A Stochastic Approach to Designing Affordable, Environmentally Acceptable Systems

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Abstract: The focus of the work being conducted under this grant is to create a virtual stochastic life cycle design environment that will enable designers to make decisions in the presence of uncertainty while considering all aspects relevant to the design at the earliest possible time. This paper describes a portion of this research involving the application of a probabilistic method which allows designers to make direct trades between probability of meeting design goals and product performance (such as specific fuel consumption). The example described here is focused on the cycle selection for a notional commercial aircraft engine such that the design merit can be quantified in terms of a *probability of meeting a design target*. Ultimately, this research will be extended to include environmental aspects such as acoustic noise and emissions requirements.

Introduction: Today's world is characterized by a growing environmental awareness, particularly with respect to acoustic noise and pollutants emitted by vehicles. This trend is very evident in the aircraft gas turbine engine business where performance has always been essential and the addition of new environmental constraints is tending to push current technology to its limits while degrading the economic viability of the system. The objective of this work is to enable the designer to leverage existing design margin to accommodate the increasingly strenuous environmental requirements without compromising performance or requiring the infusion of exotic new technologies [1]. This is done by accounting for the uncertainty inherent at the preliminary design level such that a probabilistic approach can be used to *analytically* estimate the design margin required to meet the design goals. Furthermore, the probabilistic approach allows the designer to select a design margin that is consistent with the level of risk that is deemed acceptable by program management.

Approach to Probabilistic Design: The objective of the method described here is to enable the designer to *analytically* estimate the amount of cycle design margin necessary to compensate for uncertainty in engine component performance uncertainty. This is accomplished using an advanced probabilistic technique known as fast probability integration (FPI) [2] in combination with response surface methods [3] to enable efficient and accurate estimation of response distributions based on user-defined distributions for component performance uncertainty.

The approach is to select ranges for a set of cycle parameters of interest (in this case, fan pressure ratio and extraction ratio are used as an example). Next, a distribution is assigned to each of the component uncertainties of interest. A design of experiments is used to select a set of engine cycles to be examined while the distributions on the component uncertainties remain fixed for all cycles. The FPI method is then used to calculate cumulative distribution functions (CDFs) for all responses of interest. The result is a set of CDFs, one for each cycle per response. This data is then used in conjunction with response surface methods to construct a set of "probability contours" for probability of meeting a target value as a function of the cycle parameters [4].

Results for Commercial Engine Design: The basic problem examined here is the cycle design of an engine suitable to power a notional large commercial transport. In this case, the cycle parameters of interest are fan pressure ratio and extraction ratio. The uncertainty parameters are: booster efficiency, compressor efficiency, high pressure turbine efficiency, low pressure turbine efficiency, fan nozzle thrust coefficient, compressor mid-frame pressure loss, and compressor discharge chargeable cooling air. Ranges for these distributions are selected based on design experience of our industrial partner. The responses of interest here are: probability of meeting a aircraft design range target, engine weight, and fuel burn for a 3,000 nm mission.

Results for this study are shown in Figure 1 which shows contours for probability of meeting a design range target and contours of constant 3,000 nm fuel burn. The shaded area in the lower right is non-feasible due to violation of the upper limit on fan diameter (imposed to ensure adequate ground clearance). Note that the probability contours indicate that there is roughly a 62% chance that the design range target can be met or exceeded for the best design range cycle. Also

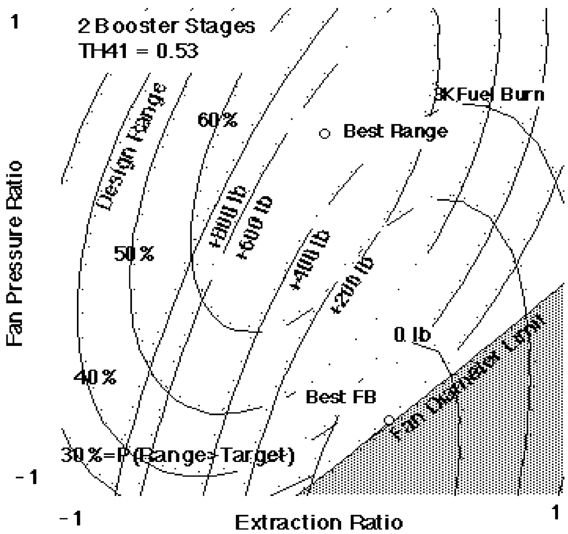

Figure 1: Probability Contours for Design Range vs 3K Fuel Burn [4]

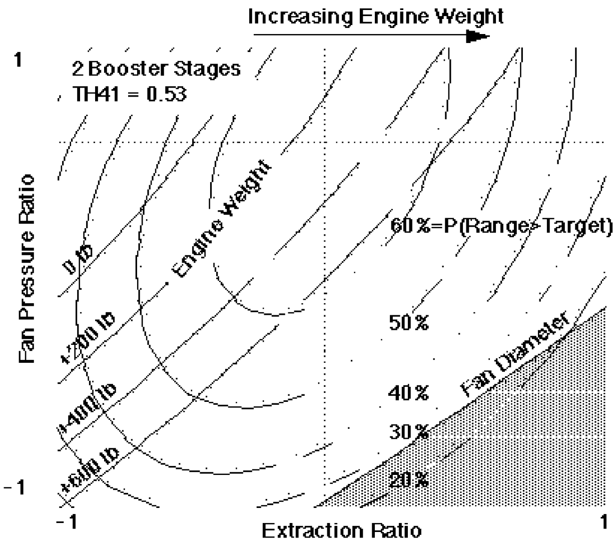

Figure 2: Probability Contours for Design Range vs Engine Weight [4]

note that the best fuel burn cycle is limited by the fan diameter constraint. A similar picture is shown in Figure 2 for contours of engine weight versus probability of meeting design range target. Furthermore, it is clear from this figure that a 5% decrease in probability of meeting the design range target is worth roughly 200 pounds in engine weight. This is information that is useful in trading performance against margin and is not ordinarily available to the designer. This will be instrumental in modeling the environmental constraints given that these aspects are relatively new and typically highly uncertain.

Conclusions and Future Directions: The probabilistic approach to engine cycle design described here is the first step towards the creation of a comprehensive approach to engine cycle design accounting for uncertainty. This technique provides information as to the design margin available and sensitivity of responses to design margin that is not ordinarily available to the designer. Ongoing and future work is focused on adding acoustic noise and engine emissions requirements to the method described here such that these aspects can be treated probabilistically.

Publications: The following publications are direct results of the research funded by this grant.

- Mavris, D.N., and DeLaurentis, D.A., "A Stochastic Approach for Aircraft Affordability," 21st ICAS, Paper 98-6.1.3.
- Mavris, D.N., Macsotai, N.I., and Roth, B., "A Probabilistic Design Methodology for Commercial Aircraft Engine Cycle Selection," SAE985510.
- Mavris, D.N., Kirby, M.R., and Qiu, Songtao, "Technology Impact Forecasting for a High Speed Civil Transport," SAE985547.

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