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Using Probabilistic Analysis to Assess the Reliability of Predicted SRB Aft-Skirt Stresses

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Introduction

Probabilistic failure analysis is a tool to predict the reliability of a part or system. In situations where a part can be designed to carry loads well below its strength, probabilistic failure analysis is not necessary. When a part must be designed to carry loads almost equal to its strength, however, the variability in the loads and strength should be considered in order to ensure acceptable reliability. Probabilistic analysis methods were applied to an example problem as a step toward evaluating the usefulness of the method for MSFC engineers. For this project, probalistic techniques were used to predict critical stresses which occur in the solid rocket booster aft-skirt during main-engine buildup, immediately prior to lift-off.

Background

During a structural test of the skirt, the skirt failed at a load corresponding to a factor of safety of 1.28. Because this was less than the desired factor of safety of 1.40, the skirt attracted a lot of attention. One of the outcomes was the skirt supports, called hold down posts (HDP), were instrumented with strain gages in order to determine the actual peak loads on the skirt. These loads occur during the approximately seven-second period immediately prior to lift-off, when the main engines are building up maximum thrust.

Unfortunately, the measured loads (specifically the Z component) do not agree with the calculated loads nor with equilibrium! As a result, the predicted aft-skirt stresses have been unreliable. The goal of my summer project was to investigate the deviations in the predicted skirt stresses due to deviations in the measured HDP strains. The effects of deviations of other parameters affecting the predicted skirt stresses were also studied.

Analysis Procedure

The procedure of calculating skirt stresses based on measured HDP strains is illustrated in the diagram in Figure 1. The procedure begins with peak HDP strains measured during the main-engine build-up phase, immediately prior to lift-off. Next, the strains are multiplied by calibration constants to yield the forces at the top of the hold down posts (HDP loads). (The HDP loads are equal and opposite to the loads on the skirt, as shown in Figure 1.) In the last step, the HDP loads are multiplied by the skirt stress-indicator equations to yield the skirt stresses in the vicinity of the weld region.

Skirt Stresses from Hold Down Post Strains

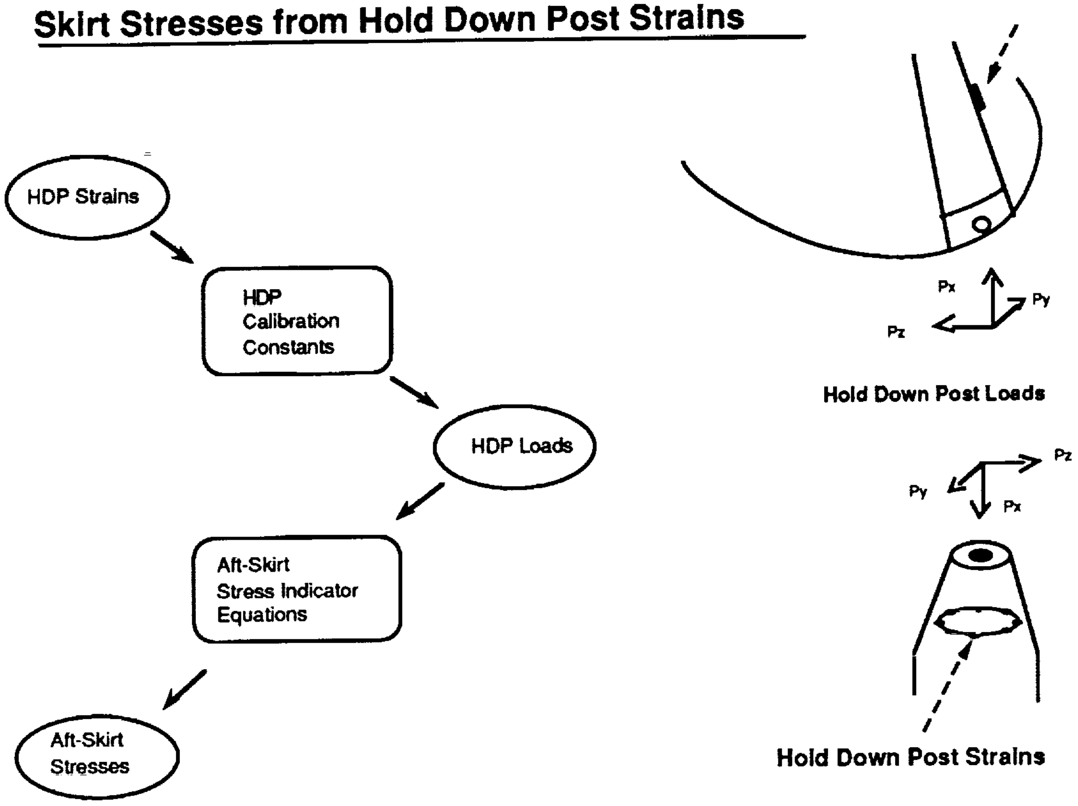


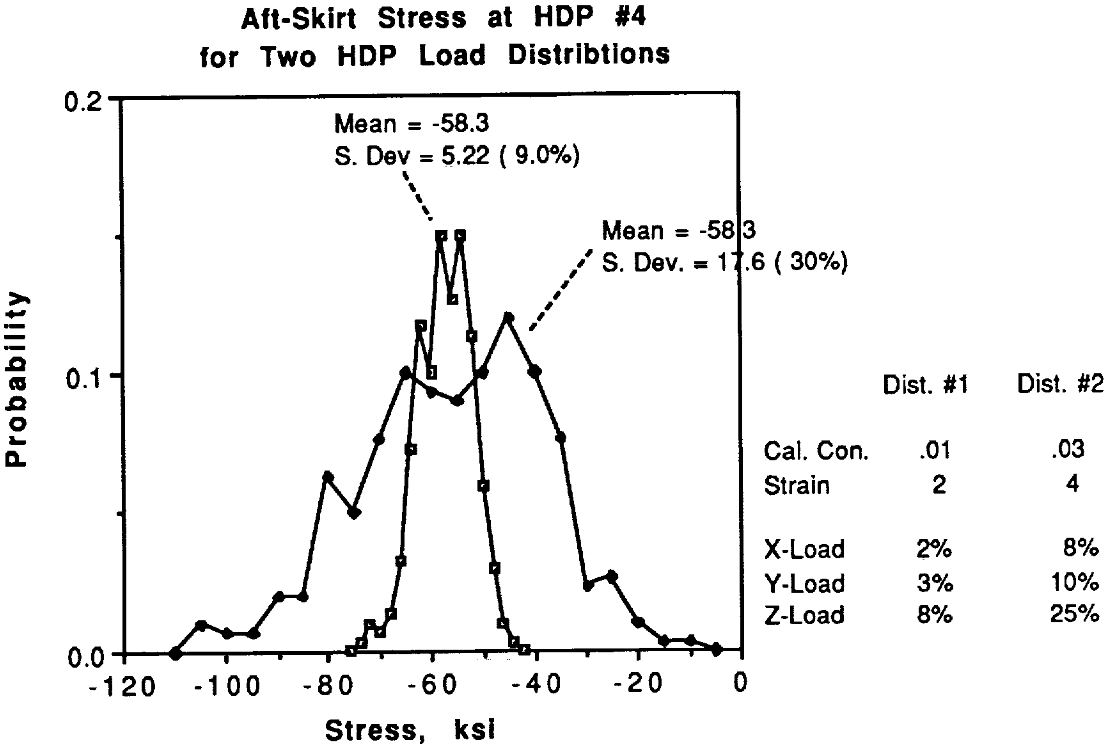
Figure 1. Diagram and flow chart of predicting skirt stresses from hold down post (HDP) strain measurements.

A distribution of predicted skirt stresses was generated using Monte Carlo simulation. Using this technique, HDP strains were drawn at random from assumed distributions and multiplied by the calibration constants to yield HDP loads. The procedure was repeated 300 times, each time drawing a new set of strains at random from the strain distributions. The result was a distribution of HDP loads. The HDP load distributions were then used as input in another Monte Carlo simulation to produce distributions of skirt stresses.

The results from two of the most significant analyses are discussed below. In these analyses, actual peak strains and calibration constants from shuttle flight STS-27 were used as the means of the distributions. The peak strains ranged from 40 to 277 microstrains and the calibration constants ranged from 0.008 to 0.322. The strains were assumed to vary uniformly about their means +/- 2 microstrains and the HDP calibration constants were assumed to vary uniformly about their means by +/- .01.

Results

The resulting load distributions had coefficients of variation (standard deviation divided by the mean) of 2%, 3%, and 8% for the X, Y, and Z loads. The Z load distribution has a much larger deviation than either the X or Y load distributions. The recorded HDP loads from numerous shuttle launches show this same trend. This study determined that the higher deviation of the Z loads was due to the way the strain gages are oriented in the hold down posts and the small magnitude of the HDP strains (less than 200 microstrain).



	Dist. #1	Dist. #2
Cal. Con.	.01	.03
Strain	2	4
X-Load	2%	8%
Y-Load	3%	10%
Z-Load	8%	25%

Figure 2. Predicted aft-skirt stress distributions.

The load distributions were used in turn for another Monte Carlo simulation to generate skirt stress distributions. The distribution of stresses near HDP #4 is shown in Figure 2 as the narrower distribution. A second analysis, using a more conservative strain variation of +/- 4 microstrains and a calibration constant variation of +/- .03, is also plotted in Figure 2.

The stress distribution plotted in Figure 2 shows that even for very optimistic (unconservative) strain and calibration constant deviations (2 microstrain and .03 calibration constant), the predicted stresses range from 45 ksi to 70 ksi. Because the actual skirt stresses are not separated from the failure stress by a comfortably large margin, this is considered to be too large of a deviation.

Summary and Conclusions

More than any other HDP load component, the Z-loads are sensitive to variations in strains and calibration constants. Also, predicted aft-skirt stresses are strongly affected by HDP load variations. Therefore, the instrumented hold down posts are not effective load transducers for Z-loads, and, when used with aft-skirt stress indicator equations, yield estimates with large uncertainty.

Monte Carlo simulation proved to be a straight-forward way of studying the overlapping effects of multiple parameters on predicted equipment performance. An advantage of probabilistic analysis is the degree of uncertainty of each parameter is stated explicitly by its probability distribution, allowing it to be communicated among engineers.

It was noted, however, that the choice of parameter distribution had a large effect on the simulation results. Many times these distributions must be assumed. In my opinion, the engineer who is actually designing or analyzing the part should be responsible for the choice of parameter distributions. Therefore, it is important for the designer or analyst to understand probabilistic analysis so that he can make valid assumptions when using it.