960	1207.0	493	150.3	236
2-19	42	.307	520.4	236.0	520	235.9	44	6.7	.936	06	315	8,380	2554.2	9,070	2764.5	8060	2456.7	7520	2292.1	210	203	1675	510.5	1328	404.8	44	13.4	212
2-20	42	.304	536.1	243.2	520	235.9	37	2.8	.961	04	225	9,290	2831.6	9,370	2856.0	8770	2673.1	8130	2478.1	218	210	3550	1082.0	2960	902.2	302	92.0	229
2-21	42	.303	538.2	244.1	520	235.9	41	5.0	.962	05	045	9,170	2795.0	9,860	3005.3	9290	2831.6	7980	2432.3	210	203	3120	951.0	2477	755.0	368	81.7	228
2-22	42	.292	536.3	243.3	520	235.9	54	12.2	.930	Calm	---	9,110	2776.7	9,820	2993.1	8440	2572.5	7340	2237.2	214	203	3590	1094.2	2467	751.9	219	66.8	225
2-23	222	.291	535.7	243.0	520	235.9	56	13.3	.928	17	270	8,700	2651.8	10,760	3279.6	9060	2761.5	6970	2124.5	199	189	----	------	----	------	---	-----	---
2-27	42	.326	497.1	225.5	480	217.7	38	3.3	.955	Calm	---	7,950	2423.2	8,800	2682.2	8110	2471.9	6830	2081.8	211	203	2110	643.1	1665	507.5	170	51.8	220
2-37	42	.296	531.1	240.9	520	235.9	52	11.1	.933	04	220	9,450	2880.4	10,020	3054.1	7840	2389.6	7320	2231.1	215	206	----	------	----	------	---	-----	---
2-41	42	.273	528.8	239.9	520	235.9	85	29.4	.872	Calm	---	10,380	3163.8	11,230	3422.9	8290	2526.8	7230	2203.7	218	203	3200	975.4	1428	435.2	117	35.7	221
2-44	222	.287	534.2	242.3	520	235.9	69	20.6	.902	18	280	9,390	2862.1	10,770	3282.7	7920	2414.0	7140	2176.3	208	196	1930	588.3	1334	406.6	58	17.7	222



(a) Rotation 20 knots prior to intended lift-off. $t_r = 42.5$ *sec;* $t_{LOF} = 47.5$ *sec;* $t_a = 51.5$ *sec;* $V_{i_r} = 187$ *knots;* $V_{i_{LOF}} = 206$ *knots;* $V_{i_a} = 215$ *knots.*

Figure 2. Time histories of two typical XB-70 takeoffs.



(b) Rotation 30 knots prior to intended lift-off. $t_r = 41.0$ *sec;* $t_{LOF} = 49.5$ *sec;* $t_a = 58.5$ *sec;* $V_{i_r} = 186$ *knots;* $V_{i_{LOF}} = 212$ *knots;* $V_{i_a} = 225$ *knots.*

Figure 2. Concluded.

is generally ±0.1g, the magnitude increases with distance forward of this location until, at the cockpit, the variation is nearly ±0.5g. Compared with the other locations shown, the cockpit acceleration trace tends to have sharper peaks, which are approximately 180° out of phase with similar traces for these other locations. In accordance with the pilots' observations, figure 2(a) shows that the normal accelerations significantly increase after a speed of approximately 90 knots is reached and then tend to decrease at higher speeds well before rotation. The data also show that the accelerations increase again near the time of rotation, but the pilots did not find them to be particularly objectionable at this point. Once the nose was raised to 8° attitude, where most of the weight was off the main gear, the cockpit acceleration was comparable to the other accelerations.

Figure 3 substantiates the general opinion of the pilots that the rough ride of the XB-70 airplane did not materially affect their ability to initiate the rotation maneuver. The data were obtained from pilot reports on the intended versus the actual rotation speeds. When compared with the 45° line of perfect agreement, the speed differences are satisfactorily small. Considering the transient nature of these observations and the variety of cockpit instruments used during the test program, the accuracy of this information is within approximately 2 knots.

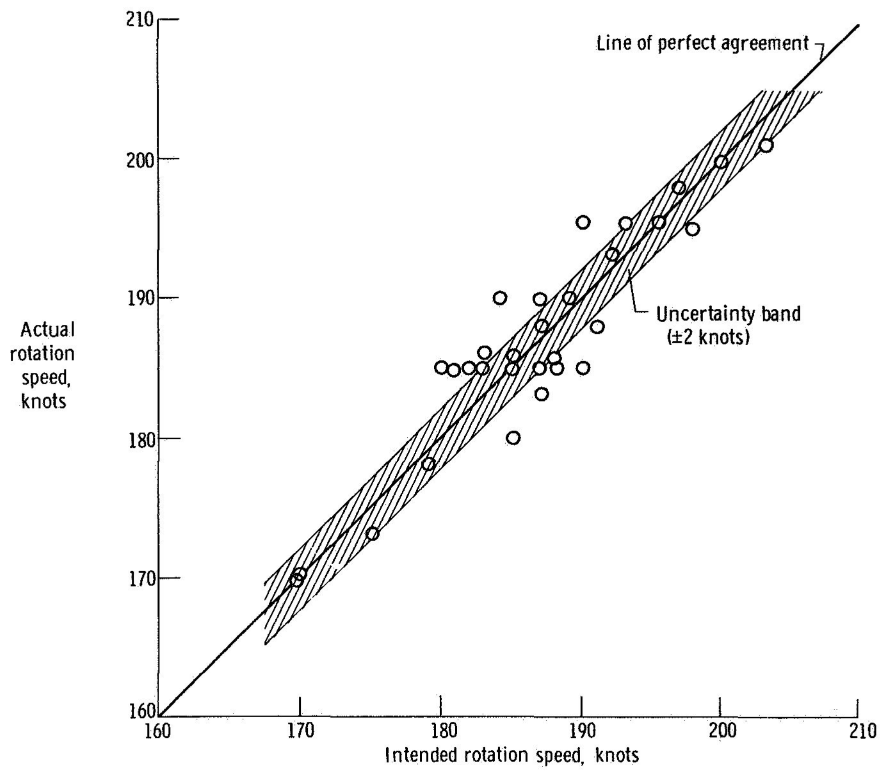
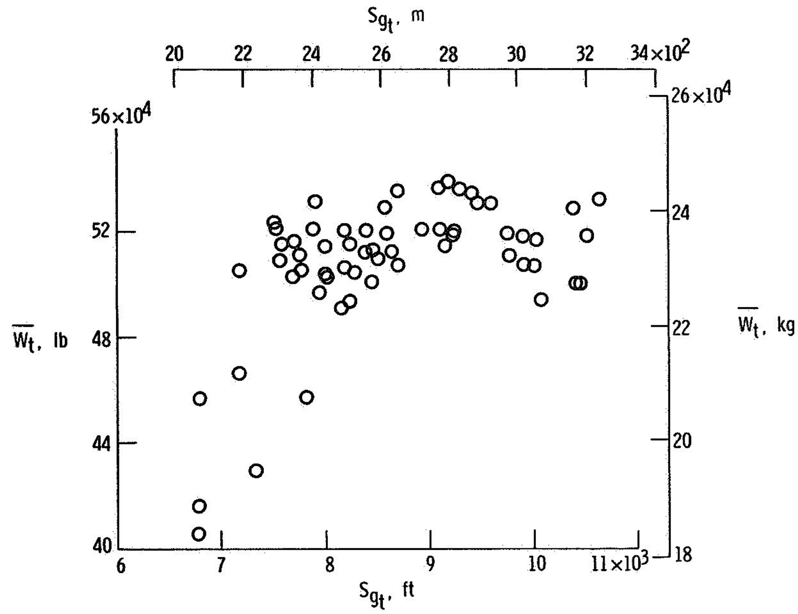


Figure 3. Comparison of actual velocity at initiation of rotation with intended velocity.

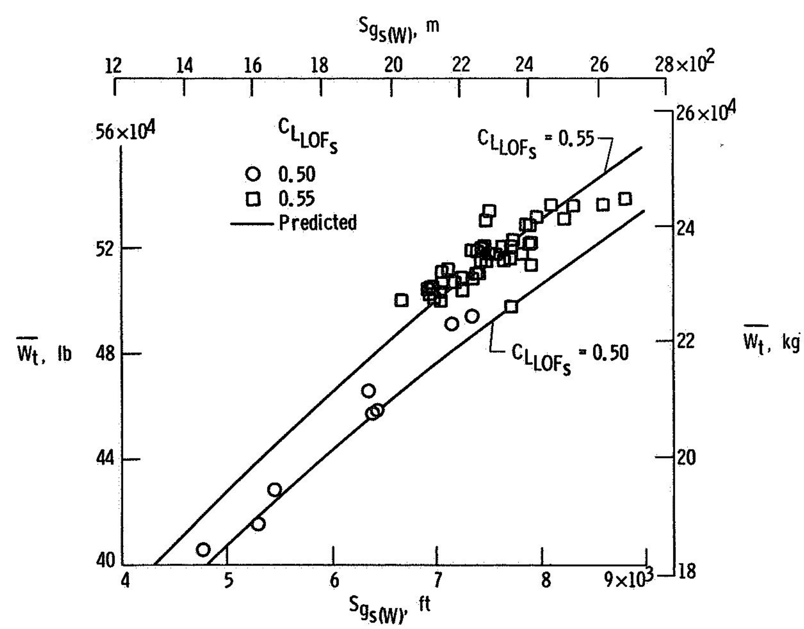
As discussed later, the variations in technique of rotating the aircraft (slow or fast, overrotations or underrotations) caused large differences in takeoff performance. The faster rotations, initiated 20 knots prior to intended lift-off, were favored by the pilots because it was easier to attain the desired lift-off conditions. For example, figure 2(b) shows that, when rotation was initiated 30 knots prior to intended lift-off, the desired takeoff attitude was attained approximately 2 seconds prior to lift-off. Figure 2(a) indicates that the takeoff attitude was attained coincidentally with lift-off when rotation was initiated 20 knots prior to intended lift-off.

Predicted and Measured Ground Roll Performance

The takeoff performance of the XB-70 airplane was greatly affected by variations of atmospheric conditions, airplane weight, and pilot technique of rotating the airplane prior to lift-off. The fact that weight alone was not the sole factor is reflected in figure 4(a), which presents the test ground roll distance to lift-off as a function of average aircraft weight during ground roll. Although all the takeoffs were from the same runway, a dispersion of about 3000 feet (900 meters) resulted for a typical weight of 520,000 pounds (236,000 kilograms). Figure 4(b) presents takeoff performance with



(a) Uncorrected data.



(b) Standardized data.

Figure 4. Variation of XB-70 ground roll distance at lift-off with average aircraft weight during ground roll.

the same data points shown in figure 4(a) but with distances corrected to zero wind, constant lift coefficient at lift-off, and standard thrust and air density. The predicted performance curves, to be discussed later, are based on the simplified calculation outlined in appendix B and on the lift, drag, and thrust curves of reference 8. The lighter weight takeoffs (< 500,000 lb (227,000 kg)) were corrected to a $C_{L_{LOF_s}}$ of 0.50, and the data of the heavier weight takeoffs ($W_t \geqq$ 500,000 lb (227,000 kg)) were corrected to a $C_{L_{LOF_s}}$ of 0.55.

The close correlation of the magnitudes and trends of the test data and predicted curves in figure 4(b) shows that the standardization procedures of appendix A effectively account for variations between test and standard conditions. Further verification of this is shown in figure 5, in which the variations of standardized velocity with standardized ground distance at rotation for several airplane weights are presented. The predicted curves (based on appendix B) indicate larger ground roll distances than shown by the test data. Other performance data on the XB-70 airplane indicate that the predicted thrust of reference 8 is approximately 3 percent low, which accounts for most of the 300- to 400-foot (90- to 120-meter) discrepancy in ground roll distance for a 520,000-pound (236,000-kilogram) airplane. Thus, it is concluded that the simple prediction techniques are adequate for determining distance as a function of velocity at initiation of rotation to an accuracy of about 100 feet (30 meters). The ±250 feet (±75 meters) of scatter in the takeoff data at a given velocity is attributed to variations in pilot techniques in advancing the throttles to maximum afterburner during the initial ground roll and to slight inaccuracies in the test data and correction procedures used.

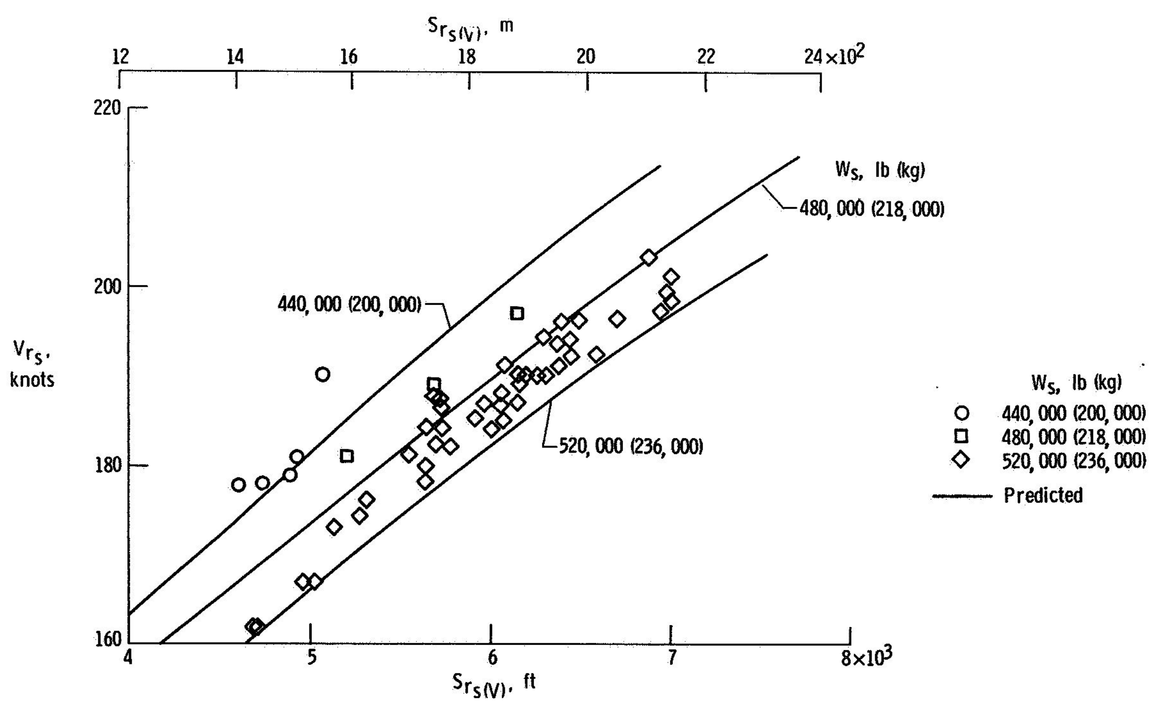


Figure 5. Variation of XB-70 ground roll distance at initiation of rotation with velocity.

Effects of rotation on ground roll performance.— Figure 6 shows the variation of velocity with standardized ground distance at lift-off for several airplane weights. The predicted curves from figure 5 are presented for reference. Although it appears that flight and predicted results agree, this is not a valid comparison because the predicted curves do not include the effects of rotation. Also, the predicted curve for 520,000 pounds (236,000 kilograms) would be as much as 400 feet (120 meters) shorter than indicated by the data if corrected for the deficiency in predicted thrust, as just discussed. This 400-foot (120-meter) difference is caused by the variations in drag due to lift during a nominal rotation and should be accounted for in the predictions. These effects of rotation become apparent when the flight results of figures 5 and 6 are compared. The apparent increase in scatter in figure 6 of approximately 300 feet (90 meters) at a given velocity over the scatter in figure 5 is caused by the variations in pilot technique in rotating the aircraft to the takeoff attitude. This too should be accounted for in more precise predictions.

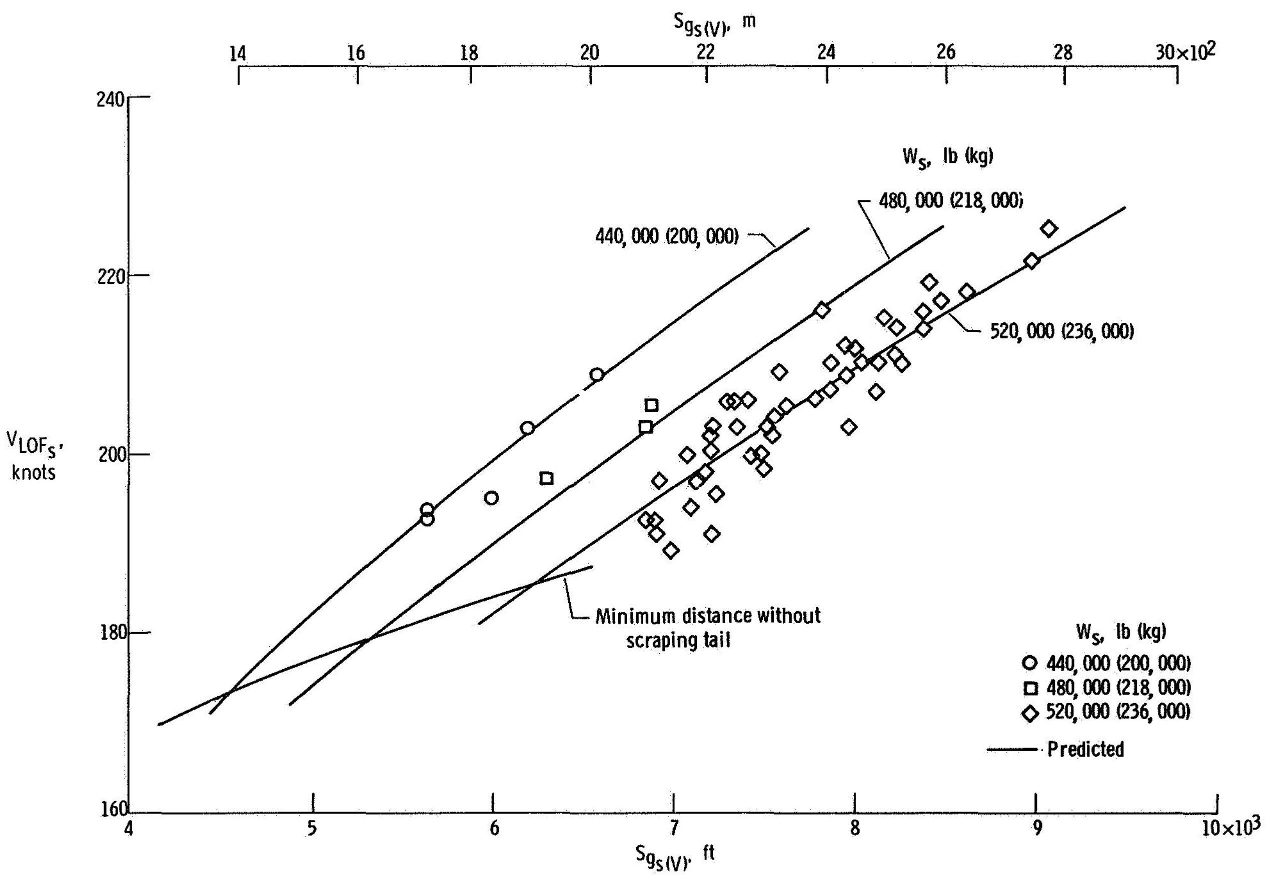


Figure 6. Variation of XB-70 ground roll distance at lift-off with velocity.

The complexity of predicting the effects on performance of all possible rotation techniques is illustrated in figure 7. This figure shows only one class of rotation, in which it is assumed that the pilot initiates the rotation at the intended speed and that he arrives at a designated steady-state attitude. Also shown are the predicted lift-off boundaries for takeoff and zero-acceleration boundaries for an airplane weight of

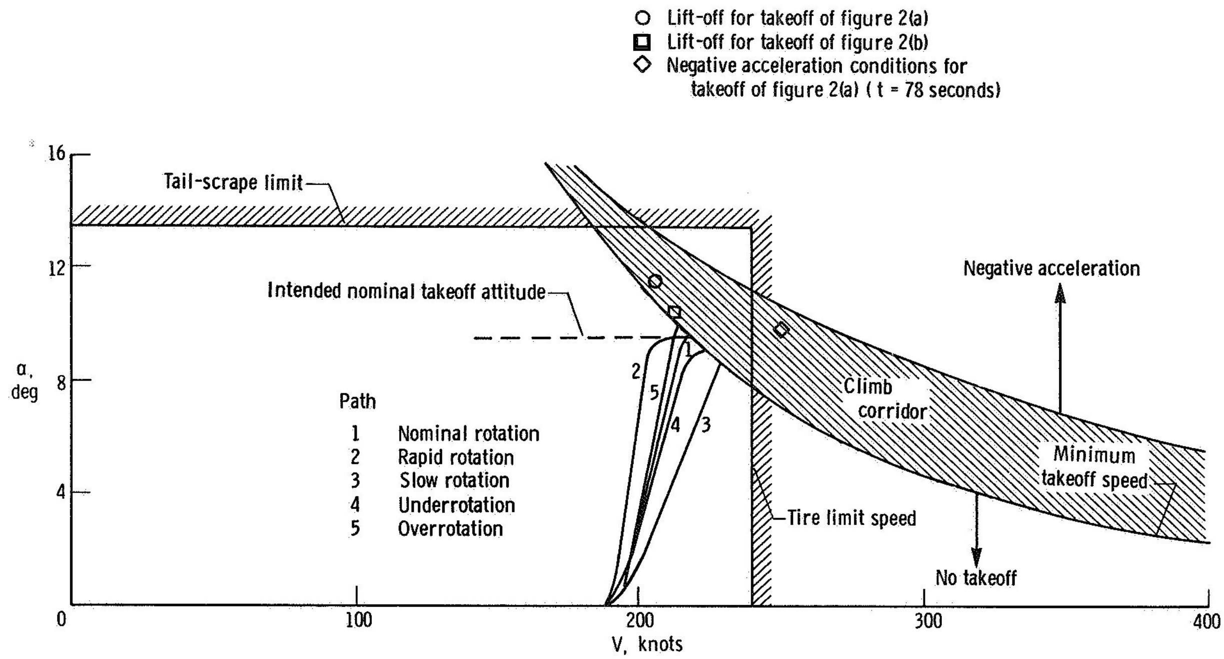


Figure 7. XB-70 envelope of angle of attack and velocity for takeoff. W = 520,000 lb (236,000 kg).

520,000 pounds (236,000 kilograms) (based on ref. 8). Data from the takeoff time histories (fig. 2) are also shown for reference. Only a general comparison is intended, because the curves are calculated for standard, sea-level conditions and the data points are actual test conditions.

Path 1 of figure 7 represents a nominal rotation for which the airplane arrives at the intended attitude at the proper velocity for takeoff. Path 2 indicates a rapid rotation in which the drag and distance penalty paid depends on how early the airplane reaches the takeoff attitude. Path 3 illustrates a slow rotation in which the airplane lifts off before the desired attitude is reached. The distance penalty lies in the time and distance it takes to accelerate to the higher speed. Path 4 represents an underrotation with performance penalties similar to those for the slow rotation (path 3). Path 5 shows an overrotation which, when executed properly, can produce shorter ground roll; however, it places the airplane nearer the limits imposed by the tail-scrape angle and the zero-acceleration boundary and minimum control speeds for engine-out conditions. When other types of rotation techniques are included, the matrix of conditions to be considered becomes very large.

To further illustrate the effects of rotation on XB-70 performance, figure 8 presents the velocity change during the rotation phase versus the corresponding time to rotate the aircraft. For takeoffs with intended rotation velocity increments of 20 knots, the actual increments varied from 9 knots lower to 2 knots higher than the intended 20 knots. For the takeoffs with intended increments of 30 knots, the actual values varied from 3 to 7 knots lower than desired. These results show that the actual velocity changes were generally less than intended. This dispersion resulted mainly from variations in the rotation profiles, such as those shown in figure 7. Note that the dispersion of rotation time is directly proportional to the nominal rotation times

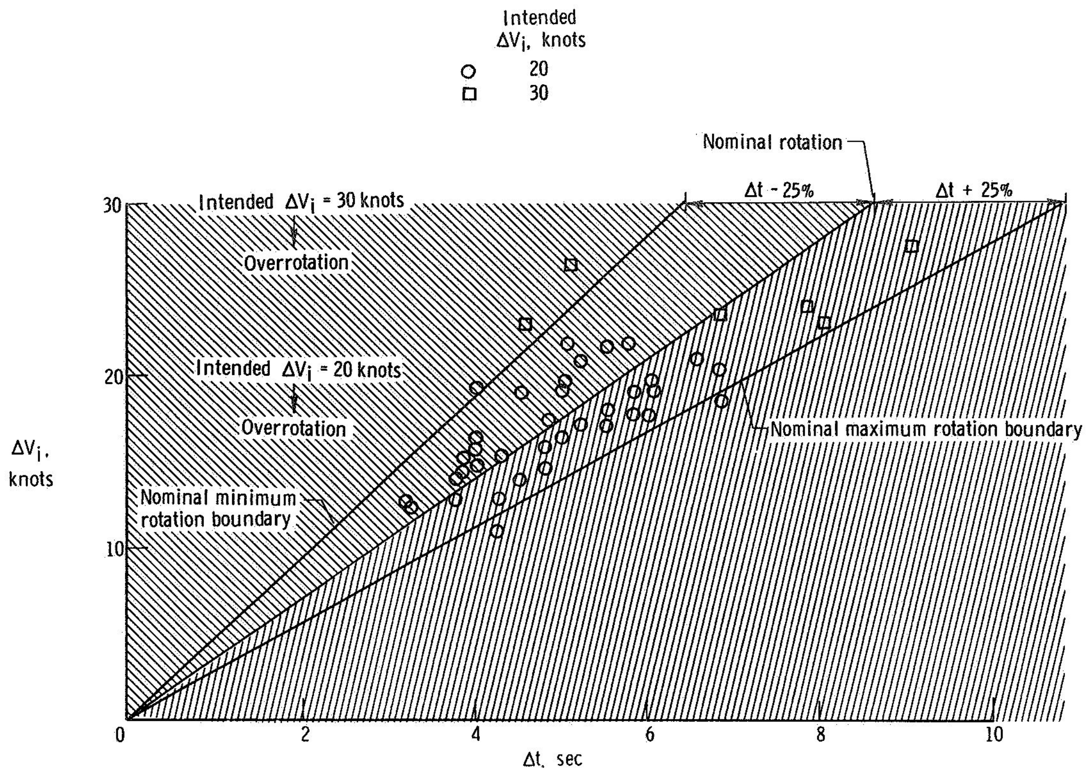


Figure 8. XB-70 incremental speed change during rotation as a function of rotation time.

and generally falls within 25 percent of the nominal. The large dispersion in rotation times for the intended 30-knot velocity increments represents a variation in takeoff distance of 1500 feet (460 meters).

Also, as indicated in figure 8, rotations covering less than the planned velocity increment tend toward an overrotation condition, because a higher takeoff attitude generally results. This tendency toward overrotation was not considered to be a problem for the XB-70 airplane when rotations were initiated 20 knots prior to lift-off; however, rotations initiated 30 knots prior to lift-off usually resulted in early arrival at the takeoff attitude, overrotation, or both.

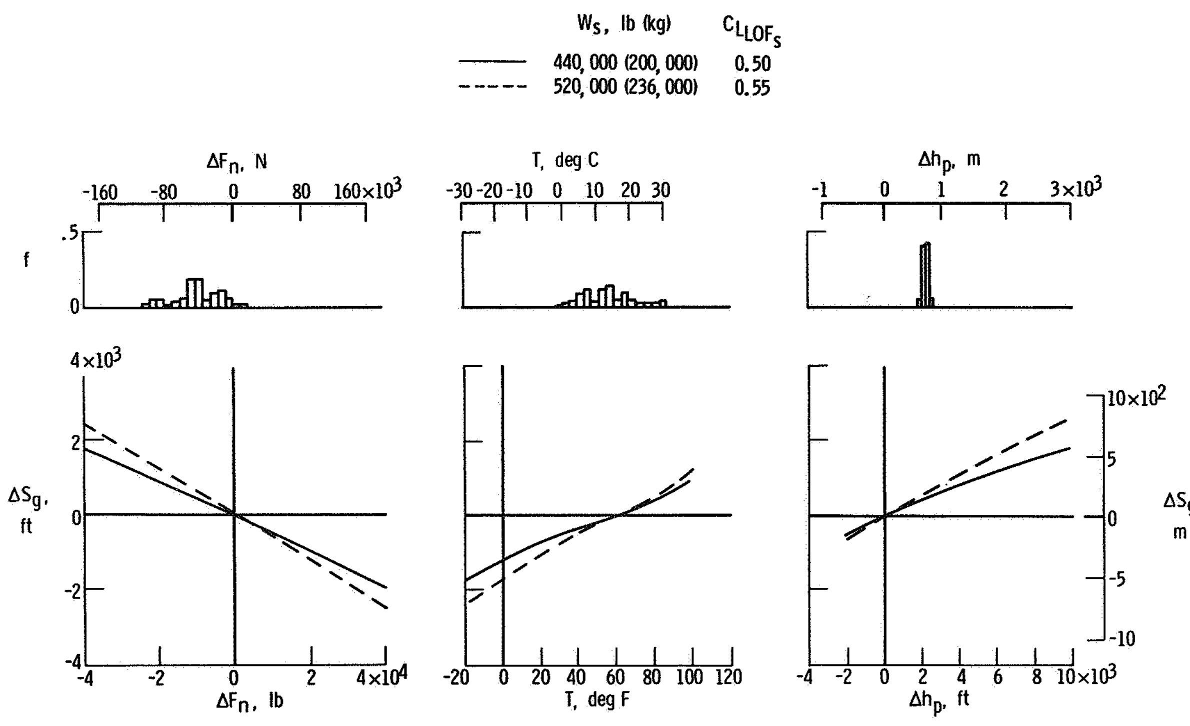
From this discussion, it is evident that pilot techniques of rotating the XB-70 airplane had significant effects on the takeoff performance. Further, these effects were not accounted for in the conventional means of standardizing takeoff data or in predicting the takeoff performance of the XB-70 airplane. The effect of varying rotation techniques on takeoff performance can be analyzed. (See, for example, reference 1.) However, more work is required to include rotation variables in standardizing test data and in more fully defining the rotation effects on performance from a limited number of takeoff tests.

Effects of other variables on ground roll performance. — The effects of individual parameters such as temperature, pressure, density, wind, runway slope, and friction on ground roll distance were evaluated by using the equations of appendix A. Shown in figure 9 are the effects of these parameters on ground roll distance as they vary from sea-level standard conditions. Included are the distributions of these quantities from standard values for the 59 XB-70 takeoffs studied. Thus, the figure shows the amount by which ground roll distances were aided or penalized by variations of each parameter for the tests. For example, the frequency-distribution bar graph in figure 9(a) indicates that 40 percent of the tests had thrust values of 8000 pounds (35,600 newtons) to 12,000 pounds (53,400 newtons) lower than standard, sea-level thrust. These variations were accounted for in the standardization. As seen, a correction of this magnitude causes the standard distance to be about 500 feet (150 meters) less than measured. Also, as shown, the ground roll distances had a dispersion of about 1500 feet (460 meters) because of thrust variations alone.

Figures 9(b) and 9(c) show the effect of temperature and ambient pressure (pressure altitude) on ground roll distance resulting from their effect on thrust. As shown, temperature was much more significant than pressure altitude; pressure-altitude variation resulted in only approximately 200 feet (60 meters) of distance change.

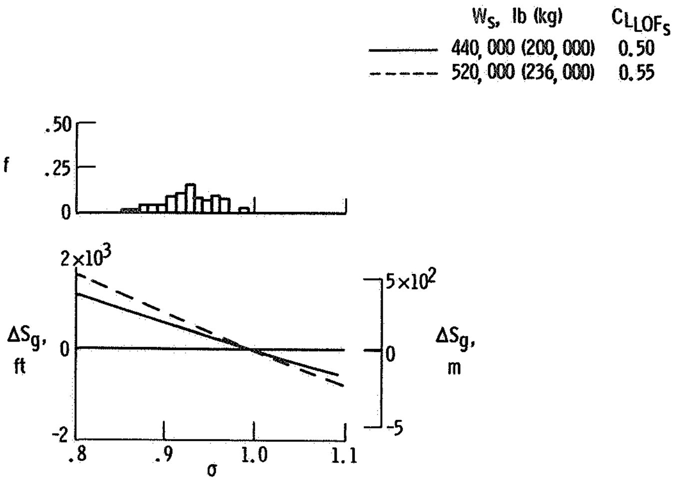
Figures 9(d) and 9(e) show the effect of ambient density and wind, respectively, on the measured ground roll distances. Density variations accounted for approximately 1000 feet (300 meters) variation in ground roll distance, and wind variations accounted for about 1500 feet (460 meters) dispersion.

Figures 9(f) and 9(g) show the effects of runway grade and rolling friction on XB-70 ground roll distance. Because all tests were conducted from the same relatively flat, dry runway, no frequency-distribution bar graphs are presented.

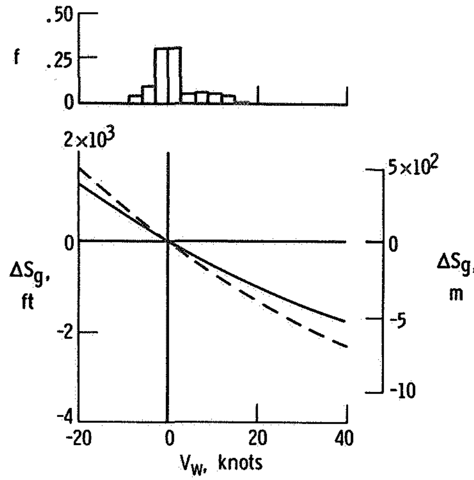


(a) Thrust. *(b) Temperature.* *(c) Pressure altitude.*

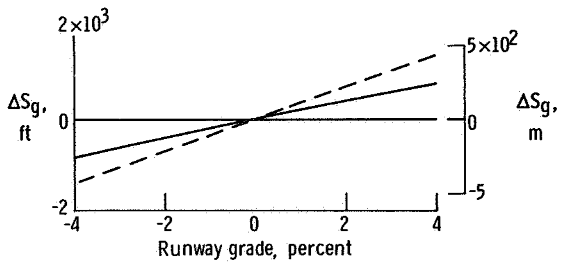
Figure 9. Effect of variation of takeoff parameters on XB-70 ground roll distance.



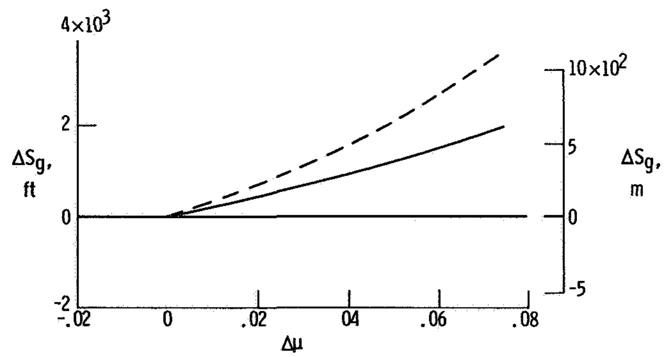
(d) Density.



(e) Headwind.



(f) Runway grade.



(g) Coefficient of rolling friction.

Figure 9. Concluded.

Air-Phase and Field-Length Performance

Figure 10 presents the standardized air-phase performance in terms of distance versus specific kinetic-energy gain h_V from lift-off to a height of 35 feet (10.7 meters). Distances are standardized for ambient density, thrust, and airplane weight and are corrected to a zero-wind condition. As noted in appendix A, the standardization equation assumes that test and standard lift coefficients are the same at takeoff and at the air-phase height of 35 feet (10.7 meters). When h_V is zero, all the excess thrust is used for climbing, without any increase in speed. In this instance, the predicted minimum air-phase distance is 280 feet (85 meters) for an airplane weight of 520,000 pounds (236,000 kilograms). It should be noted that, under normal operating conditions, the air-phase distances ranged between 800 feet (240 meters) and 4000 feet (1200 meters), indicating that an accelerating climbout was preferred by the pilots.

The predicted air-phase performance curves shown in figure 10 were calculated by using equation (B5). These curves represent the average of the test lift coefficients

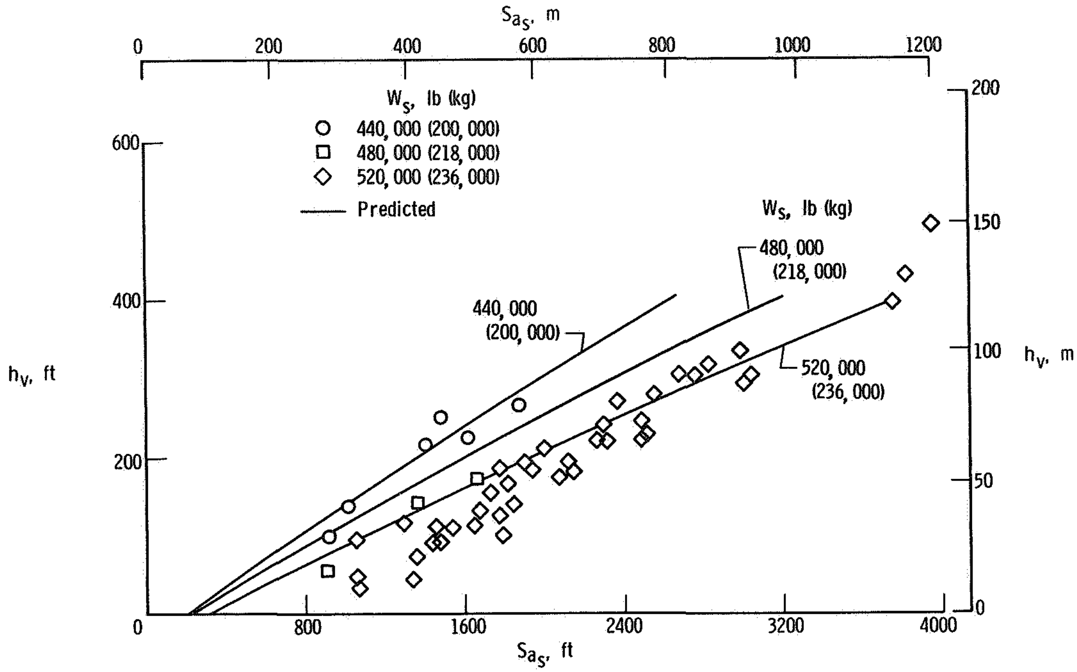


Figure 10. Variation of XB-70 air-phase distance with kinetic-energy gain during initial climb to a height of 35 feet (10.7 meters).

at lift-off. For an energy gain of less than 200 feet (60 meters), the predicted air-phase distances are shorter than indicated by the flight data, because the angle of attack after lift-off for the steeper climbouts (i.e., those associated with small h_V) generally increases over that at lift-off. This causes higher drag and, hence, longer distances for a given energy value than when angle of attack is not increased. The larger test air-phase distances agree well with predictions because, for the more gradual climbouts, the angle of attack was generally constant after lift-off. (See fig. 2(b).)

The standardized takeoff performance is shown in figure 11 as total distance from brake release to the air-phase height. The predicted curves are for constant kinetic-energy increments h_V and an airplane weight of 520,000 pounds (236,000 kilograms). These predicted curves are based on a constant lift coefficient. The minimum total takeoff distance to clear a 35-foot (10.7-meter) obstacle is shown. This minimum distance is a function of the minimum lift-off speed and the climb gradient as indicated by the energy gain during the climbout. The nominal operational performance, indicated as a fairing of the 520,000-pound (236,000-kilogram) test data, parallels the minimum curve. As indicated for a 200-foot (60-meter) energy gain, the nominal performance is approximately 500 feet (150 meters) longer than the predicted minimum distance. The inset in figure 11 shows the lift-off speeds required for minimum distance as a function of the energy gain h_V during the airphase. The lift-off speeds corresponding to the minimum distances for a 200-foot (60-meter) h_V are approximately 5 knots greater than the minimum lift-off speeds defined by the tail-scrape angle in figure 6.

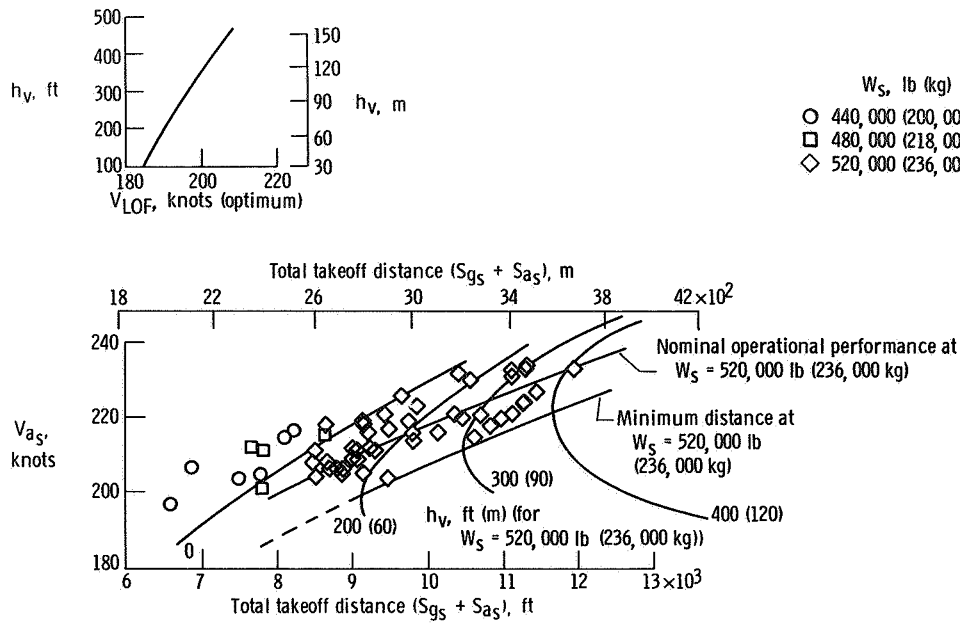
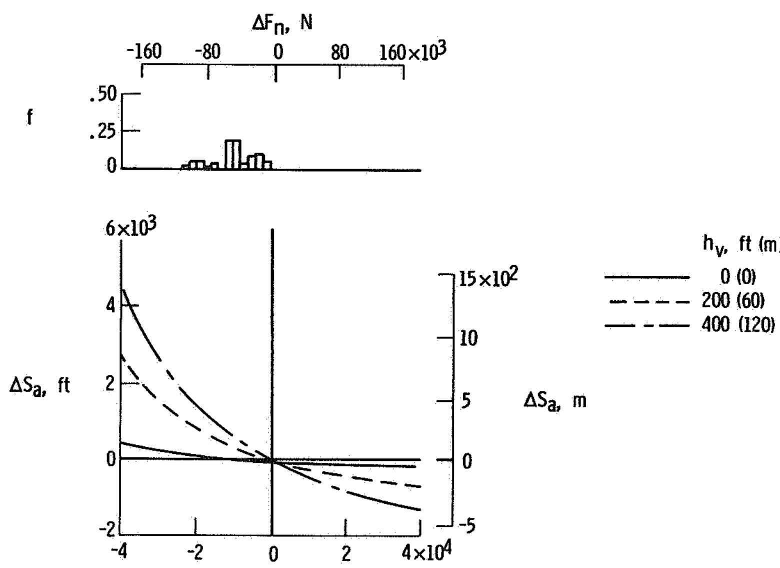


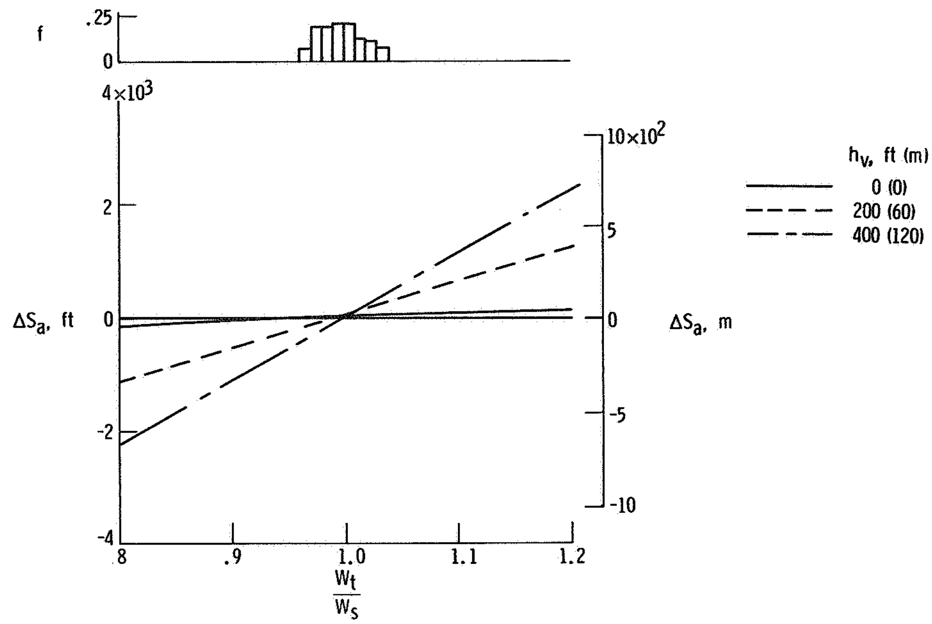
Figure 11. Variation of XB-70 takeoff distance with velocity at a height of 35 feet (10.7 meters).

Figures 12(a) to 12(c) show the effect of variations of thrust, weight, and ambient density, respectively, on air-phase distance. Also included, as in figure 9, are frequency-distribution bar graphs. As shown, for small values of h_V (i.e., minimum-distance air-phase climbouts), air-phase corrections are generally small. Of the three parameters, thrust caused the largest variation in air-phase distance; on some takeoffs a thrust deficiency increased the air-phase distance by more than 1500 feet (460 meters).

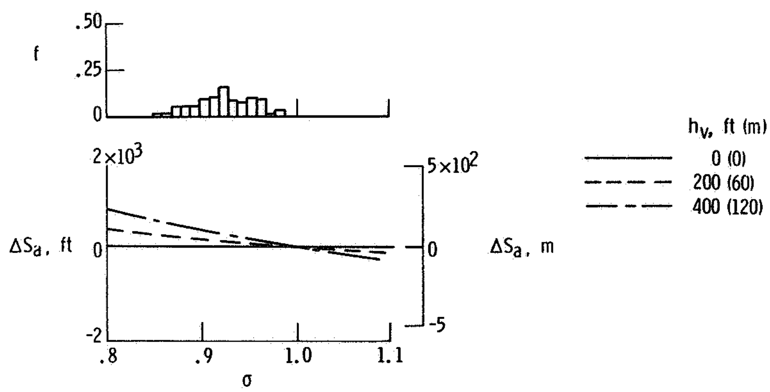


(a) Thrust.

Figure 12. Effect of variation of takeoff parameters on XB-70 air-phase distance. W_s = 520,000 lb (236,000 kg).



(b) Weight.



(c) Density.

Figure 12. Concluded.

CONCLUDING REMARKS

Analysis of takeoff performance data for the XB-70 airplane and comparison of the data with simple predictions led to the following conclusions, which may be pertinent to other supersonic aircraft of similar configurations. (All specific performance values are for a takeoff weight of 520,000 pounds (236,000 kilograms).)

Simplified performance prediction equations adequately represented the takeoff performance prior to rotation. For example, distance from brake release to initiation of rotation was determined with the variation of velocity to an accuracy of approximately 100 feet (30 meters). Refined prediction techniques need to be applied to properly account for performance during the rotation phase, which is significantly affected by varying aerodynamic drag.

Because of the significant drag at the high aircraft attitudes required for takeoff, the standardized ground roll distance for a given velocity was increased nominally by 400 feet (120 meters) over that which would occur with no increase in drag. Variations in pilot technique to rotate the aircraft caused a 300-foot (90-meter) dispersion in ground roll distance at a given velocity. The shorter duration rotations initiated 20 knots prior to lift-off were preferred because they minimized the rotation distance and were more easily executed.

Standardized performance for all engines operating during climb from lift-off to a height of 35 feet (10.7 meters) (air phase) was marginal because of low longitudinal accelerations, resulting from high induced drag at lift-off attitude. Air-phase distances varied from 800 feet (240 meters) to 4000 feet (1220 meters), depending on the climbout technique used. The nominal air-phase performance resulting from the tests was only 500 feet (150 meters) longer than for the theoretical minimum distance for any given energy gained.

The conventional methods used for standarizing takeoff distance were generally satisfactory prior to rotation; however, additional work is required to include rotation variables in standardizing test data and in more fully defining the rotation effects on performance from a limited number of takeoff tests.

Flight Research Center,
National Aeronautics and Space Administration,
Edwards, Calif., September 18, 1970.

APPENDIX A

STANDARDIZATION PROCEDURES FOR EVALUATING TAKEOFF PERFORMANCE

The analysis of takeoff data requires that the random, test-day, atmospheric conditions and pilot techniques be normalized to standard conditions. Procedures and equations for accomplishing this are presented in references 9 and 10. Interpretation and application of these procedures and equations to evaluation of the XB-70 performance are discussed in this appendix.

Standardization of Ground Roll Distance

Distance related to weight. – Corrections are first made to refer the test distance to zero wind, constant lift coefficient, and zero runway grade. The latter correction was not necessary for the tests of this report. Wind corrections were made by using the following equation (from refs. 9 and 10):

$$S_{g_W} = S_{g_t}\left(\frac{V_{LOF} + V_W}{V_{LOF}}\right)^{1.85} \tag{A1}$$

in which the velocities V_{LOF} and V_W are measured with respect to the ground. The value of the exponent in this equation is an empirical value that corrects distance variations resulting from dependence of excess thrust on wind.

To effectively eliminate the lift-off velocity V_{LOF} as a variable for determining the relationship of ground roll distance to aircraft weight, the ground roll distance is corrected to a constant lift coefficient $C_{L_{LOF_s}}$ by using the equation

$$S_{g_{C_L}} = S_{g_t}\left(\frac{\overline{a_{x_t}}}{\overline{a_{x_{C_L}}}}\right)\left(\frac{V_{LOF_{C_{L_s}}}}{V_{LOF_t}}\right)^2 \tag{A2}$$

where

$$V_{LOF_{C_{L_s}}} = \left(\frac{W_t - F_{n_{LOF_t}} \sin \alpha_{LOF_t}}{0.5\rho S C_{L_{LOF_s}}}\right)^{1/2} \tag{A3}$$

which results from equating aircraft weight with aerodynamic lift and vertical component of thrust at the selected value of lift coefficient $C_{L_{LOF_s}}$. The contribution of the thrust term is not included in reference 9, but must be taken into account for the large thrust values of the XB-70 airplane if an error of several hundred feet in standardized distance is to be avoided. The value of $F_{n_{LOF_t}}$ in equation (A3) was used as 150,000 pounds (667,200 newtons), and α_{LOF_t} was assigned a value of 9.9°, corresponding to a $C_{L_{LOF_s}}$ of 0.50, and 10.9°, for a $C_{L_{LOF_s}}$ of 0.55, representing an average of the test conditions.

The term $\frac{\overline{a_{x_t}}}{\overline{a_{x_{C_L}}}}$ can vary significantly from 1 if a_x varies much with lift-off speed. However, a value of 1 was found to be satisfactory for the XB-70 performance evaluation.

After the test ground roll distance S_{g_t} is corrected to zero wind, constant $C_{L_{LOF_s}}$, and zero runway grade, it can be further corrected to standard weight, density, and thrust by using the equation

$$S_{g_s} = S_{g_c}\left[\frac{\frac{W_s}{\overline{W_t}}\frac{\sigma_t}{\sigma_s}}{\frac{2g}{\overline{W_t}}\frac{S_{g_c}}{\left(V_{LOF}\right)^2}\left(\frac{\overline{W_t}}{W_s}\overline{F_s} - \overline{F_t}\right) + 1}\right] \tag{A4}$$

where S_{g_c} is the previously corrected test ground roll distance. For standardizing the distance to establish its weight dependence, the standard weight is set equal to the test weight.

For XB-70 performance evaluation, the average thrust values $\overline{F_t}$ and $\overline{F_s}$ were approximated by using the test values at $V = 0.75V_{LOF}$, as suggested in reference 9. Because aircraft-measured thrust data were limited, the engine manufacturer's specification curves (ref. 11) were used to obtain both $\overline{F_{g_s}}$ and $\overline{F_{g_t}}$, and these values were used in lieu of $\overline{F_{n_s}}$ and $\overline{F_{n_t}}$. This procedure is satisfactory because the value of the quantity $\left(\frac{\overline{W_t}}{W_s}\overline{F_{g_s}} - \overline{F_{g_t}}\right)$ (eq. (A4)) is acceptably close to the value of $\left(\frac{\overline{W_t}}{W_s}\overline{F_{n_s}} - \overline{F_{n_t}}\right)$. The adequacy of this approximation was verified during the takeoffs for which values of measured thrust were available. However, because F_{g_s} values from reference 11 are larger than corresponding values of F_{n_s} based on the few available thrust measurements, ground roll and air-phase standardized distance corrections based on $\overline{F_{g_s}}$ are slightly smaller than those based on $\overline{F_{n_s}}$. The magnitude of this discrepancy is estimated to be less than 1 percent of the true distance for any of the XB-70 tests and is dependent on the values of ambient temperature and pressure used to standardize the thrust.

Distance related to velocity. – To relate ground roll distance to velocity, the ground roll distance is not corrected to maintain constant $C_{L_{LOF}}$, because velocity must be retained as a variable. Instead, the velocity is corrected by assuming that $C_{L_{LOF}}$ is constant for the test and standard-day conditions. The required correction is derived as follows: Assume that W = L at lift-off, then $C_{L_{LOF_t}}$ and $C_{L_{LOF_s}}$ can be written as

$$C_{L_{LOF_t}} = \frac{2\overline{W_t}}{\rho_t \left(V_{LOF_t}\right)^2} \qquad \text{(A7)}$$

$$C_{L_{LOF_s}} = \frac{2W_s}{\rho_s \left(V_{LOF_s}\right)^2} \qquad \text{(A8)}$$

Since the test and standard-day lift coefficients are assumed to be constant, equating equations (A7) and (A8) results in

$$\frac{2W_t}{\rho_t \left(V_{LOF_t}\right)^2} = \frac{2W_s}{\rho_s \left(V_{LOF_s}\right)^2} \qquad \text{(A9)}$$

and

$$V_{LOF_s} = \sqrt{\frac{W_s}{W_t} \frac{\rho_t}{\rho_s}} \, V_{LOF_t} \qquad \text{(A10)}$$

Equation (A10), then, is the equation that is to be used for correcting lift-off velocity when equation (A4) is used for establishing the relation of S_{g_s} with lift-off velocity.

To establish the XB-70 ground roll relationship to lift-off velocity, it was found best not to correct the ground roll distance to a zero-wind condition. By neglecting the effects of wind velocity on excess thrust, the effect of the wind correction is merely to shift the data points along the curves presented in figures 5 and 6. An error analysis showed that the difference in calculated ground roll distance due to the estimated change in excess thrust is considerably less than the likely error in distance due to uncertainties in the applied value of wind velocity V_w.

As indicated in the preceding discussion, equation (A4) was used directly, without any corrections to the test ground roll distance. Corrected distances were calculated for the standard weights shown in figure 5 and plotted as a function of corrected or standard velocity.

Standardization of Air-Phase Distance

The general formula derived in reference 9 and used to standardize XB-70 air-phase distance is

$$S_{a_s} = S_{a_t}\left[\frac{\frac{\overline{W_s}}{\overline{W_t}}\frac{\sigma_t}{\sigma_s}h_v + h_a}{(h_v + h_a) + S_{a_t}\left(\frac{\overline{F_{n_s}}}{\overline{W_s}} - \frac{\overline{F_{n_t}}}{\overline{W_t}}\right)}\right] \tag{A11}$$

where h_a is the air-phase height, considered to be 35 feet (10.7 meters) for calculations in this report, and

$$h_v = \frac{V_a^2 - V_{LOF}^2}{2g} \tag{A12}$$

is the specific kinetic-energy gain during the air phase. This equation assumes that test and standard lift coefficients are the same both at takeoff and at the air-phase height. It also assumes that excess thrust is constant. For the XB-70 airplane, $\overline{F_{n_t}}$ and $\overline{F_{n_s}}$ were referenced at lift-off. Small corrections to account for aircraft drift were made to S_{a_t} by assuming that the XB-70 airplane drifted with the wind during the air-phase period. By using this equation, air-phase performance can be conveniently expressed by a plot of S_{a_s} versus h_v. In general, S_{a_t} can be standardized to a constant lift coefficient, but for the XB-70 data this correction was found to vary erratically and therefore was not made.

APPENDIX B

RELATIONSHIPS FOR PREDICTING TAKEOFF PERFORMANCE

The general equation for predicting takeoff ground roll distance is

$$S_g = \frac{W}{2g} \frac{{V_{LOF}}^2}{F_n - (D + \mu W - \mu L \cos \alpha)} \tag{B1}$$

Expanding and simplifying by using average values of the quantities rather than the time-varying functions, the equation becomes

$$S_g = \frac{\overline{W}}{2g} \frac{{V_{LOF}}^2}{\overline{F_n} - \frac{1}{2}\rho S\overline{V}^2(\overline{C_D} - \overline{C_L}\bar{\mu}) - \mu\overline{W}} \tag{B2}$$

Equation (B2) can be used directly to determine the relationship of S_{g_s} to V_{LOF_s} for given values of W_s. However, for determining the relationship of S_{g_s} to W, the lift-off velocity V_{LOF} can be expressed in terms of weight, thrust, and lift coefficient at lift-off as follows:

$$\left.\begin{aligned} L &= C_L \tfrac{1}{2}\rho V^2 S \\ W &= L + F_{n_{LOF}} \sin \alpha_{LOF} \end{aligned}\right\} \tag{B3}$$

This leads to the expression

$$V_{LOF} = \sqrt{\frac{W_{LOF} - F_{n_{LOF}} \sin \alpha_{LOF}}{\frac{1}{2}\rho S C_{L_{LOF}}}} \tag{B4}$$

Thus, by selecting standard values of $C_{L_{LOF}}$, V_{LOF} can be calculated and substituted into equation (B2). Hence, S_g can be determined as a function of W for given values of C_{LOF}.

For calculations of the XB-70 performance, $\overline{C_D}$ and $\overline{C_L}$ were taken at $\alpha = 0°$, appropriate to conditions prior to rotation (values were obtained from ref. 8). Hence, the calculations do not reflect rotation effects on performance. The quantity $\overline{F_n}$ was determined as a function of velocity (from ref. 8) where the velocity was taken as $0.75V_{LOF}$.

The air-phase distance can be written in equation form as

$$S_a = \frac{W(h_V + h_a)}{\overline{F_n} - \frac{1}{2}\rho\overline{V}^2\overline{C_{D_s}}} \tag{B5}$$

where h_V is defined by equation (A12). For a given $C_{L_{LOF}}$, equation (B4) can be used to calculate V_{LOF}. For a given h_V, V_a can then be determined and, hence, $\overline{V}$.

For the XB-70 air-phase calculations, F_n was determined as a function of V (obtained from ref. 8). Weight was estimated to decrease by 4000 pounds (1800 kilograms) from brake release to lift-off. The curves shown in figure 10 represent averages of values calculated for $C_{L_{LOF}}$ values of 0.50 and 0.55.

The following table lists the values of the required quantities used to calculate the predicted performance curves shown in figures 4(b), 5, 6, 10, and 11:

Quantity	Value	Source
Ground roll performance		
$\overline{C_{L_{LOF}}}$, trimmed in ground effect	0.55	Reference 8
$\overline{C_D}$, trimmed in ground effect (estimated)	0.0225	Reference 8
$\overline{F_n}$	Variable with $\overline{V}$	Reference 8
$F_{n_{LOF}}$	150,000 lb (667,200 N)	Reference 8
α_{LOF}	9.9° for C_L = 0.50; 10.9° for C_L = 0.55	Reference 8
μ	0.025	
ρ	0.002377 slugs/ft^3 (1.225 kg/m^3)	Standard sea level
g	32.17 ft/sec^2 (9.8 m/sec^2)	Standard sea level
Air-phase performance		
$C_{L_{LOF_s}}$	0.50, 0.55	
C_D, trimmed in ground effect	0.085 for C_L = 0.50; 0.103 for C_L = 0.55	Reference 8
$\overline{F_n}$	Variable with velocity	Reference 8
ρ	0.002377 slugs/ft^3 (1.225 kg/m^3)	Standard sea level

REFERENCES

1. Hall, Albert W.: Take-Off Distances of a Supersonic Transport Configuration as Affected by Airplane Rotation During the Take-Off Run. NASA TN D-982, 1961.

2. Weirich, Robert L.: Analytical Determination of the Take-Off Performance of Some Representative Supersonic Transport Configurations. NASA TN D-2308, 1964.

3. Jackson, Charles T., Jr.; and Snyder, C. Thomas: A Simulator Study of Take-Off Characteristics of Proposed Supersonic Transports. Conference on Aircraft Operating Problems, NASA SP-83, 1965, pp. 149-157.

4. Snyder, C. Thomas; and Jackson, Charles T., Jr.: A Piloted Simulator Study of Takeoff Performance and Handling Qualities of a Double-Delta Supersonic Transport. NASA TN D-4396, 1968.

5. Wolowicz, Chester H.: Analysis of an Emergency Deceleration and Descent of the XB-70-1 Airplane Due to Engine Damage Resulting From Structural Failure. NASA TM X-1195, 1966.

6. Wilson, Ronald J.; and McKay, James M.: Landing Loads and Accelerations of the XB-70-1 Airplane. NASA TN D-4836, 1968.

7. Anon.: AFFTC Test Facilities Handbook, Section V. FTC-TIH-63-2003, Air Force Flight Test Center, U.S. Air Force, [1964], pp. 32-38.

8. Bowman, Paul V.: Estimated Performance Report for the XB-70A Air Vehicle No. 2. NA-65-661, North American Aviation, Inc., July 26, 1965.

9. Lush, Kenneth J.: Standardization of Take-Off Performance Measurements for Airplanes. Tech. Note R-12, Air Force Flight Test Center, U.S. Air Force.

10. King, James J.; Neale, Philip E., Jr.; Schweikhard, William G.; and Stafford, Thomas P.: Aerodynamics Handbook for Performance Flight Testing. Volume I. AFFTC-TN-60-28, USAF Experimental Flight Test Pilot School, Air Force Flight Test Center, U.S. Air Force, July 1960.

11. Michaels, J. M.; Fisk, W. S.; McManus, H. L.; and Henderson, R. L.: YJ93-GE-3 Turbojet Engine. Rep. No. R61FPD321, Flight Propulsion Div., General Electric, Sept. 1961.

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16. Abstract

XB-70 airplane standardized takeoff data are compared with simple predictions based on aerodynamic and engine estimates. Effects of atmospheric and aircraft variables on takeoff distance are evaluated. Although experimentation with various techniques for aircraft rotation to lift-off attitudes was limited, the effect of the pilot techniques used are discussed and compared.

Predictions of distance from brake release to initiation of rotation as a function of velocity were found to be accurate to approximately 100 feet (30 meters). Because of the significant drag at the high aircraft attitudes required for takeoff, the standardized ground roll distance for a given velocity was increased nominally by 400 feet (120 meters) over the distance which would occur with no increase in drag. Standardized performance during climb from lift-off to a height of 35 feet (10.7 meters) with all engines operating was marginal because of low longitudinal accelerations, resulting from high induced drag at lift-off attitude. Additional work is required to include rotation variables in standardizing test data and in more fully defining the rotation effects on performance from a limited number of takeoff tests.

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