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METEOROLOGICAL ASPECTS OF HIGH-ALTITUDE TURBULENCE ENCOUNTERED BY THE XB-70 AIRPLANE

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INTRODUCTION

As a result of the supersonic transport (SST) aircraft development program, there is an increased need for information on high-altitude atmospheric turbulence and ambient-temperature transients. Little data exist on these atmospheric features for altitudes between 40,000 feet (12,200 meters) and 80,000 feet (24,400 meters), the interval within which the SST is expected to climb and cruise at supersonic speeds. Although high-altitude-turbulence information in the form of derived-gust-velocity statistics has been obtained over a period of several years during routine operational missions of the U-2 airplane (refs. 1 and 2), data on the associated meteorological conditions have not been available until recently (refs. 3 and 4). An additional source of these data has been provided by turbulence and temperature transients encountered during test flights of the XB-70 airplane, which is similar in configuration and performance to the proposed SST. A preliminary evaluation of the XB-70 airplane response in turbulence is given in reference 5.

This paper discusses the preliminary results of a study of meteorological features associated with turbulence encountered by the XB-70 airplane at flight levels above 40,000 feet (12,200 meters). Also, three of the larger temperature transients encountered during level flight at high altitudes are described. This study was conducted at the NASA Flight Research Center, Edwards, California, and covers XB-70 airplane flights made between April 1965 and March 1966 over the Western United States.

FLIGHT-TEST INSTRUMENTATION

Instrumentation used in the XB-70 airplane flight-test program furnished measurements of the airplane center-of-gravity normal acceleration, altitude, airspeed, total temperature, location, time of day, and rawinsonde observations of the upper-air winds and temperatures. The XB-70 flight tests were conducted over the Western United States, as shown by the shaded area in figure 1. Within this area, ground-based tracking radar were used to determine the airplane location. The stations from which rawinsonde observations were available for this area are also shown in the figure.

An NASA VGH recorder (ref. 6) carried in the XB-70 airplane provides time-history traces for the values of airspeed, normal acceleration at the airplane center of gravity, and pressure altitude. When the airplane was flying through turbulence, rapid fluctuations appeared on the normal-acceleration trace and irregular disturbances could be noted on the airspeed trace, as shown in figure 2. The maximum peak-to-peak increment in normal acceleration $(\Delta a_{n_{max}})$ at the airplane center of gravity was determined for each turbulence encounter and was used as an estimate of the turbulence intensity. Total temperature was measured by a Rosemount Engineering Company model 102AE probe mounted on the bottom of the engine air inlet and forward of the nose-gear compartment. Mach number was determined from pitot-static pressure measurements at the nose boom and was used to derive ambient temperature from the total-temperature measurements. The data from the total-temperature probe and the airplane pitot-static sensors were recorded directly on an airborne digital magnetic-tape recorder.

TURBULENCE-SAMPLING PROCEDURE

For the purposes of this paper, the turbulence encounters were separated into three arbitrary intensity categories. Flight segments with no turbulence or turbulence in which $\Delta a_{n_{max}}$ was less than 0.25g were designated as category T_0. The more intense turbulence encounters were designated as category T_1, when $\Delta a_{n_{max}}$ was equal to 0.25g or more but less than 0.40g, and as category T_2 when $\Delta a_{n_{max}}$ was equal to 0.40g or more. Pilots of the XB-70 airplane frequently referred to the turbulence intensity in categories T_1 and T_2 as "light" and "moderate," respectively. In comparison, it was often noted that relatively less intense turbulence ratings were given by the pilots of smaller and less flexible aircraft flying with the XB-70.

Because of the "patchy" nature of clear-air turbulence, the selection of turbulence encounters followed a different procedure for the very light and nonturbulent encounters than for the more intense encounters. This difference was a restriction on the T_0 encounters that limited them to flight segments in which the airplane pressure altitude was held constant (±1000 feet or ±300 meters) for a distance exceeding 100 nautical miles (180 kilometers). This restriction was followed in an attempt to avoid erroneous estimates of turbulence intensity resulting from sampling too short a distance for any given meteorological condition. For the more intense encounters, this restriction was not used because it was felt that the bias resulting from a reduced number of samples would be greater than the bias caused by including the encounters from brief exposures to the more intense turbulence layers.

After separating the turbulence encounters into the three intensity categories, meteorological parameters were selected for evaluation from rawinsonde data. This selection was made with consideration of the relevance of the parameters to clear-air turbulence and the ease of obtaining the parameters directly from rawinsonde data. With these considerations in mind, six parameters resulted: (1) the wind speed at the altitude of the maximum wind, (2) the wind speed at the 100-millibar level (approximately 53,000 feet or 16,200 meters pressure altitude), (3) vertical wind shear at lower altitudes, (4) vertical wind shear at the flight altitude, (5) temperature lapse rate at the flight altitude, and (6) temperature inversion at the flight altitude. Flight-altitude wind shear, lapse, or inversion layers having values less than 0.005 sec^{-1}, 4.0 C°/km, or 5.0 C°/km, respectively, were not considered to be significant and were not included in this evaluation.

The XB-70 turbulence encounters were often separated from the available rawinsonde observations by 5 hours in time and by 70 nautical miles (130 kilometers) in distance. Therefore, the vertical wind-shear, lapse, or inversion layers within 2000 feet (600 meters) of the flight altitude were considered to be at the flight altitude in order to allow for altitude changes of these layers with time or location or both. Although it is highly desirable to have rawinsonde observations closer to the airplane flight in both time and distance, the separations involved in this study are of practical interest because of their similarity to the SST operational situation. The strongest wind-shear layers at lower altitudes were all found to be 5000 feet (1500 meters) or more below the flight altitude. Wind shear at these lower altitudes is considered to be indirectly related to flight-altitude turbulence. The risk of improperly assuming that wind shear at altitudes between 2000 feet and 5000 feet (600 meters and 1500 meters) below the flight altitude was directly or indirectly related to the turbulence encounters was avoided by neglecting the data in this altitude interval.

After the pertinent meteorological parameters were selected, they were tabulated for the high-altitude turbulence encounters. In some instances, the airplane flight path during the constant-altitude segments in category T_0 crossed the area of more than one upper-air station. In instances where the rawinsonde data showed the meteorological parameters for both stations to be similar, only one was used for the tabulation. However, if any of the meteorological parameters differed significantly between the stations, both were entered in the tabulation. For T_1 and T_2 intensity turbulence, frequently repeated turbulence encounters were experienced near the same rawinsonde observation and essentially in the same atmospheric layer on a given flight. This repetition was avoided in the tabulation by selecting only the encounter having the largest value of $\Delta a_{n_{max}}$. That is, when more than one encounter was located within the area of a given rawinsonde observation and within 2000 feet (600 meters) in altitude or within the same meteorological layer, only the encounter with the largest $\Delta a_{n_{max}}$ was selected for tabulation. A total of ~~69~~ 68 samples, 25 in category T_0, 27 in category T_1, and 16 in category T_2, at flight levels above 40,000 feet (12,200 meters), was obtained by using this procedure.

METEOROLOGICAL COMPARISON OF THE TURBULENCE-INTENSITY CATEGORIES

In general, it was found that the more intense high-altitude turbulence, category T_2, is usually associated with the larger values of wind velocity, vertical wind shear, lapse, or inversion layers as can be noted in table I. Typical illustrations of these features based on data taken from several flights are shown by the wind and temperature profiles in figure 3.

While flying across the area covered by the profile in figure 3(a), the XB-70 airplane was gradually changing altitude from 63,000 feet (19,200 meters) to 65,000 feet (19,800 meters). No turbulence was encountered during this portion of the flight through relatively quiet atmospheric conditions. As shown, the wind speed reached a maximum of less than 50 knots (26 meters/second) below 30,000 feet (9100 meters) altitude and decreased to low values at the higher altitudes. Also, no appreciable wind shear, lapse, or inversion layers were present near the flight altitude. Figure 3(b) shows the profiles for turbulence encountered during cruise at 57,700 feet (17,600 meters) in which $\Delta a_{n_{max}}$ reached 0.65g. Here, the wind speed gradually decreases from more than 75 knots (39 meters/second) below 40,000 feet (12,200 meters) to relatively lower speeds above 55,000 feet (15,200 meters). The temperature profile shows the flight altitude to be at the top of a pronounced lapse layer with strong inversion layers both above and below. Figure 3(c) shows the profile for a deep layer of turbulence encountered during a climb between 52,000 feet (15,800 meters) and 59,000 feet (18,000 meters). The wind speed has a maximum of greater than 100 knots (51 meters/second) at 40,000 feet (12,200 meters) and is also notably high at the altitudes of the turbulence encounters. Several alternate layers of lapse and inversion are observed in the temperature profile. For this example, the largest value of $\Delta a_{n_{max}}$ also appears in a layer of pronounced lapse.

A more direct meteorological comparison between the categories of T_0, T_1, and T_2 is obtained by summarizing the data in table I in terms of the percentage of samples in each category that equals or exceeds specified values for each of the meteorological parameters. For this purpose, values were selected for the parameters that appeared to discriminate well between the T_1 and T_2 samples, such as $V_{max} \geqq 70$ knots (36 meters/second), $V_{100} \geqq 40$ knots (21 meters/second), $\left(\frac{\partial V}{\partial z}\right)_{low} \geqq 0.020$ seconds, $\left(\frac{\partial V}{\partial z}\right)_{flt} \geqq 0.005\ sec^{-1}$, $\gamma_{flt} \geqq 4.0$ C°/km, and $-\gamma_{flt} \geqq 5.0$ C°/km. It can be noted in table II that the specified values are met by a greater percentage of the samples in category T_2 than in categories T_0 and T_1.

The trend shown for all of the meteorological parameters in table II and the absence of any single predominant parameter indicate that a variety of disturbance mechanisms can generate significant high-altitude turbulence. It is conceivable that these disturbances may include strong frontal systems, sharp pressure troughs, and lee wave activity developed in the troposphere as well as strong stability deviations and wind-shear layers generated within the stratosphere.

It is believed to be important that several parameters be considered in determining the presence of more intense turbulence (category T_2) rather than a single parameter such as wind shear, lapse, or inversion rate. This can be demonstrated by comparing the intensity categories on the basis of the number of encounters with three or more meteorological parameters meeting the specified values. As shown in table III, few samples (7 of 52) from categories T_0 and T_1 but a majority of samples (12 of 16) from category T_2 meet the specified values for three or more of the meteorological parameters. In addition to indicating the variety of parameters involved, the contrast shown by this comparison is also interpreted as illustrating the usefulness of rawinsonde data for describing atmospheric conditions associated with high-altitude turbulence.

TEMPERATURE TRANSIENTS

Rapid changes in ambient temperature have been experienced by the XB-70 airplane during level flight at high altitudes. Temperature transients can cause a change in Mach number that affects the airplane propulsion system in a manner similar to a gust along the longitudinal axis of the airplane.

Three examples of temperature transients are illustrated by the temperature time histories in figure 4. The time history of figure 4(a) was obtained in smooth air at an altitude of 60,000 feet (18,300 meters) in the vicinity of mountain wave activity. Here, a temperature change of approximately 7 C° occurred in 15 to 20 seconds over a distance of about 6 nautical miles (11 kilometers). Figure 4(b) shows a temperature transient that was experienced in very light turbulence between areas of turbulence intensity T_2. In this instance, a change of 5 C° occurred in 2 seconds, or in a distance of slightly less than 1 nautical mile (2 kilometers) at an altitude of 60,000 feet (18,300 meters). Very light turbulence was also present during the temperature transient shown in figure 4(c). During this transient, at a flight level of 63,500 feet (19,400 kilometers), a change of 7 C° was experienced in approximately 3 seconds or in a distance of slightly more than 1 nautical mile (2 kilometers). In both of the latter two temperature transients, the horizontal temperature gradient along the flight path reached a maximum value of 1.5 C° to 2.0 C° per thousand feet (0.8 to 1.1 C°/kilometers).

The vertical profiles of wind and temperature measured in the vicinity of the temperature transients shown in figure 4 are illustrated in figure 5. It is noted that all three temperature profiles show a tropopause above 50,000 feet (15,200 meters), which is higher than the normal tropopause altitude and within 10,000 feet (3000 meters) of the flight altitude. The most apparent difference between the sounding for the more gradual temperature change in the mountain wave activity (fig. 5(a)) and the soundings for sharp temperature transients (figs. 5(b) and (c)) is the increased stability of the mountain wave profile in the deep inversion layers above the tropopause where the temperature increases more than 15 C°.

In view of the potential influence of temperature transients on the SST propulsion control system, as well as their possible association with high-altitude turbulence, detailed information is needed on the meteorological conditions in which they are generated. This information would help to define the physical limitations on the maximum possible temperature-change amplitudes and gradients.

CONCLUDING REMARKS

A study of turbulence encountered by the XB-70 airplane has shown that turbulence of significant intensity at SST supersonic climb and cruise altitudes is related to wind velocity, vertical wind shear, and temperature parameters obtained from rawinsonde measurements. The data illustrate that high-altitude turbulence is found in several situations that are characterized by various combinations of meteorological parameters. Temperature transients encountered at altitudes near 60,000 feet (18,300 meters) by the XB-70 airplane in which the ambient temperature changed more than 5 C° and the horizontal gradient along the flight path exceeded 1.5 C° per 1000 feet (300 meters) were also illustrated.

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SYMBOLS

$\Delta a_{n_{max}}$	maximum peak-to-peak increment in normal acceleration at the airplane center of gravity, g units
g	acceleration of gravity, 32.2 ft/sec^2 (9.8 m/sec^2)
h_p	pressure altitude, ft (m)
ΔT	peak-to-peak change in ambient temperature, C°
V_{max}	wind velocity at the level of maximum wind, knots (m/sec)
V_{100}	wind velocity at the 100-millibar level (approximately 53,000 feet or 16,200 meters pressure altitude), knots (m/sec)
$\left(\frac{\partial V}{\partial z}\right)_{low}$	vertical wind shear for a shear layer below the flight altitude, sec^{-1}
$\left(\frac{\partial V}{\partial z}\right)_{flt}$	vertical wind shear for a shear layer at the flight altitude, sec^{-1}
γ_{flt}	lapse rate for a layer of low static stability at the flight altitude, C°/km
$-\gamma_{flt}$	inversion rate for a layer of high static stability at the flight altitude, C°/km

TABLE I. – TURBULENCE SAMPLES

Flight date	Flight number*	$\Delta a_{n_{max}}$, g units	h_p, ft (m)	V_{max}, knots (m/sec)	V_{100}, knots (m/sec)	$\left(\frac{\partial V}{\partial z}\right)_{low}$, sec^{-1}	$\left(\frac{\partial V}{\partial z}\right)_{flt}$, sec^{-1} (†)	γ_{flt}, C°/km (†)	$-\gamma_{flt}$, C°/km (†)
Category T_0									
4/28/65	1-11	**	60.0×10^3 (18.3×10^3)	54 (28.0)	15 (8.0)	0.011	-----	----	----
5/7/65	1-12	0.20	59.0 (18.0)	28 (14.0)	18 (9.0)	.019	-----	8.4	10.0
5/7/65	1-12	**	64.0 (19.5)	99 (51.0)	18 (9.0)	.023	-----	----	5.0
6/16/65	1-13	0.20	64.0 (19.5)	62 (32.0)	14 (7.0)	.008	-----	5.0	7.0
6/16/65	1-13	**	64.0 (19.5)	33 (17.0)	14 (7.0)	.009	-----	----	----
7/1/65	1-14	**	66.0 (20.1)	86 (44.0)	11 (6.0)	.014	-----	----	----
7/27/65	1-15	**	66.0 (20.1)	67 (34.0)	16 (8.0)	.008	-----	----	----
9/22/65	1-16	0.15	61.0 (18.6)	42 (22.0)	23 (12.0)	.007	-----	----	----
9/22/65	1-16	**	65.0 (19.8)	38 (20.0)	22 (11.0)	.009	-----	----	----
10/16/65	2-9	**	57.0 (17.4)	119 (61.0)	14 (7.0)	.014	-----	----	----
10/16/65	2-9	**	57.0 (17.4)	68 (35.0)	9 (5.0)	.013	-----	----	6.0
11/2/65	2-11	0.20	56.0 (17.1)	37 (19.0)	16 (8.0)	.007	0.008	----	6.0
11/30/65	1-22	0.20	51.0 (15.5)	42 (22.0)	33 (17.0)	.007	-----	----	----
11/30/65	1-22	**	56.0 (17.1)	35 (18.0)	27 (14.0)	.005	-----	----	----
11/30/65	1-22	**	56.0 (17.1)	49 (25.0)	25 (13.0)	.006	-----	----	----
12/1/65	2-13	**	60.0 (18.3)	98 (50.0)	30 (15.0)	.022	-----	----	8.0
12/1/65	2-13	0.20	58.0 (17.7)	84 (43.0)	24 (12.0)	.013	.007	----	----
12/11/65	2-15	0.15	65.0 (19.8)	66 (34.0)	29 (15.0)	.014	-----	----	----
12/21/65	2-16	**	70.0 (21.3)	149 (77.0)	23 (12.0)	.020	-----	----	----
2/17/66	2-22	**	66.0 (20.1)	81 (42.0)	27 (14.0)	.015	-----	----	----
2/17/66	2-22	**	66.0 (20.1)	64 (33.0)	28 (14.0)	.010	-----	----	9.6
3/10/66	2-23	0.20	65.0 (19.8)	87 (45.0)	29 (15.0)	.020	-----	5.0	8.0
3/15/66	2-24	0.15	66.0 (20.1)	38 (20.0)	22 (11.0)	.012	.005	----	----
3/15/66	2-24	0.20	66.0 (20.1)	49 (25.0)	47 (24.0)	.006	.008	----	----
3/19/66	2-26	**	68.0 (20.7)	97 (50.0)	29 (15.0)	.012	-----	----	----
Category T_1									
4/20/65	1-10	0.30	57.0 (17.4)	73 (37.6)	14 (7.2)	.014	-----	----	6.0
4/28/65	1-11	.25	55.7 (17.0)	52 (26.8)	16 (8.2)	.016	-----	----	----
5/7/65	1-12	.25	47.3 (14.4)	66 (34.0)	6 (3.1)	.037	-----	4.0	----
5/7/65	1-12	.25	56.2 (17.1)	66 (34.0)	6 (3.1)	.037	-----	----	----
5/7/65	1-12	.30	58.8 (17.9)	43 (22.1)	18 (9.3)	.009	-----	5.2	----
5/7/65	1-12	.35	51.8 (15.8)	43 (22.1)	18 (9.3)	.009	.005	4.0	----
6/16/65	1-13	.25	55.2 (16.8)	91 (46.8)	24 (12.3)	.015	-----	----	----
6/16/65	1-13	.30	56.9 (17.3)	68 (35.0)	11 (5.7)	.011	.006	----	7.6
6/16/65	1-13	.25	47.0 (14.3)	68 (35.0)	11 (5.7)	.011	.007	5.2	----
7/1/65	1-14	.30	50.3 (15.3)	48 (24.7)	14 (7.2)	.007	.010	4.5	----
9/17/65	2-5	.35	47.1 (14.4)	43 (22.1)	35 (18.0)	.010	-----	----	----
9/17/65	2-5	.25	51.0 (15.5)	43 (22.1)	35 (18.0)	.010	.005	----	7.1
9/17/65	2-5	.25	45.8 (14.0)	67 (34.5)	37 (19.0)	.011	.006	5.7	----
9/22/65	1-16	.25	53.7 (16.4)	40 (20.6)	17 (8.7)	.008	.005	----	----
9/22/65	1-16	.25	65.3 (19.9)	50 (25.7)	27 (13.9)	.010	-----	----	----
9/29/65	2-6	.30	45.7 (13.9)	88 (45.3)	27 (13.9)	.010	.010	----	----
10/14/65	1-17	.25	53.7 (16.4)	27 (13.9)	14 (7.2)	.010	-----	----	----
11/2/65	2-11	.35	56.0 (17.1)	56 (28.8)	25 (12.9)	.011	-----	----	----
1/12/66	2-18	.25	63.7 (19.4)	70 (36.0)	35 (18.0)	.014	.007	----	----
1/12/66	2-18	.30	67.4 (20.5)	57 (29.3)	33 (17.0)	.009	-----	----	----
1/12/66	2-18	.25	53.0 (16.2)	64 (32.9)	56 (28.8)	.013	.015	6.8	6.8
2/9/66	2-20	.25	46.4 (14.1)	84 (43.2)	15 (7.7)	.010	-----	----	----
2/9/66	2-20	.30	49.5 (15.1)	76 (39.1)	16 (8.2)	.015	.005	----	5.2
2/9/66	2-20	.30	55.9 (17.0)	85 (43.7)	20 (10.3)	.023	-----	----	----
3/10/66	2-23	.35	41.3 (12.6)	82 (42.2)	33 (17.0)	.018	.007	----	----
3/10/66	2-23	.25	65.4 (19.9)	72 (37.0)	30 (15.4)	.026	.005	----	----
3/17/66	2-25	.25	66.0 (20.1)	105 (54.0)	42 (21.6)	.024	-----	----	----
Category T_2									
4/20/65	1-10	.65	57.7 (17.6)	79 (40.6)	26 (13.4)	.010	-----	6.2	24.0
4/20/65	1-10	.70	46.6 (14.2)	58 (29.8)	39 (20.1)	.012	.008	----	14.5
9/22/65	1-16	.45	43.0 (13.1)	25 (12.9)	19 (9.8)	.014	-----	5.9	----
9/22/65	1-16	.40	60.3 (18.4)	49 (25.2)	33 (17.0)	.021	.009	----	11.0
12/2/65	1-23	.40	45.2 (13.8)	113 (58.1)	41 (21.1)	.032	.013	----	----
12/2/65	1-23	.40	50.2 (15.3)	136 (70.0)	54 (27.8)	.035	.007	5.2	----
12/2/65	1-23	.40	46.8 (14.3)	136 (70.0)	54 (27.8)	.035	.005	----	----
12/2/65	1-23	.45	49.5 (15.1)	122 (62.8)	41 (21.1)	.020	-----	4.7	----
12/7/65	1-24	.40	61.6 (18.8)	72 (37.0)	36 (18.5)	.017	.005	6.6	----
1/3/66	2-17	.55	51.2 (15.6)	56 (28.8)	30 (15.4)	.015	-----	----	----
1/3/66	2-17	.55	60.0 (18.3)	65 (33.4)	27 (13.9)	.017	.010	----	5.0
3/15/66	2-24	.55	58.1 (17.7)	72 (37.0)	40 (20.6)	.017	-----	6.5	5.8
3/19/66	2-26	.70	52.0 (15.8)	122 (62.8)	47 (24.2)	.022	.007	----	27.0
3/19/66	2-26	1.05	54.8 (16.7)	122 (62.8)	47 (24.2)	.022	.007	8.0	7.5
3/19/66	2-26	1.20	57.0 (17.4)	122 (62.8)	47 (24.2)	.022	.005	8.0	7.5
3/19/66	2-26	.50	60.1 (18.3)	120 (61.7)	40 (20.6)	.021	.005	8.0	6.6

*First digit indicates airplane number; succeeding numbers denote flight for that airplane.

**Nonturbulent.

†Values not given for $\left(\frac{\partial V}{\partial z}\right)_{flt}$, γ_{flt}, and $-\gamma_{flt}$ were less than 0.005 sec^{-1}, 4.0 C°/km, and 5.0 C°/km, respectively.

TABLE II. – PERCENT OF SAMPLES MEETING THE SPECIFIED VALUES OF THE METEOROLOGICAL PARAMETERS FOR CATEGORIES T_0, T_1, AND T_2

Parameter	Specified value	Turbulence-intensity category		
		T_0, percent	T_1, percent	T_2, percent
V_{max}	≧70 knots (36 m/sec)	36	37	69
V_{100}	≧40 knots (21 m/sec)	4	7	56
$\left(\frac{\partial V}{\partial z}\right)_{low}$	$\geqq 0.020\ sec^{-1}$	16	9	56
$\left(\frac{\partial V}{\partial z}\right)_{flt}$	$\geqq 0.005\ sec^{-1}$	16	48	69
γ_{flt}	≧4.0 C°/km	12	26	56
$-\gamma_{flt}$	≧5.0 C°/km	32	18	56

TABLE III. – COMPARISON OF CATEGORY T_0 AND T_1 WITH T_2

	Cases meeting less than three specified values	Cases meeting three or more ~~than three~~ specified values
T_0 and T_1	45	7
T_2	4	12

Rawinsonde observation stations

BOI	Boise, Idaho	INW	Winslow, Ariz.	SLC	Salt Lake City, Utah
EDW	Edwards, Calif.	LAS	Las Vegas, Nev.	WMC	Winnemucca, Nev.
ELY	Ely, Nev.	LND	Lander, Wyo.		
GJT	Grand Junction, Colo.	OAK	Oakland, Calif.		

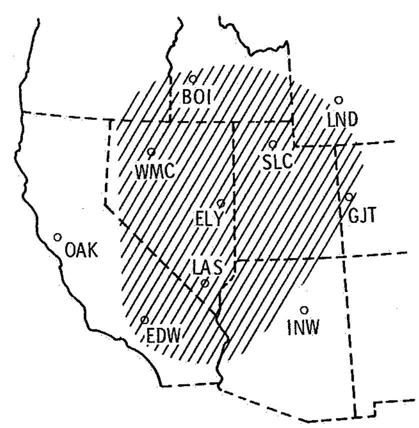


Figure 1.– XB-70 flight-test area and location of rawinsonde stations.

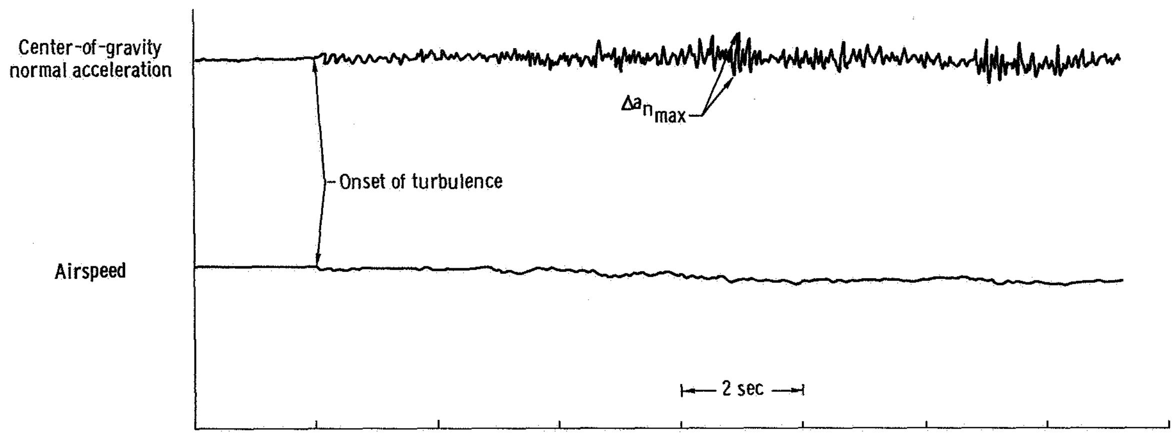
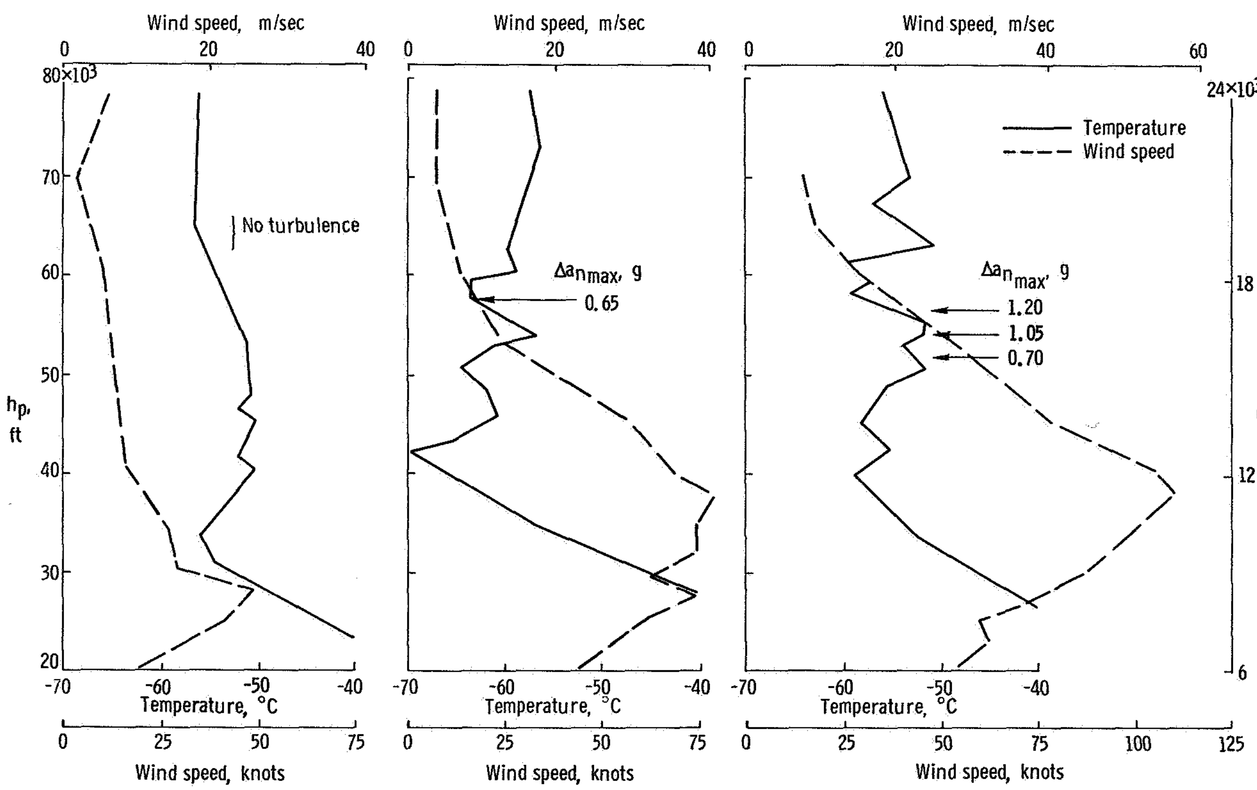


Figure 2.– VGH time history of the XB-70 normal acceleration and airspeed in turbulence.

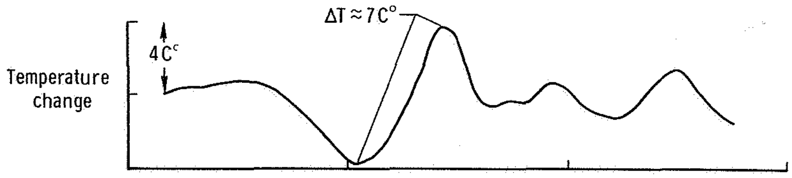


(a) No turbulence.

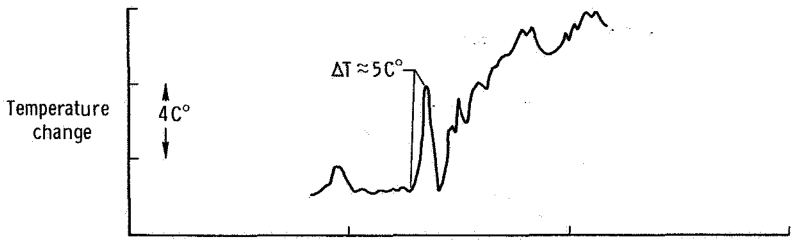
(b) Turbulence during constant-altitude cruise.

(c) Turbulence during climb.

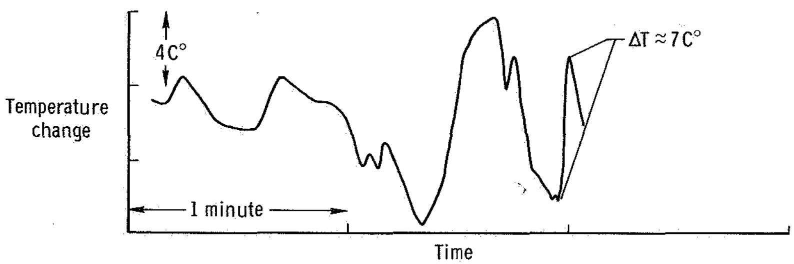
Figure 3.– Examples of wind and temperature profiles for various turbulence conditions encountered by the XB-70 airplane.



(a) Mountain wave.

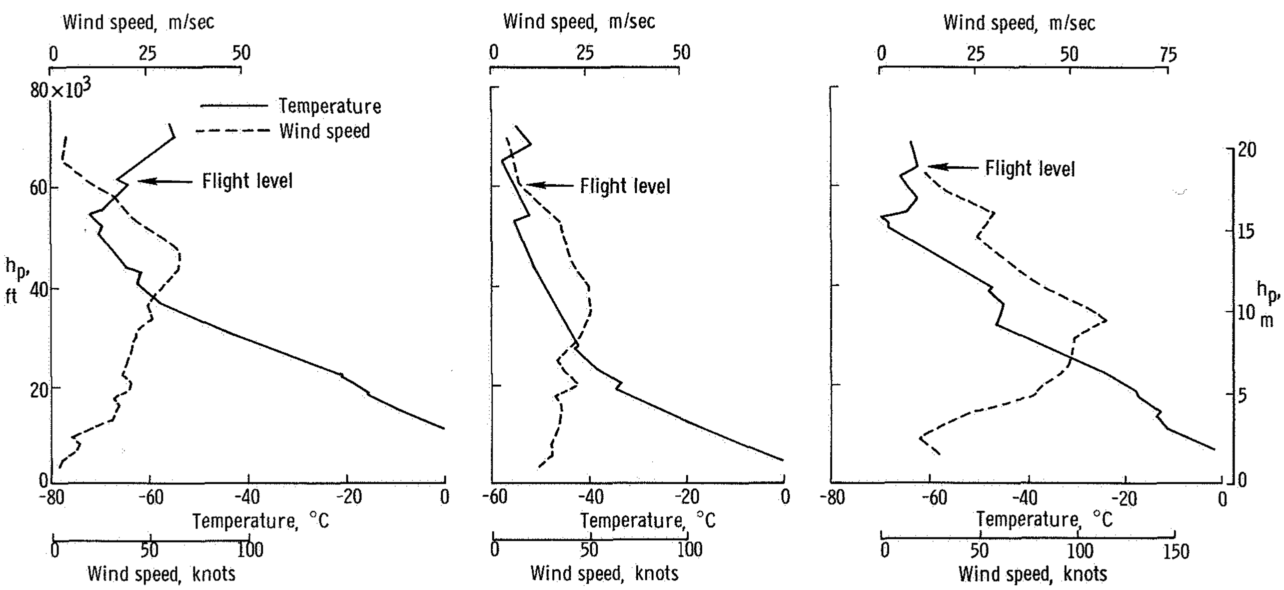


(b) 5 C° transient.



(c) 7 C° transient.

Figure 4.– Time histories for high-altitude temperature transients encountered by the XB-70 airplane.



(a) Mountain wave.
(b) 5 C° transient.
(c) 7 C° transient.

Figure 5.– Upper-air wind and temperature profiles for temperature transients encountered by the XB-70 airplane.