The Robust Gas Turbine Project
M.I.T. Gas Turbine Laboratory

Prof. David Darmofal, Prof. Daniel Frey, Prof. Edward Greitzer, Prof. Ian Waitz

Variability in engine performance due to manufacture and in-service conditions is a key factor in gas turbine product quality. While a given design may be satisfactory at the nominal conditions, if small perturbations in geometry or operating state lead to large variations in performance, the engine is not robust and the quality will be less than desired. The need is for (1) engines that are robust to variability, and (2) next-generation design tools to help develop these improved engines.

The M.I.T. Gas Turbine Laboratory (GTL) has a long history of developing advanced technologies and engineering methodologies to improve the performance of next-generation engines. The driving goal of our past efforts has generally been performance-related. In the current environment, however, the "ilities" (affordability, durability, reliability, maintainability, operability, etc.) play an increasingly important role in setting product quality. To respond to this changing environment, the GTL has launched a new effort in the robust design of gas turbines with a particular focus on aerothermal robustness. The long-term goals of this program are:

1. Identification and quantification of key drivers for uncertainty and engine-to-engine variability in aerothermal quality including validation against data

2. Definition of criteria for the design of engines with a commercially-significant reduction in sensitivity to uncertainty and variability including analysis of cost trade-offs

3. Development of improved processes for monitoring and controlling the effects of variability on aerothermal quality

4. Implementation of one or more of the above elements in an industrial setting

This effort currently includes four faculty members and four graduate students encompassing extensive experience in turbomachinery, robust and probabilistic design, and computational modeling. Industrial linkages are viewed as a critical part of the long-term success of this program, and active collaborations with industrial partners are continually being developed.

In the past robustness has often been achieved through a combination of factors of safety which reduce performance, tight tolerances which drive up costs, and frequent maintenance which also drives up costs. The robust design approach is to cost effectively blend the reduction of engine sensitivity to variability through design with the control of variability at its source. Robust design must account for both the sources and impact of variability throughout the design cycle. A canonical robust design cycle is illustrated in Figure 1.

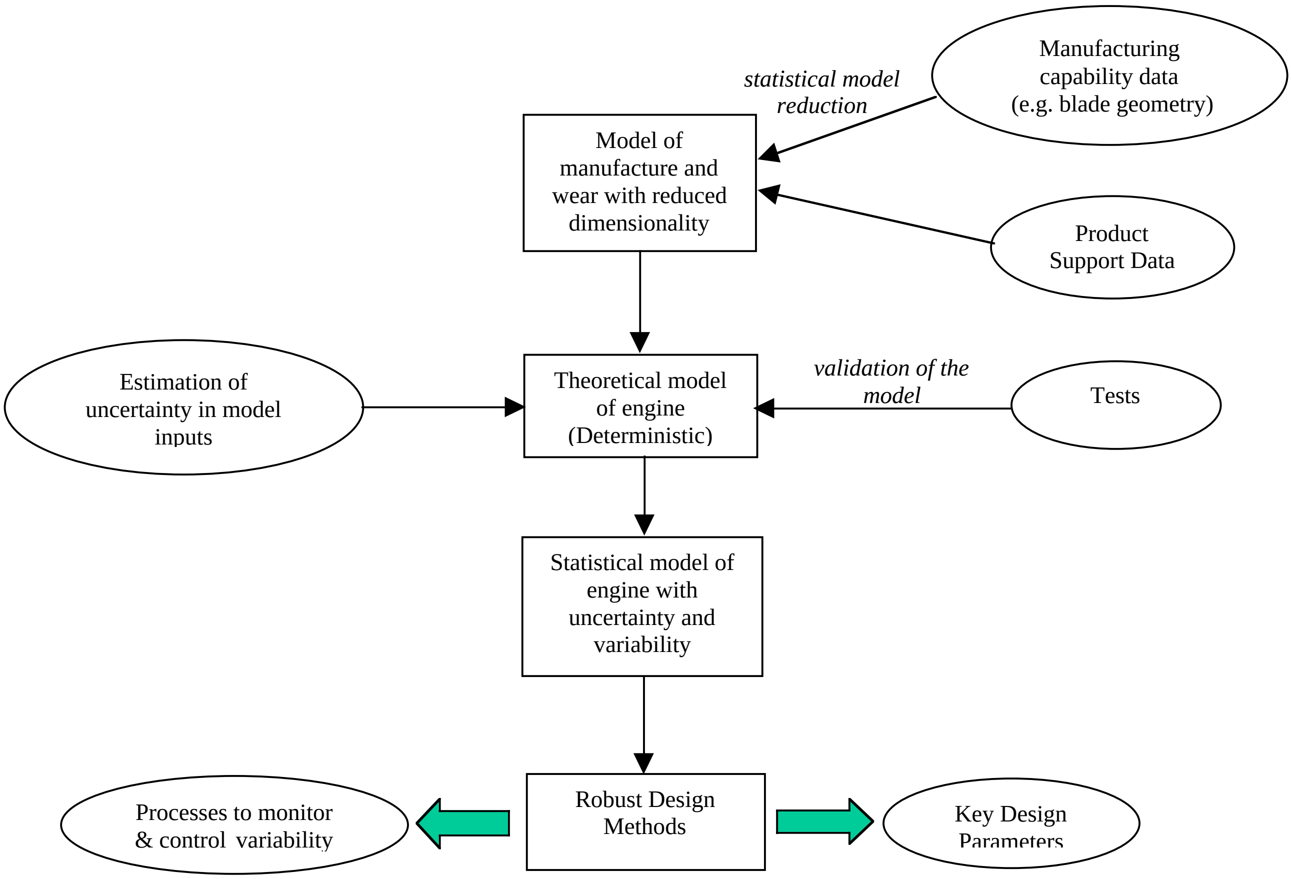

Figure 1: A robust design cycle for a gas turbine engine

Several barriers exist in achieving an effective implementation of a robust design cycle:

> **Statistical barrier:** accurate yet efficient characterization of input variability and uncertainty.
>
> **Aerothermal barrier:** accurate yet efficient modeling of aerothermal effects relevant to variability and uncertainty in engine aerothermal quality.
>
> **Probabilistic barrier:** accurate yet efficient quantification of the variation in aerothermal quality due to input variation and uncertainty.
>
> **Cost barrier:** realistic modeling of the cost impact of aerothermal variability and uncertainty.

These methodological barriers are common for all our applications of robust design to gas turbine engines. As the project matures, we believe the knowledge gained by facing these barriers will form the core competency of our group and its (past and present) members.

Within the group, we have several on-going applications of robust design. These include:

- **Robust design of compressor airfoils with geometric variability:** the focus of this work is quantification of the impact of manufacturing variability on the efficiency of compressor airfoils and the subsequent robust design of an airfoil with reduced performance variability.

- **Impact of internal flow system uncertainty on turbine blade durability:** turbine blade durability is highly sensitive to internal cooling; in this work, we seek to identify the key sources of variability and uncertainty within the internal flow system which lead to uncertainty in turbine blade life.

- **Robust design of combustion processes:** the goal of this project is to identify the key drivers of variability in combustion stability and emissions. The technical issue is whether combustor architectures exist which offer potential for improving the robustness of combustion processes while maintaining low emissions.