# A Design Heritage-Based Forecasting Methodology for Risk Informed Management of Advanced Systems

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The development of next generation systems often carries with it the promise of improved performance, greater reliability, and reduced operational costs. These expectations arise from the use of novel designs, new materials, advanced integration and production technologies intended for functionality replacing the previous generation. However, the novelty of these nascent technologies is accompanied by lack of operational experience and, in many cases, no actual testing as well. Therefore some of the enthusiasm surrounding most new technologies may be due to inflated aspirations from lack of knowledge rather than actual future expectations.

This paper proposes a design heritage approach for improved reliability forecasting of advanced system components. The basis of the design heritage approach is to relate advanced system components to similar designs currently in operation. The demonstrated performance of these components could then be used to forecast the expected performance and reliability of comparable advanced technology components. In this approach the greater the divergence of the advanced component designs from the current systems the higher the uncertainty that accompanies the associated failure estimates.

Designers of advanced systems are faced with many difficult decisions. One of the most common and more difficult types of these decisions are those related to the choice between design alternatives. In the past decision-makers have found these decisions to be extremely difficult to make because they often involve the trade-off between a known performing fielded design and a promising paper design. When it comes to expected reliability performance the paper design always looks better because it is on paper and it addresses all the know failure modes of the fielded design.

On the other hand there is a long, and sometimes very difficult road, between the promise of a paper design and its fulfillment; with the possibility that sometimes the reliability promise is not fulfilled at all. Decision makers in advanced technology areas have always known to discount the performance claims of a design to a degree in proportion to its stage of development, and at times have preferred the more mature design over the one of lesser maturity even with the latter promising substantially better performance once fielded. As with the broader measures of performance this has also been true for projected reliability performance. Paper estimates of potential advances in design reliability are to a degree uncertain in proportion to the maturity of the features being proposed to secure those advances. This is especially true when performance-

enhancing features in other areas are also planned to be part of the developmental program.

Several years ago the US Air Force recognized the need to include maturity estimates in their development planning processes. While they saw no alternative to expert judgment in obtaining estimates of maturity they at least wanted to bring some order to that judgment. For this reason a "Technology Maturity Scale" was created, an example of which is presented in Figure 1. On this scale representative graduations are made from one (1) to nine (9) with 1 representing the lowest maturity and 9 the highest. Along the scale calibrating phrases were added along with examples to allow the expert reviewer to establish his maturity estimates on a less subjective basis. The phrase correlations to the numeric scale were intentionally overlapping in recognition of the inherent uncertainty or "fuzziness" in the process of assignment beginning with the "Basic Technology or Research Level" as the least mature and with the availability of "Integrated System Tested Units Deployed and Operational" as the most mature. No design was seen as completely mature, ( 10 on the scale), because in developmental programs, such as the ones that the Air Force was addressing, there was always thought to be at least some tailoring required of even off-the-shelf designs. When the maturity of the designs were reviewed against this scale and maturity values assigned these values would be used to weight the alternatives so that designs of high performance promise, but low maturity, would have had their potential value to the developed program adjusted accordingly. In this way, although it was never mentioned, the approach attempted to estimate the probability that the system fielded would have the performance promised. Or in other words, it discounted the promised performance of immature designs during trade studies leading up to the selection of a final design.

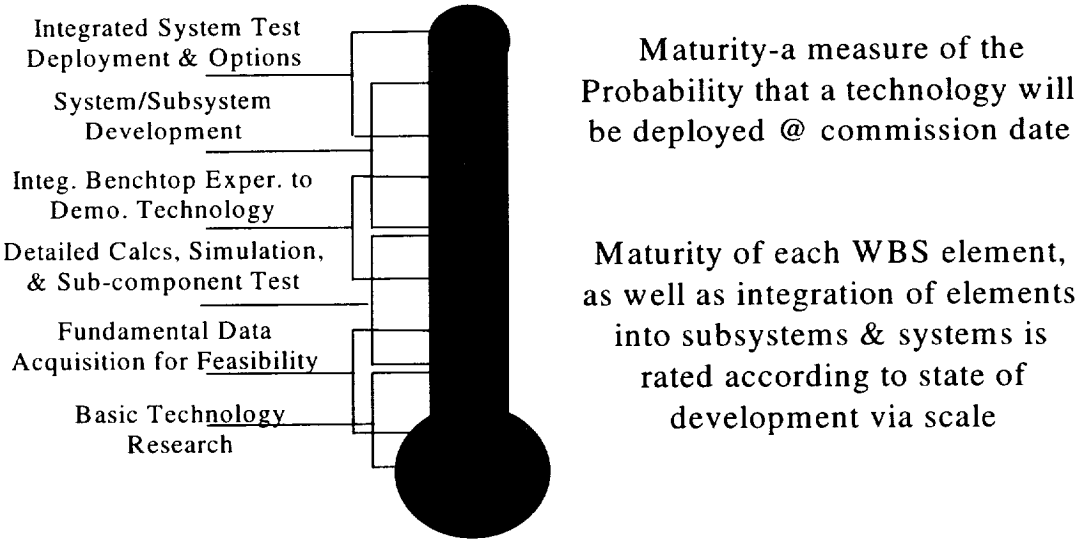
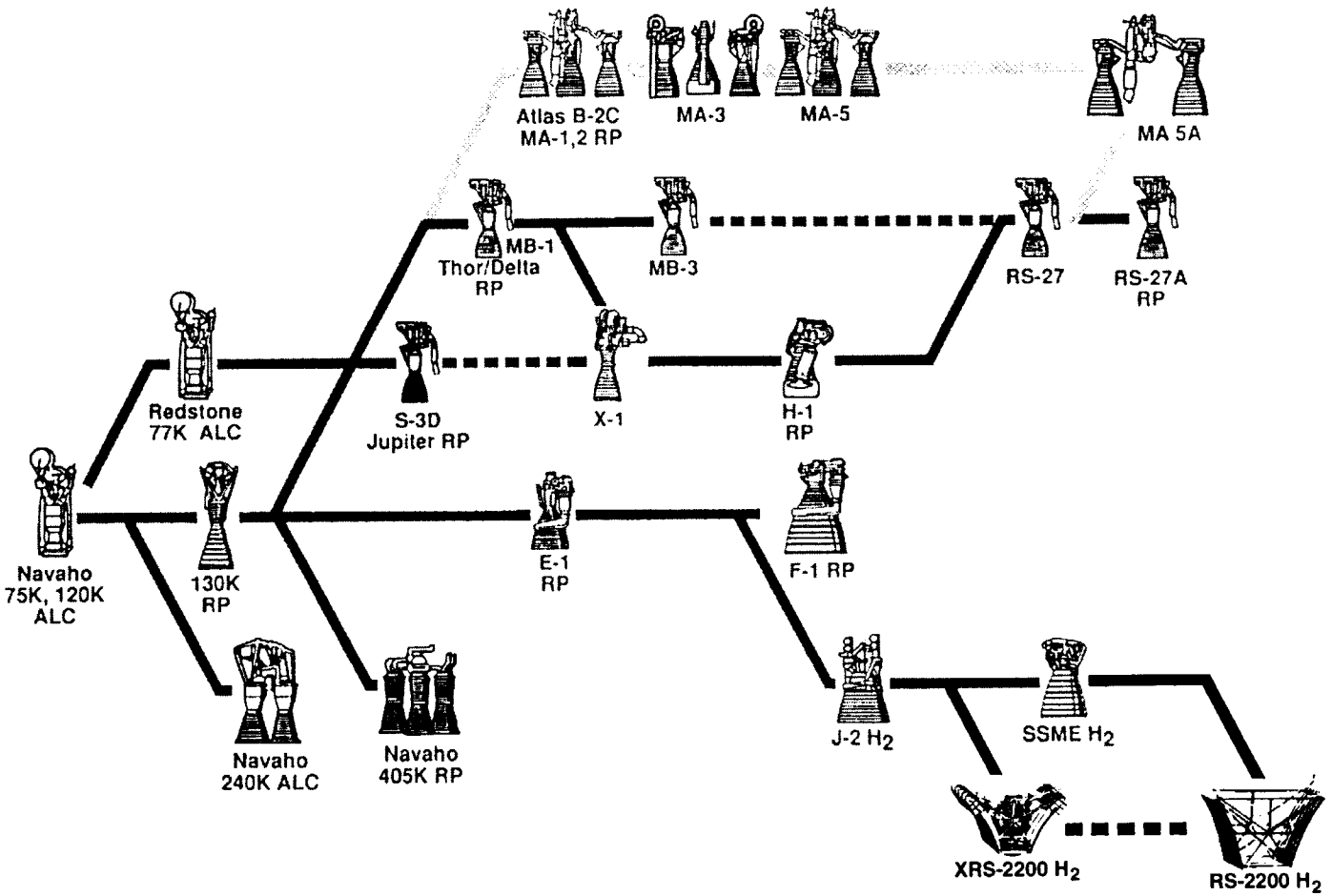



**Figure 1 : US Air Force Technology Rating Scale**

As useful as this approach was, it was limited in that it did not take into account the variation to be expected in maturity projections. That is, not only should the

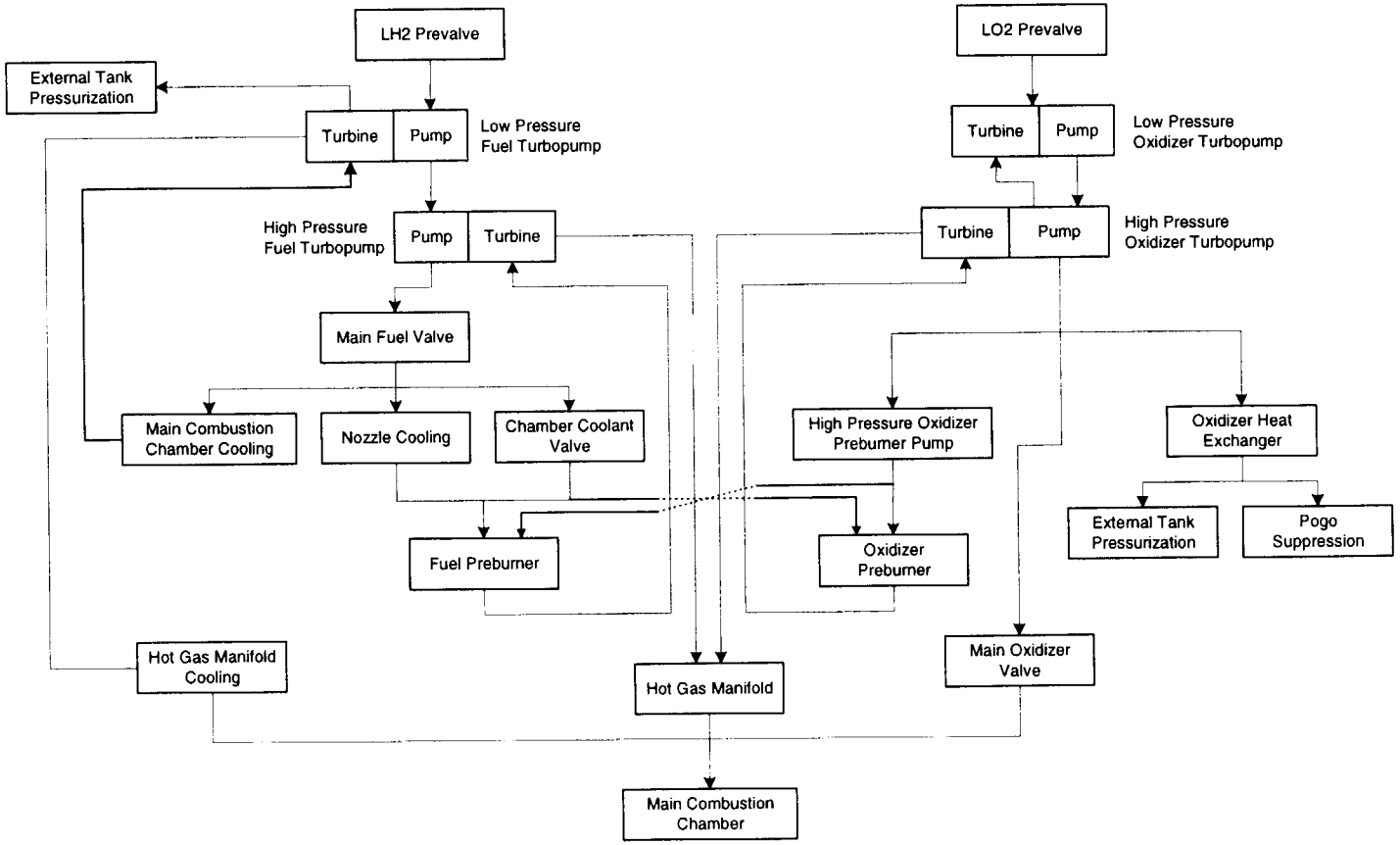
projected performance of immature designs be taken into account, but also the variation around the expected value would be expected to be larger the more immature the design. The authors modified the Air Force approach to account for this expected variation by using a probability distribution to represent the variation around the expected value at each maturity level, and correspondingly increased the variation by use of increased error factors (EF) for more immature designs. These error factors were calculated by taking the ratio of the 5%ile to the median (or 50%ile) for an assumed lognormal distribution, and therefore represented a measure of spread in the distribution about this central value. These distributions and error factors were then applied as appropriate depending upon the maturity of each of the individual design alternatives selected to represent their expected delivered reliability. The overall expected reliability of the baseline design, (i.e. the design created by selecting the preferred lower level alternative in each instance), was then estimated by creating a Monte Carlo model which sampled from each lower level distribution thus creating a distribution representing the expectations of the entire design.

# RS-2200 Family Tree



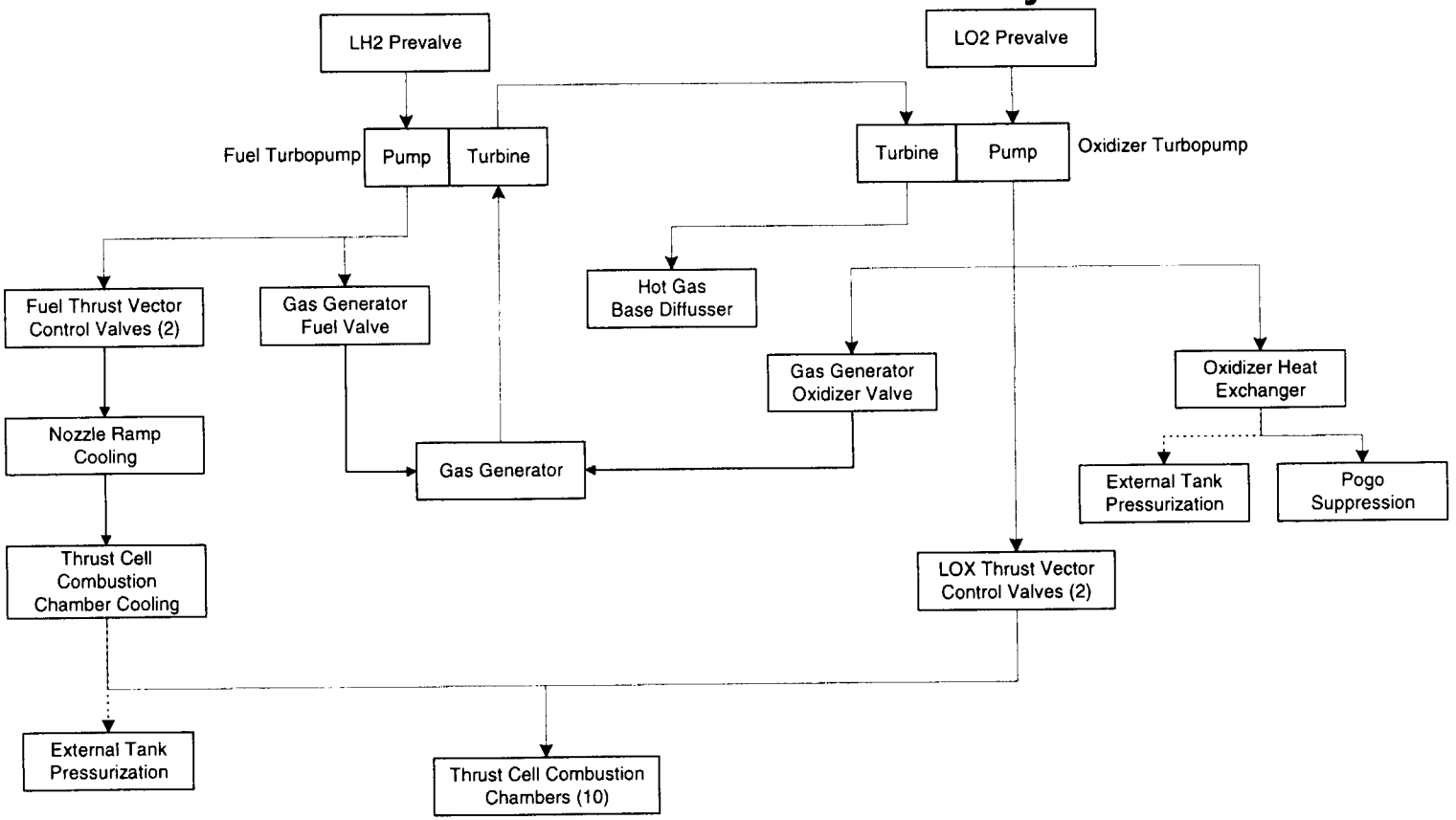
# Block II Engine Schematic

## SSME Staged Combustion Cycle



# Not a chip off the old Block II

## RS-2200 Gas Generator Cycle

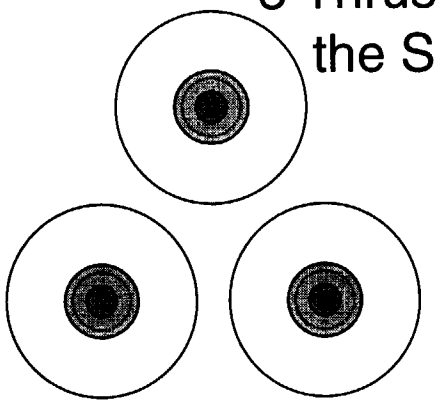


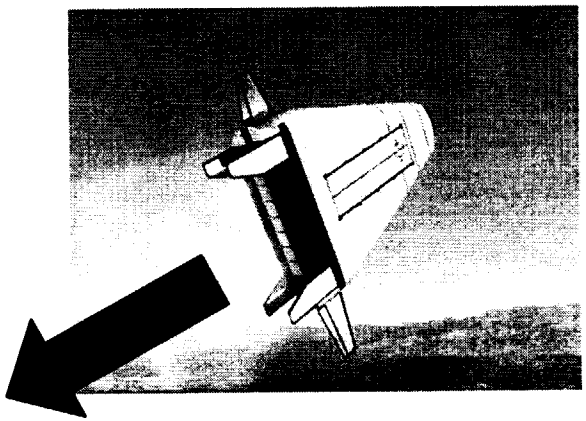
# Functional Comparison of Components

| RS-2200 | SSME |
| --- | --- |
| – Fuel Turbopump | – High Pressure Fuel Turbopump |
| – Oxidizer Turbopump | – High Pressure Oxidizer Turbopump |
| – Gas Generator | – Preburner |
| – Hot Gas Base Diffuser | – Hot Gas Manifold |
| – Nozzle Ramp | – Bell Nozzle |
| – Thrust Cell Injector | – Main Injector |
| – Thrust Cell Chamber | – Main Combustion Chamber |
| – Oxidizer Heat Exchanger | – Oxidizer Heat Exchanger |

# Quantity Comparison

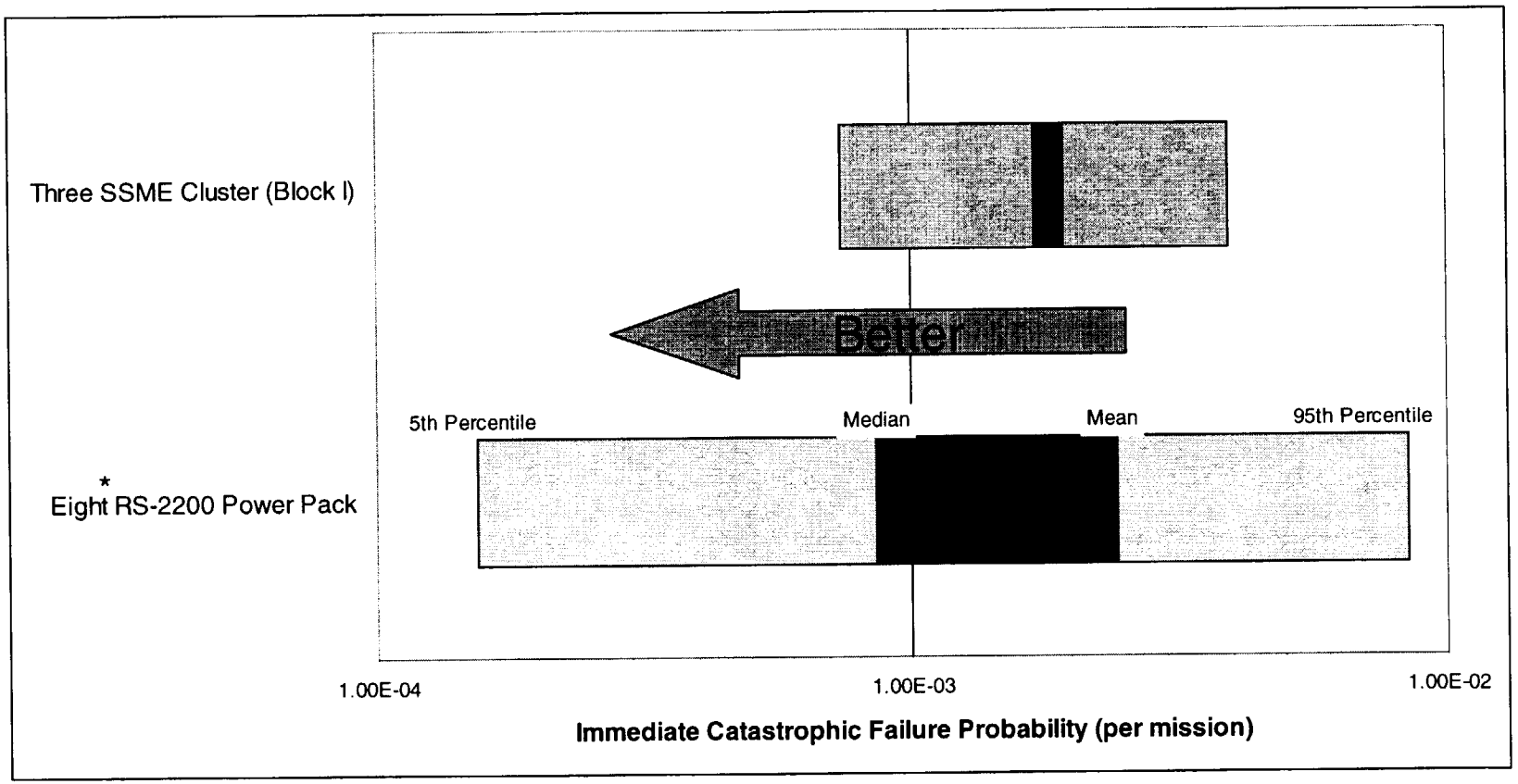
3 Thrust Chambers on
the Space Shuttle





80 Thrust Cells on the VentureStar

# RS-2200 ICF Probability




*Individual engines expected to be much more reliable.