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WEATHER SUPPORT FOR THE X38 131R FREE FLIGHT 3 DECEMBER 13, 2001

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1. BACKGROUND

The 3rd Free Flight of the X38 131R vehicle occurred on December 13, 2001. These flight tests have evolved over the past few years. Bellue and Brody (1999) described weather support for X38 flight tests. A variety of X38 weather flight rules (NASA 2001) described by Bellue and Garner (1999) are used in each test to insure safety of flight and achieve accurate test objectives. Bellue and Donohue (2000) described how specific forecasts of upper air winds are used.

The test was originally scheduled for December 12, 2001, but problems with the B52 aircraft caused a scrub and a reschedule of the test the following day. The planned landing time for the X38 vehicle was approximately 1730 UTC, but equipment delays with the B52 bomber's readiness pushed the launch and landing time later in the day. In fact, the originally planned landing site was on the north end of the Edwards AFB lakebed, but delays required a repositioning of the recovery site and team to the south end of the Edwards lakebed. These delays caused an adjustment in the mission timeline and required more upper air soundings to be taken. When the X38 vehicle was finally released at about 45 000 feet, it encountered an area of turbulence on its descent at about 35 000 feet. The B52 encountered turbulence on its descent, as well. The magnitude of this turbulence event was unforeseen by forecasters since patterns in the forecast models did not indicate the presence of a significant wind speed maximum at the observed altitude or time. The forecast wind speeds were 50 knots at altitude with wind shears of less than 10 knots per 1 thousand feet, well within the flight rule limits. Also, there were no PIREPs in the area to alert forecasters and to help identify the existence of this wind shear zone.

The SMG support team worked in two shifts since support to Shuttle Operations was being conducted, as well. The morning team was relieved at 12:00 CDT. The last four soundings from Edwards (additional soundings required due to the delay in the B52 take-off) were not received on time through the normal method at SMG. Eventually these were re-transmitted via email from our Dryden counterpart, who was monitoring the test.

Real-time analysis of the data leading up to the event showed conditions as forecasted and within the X-38 Flight Rule limits. These limits state that the upper wind speeds must allow for the ability to keep all parachutes on the Edwards Range from the altitude of drogue deploy through the altitude of drogue release and wind speeds must be less than or equal to 55 knots from the altitude of post drogue release down to the surface. However, post analysis of the high-resolution wind data at altitude revealed a stronger wind speed maximum than forecasted and a slight wind shift.

Upper wind forecast amendment criteria are set forth in the X-38 Flight Rules. Once the B52 aircraft takes off the forecast amendment criteria change and any exceedence of limits by 50 percent or as defined by wind speeds greater than 82 knots from drogue release to the surface require a forecast update. These amendment criteria may have been met with data taken from the final balloon before B52 take-off. However, without the timely receipt of these data there was no way to know at the time if these criteria were met.

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2. TEST RESULTS

The X38 vehicle landed successfully and all elements landed within the Edwards Range. Table 1 lists the predicted versus the actual impact results using the X38 "Mission Predictor" software*. The first column lists the actual impact or landing point in latitude and longitude. The subsequent columns show the latitude and longitude and delta in feet from the actual impact points using the: 1) planning wind, the last sounding (1745 UTC) prior to B52 take-off, 2) the Jimsphere wind taken at landing time, 3) the Jimsphere wind at landing time initialized with the Embedded Global positioning satellite Inertial navigation system (EGI) state, and 4) the SMG forecast winds issued 6 hours prior to landing. The SMG forecast data run through the X38 "Mission Predictor" software (Bellue 2000) have demonstrated remarkable results, usually comparable to predictions using the jimsphere data and Jimsphere EGI initialized data. Table 2 lists the results from the X-38 V-132 Free Flight test of March 30, 2000. Comparing the two tables shows that results from the X-38 V131R Free Flight 3 test to be significantly poorer. The V-132 test was conducted under nominal conditions with no disruptions to the timeline. Some of the V-131R test inaccuracies may be attributed to the difference in the forecast valid times caused by the B-52 delays. The initial time was 1730 UTC versus the actual landing time of 2245 UTC. Two Programmed Test Inputs (PTIs)** were lost initially due to the encountered wind shear. One was regained as a result of the wind changes since vehicle responded as if encountering a wind gust. The X-38 vehicle was released from the B52 well within planned tolerances. The hatch door, pilot chute, and drogue chute all landed well within the range safety ellipse computed with the 1745 UTC planning wind taken from the actual balloon sounding rather than the forecast wind.

Table 3 shows results for the V-131R Free Flight 3 test compared to the averages from the previous 8 flight tests. The V-131R Free Flight 3 test results were well within limits of previous tests.

3. UPPER LEVEL SUMMARY

Six rawinsonde balloons were launched in support of X-38 flight day operations (1130 UTC, 1315 UTC, 1445 UTC, 1745UTC, 1915 UTC and 2045 UTC), covering preflight through postflight activities. A jimsphere, a radar skin-tracked Mylar balloon, was launched on the lakebed to provide high resolution and accurate wind data nearest to the landing time.

A. Wind Speed and Direction

Wind speeds were generally light for much of the day, remaining less than 10 knots below 10,000 feet. Figure 1 is a plot of the wind speeds vs. altitude including all the rawinsonde observations and the jimsphere. The 1130 UTC rawinsonde observation measured a peak wind of 54 knots at 32,000 feet. The wind speeds were forecasted and observed to decrease during the morning. This trend is seen in the 1315 UTC and 1745 UTC speed profiles. The wind speeds reached their minimum at the jet stream altitudes. Therefore, there was no time to advise the flight crew of the presence of the strong wind shear at 36,000 feet since there was nothing abnormal in the 1745 UTC that contradicted the upper wind forecast and no further soundings were available to the forecasters until after B-52 Take-off. The 2205 UTC jimsphere wind speed profile was similar with a maximum jet stream speed of 62 knots at 36,000 feet. The jimsphere verified the rapid increase in jet stream wind speed that was observed by the 2045 UTC rawinsonde.

Wind directions were generally variable below 15,000 feet through 1915 UTC. Figure 2 is a plot of altitude vs. wind direction in degrees from true north. The first two rawinsonde observations, 1130 UTC and 1315 UTC, observed wind directions from west to northwest from 16,000 feet to the X-38 release altitude of 45,000 feet. The wind directions started to transition primarily from the north to northeast

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** "Mission Predictor" software created by Dallas Ives, NASA, uses observed upper air winds to predict where 5 pieces of X38 hardware will land when released from the X-38 vehicle on descent. In addition, the software predicts the X-38 release point and altitude from the B-52 aircraft.*

***Programmed Test Inputs are instructions sent to the vehicle while in flight to see how it responds to the flight environment.*

Table 1. V-131R Free Flight 3 (12/12/2001) Predicted Versus Actual Impact Results

X-38 V-131R Free Flight 3 (12/13/01 – 2245 UTC) Predicted vs. Actual					
	Actual	**Predictions 1745 wind** (Planning Wind)	**Predictions Jimsphere Wind (2205 UTC)**	**Predictions Jimsphere Each piece initialized with EGI state**	**Predictions JSC forecast wind**
Parafoil Hatch Door (Predicted ellipse radius = 5839 ft)					
Latitude	34.8703	34.8693	34.8708	34.8706	34.8685
Longitude	-117.7955	-117.7854	-117.7860	-117.7918	-117.7736
Δ from actual, ft		3052	2856	1113	6603
Drogue/Parafoil Bag (Predicted ellipse radius = 13,526 ft)					
Latitude	34.8452	34.8226	34.8379	34.8443	34.8085
Longitude	-117.8042	-117.8052	-117.7927	-117.7981	-117.7689
Δ from actual, ft		8231	4355	1859	17047
Pilot/Drogue Bag (Predicted ellipse radius = 5291 ft)					
Latitude	34.8613	34.8669	34.8694	34.8692	34.8661
Longitude	-117.7992	-117.7904	-117.7901	-117.7960	-117.7779
Δ from actual, ft		3335	3958	3031	6625
Mortar Lid (Predicted ellipse radius = 7413 ft)					
Latitude	Not found				
Longitude					
Δ from actual, ft					
Sabot (Predicted ellipse radius = 4287 ft)					
Latitude	Not found				
Longitude					
Δ from actual, ft					
X-38 Vehicle at B52 Release - 1745 Wind					
	EGI	**Planned**	**Delta**	**Tolerance**	
Latitude	34.9283	34.9301	655 ft	1500 ft	
Longitude	-117.6816	-117.6772	1320 ft	1500 ft	
Altitude	44848	45000	152 ft	300 ft	
True Air Speed	748*	718	30 fps	17 fps	
Azimuth	251.1	252	.9 deg	3 deg	
X-38 Vehicle at Parafoil Deploy (Drogue Release) - 1745 Wind					
	EGI	**Planned**	**Delta, ft**		
Latitude	34.88992	34.88889	375 ft		
Longitude	-117.80884	-117.8	2653 ft		
Altitude	17520	18782	1262 ft		

- EGI ground speed adjusted to true air speed with Jimsphere wind

Table 2. V-132 Free Flight 3 3/30/2000 Predicted Versus Actual Impact Results

X-38 V-132 Free Flight 3 (3/30/00) Predicted vs. Actual					
	Actual	**Predictions 1345 wind** (Planning Wind)	**Predictions Jimsphere Wind**	**Predictions Jimsphere Each piece initialized with EGI state**	**Predictions JSC forecast wind**
Parafoil Hatch Door (Predicted ellipse radius = 5202 ft)					
Latitude	34.8842	34.8756	34.8727	34.8801	34.8716
Longitude	-117.7521	-117.7298	-117.7520	-117.7561	-117.7544
Δ from actual, ft		7386	4186	1200	4662
Drogue/Parafoil Bag (Predicted ellipse radius = 9395 ft)					
Latitude	34.8703	34.8616	34.8518	34.8633	34.8475
Longitude	-117.8116	-117.7825	-117.8125	-117.8159	-117.8270
Δ from actual, ft		9287	6738	2855	9498
Pilot/Drogue Bag (Predicted ellipse radius = 4709 ft)					
Latitude	34.8825	34.8742	34.8718	34.8767	34.8705
Longitude	-117.7593	-117.7343	-117.7568	-117.7609	-117.7600
Δ from actual, ft		8086	3966	2165	4373
Mortar Lid (Predicted ellipse radius = 6647 ft)					
Latitude	Not found				
Longitude					
Δ from actual, ft					
Sabot (Predicted ellipse radius = 3781 ft)					
Latitude	Not found				
Longitude					
Δ from actual, ft					
X-38 Vehicle at B52 Release - 1345 Wind					
	EGI	**Planned**	**Delta**	**Tolerance**	
Latitude	34.9367	34.9345	800 ft	1500 ft	
Longitude	-117.6724	-117.6686	1140 ft	1500 ft	
Altitude	38828	39,000	172 ft	300 ft	
Ground speed	638.2	625.5	12.7 fps	17 fps	
Azimuth	253.8	252	1.8 deg	3 deg	
X-38 Vehicle at Parafoil Deploy (Drogue Release) - 1345 Wind					
	EGI	**Planned**	**Delta, ft**	EGI Initialized	EGI Initialized
Latitude	34.9097	34.8995	3712	34.9048	34.9050
Longitude	-117.7730	-117.7631	2970	-117.7741	-117.7801
Altitude	15568	15,309	741	Δ = 2778 ft	Δ = 2732 ft

Table 3. V131R – FF3 B52 Release Accuracy

X-38 Vehicle at B52 Release					
	EGI	**Planned (1745 wind)**	**Delta**	**Tolerance**	**Average - 8 flights**
Latitude	34.9283	34.9301	655 ft	1500 ft	705 ft
Longitude	-117.6816	-117.6772	1320 ft	1500 ft	716 ft
Altitude	44848	45000	152	300 ft	141 ft
True Air Speed	748*	718	30 fps	? fps	23 fps**
Azimuth	251.1	252	.9 deg	3 deg	1.4 deg

* Embedded Global positioning satellite Inertial navigation system (EGI) ground speed adjusted to true air speed with Jimsphere wind
** Average for last 2 flights

between 16,000 feet and 37,000 feet after 1745 UTC. Above the jet stream altitude of 37,000 feet, the wind direction was primarily northwesterly. After 1745 UTC, there was little run-to-run variation in wind direction. At the altitude where turbulence was encountered, there was little in the way directional shear, 5 to 8 degrees per 1000 feet observed from the 2045 UTC rawinsonde and the 2205 UTC jimsphere. This would indicate the primary source of the shear was vertical speed shear with approximately 3% due to directional shear. Figure 3 is a plot of calculated wind shear, knots per 1000 feet, for each rawinsonde with the exception of the 1130 UTC observation. The jimsphere observation is also included. The plot shows that the wind shears for the first three observations were less than 16 kt/kft. For the X-38, a vehicle with high wingloading, wind shear less than 18 to 20 kt/kft should not affect the vehicle's performance in freeflight. However, by 2045 UTC, the wind shear increased to a value approaching 28 kt/kft at 36,000 feet. Not only is it a significant increase in shear value but of sufficient magnitude to be felt by X-38 and the B-52 mothership. Any shear over 20 kt/kft would be sufficient to generate at least light turbulence for a typical military aircraft (F-15, F-16, etc.). The high shear values are also seen in the jimsphere profile with a value near 24 kt/kft at 38,000 feet.

B. Temperatures

Flight day temperature profiles were generally consistent with an 8°C inversion with a thickness of 1630 feet AGL at 1130 UTC. Figure 4 is a plot of altitude vs. temperatures in degrees Celsius. By 1745 UTC, solar heating has warmed the surface sufficiently to break the inversion. Most of the temperature profiles during the day were colder than the standard atmosphere. The only exception is the 1445 UTC observation, which will not be considered. This profile has a positive 6-8°C bias throughout the profile. The remaining temperature profiles appear to be good. The strength of the tropopause inversion varied in strength and altitude throughout the day. The temperature profile to note is the 2045 UTC observation. The inversion at the tropopause strengthens significantly and lowers to an altitude of 35,000 feet. The strengthening and lowering of the inversion may be due to a mesoscale or synoptic feature, like a jet streak, that resulted in the increased winds and tropopause inversion. The inversion would also act as a barrier to prevent the wind speeds at higher altitudes from increasing.

4. SUMMARY

Significant wind shear developed late in the mission countdown and launch of the third flight of the X-38 V131R on December 13, 2001. The rawinsonde observations taken during the preflight, including observations up to the 1915 UTC balloon did not indicate any significant wind shear or turbulence. In addition, the forecast model point data did indicate a brief increase in jet stream winds during the time of the X-38 launch. However, the model data underpredicted the intensity of the maximum jet. There were no PIREPS in the area that mentioned turbulence. Post-analysis of the upper wind data shows that forecasters at SMG

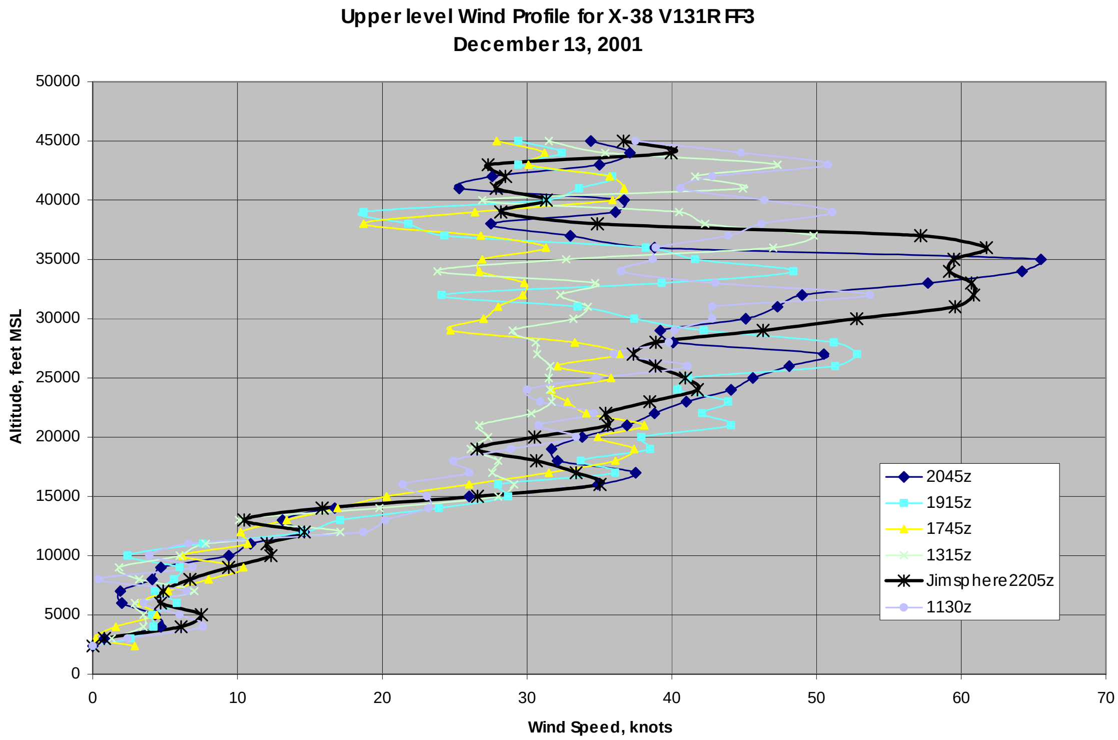

Figure 1. Wind speed profiles from Rawinsonde and Jimsphere

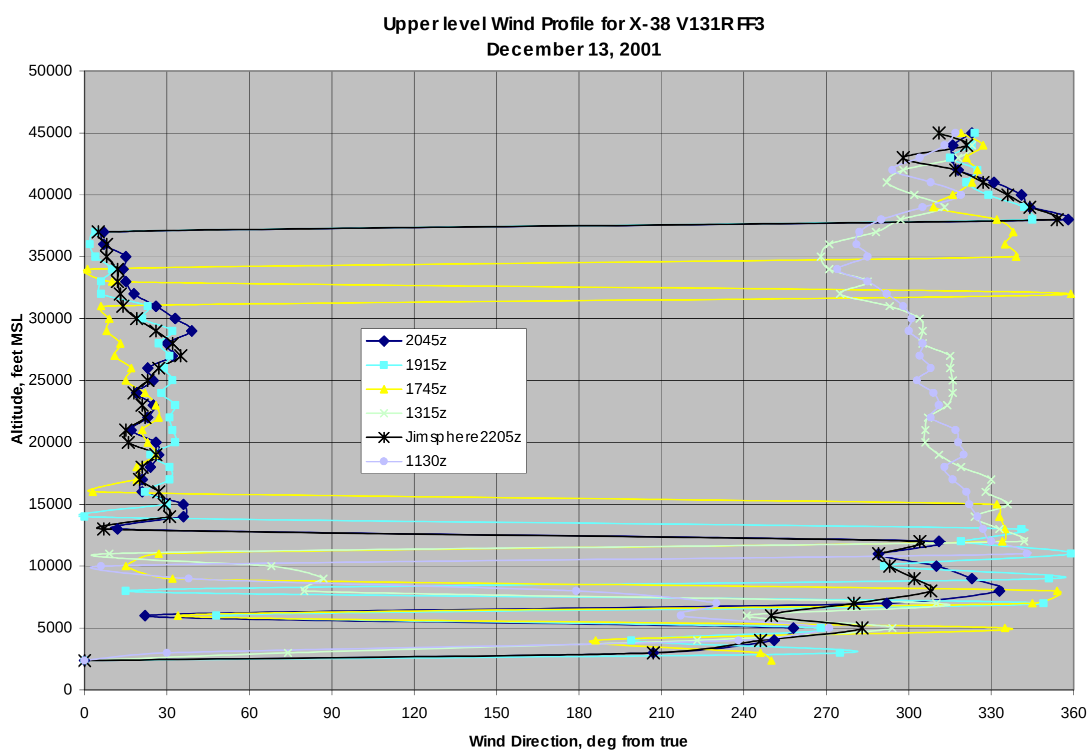

Figure 2. Wind direction profiles from Rawinsonde and Jimsphere

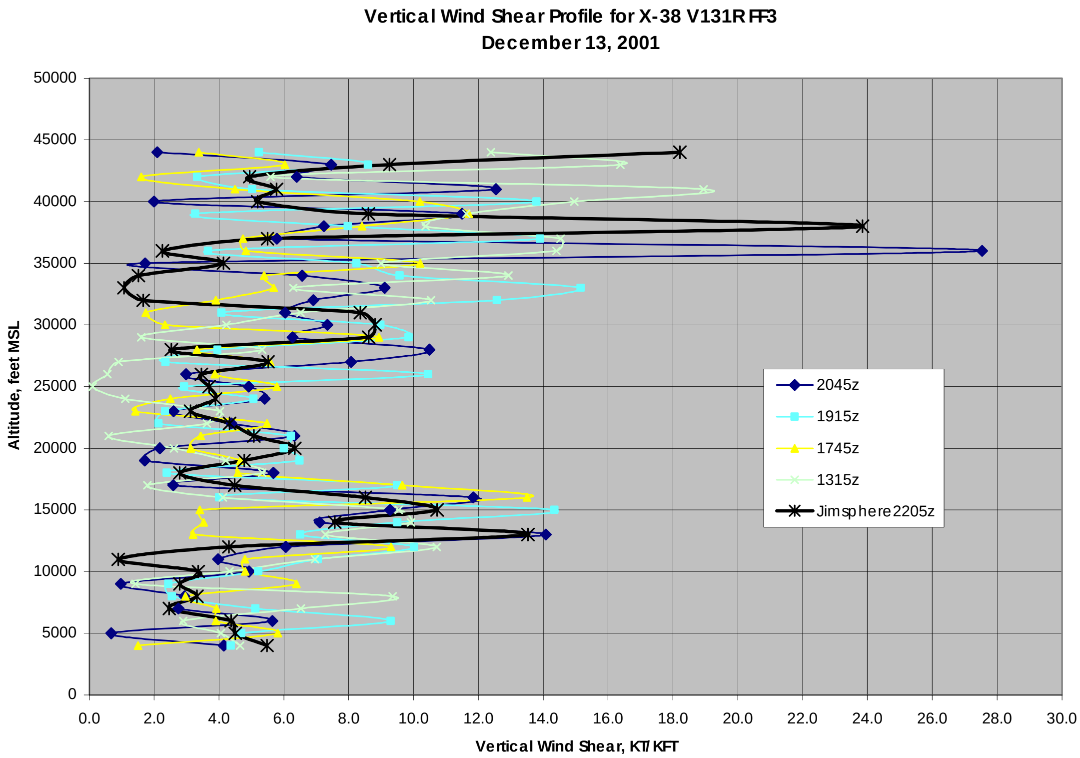

Figure 3. Calculated vertical wind shear profiles from Rawinsonde and Jimsphere data

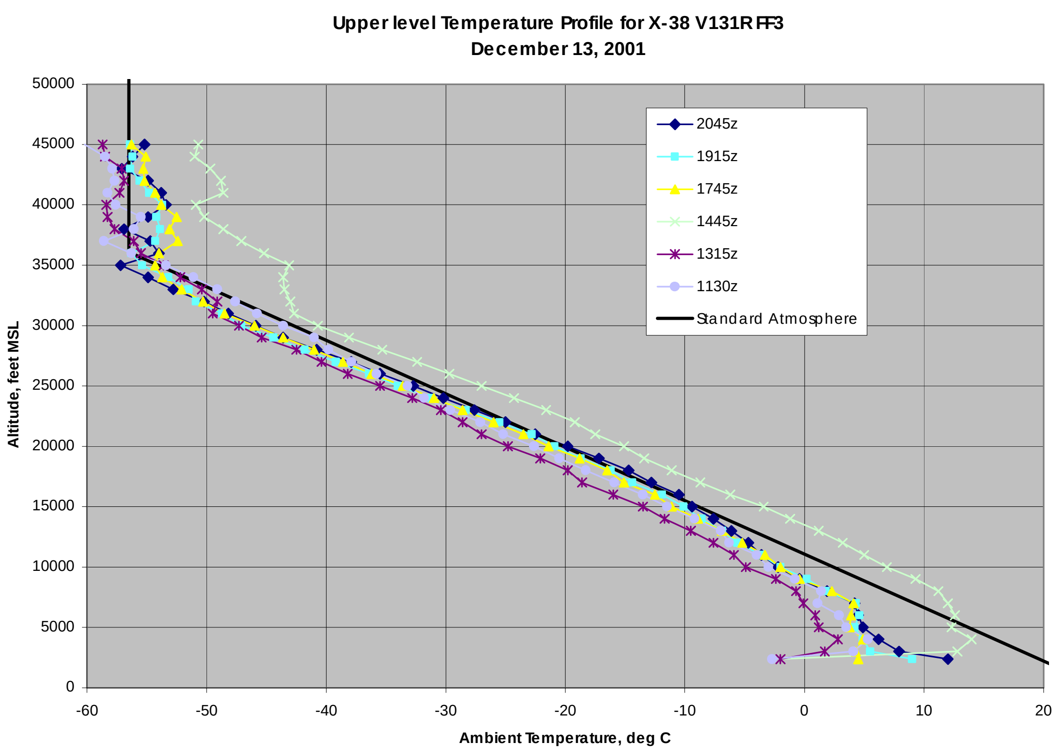

Figure 4. Ambient Temperature profile from Rawinsonde data

or at Dryden could not have predicted the sharp increase in upper winds nor could they have notified the Mission Director or flight team in time. Although the original forecasts were updated and amended, there were no indicators that turbulence would have developed. It is unlikely the 3+ hour delay in the X-38 launch time was a contributing factor, with the exception of the shear not being present during the original scheduled takeoff/launch time. It is important to note that the X-38 and the B-52 were never in danger due to the existence of turbulence. The X-38 operated nominally and the B-52 pilots did not report any problems with stability and control during the descent through the shear.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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