

Assessment of atmospheric winds aloft during NASA Space Shuttle Program day-of-launch operations

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The Natural Environments Branch at the National Aeronautics and Space Administration's Marshall Space Flight Center monitors the winds aloft at Kennedy Space Center in support of the Space Shuttle Program day of launch operations. High resolution wind profiles are derived from radar tracked Jimsphere balloons, which are launched at predetermined times preceding the launch, for evaluation. The spatial (shear) and temporal (persistence) wind characteristics are assessed against a design wind database to ensure wind change does not violate wind change criteria. Evaluations of wind profiles are reported to personnel at Johnson Space Center.

Nomenclature

IP	= In-plane wind component (ft/s)
OP	= Out-of-plane wind component (ft/s)
u and v	= east-west and north-south wind components, respectively (ft/s)
w_s	= Wind velocity (ft/s)
α	= Flight azimuth (degrees)
θ	= Wind direction (degrees)

I. Introduction

THE Natural Environments Branch at the National Aeronautic 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. During the countdown, the spatial and temporal variability of the winds are assessed against databases and other wind measurements to ensure wind change does not violate wind change criteria. High resolution (100 ft) wind measurements are made by the Jimsphere balloon system¹. The resulting wind profiles are used as input to computer code to generate and validate vehicle steering commands which alleviate loads on the vehicle during ascent phase of missions.

II. Background

The Space Shuttle program employs a radar tracked balloon system for making high resolution wind measurements. High resolution wind measurements are used as input for vehicle steering commands. The steering commands alleviate loads on the vehicle as it ascends through the atmosphere. Known as a Jimsphere¹, the balloon is a Mylar coated spherical balloon that uses roughness elements to reduce induced oscillations inherent in spherical balloons. The Jimsphere is 2 m (6.56 ft) in diameter and has 398 roughness elements. A picture of the Jimsphere is shown in Fig. 1.

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During ascent the Jimsphere rises at approximately 5 m/s (17 ft/s) and is tracked by radar with a sampling rate of 10 Hz, resulting in an effective vertical resolution² of 0.5 m (2 ft) up to 15 km (50,000 ft). 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 layer². The software attempts to maintain an accuracy of 1 m/s (3.3 ft/s) 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 components².



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

III. Day of Launch Assessments

For Space Shuttle operations, day of launch winds assessment performed by MSFC Natural Environments Branch consists of monitoring the temporal and spatial change in winds during the launch countdown. The process includes comparing winds measurements against climatological databases. These databases, constructed by the MSFC Natural Environments Branch, 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 launched 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 in-plane and out-of-plane wind velocity components. In-plane wind component is oriented along the vehicle, whereas out-of-plane is oriented normal to the vehicle. To convert into in-plane and out-of-plane wind components

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

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

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 subsections describe the assessments in more detail performed by MSFC Natural Environments Branch on day of launch.

A. 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. The independent measurement sources consist of a 50-MHz Doppler Radar Wind Profiler and a low resolution rawinsonde system. The climatological database

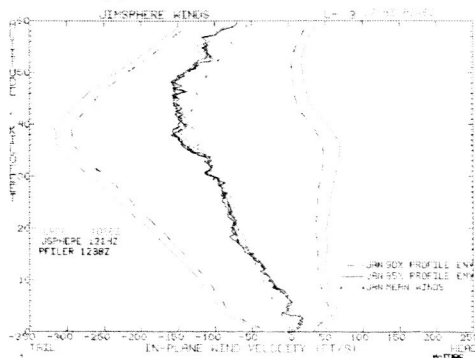


Figure 2. Climatological and comparison profile of measured Jimsphere In-Plane wind velocities with rawinsonde and Radar Wind Profiler measured wind velocities. Source: MSFC Day-of-launch real-time data display.

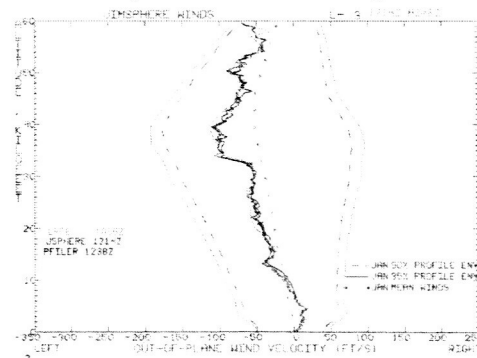


Figure 3. Climatological and comparison profile of measured Jimsphere Out-of-Plane wind velocities with rawinsonde and Radar Wind Profiler measured wind velocities. Source: MSFC Day-of-launch real-time data display.

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 delivered to JSC. Examples for in-plane and out-of-plane winds are shown in figures 2 and 3.

B. Shear Assessment

As the vehicle ascends it is subjected to a range of wind velocity shears which could amplify loads at points along the vehicle. To protect the vehicle from launching in a strong shear environment, the MSFC Natural Environments Branch 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 (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 4.

DESIGN SHEAR VS. MAXIMUM SHEAR

JIMSPHERE 11202

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

102 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	46500	24.4	20.61	32500	25.0
2400	21.80	46900	21.7	27.73	32700	28.3
3000	28.38	49100	24.1	26.76	33000	23.2

MAX MS = 134.68 MD = 267.00 AT ALT = 42000.
 MAX IP = -134.48 MD = 267.00 AT ALT = 42000.
 MAX OP = -65.12 MD = 2.00 AT ALT = 3400.

From Previous Launches already at bottom 51 Nov 1967 10:40:00

Figure 4. Output of "design shears" at 300, 600, 1200, 1800, 2400 and 3000 ft intervals and the maximum wind velocities from a Jimsphere balloon profile. Source: MSFC Day-of-launch real-time data display.

C. 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.

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 statistics³. Results of wind persistence check are reported in the balloon summary assessment package.

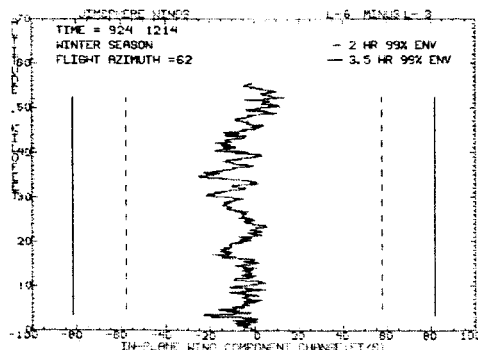


Figure 5. In-Plane wind component change over 3-hr period plotted against 2 and 3.5 hr persistence 99th percentile envelopes. Source: MSFC Day-of-launch real-time data display.

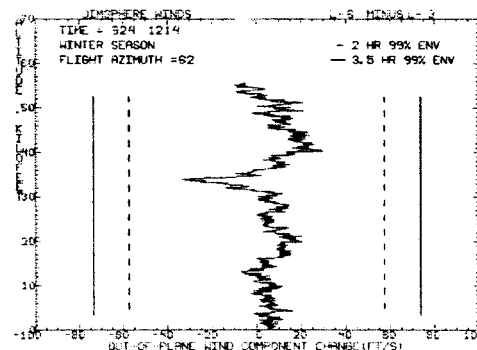


Figure 5. Out-of-Plane wind component change over 3-hr period plotted against 2 and 3.5 hr persistence 99th percentile envelopes. Source: MSFC Day-of-launch real-time data display.

In the event of an exceedance, engineering analysis is required to determine the relevance of the observed wind changes to trajectory/loads variables and whether or not the vehicle can be cleared for launch. An example of the 3.5 hr wind persistence plots are shown in Fig. 5 and 6.

IV. Conclusion

The assessment of winds aloft is both a critical and required function of a Space Shuttle mission. The MSFC Natural Environments Branch monitors real-time wind conditions by performing the necessary spatial and temporal wind assessments to ensure day-of-launch wind does not violate established wind criteria.

References

- ¹Scoggins, J. R., "Spherical balloon wind sensor behavior," *J. Appl. Meteor.*, Vol. 4, 1967, pp. 139-145.
- ²Wilfong, T. L., Smith, S. A., Crosiar, C. L., "Characteristics of High-Resolution Wind Profiles Derived from Radar-Tracked Jimspheres and the Rose Processing Program," *J. Atmos. Oceanic Technol.*, Vol. 14, 1997, pp. 318-325.
- ³Gumbel, E. J., *Statistics of Extremes*, Columbia University Press, New York, 1958.