**Table 1 Experimental coefficients measured in the U.S. Army Research Laboratory Transonic Range**

| | $C_{D_0}$ | $C_{D^2_\delta}$ | $C_{L_\alpha}$ | $C_{M_\alpha}$ |
|---|---|---|---|---|
| DM13 standard | 0.31 | 6.3 | 7.7 | −16.5 |
| DM13 gimbaled | 0.35 | 13.7 | 6.8 | −20.0 |

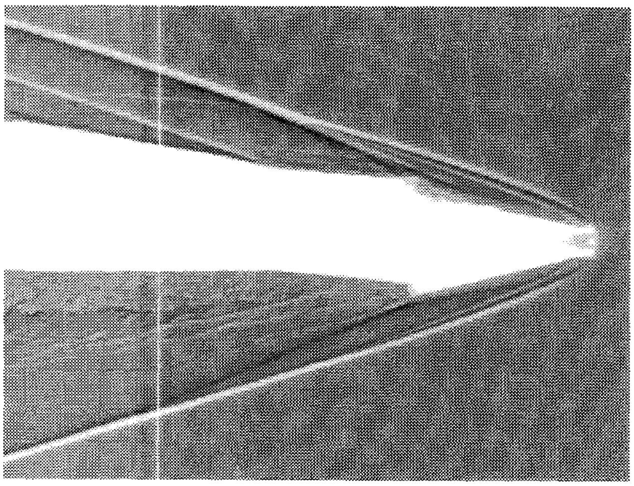

Fig. 2 Spark shadowgraph of gimbal nose projectile at entry to transonic range.

## Experiment

A series of experiments was performed to explore nose functioning and measure resulting aerodynamics. A 120-mm DM13 kinetic energy projectile was modified with a gimbal nose. Because the gimbal is supported on a stanchion, the maximum free rotation of the nose is limited to 10 deg, which is less than the maximum yaw expected. Six of these rounds were built and fired through the U.S. Army Research Laboratory Transonic Range. All of the projectiles survived launch with the gimbal noses intact; however, some separation was observed between the base of the cone and the forward shoulder of the projectile. This separation may affect the aerodynamics of the round, particularly the drag. The gimbal nose did function as intended. This is illustrated by the spark shadowgraph in Fig. 2. The projectile body clearly has appreciable yaw while the nose is turned into the flow.

A comparison of the aerodynamic coefficients with and without the gimbal nose is presented in Table 1. These measurements have 5–10% accuracy for zero yaw drag and static moment and 10–20% accuracy for lift and drag due to yaw.[6] The two drag terms represent the zero yaw drag and drag associated with yaw. The gimbal nose projectile has 13% greater zero yaw drag than the standard DM13. This may reflect the influence of the nose separation after launch. The drag associated with yaw is significantly higher for the gimbal case. This may be attributable to the formation of strong shocks off the projectile shoulder as it is uncovered in the yawed state (Fig. 2). However, when multiplied by the yaw squared, this drag component is an order of magnitude smaller than the zero yaw drag. As the round moves downrange, the yaw damps and this effect becomes even less important.

The lift and moment coefficients show the same trend as predicted by the simple estimates in the preceding section. The magnitude of the difference between standard and gimbal nose is less than predicted, which may be associated with both the crudeness of the estimate technique and the effects of nose standoff after launch. Even with these values, it would be expected that for the same launch yaw rate the gimbal nose would show 10% less maximum yaw and 28% less aerodynamic jump than the standard round.

## Conclusions

A technique is examined to reduce the nose lift on fin-stabilized projectiles. Potential advantages of the technique include reducing first maximum yaw and aerodynamic jump. Experimental results fell short of simplistic estimates but showed worthwhile improvement in flight characteristics. It is necessary to further improve the design to reduce separation between the nose and the projectile associated with decompression upon release from the gun. The benefit of a fully functional design would then have to be weighed against the additional complexity and cost of the finished projectile.

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# Risk Assessment Consequences of the Lognormal Distribution of Midtropospheric Wind Changes


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## Introduction

A RECENT study showed that the vector magnitude of wind changes in the region between 6- and 17-km altitude is lognormally distributed.[1] The study was limited to the winter season over the Kennedy Space Center (KSC) and encompassed wind changes over periods of 0.25, 1, 2, and 4 h. The measurements were made using the 50-MHz Doppler Radar Wind Profiler (DRWP) at KSC as described by Wilfong et al.[2] The winter season was selected because climatology suggested that the largest wind changes would be observed then. The altitude and time envelopes were selected on the basis of the region of greatest interest to the Shuttle and Titan launch communities for ascent loads. This Note examines the consequences of the lognormality of the wind-change distribution for risk analysis of launch wind changes. It does not address the associated problem of risk analysis of vehicle loads because loads are related to the winds in a highly nonlinear and vehicle-specific way.

## Lognormal Distribution

A variable $y$ is lognormally distributed if it is related to a normally distributed (Gaussian) variable $x$ having mean $M$ and standard deviation $S$, such that


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Table 1 Typical values of mean $M$ and standard deviation $S$ of natural logarithm of wind change for specified time intervals

| | Time interval, h | | | |
|---|---|---|---|---|
| | 0.25 | 1 | 2 | 4 |
| $M$, m/s | 0.2 | 0.8 | 1.1 | 1.5 |
| $S$, m/s | 0.70 | 0.65 | 0.63 | 0.63 |

$$y = \exp(x) \tag{1}$$

In such a case, the $n$th raw (not central) moment of $y$ is given[3] by

$$\langle y^n \rangle = \exp(nM + n^2 S^2/2) \tag{2}$$

This easily translates to the following expressions for the mean $\mu$ and standard deviation $\sigma$ for $y$:

$$\mu = \exp(M + S^2/2) \tag{3}$$

$$\sigma^2 = \exp(2M + 2S^2) - \mu^2 \tag{4}$$

Typical values of $M$ and $S$ observed for the winter season over KSC for wind changes $y$ in meters per second are presented in Table 1.

## Implication of Lognormal Distribution for Risk Analysis

The implication of the lognormal distribution for risk analysis is that extreme events will occur much more frequently than with a Gaussian distribution. To quantify how much more frequently, we examine the $N$-sigma event. Standard analysis-of-variance techniques used to assess risk take a historical data set such as a wind-change climatology and compute the mean and standard deviation. The probability of rare events occurring is estimated by computing how far the event $Y$ deviates from the mean in units of the standard deviation. This results in a $Z$ score for the event, where

$$Z = (Y - \mu)/\sigma \tag{5}$$

The probability that $y > Y$ can be determined for a Gaussian distribution by looking up the value in a table of normalized standard deviations[4] or using, for example, the function 1-NORMSDIST in an Excel® spreadsheet. The $N$-sigma event is the one for which $Z > N$. A typical analysis may accept risks for the three-sigma event for which the Gaussian probability is 0.00135.

For the lognormal distribution, the correct analysis requires additional steps to get the right probability. The correct $Z$ score from which to get the $N$-sigma probability using Gaussian tables is

$$Z(N) = \frac{\ln(\mu + N\sigma) - M}{S} \tag{6}$$

because the logarithm of $y$ is what is normally distributed. Because $\mu$ and $\sigma$ can both be derived from $M$ and $S$, we also can derive $Z(N)$ from $M$ and $S$. The result eliminates $M$ and leaves $Z$ as a function of $N$ and $S$ as follows:

$$Z(N) = \frac{S^2/2 + \ln\{1 + N\mathrm{SQRT}[\exp(S^2) - 1]\}}{S} \tag{7}$$

This value of $Z$ will be smaller than $N$ for $N > 1$ and $S$ in the range reported in Ref. 1. The resulting probability will be larger, meaning that the event occurs more often than it would if the distribution were Gaussian. Table 2 quantifies these results for values of $N$ and $S$ appropriate to space-launch risk analysis.

The effects are dramatic. For the lognormal parameter $S = 0.6$, the three-sigma event is nearly 13 times more likely for a lognormal distribution than for a Gaussian one, and the five-sigma event is 11,000 times more likely. If the limits for acceptance of the risk of an unobserved wind change for a given launch vehicle were computed on the basis of Gaussian probabilities at the three-sigma level or greater, the risk would be seriously underestimated.

Table 2 $Z$ scores and probabilities relative to Gaussian for events deviating from the mean by $N$-sigma for $N$ = 1–5 for values of the lognormal parameter $S$ from 0.3–0.8

| $N\backslash S$ | 0.30 | 0.40 | 0.50 | 0.60 | 0.70 | 0.80 |
|---|---|---|---|---|---|---|
| | | | *Z score* | | | |
| 1 | 1.042 | 1.071 | 1.104 | 1.143 | 1.186 | 1.233 |
| 2 | 1.745 | 1.715 | 1.701 | 1.700 | 1.710 | 1.728 |
| 3 | 2.326 | 2.227 | 2.160 | 2.117 | 2.092 | 2.082 |
| 4 | 2.820 | 2.652 | 2.533 | 2.450 | 2.394 | 2.357 |
| 5 | 3.250 | 3.015 | 2.847 | 2.728 | 2.642 | 2.583 |
| | | | *Probability of event relative to Gaussian* | | | |
| 1 | 9.37E−01 | 8.96E−01 | 8.49E−01 | 7.97E−01 | 7.43E−01 | 6.86E−01 |
| 2 | 1.78E+00 | 1.90E+00 | 1.95E+00 | 1.96E+00 | 1.92E+00 | 1.85E+00 |
| 3 | 7.42E+00 | 9.61E+00 | 1.14E+01 | 1.27E+01 | 1.35E+01 | 1.38E+01 |
| 4 | 7.59E+01 | 1.26E+02 | 1.78E+02 | 2.25E+02 | 2.63E+02 | 2.90E+02 |
| 5 | 2.01E+03 | 4.48E+03 | 7.67E+03 | 1.11E+04 | 1.43E+04 | 1.71E+04 |

Table 3 Number of standard deviations from the mean required to reduce the probability of occurrence to the value equivalent to $Z$ standard deviations in a Gaussian distribution for values of the lognormal parameter $S$ from 0.3 to 0.8

| $Z\backslash S$ | 0.30 | 0.40 | 0.50 | 0.60 | 0.70 | 0.80 |
|---|---|---|---|---|---|---|
| 1 | 0.95 | 0.91 | 0.85 | 0.79 | 0.72 | 0.65 |
| 2 | 2.42 | 2.53 | 2.62 | 2.69 | 2.73 | 2.74 |
| 3 | 4.40 | 4.96 | 5.54 | 6.16 | 6.78 | 7.40 |
| 4 | 7.08 | 8.58 | 10.36 | 12.47 | 14.93 | 17.76 |
| 5 | 10.70 | 13.97 | 18.30 | 23.97 | 31.34 | 40.82 |

To correctly set the thresholds for acceptable risk using Gaussian tables, the value of $Z(N)$ should be selected from the Gaussian tables and the resulting value of $N$ computed from

$$N(Z) = \frac{\exp(SZ - S^2/2) - 1}{\mathrm{SQRT}[\exp(S^2) - 1]} \tag{8}$$

The results are presented in Table 3. Thus, for example, if the acceptable risk is equivalent to the Gaussian probability of the three-sigma event, then for $S = 0.6$, one must actually be willing to accept values of $y$ up to $\mu + 6.16\sigma$, not just up to $\mu + 3\sigma$.

## Conclusions

The use of Gaussian probabilities for estimating the risks of unacceptable wind changes for space launch operations results in a serious and nonconservative error. The correct analysis requires probabilities based on the actual distribution, which is lognormal. The lognormality of the distribution also suggests the possibility that reduction of the risk to acceptable levels may require the use of devices such as the DRWP, which can observe these wind changes as they occur without the time delays associated with balloons.

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