6.11 METEOROLOGICAL SUPPORT AND MODELING FOR THE NASA X-43A HYPERSONIC RESEARCH VEHICLE

Elizabeth J. Carter *
Firnspiegel LLC, Kings Beach, California
Edward H. Teets, Jr.
NASA Dryden Flight Research Center, Edwards, California

1. INTRODUCTION

The NASA X-43A hypersonic research vehicle program is a joint program between Langley Research Center in Hampton Virginia, Dryden Flight Research Center in Edwards California, and some industry. The X-43A employs scramjet technology, is an uninhabited, air-breathing aircraft which will operate at speeds up to Mach 10. The meteorologists at Dryden Flight Research Center provide the program with meteorological analysis for in flight airdata calibrations. Data presented is considered experimental. The model data provided limited information in the formulation of the X-43A atmospheric reference model for airdata calibration.

2. THE X-43A PROGRAM

The X-43A Hyper-X program objectives are to demonstrate the use of supersonic combustion ramjet (scramjet) technologies at hypersonic speeds on sub-scale vehicles known as X-43A's. Figure 1 is a photograph of the X-43A mock-up. Conventional turbojets operate by compressing air with fan-like blades in a compressor and mixing this air with fuel to produce thrust. In ramjet engines a stream of air is compressed by the forward speed of the vehicle and mixed with the fuel. Normal ramjets operate with subsonic internal airflow speeds for combustion (Mach 2 to Mach 5 – combustion chambers overheat at higher speeds) whereas scramjet technology employs ramjet engines but operate with supersonic internal airflow speeds (faster than Mach 6.7). Not having to carry its own oxygen for combustion, scramjet technologies require half the weight at liftoff increasing more payload for the same cost or longer flight durations.

* *Corresponding author address*: Elizabeth J. Carter, Firnspiegel LLC, 8130 North Lake Blvd., P.O. Box 2720, Kings Beach, California 96143-2720 U.S.A.; email: ecarter@weatherextreme.com

The X-43A vehicle, made by MicroCraft, Inc. of Tullahoma, Tennessee, weighs 2,700 pounds and is 12 feet long with a wing span of approximately 5 feet. An air-breathing scoop is located along the bottom of the craft. The X-43A is made of special heat-resistant carbon material. The fuel for the vehicle is hydrogen. A B-52 will carry a Pegasus® (a registered trademark of Orbital Sciences Corporation of Dulles, Virginia) booster to which the X-43A is attached. The B-52 will drop the booster with the X-43A attached to it at an altitude of about 24,000 feet. The Pegasus® booster will then acclerate the X-43A to speeds between Mach 7 and Mach 10 and altitude of approximately 95,000 feet where at booster burnout the X-43A will separate from the rocket and fly a predetermined flight path.

Figure 1. Photograph of the X-43A mock-up. Photo courtesy: NASA Dryden Flight Research Center Photo Collection. Photo by: NASA.

3. METEOROLOGICAL SUPPORT & MODELING

Currently Dryden Flight Research Center meteorologists perform in-flight airdata calibration in support of NASA research flights. In-flight airdata calibrations are used to determine the aerodynamic influence of an airplane on pitot-static pressure measurements of altitude and speed (Ehernberger, et al., 1992). Conventional in-flight airdata calibration techniques are not entirely satisfactory for research aircraft because of location limitations and added equipment requirements for flight envelope (Ehernberger, et al., 1992). The meteorological analysis involved in support of airdata calibration can be quite time consuming and labor intensive for the NASA meteorologists. It is hoped that atmospheric modeling support for these flight programs will shorten the time necessary to provide meteorological support as well as providing additional accuracy of forecasts.

4. X-43A CAPTIVE-CARRY & LAUNCH DAYS

On April 28, 2001, a successful "captive-carry" of the X-43A occurred. This captive-carry was a dress rehearsal for the free flight launch day of the X-43A. On April 28^{th} the B-52 took off from the Dryden Flight Research Center and at 1933UTC (1233 PDT) it soared off the coast of southern California, flew a predetermined flight path and then landed at 2119UTC (1419 PDT) at Dryden.

On June 2, 2001, launch day, the plan was to drop the Pegasus® booster from the B-52 bomber off of the coast of southern California, ignite the booster and lift the X-43A up to approximately 95,000 feet and Mach 7. At this altitude, the X-43A would start its engine and travel under its own power for less than 10 seconds at a speed of Mach 7, covering about 17 miles. The craft would then coast and splash down into the Pacific Ocean. Unfortunately, just after release from the B-52, the booster fired its engine, began its ascent, and went out of control. Several hundred miles off of the coast of California, the booster with the X-43A attached had to be destroyed just 51 seconds after being released from the B-52. The second experimental craft is being readied for flight in the near future.

5. LAUNCH DAY METEOROLOGY

Launch day was June 2, 2001 and the B-52 began the initial portion of the launch phase at approximately 1900Z (1200 PDT). Figure 2 is a GOES-10 visible satellite image with an “x” marking the approximate release point of the Pegasus® booster from the B-52. The arrow extending out from the “x” indicates the intended direction of the X-43A out into the Pacific Ocean.

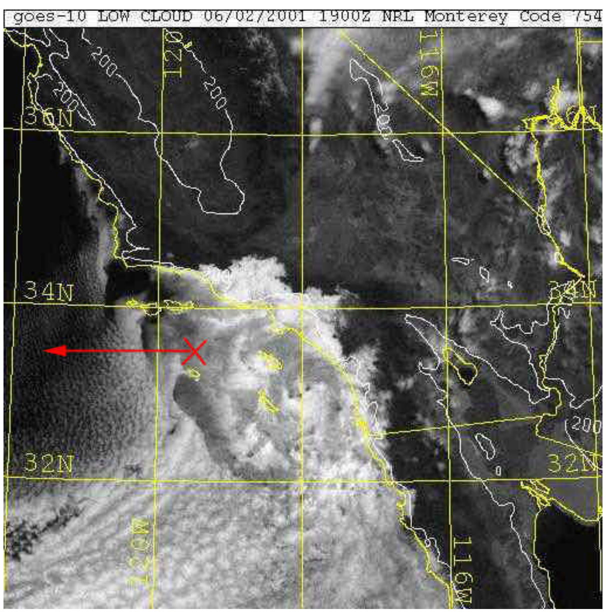

Figure 2. GOES-10 visible satellite image over southern California at 1900 UTC June 2, 2001 (from Naval Research Laboratory, Monterey, California).

On June 2, 2001 a surface low pressure system was over the Idaho/Montana region with a cold front extending southwest into Nevada and central California. As a result, a significant amount of cold air was allowed to infiltrate the high desert and mountain valleys. A surface thermal low pressure center had developed over the Arizona-Utah border with significantly higher pressure located several hundred miles off shore of southern California. By 1900Z (1200 PDT) the surface winds were being reported at 20+ knots with significant higher gusts. The winds remained 20+ kts for the remainder of the daylight hours.

Upper level winds near the California/Oregon border were observed near 60 knots at 15,000 feet. In southern California the winds were only 20 knots. At higher altitudes the winds were considerably stronger in northern California while the winds in southern California peaked near 50 knots over Edwards Air Force Base, Edwards, California. At the launch point, winds were slightly less than Edwards and were expected to decrease in velocity with time. Upper air balloon data supported this forecast as observed by balloon history of nearly 12 hours. At the predicted ocean impact point of the X-43A winds were expected to be lighter than near the coast.

During the day of June 2, 2001 upper air weather balloons were released in support of air data calibrations and trajectory analysis of the launch vehicle and the research vehicle (X-43A). Four special balloons were released at Pt. Mugu and San Nicholas Island while two special balloons each were released at Vandenberg AFB and Edward AFB.

6. MODELING THE ATMOSPHERIC CONDITIONS

The Penn State/NCAR (National Center for Atmospheric Research) MM5 (mesoscale model 5) atmospheric model was used for this project. Currently the MM5 model is being used by over 640 institutions and universities world-wide (in 31 countries). NASA Ames and NASA Goddard are using MM5 for research purposes only. Presently, NASA does not employ the MM5 for real-time weather forecasting purposes.

The MM5 model is a "community model" in the public domain, available at no cost, and is used all over the world. The model has an excellent reputation in the atmospheric community and is easily modified for a specific project. The model has multiple nest capabilities, non-hydrostatic dynamics, four dimensional data assimilation capabilities, many physics options, uses terrain-following coordinates, and is portable to a wide range of computing platforms. MM5 is used for a broad spectrum of theoretical and real-time studies from global scales down to cloud-sized scales, including such phenomena as monsoons, cyclones, hurricanes, mesoscale convective systems, land-sea breezes, fronts, mountain valley circulations, and urban heat islands.

The datasets required for input into the MM5 are:

- Topography and land use;
- Gridded atmospheric data that have at least these variables: wind, temperature, relative humidity and geopotential height; and at these

pressure levels (at a minimum): surface, 1000, 850, 700, 500, 400, 300, 250, 200, 150 and 100mb;

- Observation data that contains soundings and surface reports (optional).

The MM5 model was run on both the captive carry day and on the launch day of the X-43A. The model was set up using two domains, an outer 9km and an inner 3km horizontal resolution domain, respectively (Figure 3).

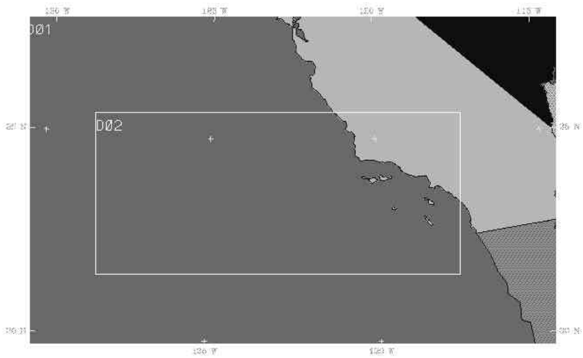

Figure 3. Outer 9km and inner 3km horizontal resolution domains run for the X-43A launch day off the coast of southern California.

Figure 4 is a plot of the 250mb winds over the inner (3km) MM5 domain at 1900 UTC (1200 PDT) June 2, 2001 (launch time). These winds compare well with the actual 250mb winds measured at 1900 UTC (1200PDT) (Figure 5). For example, on the coast of southern California the winds were measured at 40knots from the west and this is the same as forecasted using the MM5 model. Additionally, the winds over the northern California coast were measured at approximately 70 knots from the west-northwest and the MM5 model forecasted west-northwesterly winds at approximately 65 knots.

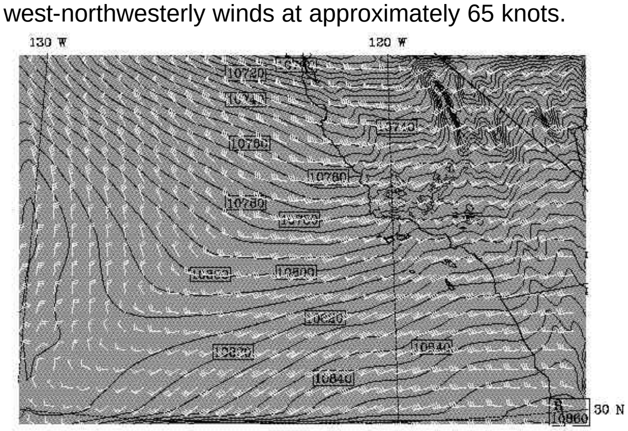

Figure 4. Plot of 250mb winds over inner 3km domain at 1900 UTC (1200 PDT) June 2, 2001.

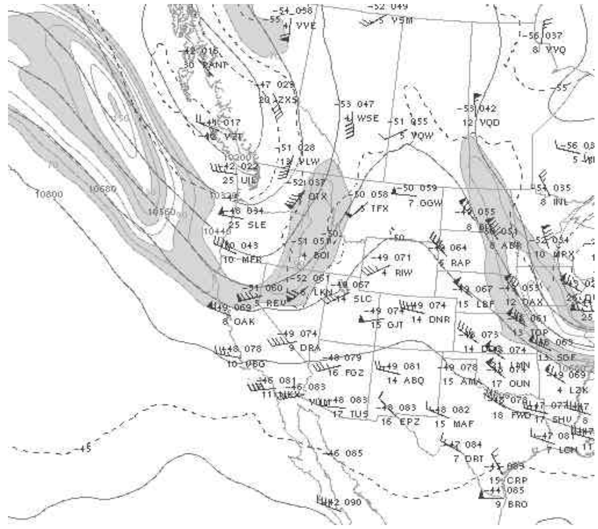

Figure 5. Actual 250mb winds at 19Z June 2, 2001.(Source: Graphics from the University of Wyoming).

The 850mb winds forecasted using the MM5 are compared to the actual 850mb winds. These figures show that when the winds are light and variable and rather changeable within short distances the MM5 model aids meteorologists greatly as the structure of these winds in regions without measurements, e.g., Pacific Ocean route of the X-43A.

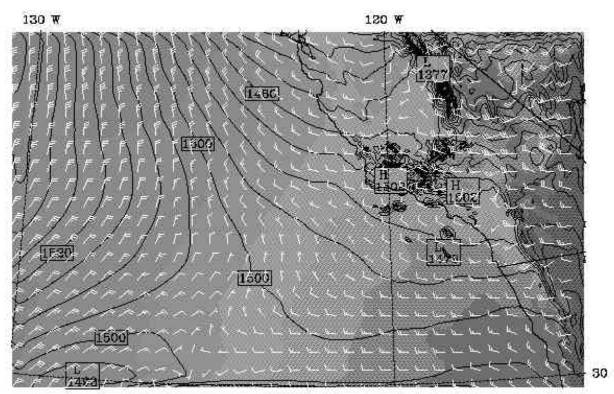

Figure 6. Plot of 850mb winds at 19Z June 2, 2001 from MM5 model output.

The MM5 model is also capable of producing atmospheric soundings at any location within the domains. For the launch day model run soundings were produced for Edward Air Force Base, Vandenberg, and for the launch site (33.5°N, 119.5°W). Figure 8 is the 1900 UTC (1200 PDT) June 2, 2001 sounding over Vandenberg produced by the MM5 model and Figure 9 is the actual 1900 UTC (1200 PDT) Vandenberg sounding. The wind profiles produced by the MM5 model are very similar to the actual Vandenberg winds. The temperature profiles are slightly different. The MM5 model forecasted a shallow fog layer over Vandenberg whereas the fog had already dissipated over the region by 1900 UTC (1200 PDT).

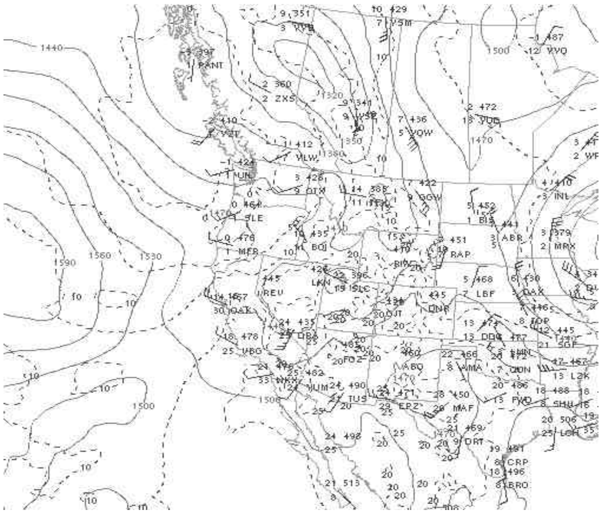

Figure 7. Actual 850mb winds at 100 UTC (1200 PDT) June 2, 2001.(Source: Graphics from the University of Wyoming).

Also, the small inversion at 750mb was forecasted by MM5 to occur at 875-850mb. The MM5 did forecast the approximate shape of the temperature profiles and the location of the tropopause.

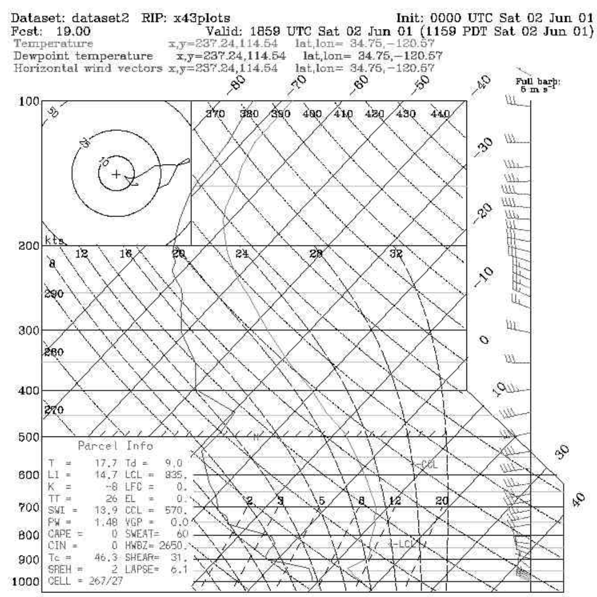

Figure 8. MM5 output of 1900 UTC (1200 PDT) June 2, 2001 sounding over Vandenberg.

A sounding was also produced directly over the launch point of the X-43A at 1900 UTC (1200PDT) June 2, 2001 using MM5. This sounding is plotted in Figure 10. The model can reproduce soundings for any location. In addition, cross sections can be made at any location desired. For example, a cross section of an intended flight path can be produced and any number of parameters can be plotted along this cross section.

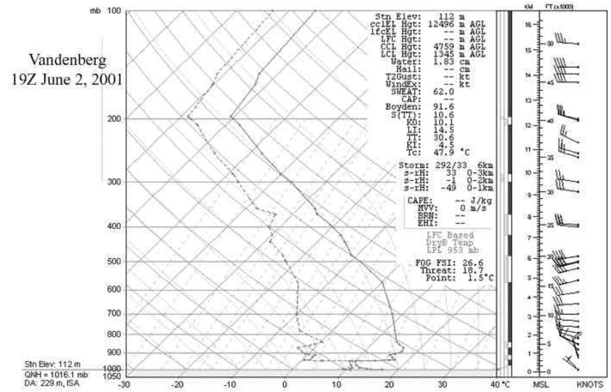

Figure 9. Actual Vandenberg sounding taken at 1900 UTC (1200 PDT) June 2, 2001.

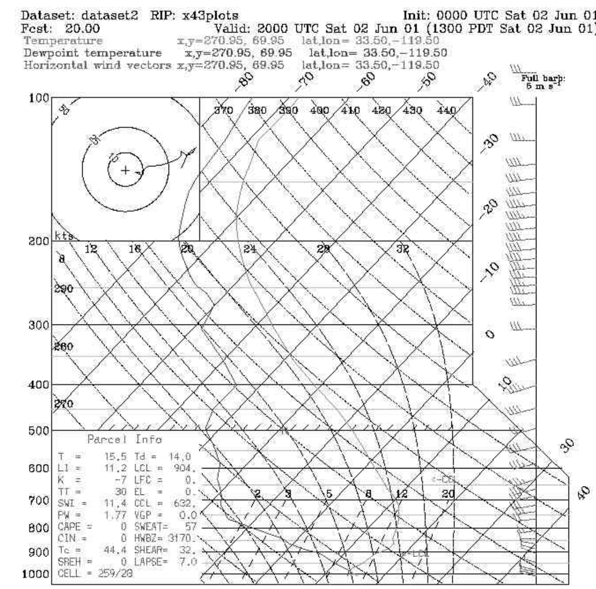

Figure 10. Sounding produced by MM5 model for launch point of X-43A at 1900 UTC (1200 PDT) June 2, 2001.

7. CONCLUSIONS

Using the model to aid in meteorological analysis in support of airdata calibration will aid NASA Dryden meteorologists by “filling in gaps” where data and measurements are not taken and by providing high-resolution forecasts of needed parameters (e.g., winds, temperatures, cloud cover).

8. ACKNOWLEDGEMENTS

This research is supported in part by NASA under contract number E04892D.

9. REFERENCES

Ehernberger, J.L., E.A. Haering, Jr., M.G. Lockhart, and E.H. Teets, 1992: Atmospheric Analysis for Airdata Calibration on Research Aircraft. 30th Aerospace Sciences Meeting & Exhibit, 6-9 Jan., Amer. Inst. of Aeronautics and Astronautics.