A Prognostic Risk Assessment Tool for Enhanced Engine Operation

Jonathan S. Litt
NASA Glenn Research Center, Cleveland, OH 44135

Overview

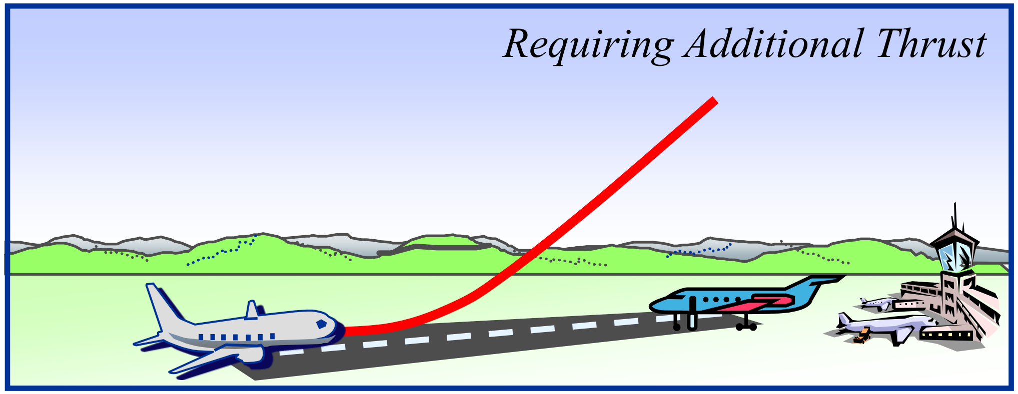
- Objectives
- Background
- Risk Management Architecture
- Engine Life Risks
- Engine Operability Risks
- Summary
- Acknowledgment

Objectives

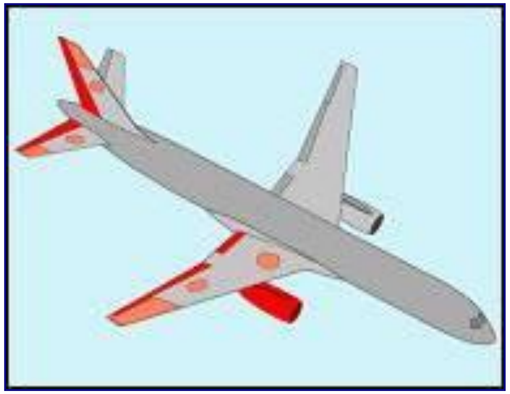
- Improve flight safety by advancing control capabilities of aircraft in emergency situations
- Determine critical engine failure modes for fast response and overthrust conditions
- Develop a prognostic tool to assess risk for fast engine response and overthrust control modes

http://www.pw.utc.com

Background
Scenario 1: Overthrust



1. Runway Incursion



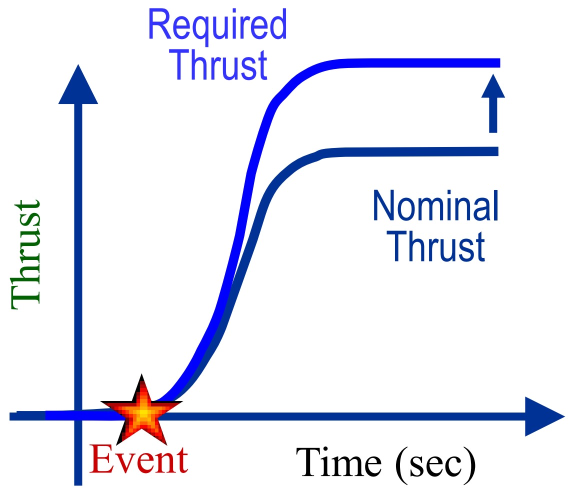
2. Wing Damage

Scenario

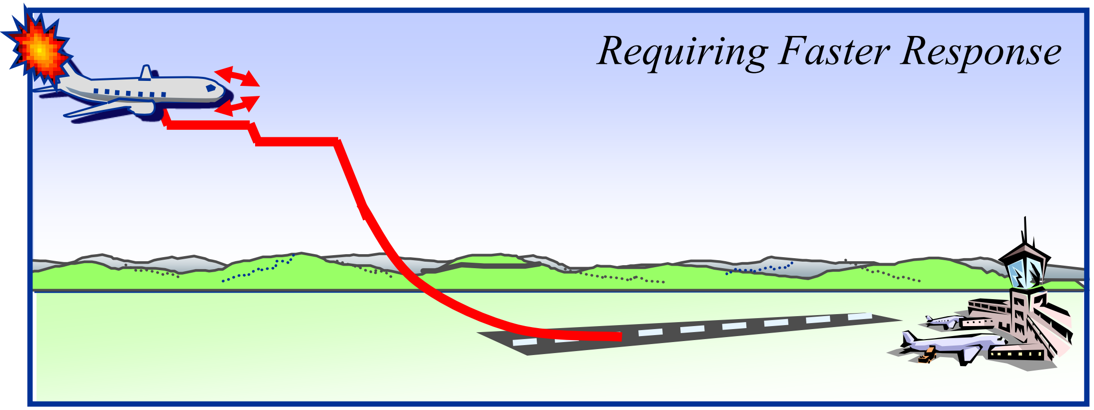
Adverse Condition
1. Plane Crossing Runway During Takeoff Roll
2. Wing Damage

Pilot Action
Snap Full Throttle – Hard Pull Up

Derived Engine Requirements
- Increased Maximum Thrust
- Runway Incursion: Short Duration (< Minute)
- Wing Damage: Long Duration (>>Minute)
- Ensure Engine Does Not Fail



Background
Scenario 2: Fast Response

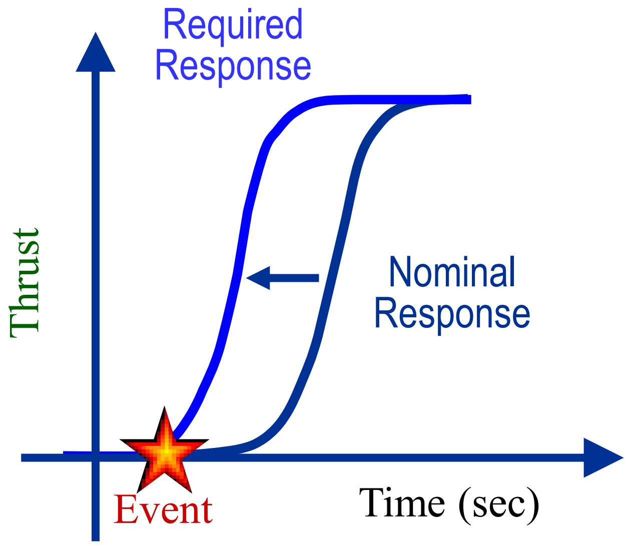


Scenario

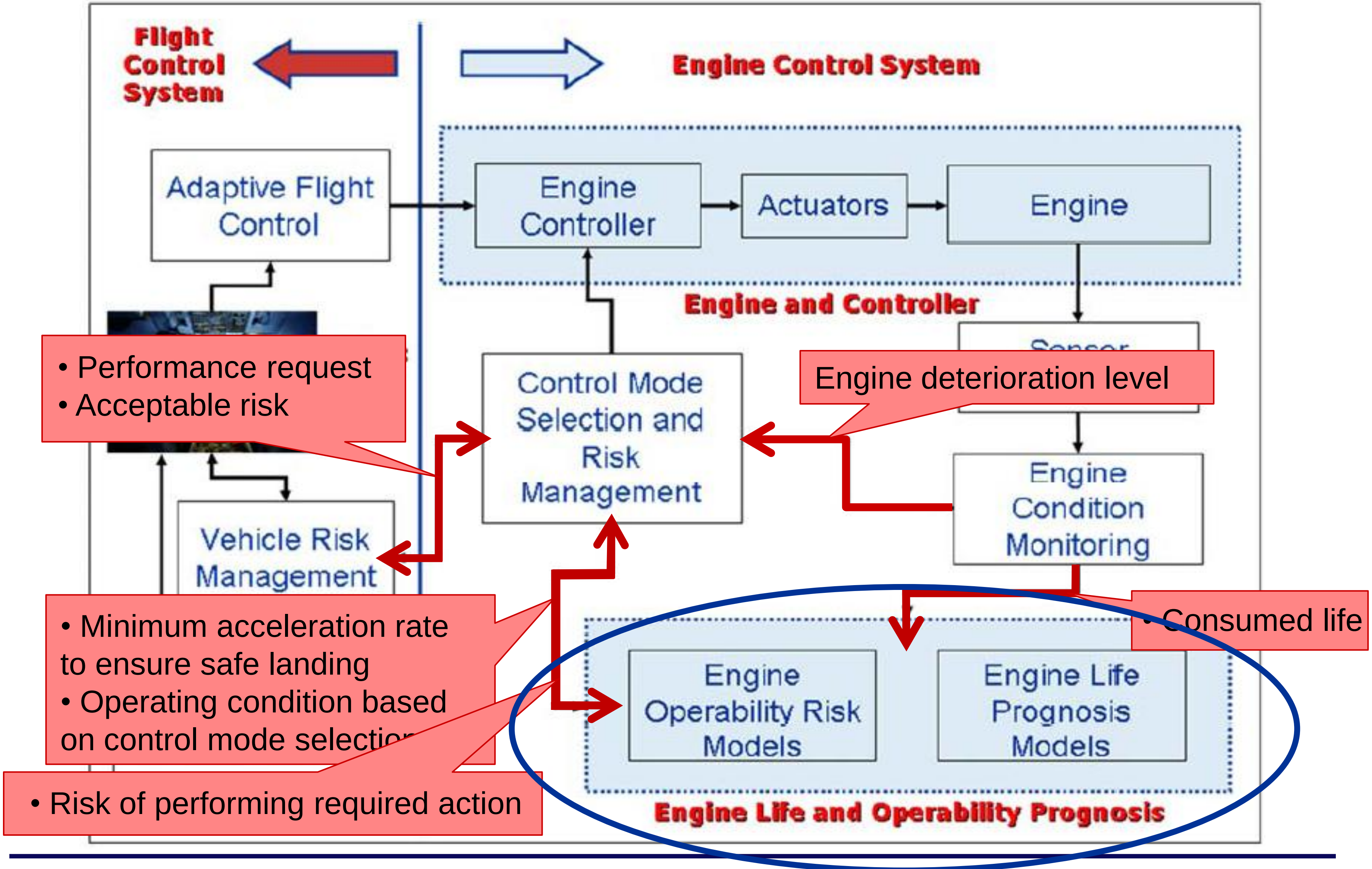
Adverse Condition
Sudden Loss of Rudder Control

Pilot Action
Asymmetric Engine Thrust Modulation

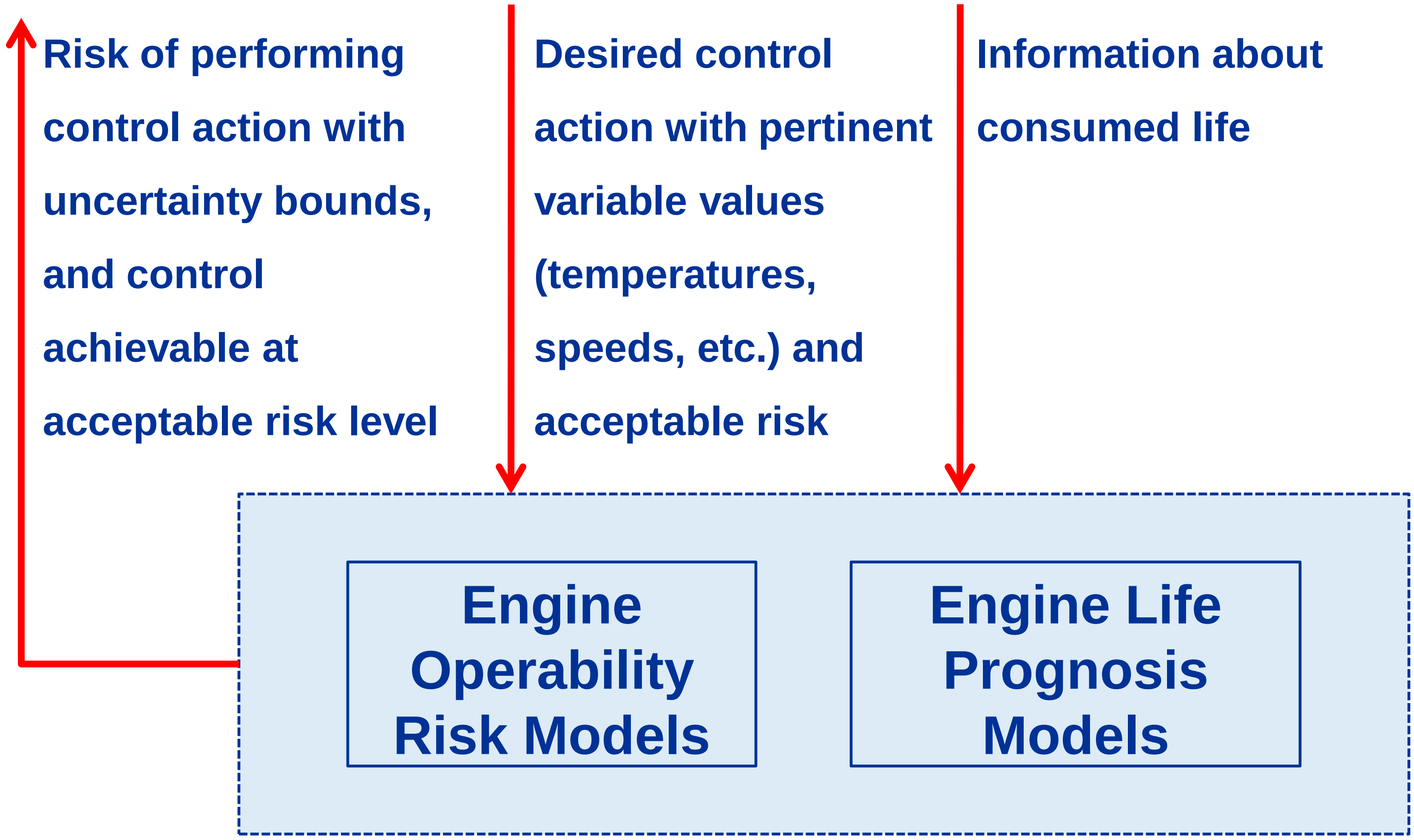
Derived Engine Requirements
- Decrease Accel / Decel Times
- Maintain Adequate Margins / No Stall



Risk Management Architecture



The Prognostic Tool Information Flow



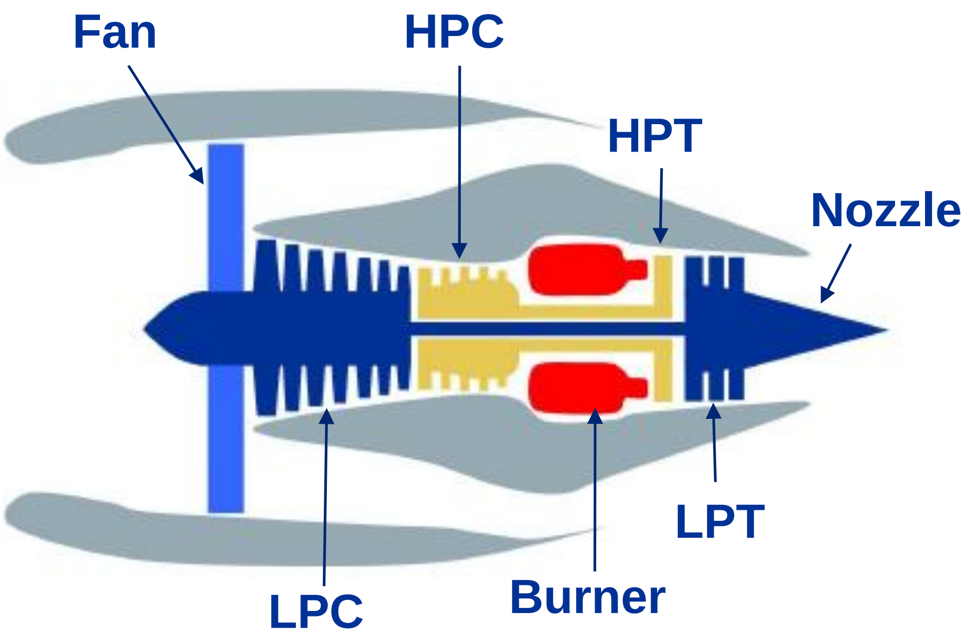
The Prognostic Tool has three main components:

- A database of engine characteristics required for risk calculation
- A set of algorithms to determine risk based on the various enhanced control modes
- On-line, real-time information computed based on (normal) past use and anticipated enhanced use in an emergency situation

RISK OF FAILURE FOR OVERTHRUST OPERATION

Assume Enhanced Control Mode Is Overspeed

Engine Failure Modes During Overthrust Operation



LPC: Low Pressure Compressor
HPC: High Pressure Compressor
HPT: High Pressure Turbine
LPT: Low Pressure Turbine

- **Disk burst due to overspeed**
- **Stress rupture of the turbine blades**

Turbine Blade Stress

Centrifugal stress: $\sigma_c = f(\rho, \omega, r_t, r_h, A_t, A_h)$

where,

ρ: blade material density

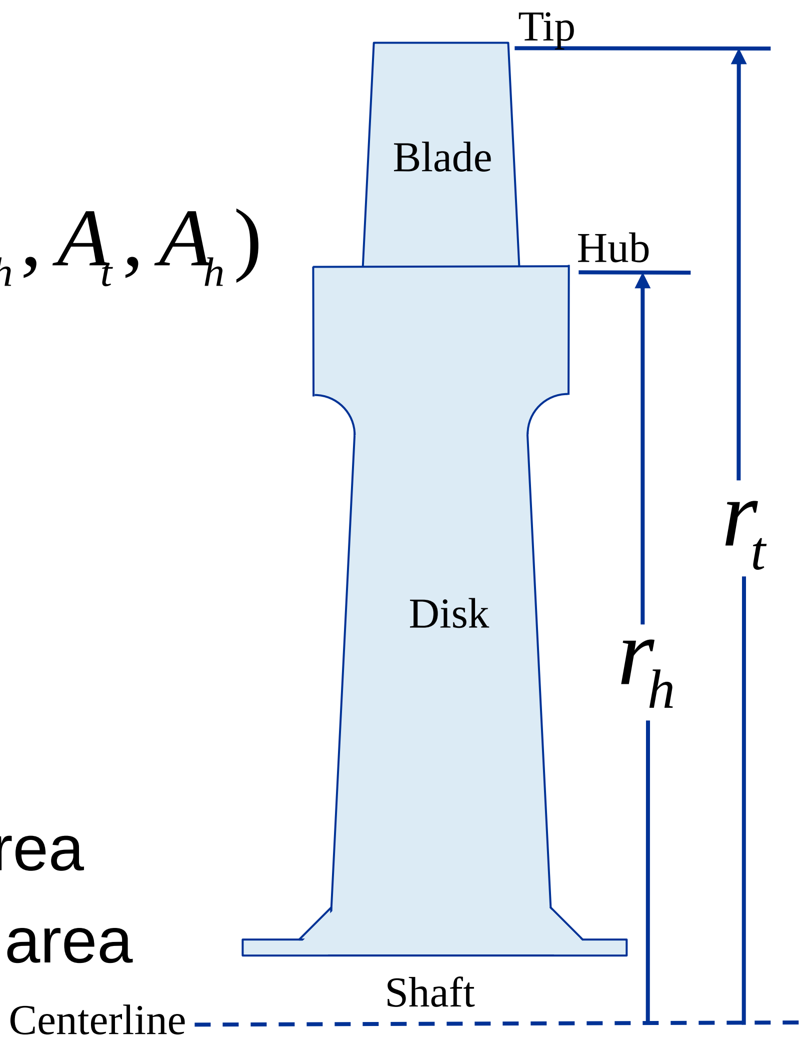
ω: rotor speed

r_t: tip radius

r_h: hub radius

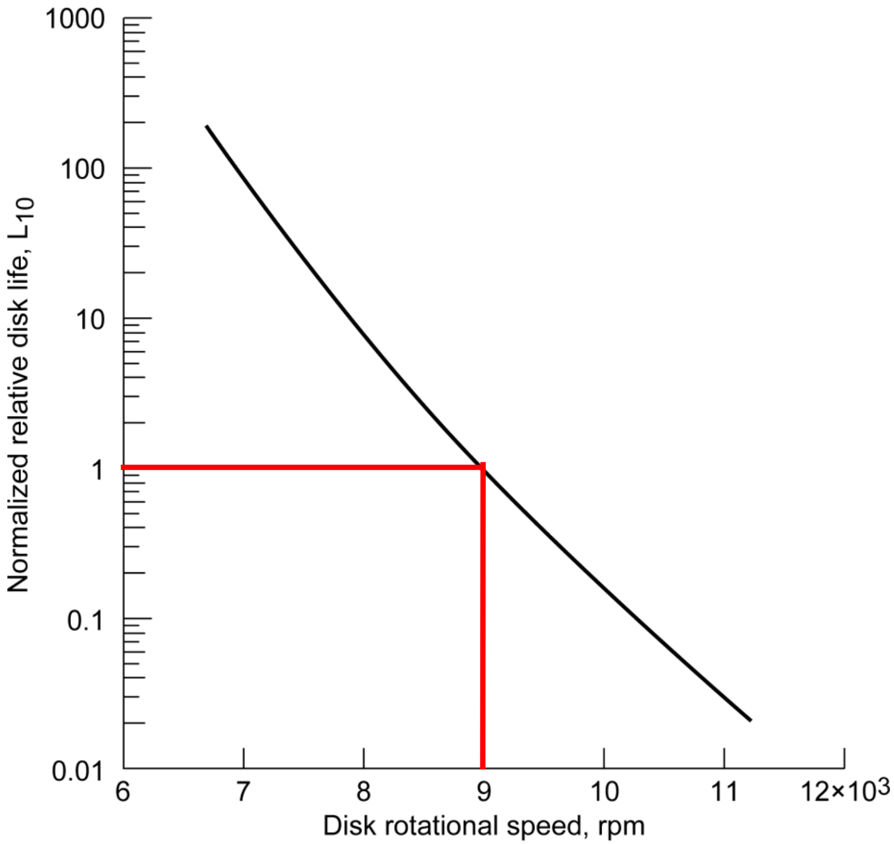
A_t: blade tip cross-sectional area

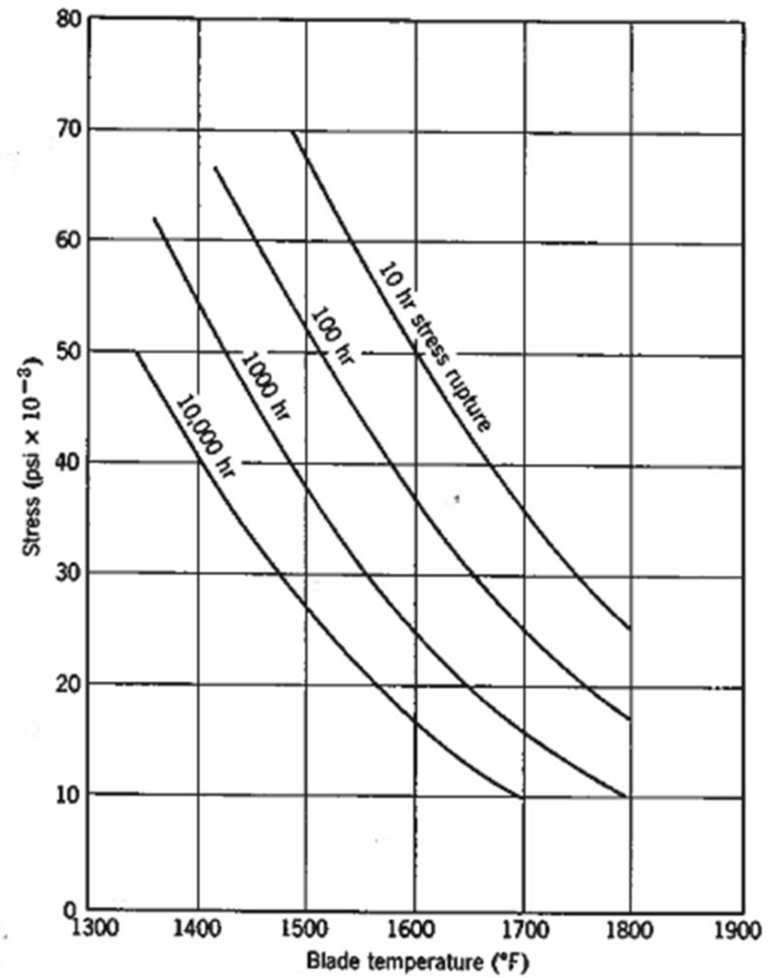
A_h: blade hub cross-sectional area



Engine Life Prognosis Model

Disk and Turbine Blade Life



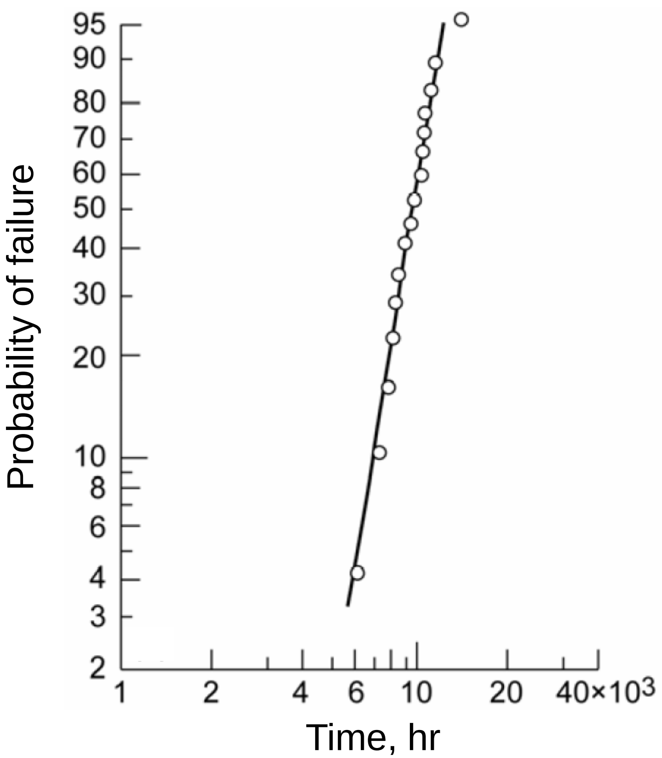


Ref: Zaretsky, E.V., Smith, T. E., August, R. "Effect of Design Variables, Temperature Gradients, and Speed of Life and Reliability of a Rotating Disk." Honolulu, HI, March 22-27, 1987.

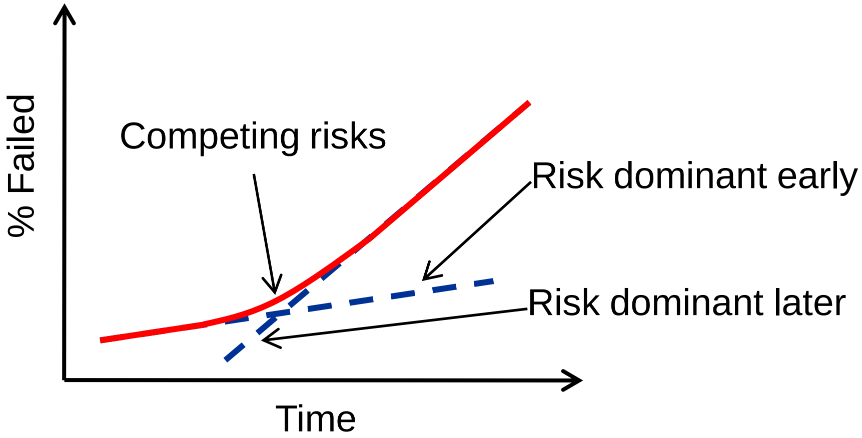
Ref: Sobey, A. J., Suggs, A. M. ,*Control of Aircraft and Missile Powerplants.* New York: John Wiley and Sons, 1963.

Weibull Analysis

Probability of failure (risk) over time with normal use



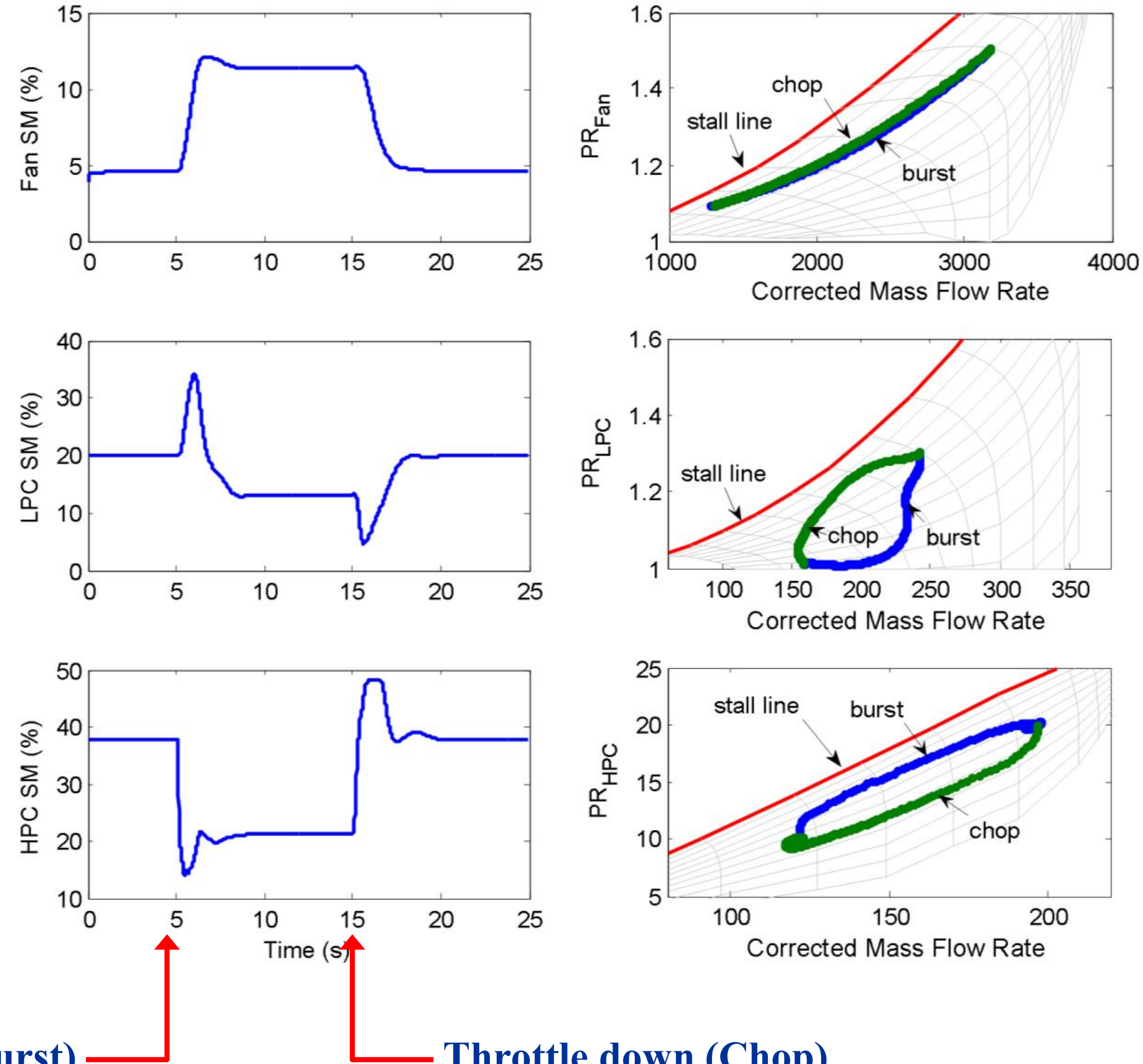
Probability of failure over time with a new risk introduced by enhanced operation



RISK OF STALL FOR FAST ENGINE RESPONSE

Assume Enhanced Control Mode Is Modified NDOT Acceleration Schedule

Burst and Chop Stall Margins



Throttle up (Burst) **Throttle down (Chop)**

Components of Stall Margin Stack Up

Example of required HPC stall margin

Cause	Systematic Deviances	Random Variances
New production engine-to-engine working line variation	0	1.5%
New production engine-to-engine stall line variation	0	4.0%
In service working line deterioration	-2.0%	
In service stall line deterioration	-4.0%	
Control system fuel metering, and other actuators	0	1.0%
Reynolds number effects	-1.0%	
Inlet distortion	-1.0%	
Transient allowance	-12%	
Total	-20%	4.4%

Stack up=Σ(Systematic Deviances)+RMS(Random Variances)

Stall margin must account for stack up

Ref: Walsh, P.P., and Fletcher, P., *Gas Turbine Performance*, Blackwell Science/ASME, 2004.

Risk of Fast Response

- Stall margin stack-up ensures against stall in the most deteriorated engine in the fleet under the worst conditions
- Reduction of allowance introduces risk
- With knowledge of some of the components of stack-up, the corresponding risk might be able to be reduced
- Using information about the engine’s condition and about the quality of estimation used to determine that information, as well as information about the size of the requested thrust transient, the risk of increasing the speed of response can be determined statistically

Summary

- Developed modular prognostic tool to determine risk for fast response and overthrust operation
- Assumed specific control modes exist for enhanced engine operation
- Developed statistical algorithms to determine risk for fast response and overthrust operation using the assumed control modes
- Risk functions were developed from information in literature

Acknowledgment

Lauren M. Sharp, NASA Glenn Co-op