P7.2 TROPOSPHERIC WIND MONITORING DURING DAY-OF-LAUNCH OPERATIONS FOR NATIONAL AERONAUTICS AND SPACE ADMINISTRATION'S SPACE SHUTTLE PROGRAM

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1. INTRODUCTION

The Environments Group at the National Aeronautics and Space Administration's Marshall Space Flight Center (NASA/MSFC) monitors the winds aloft at Kennedy Space Center (KSC) during the countdown for all Space Shuttle launches. Assessment of tropospheric winds is used to support the ascent phase of launch. Three systems at KSC are used to generate independent tropospheric wind profiles prior to launch; 1) high resolution Jimsphere balloon system, 2) 50-MHz Doppler Radar Wind Profiler (DRWP) and 3) low resolution radiosonde system. Data generated by the systems are used to assess spatial and temporal wind variability during launch countdown to ensure wind change observed does not violate wind change criteria constraints.

2. MEASUREMENTS SOURCES

2.1 *Jimsphere Balloon System*

The Space Shuttle program employs a radar tracked balloon system for making high resolution wind measurements. The high resolution wind measurements are used for as input for vehicle steering commands. The steering commands alleviate loads on the vehicle as it ascends through the atmosphere. Known as a Jimsphere, the balloon is a mylar coated spherical balloon that uses roughness elements to reduce induced oscillations inherent in spherical balloons (Scoggins 1967). The Jimsphere is 2 m (6.56 ft) in diameter and has 398 roughness elements. A picture of the Jimsphere is shown in Figure 1.

During ascent the Jimsphere rises at approximately 5 ms^{-1} and is tracked by a radar with a sampling rate of 10 Hz, resulting in an effective vertical resolution of 0.5 m up to 15 km (Wilfong et al. 1997). Post processing data retrieved from balloon converts the radar tracked data to a zonal (u) and meridional (v) wind component. Output winds are provided at 30.48 m (100 ft) increments regardless of the depth of the averaging layer (Wilfong et al. 1997). The software attempts to maintain an accuracy of 1 ms^{-1} for each wind component by adjusting the depth of the averaging layer. Due to degradation of the radar tracking capabilities as the balloon ascends the averaging layer depth increases in 30.48 m (100 ft) increments up to 121.92 m (400 ft) in an attempt to maintain accuracy for each of the wind components.

Fig. 1. Jimsphere balloon used for high resolution wind measurements.

2.2 *Automated Meteorological Profiling System – Low Resolution Flight Element*

The Automated Meteorological Profiling System – Low Resolution Flight Element (AMPS LRFE) is a rawinsonde system which calculates winds based on inverse differential Global Positioning System (GPS) methodology (Divers et al. 2000). The system also measures temperature and relative humidity but is beyond the scope of this paper. The LRFE ascends on a standard 800 g latex balloon with a 20 to 30 m

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train (Divers et al. 2000). The LRFE is shown in figure 2.

Fig. 2. AMPS-LRFE instrumentation package.

Data received from the LRFE is used as an independent data source to validate Jimsphere derived data. Wind data is transmitted at 1 Hz frequency as the system ascends. The data is then averaged to produce data at 30.48 m (100 ft) intervals (Divers et al. 2000). Since the LRFE system is used as an independent verification source, post processing algorithms are used to produce layer averaged winds at 304.8 m (1000 ft) intervals.

2.3 *50-MHz Doppler Radar Wind Profiler*

Another independent data source the Space Shuttle program employs is a vertically pointing 50-MHz Doppler Radar Wind Profiler (DRWP). The DRWP transmits a pulse of electromagnetic energy at a frequency of 49.25 MHz and measures the returned energy back to the receiver. Backscattered signal to the receiver is caused by gradients in the index of refraction within the atmosphere (Schumann et al. 1999). Unlike the balloon sounding systems, the winds measured by the DRWP occur in a column above the antenna. A picture of the antenna field is shown in figure 3.

During Space Shuttle day of launch operations the DRWP measures wind vectors at 112 levels starting at ~ 2000 m (6600 ft) with a gate spacing of 150 m (492 ft) up to 18.6 km (61000 ft) (Schumann et. al 1999). To determine a horizontal wind vector the antenna transmits a beam in three directions, one vertical and two inclined 15° from the vertical oriented at 45° (northeast) and 135° (southeast). The DRWP uses a Median Filter First Guess algorithm for post processing to produce a 5 minute consensus averaged horizontal wind components at each gate (Schumann et. al 1999).

Fig. 3. 50-MHz DRWP antenna field located at KSC.

3. DAY OF LAUNCH WIND ASSESSMENTS

For Space Shuttle operations, day of launch winds assessment performed by MSFC Environments Group consists of monitoring the temporal and spatial change in winds during the launch countdown. The process includes comparing winds measurements, made by the previously described sources, against climatological databases. These databases, constructed by the MSFC Environments Group, are certified for use by the Space Shuttle Program. Assessments are made and reported to the program at specified times prior to launch. Currently, assessments are made from Jimsphere balloons launch at 6:15, 4:30, 3:25, 2:15 and 1:10 hours prior to launch and reported to personnel at Johnson Space Center (JSC). Since the shuttle is sensitive to winds along the flight trajectory, the winds reported to the program are converted to an in-plane and out-of-plane wind velocity component. In-plane wind component is oriented along the vehicle, whereas out-of-plane is oriented normal to the vehicle. The equations to convert into in-plane and out-of-plane wind components are:

$$IP = w_s \cos((\theta - \alpha)\pi / 180) \quad (1)$$

$$OP = w_s \sin((\theta - \alpha)\pi / 180) \quad (2)$$

where *IP* and *OP* represent the in-plane and out-of-plane wind velocities, w_s is the wind velocity, θ is the wind direction (measured clockwise from North), and α is the flight azimuth. The following section describes the assessments in more detail performed by MSFC Environments Group on day of launch.

3.1 *Climatological Assessment*

The purpose of performing a climatological assessment is to determine if the winds are outside the climatological limits observed when the database was constructed. In addition, the assessment compares the Jimsphere balloon values against independent measurement sources listed in section 2. The climatological database consists of 150 independent Jimsphere profiles per month from 1800 Jimsphere profiles. For comparison against the 150 per month winds, the Jimsphere measured wind is plotted against the mean wind and the envelopes of the 90% and 95% percentile wind components for both the in-plane and out-of-plane components. Results are reported in the balloon summary assessment package. Examples for in-plane and out-of-plane winds are shown in figures 4 and 5.

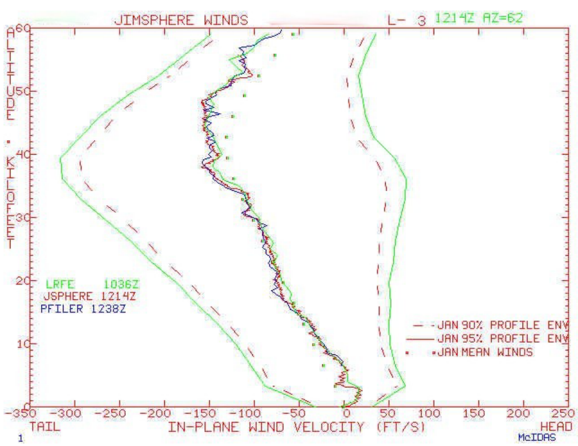


Fig. 4. Climatological and comparison profile of measured Jimsphere In-Plane wind velocities with AMPS-LRFE and 50-MHz DRWP measured wind velocities.

3.2 *Shear Assessment*

As the vehicle ascends it is subjected to a range of wind velocity shears which could lead to excessive loads at points along the vehicle. To protect the vehicle from launching in a strong shear environment, the MSFC Environments Group has produced a shear database for assessment against the observed wind profile. Maximum shears are assessed from 2.3 km (7,500 ft) to 15.2 km (50000 ft) and are calculated at the following height intervals; 91.4 m (300 ft), 182.9 m (600 ft), 365.8 m (1200 ft), 548.6 m

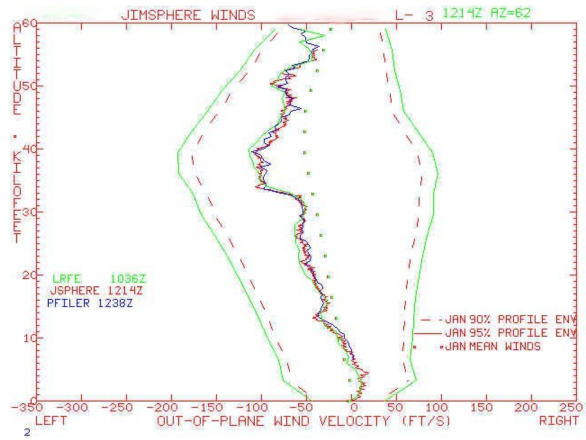
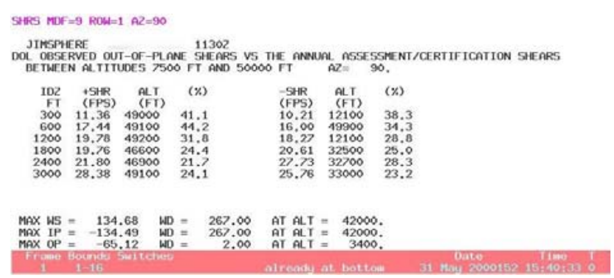


Fig. 5. Climatological and comparison profile of measured Jimsphere Out-of-Plane wind velocities with AMPS-LRFE and 50-MHz DRWP measured wind velocities.

(1800 ft), 731.5 m (2400 ft) and 914.4 m (3000 ft). Shear calculations are done for the out-of-plane component for launch azimuths of 39°, 45°, 60°, and 90°. For each height interval there is a build-up shear (positive shear) and a back-down shear (negative shear). The build-up shear represents an increase in wind velocities with height, whereas a back-down shear has wind velocities decreasing with height over the specified interval.

After each Jimsphere balloon ascent is completed the maximum build-up and back-down shear is determined at each shear interval for the selected launch azimuth. The values are then compared to a database of maximum shears and a percentage value of wind shear relative to the maximum shear is calculated. This value, referred to as the "design shear" is then reported in the balloon summary assessment package. An example of the output is shown in figure 6.



SHRS MDF=9 ROW=1 AZ=90

JIMSPHERE 11302
DOL OBSERVED OUT-OF-PLANE SHEARS VS THE ANNUAL ASSESSMENT/CERTIFICATION SHEARS
BETWEEN ALTITUDES 7500 FT AND 50000 FT AZ= 90.

IDZ FT	+SHR (FPS)	ALT (FT)	(%)	-SHR (FPS)	ALT (FT)	(%)
300	11.36	49000	41.1	10.21	12100	38.3
600	17.44	49100	44.2	16.00	49900	34.3
1200	19.78	49200	31.8	18.27	12100	28.8
1800	19.76	46600	24.4	20.61	32500	25.0
2400	21.80	46900	21.7	27.73	32700	28.3
3000	28.38	49100	24.1	25.76	33000	23.2

MAX WS = 134.68 WD = 267.00 AT ALT = 42000.
MAX IP = -134.49 WD = 267.00 AT ALT = 42000.
MAX OP = -65.12 WD = 2.00 AT ALT = 3400.
Frame Bounds Switches Date Time T
1 1-16 already at bottom 31 May 2000152 15:40:33 0

Fig. 6. Output of "design shears" at 300, 600, 1200, 1800, 2400 and 3000 ft intervals and the maximum wind velocities from a Jimsphere balloon profile.

3.3 *Persistence Assessment*

Prior to launch a set of steering commands, which incorporates wind data from a Jimsphere balloon, are transmitted to the vehicle. These steering commands are used to alleviate loads on the vehicle during ascent. Because the wind data used in the generation of steering commands is measured approximately 4.5 hours prior to launch, the shuttle program developed “knockdowns” based on 2 and 3.5-hr wind change databases to protect for loads change caused by wind change during countdown. The databases containing the 2 and 3.5-hr wind change was created by the MSFC Environments Group using wind pairs based on seasonal Jimsphere profile pairs. There are 1479 profiles that comprise the database.

Assessment of wind change is made by calculating and plotting the wind change from the Jimsphere profiles during the countdown and comparing against envelopes of the 99th percentile wind change values, independent of altitude, for 2 and 3.5-hr intervals. The wind change envelopes for the two intervals are based on Gumbel extreme probability statistics (Gumbel, 1958). Results of wind persistence check are reported in the balloon summary assessment package. In the event of an exceedance, engineering analysis is required to determine the relevance of the observed wind changes to trajectory/loads variables and if the vehicle is cleared for launch. An example of the 3.5 hr wind persistence plots are shown in figures 7 and 8.

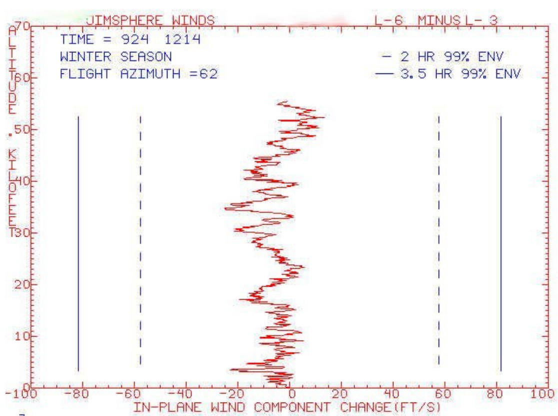


Fig. 7. In-Plane wind component change over 3-hr period plotted against 2 and 3.5 hr persistence 99th percentile envelopes.

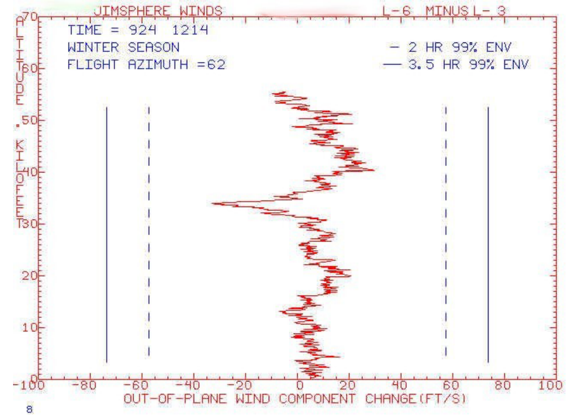


Fig. 8. Out-of-Plane wind component change over 3-hr period plotted against 2 and 3.5 hr persistence 99th percentile envelopes.

3.4 *Final Meteorological Profile*

The MSFC Environments Group is also responsible for a post-launch compilation of pertinent atmospheric data from the surface to an altitude of 121.9 km (400,000 ft). The data for this atmospheric profile is collected as close as possible to launch time. The reconstructed profile is a combination of actual empirical and model output data. Included in the profile is Jimsphere balloon data. The final meteorological profile is published within one week after the launch and becomes a part of an engineering database to be used by various engineering groups in post-launch assessment activities.

4. SUMMARY

The assessment of winds during day-of-launch operations performed by the MSFC Environments Group consists of monitoring wind conditions in real-time and in the hours preceding launch through the use of multiple instrumentation sources. These sources provide data to perform both spatial and temporal assessments of wind measurements to ensure wind change observed during countdown does not violate wind change criteria.

5. REFERENCES

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