ENGINE TEST CONFIDENCE EVALUATION SYSTEM

Multi-Dimensional Assessment of Technology Maturity Conference

13 September 2007

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Report Documentation Page

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Agenda

- **Background**
- **Description**
- **Application/Example**
- **Risk Assessment Tool**
- **Summary**

Turbine Engine "Building Block" Technology Demonstration Process

APPLIED RESEARCH (6.2)

ADVANCED TECHNOLOGY DEVELOPMENT (6.3)

TECHNOLOGY TRANSITION

Seamless Development Process

FAN

MECHANICAL SYSTEMS

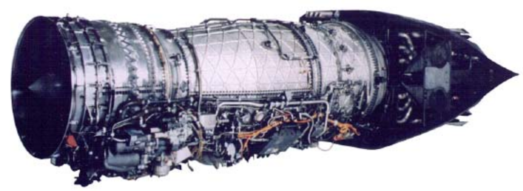
COMPRESSOR

NOZZLE

COMBUSTOR

CONTROLS

TURBINES



APSI JTDE and JETEC "ENGINE" DEMONSTRATORS

ATEGG and JTAGG "CORE" TECHNOLOGY DEMONSTRATORS

Seamless Contractor Planning

Technology Readiness Levels

System Test, Flight and Operations

System/Subsystem Development (SDD)

Technology Demonstration (ATEGG/JTDE)

Technology Development (Rig Testing)

Research to Prove Feasibility

Basic Technology Research

9 - Actual system "Flight Proven" through successful mission operations

8 - Actual system completed and "Flight Qualified" through test and demonstration

7 - System prototype demonstration in an operational environment

6 - System/Subsystem model or prototype demonstration in a relevant environment

5 - Component and / or breadboard validation in relevant environment

4 - Component and / or breadboard validation in laboratory environment

3 - Analytical and experimental critical function and / or characteristic proof - of - concept

2 - Technology concept and / or application formulated

1 - Basic principles observed and reported

Test Confidence Rating Purpose

- Test Readiness assessment of AFRL 6.3 Funded Advanced Development engine programs
  (Engine components, instrumentation, assembly and test facilities)

- Rating of program at key program milestones
  (Proposal Eval, PDR, CDR, TRR)

Test Confidence Rating Purpose

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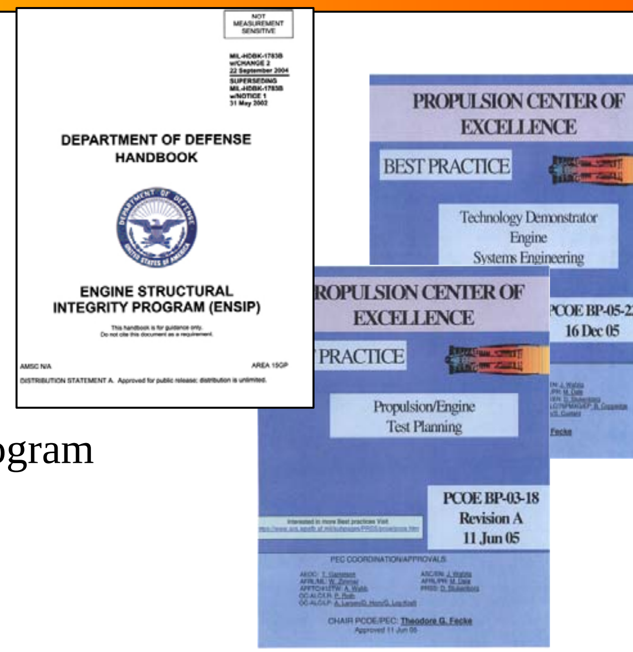
Note: Program ATD programs
1) Have signed transition plans
2) Use James Gregory IPPD process

Test Confidence Rating System



<u>APPROACH</u>

- Use 1997 Component Rating Model as starting point
- Review R&D Engine past problem data base
- Use Guidance from
  - 577th AESG Best Practice documents
  - ENSIP document HCF test Protocol
  - Existing (F135, F136, F119, etc) System Engineering Program
  - AFR 99-103 “Test & Evaluation”
- Benched marked model against previous R&D engines

<u>FEATURES OF RATING SYSTEM</u>

- “Exit criteria” at Program Kickoff, PDR, CDR, hardware delivery, Test Planning
- Hardware responsibility back to component owner
  - Component level risk assessment / mitigation
  - Review of manufacturing
  - Review of inspection records
  - Review of instrumentation & assembly
- Review of test facility past problems

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Engine Test Confidence Rating (TCR) DESCRIPTION

<u>Expanded prior MERQ advanced component rating process</u>

- Instrumentation, Assembly & Test
- Additional Component Design Information
- Extensive use of checklists guide rating process

Materials
Environment
Reaction
Quality

Engine Test Confidence Rating

Component Confidence Rating

Component
Material
Manufacturing Process
Assembly / Instrumentation Quality
Part Quality

Component Confidence Rating
Engine Assembly / Instrumentation Quality
Test Plan
Instrumentation
Test Facility / Installation
Special Test Equipment

Test Confidence Rating Calculation

START

N (1,T)
Component Number
Total Number of Components

Component Confidence Rating
Component
Material
Manufacturing Process
Assembly / Instrumentation Quality
Part Quality

$$CC_N = \sqrt[5]{C_N * M_N * MP_N * AIQ_N * PQ_N}$$

Identify Critical Technology Elements

$$CC = \sqrt[T]{CC_1 * CC_2 \cdots CC_T}$$

Test Confidence Rating
Component Confidence Rating
Engine Assembly / Instrumentation Quality
Test Plan
Instrumentation
Test Facility / Installation
Special Test Equipment

$$TC = \sqrt[6]{CC * EAIQ * TP * I * TFI * STE}$$

FINISH

TCR Evaluation

Demonstrator: Silicon Nitride Blade Example								
Date of Rating: Now Feb 07								
	High Turbine	Compressor	Combustor	Low Turbine	Fan	Mechanical Systems	Controls	Nozzle
Component	5	1	1	1	1	1	1	1
Material	6	1	1	1	1	1	1	1
Manufacturing Process	6	1	1	1	1	1	1	1
Assembly / Instrumentation Quality	6	1	1	1	1	1	1	1
			1					
Part Quality	6	1	1	1	1	1	1	1
	6480	1	1	1	1	1	1	1
	5.79	1	1	1	1	1	1	1
T	1							
		5.79						
CC		5.79						
Engine Assembly / Instrumentation Quality		6			Input			
Test Plan		6			Output			
Instrumentation		6			Less than 6			
Test Facility / Installation		9						
Special Test Equipment		9						
		101,217.07		101,217.07				
C		6.83		6.83				
Notes: Must Justify rating & Identify future risk reduction efforts								

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  - @ start of engine testing
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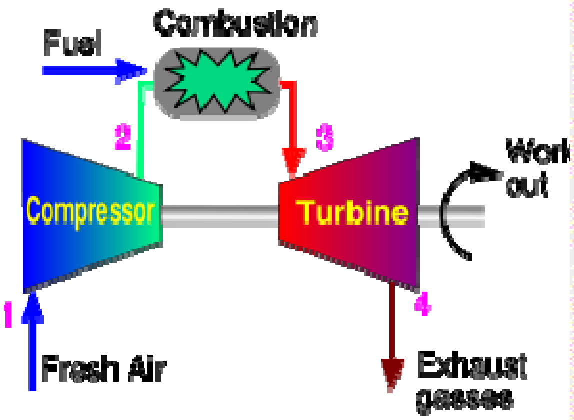
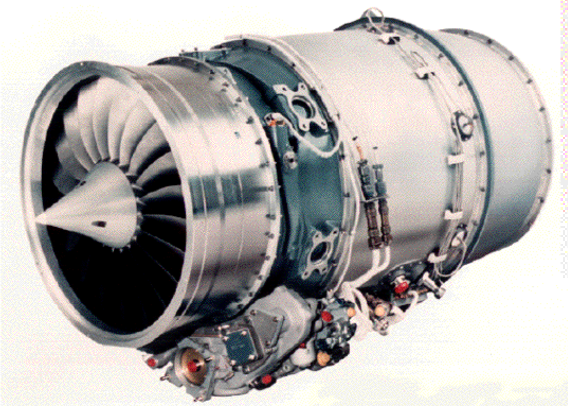
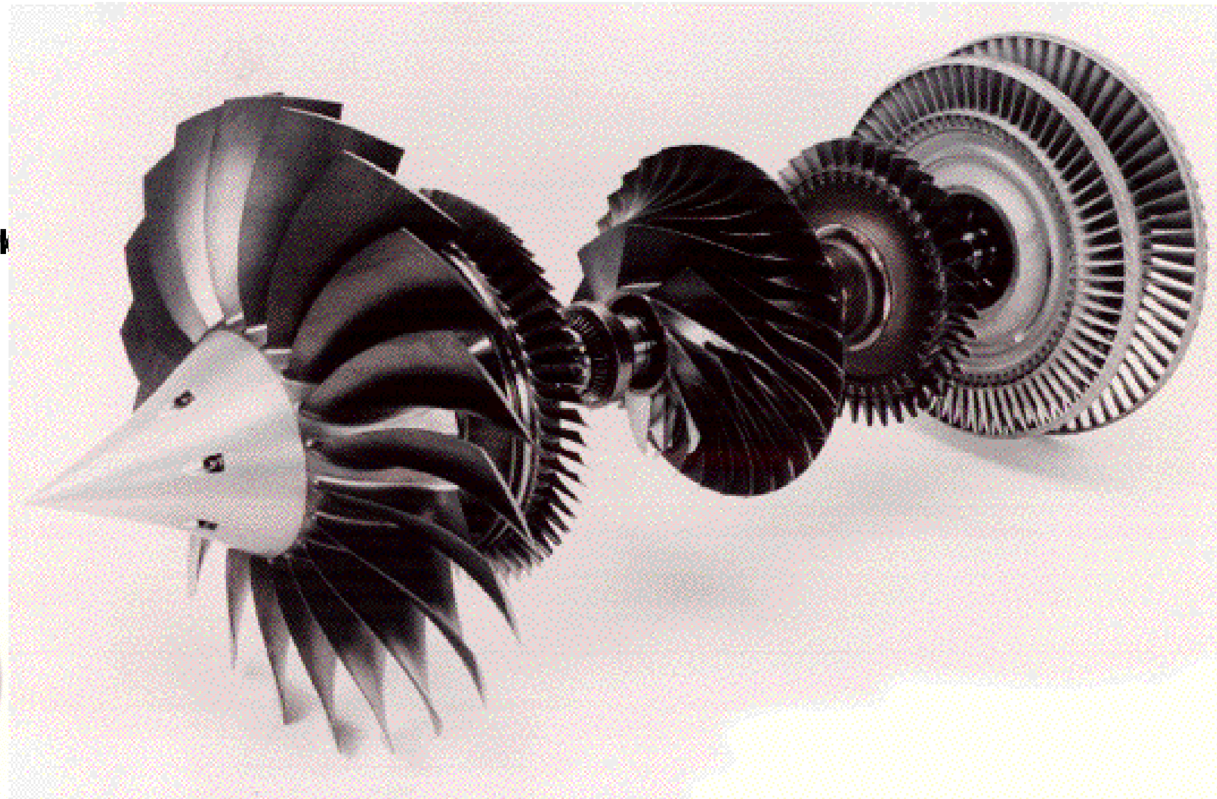
Engine Example

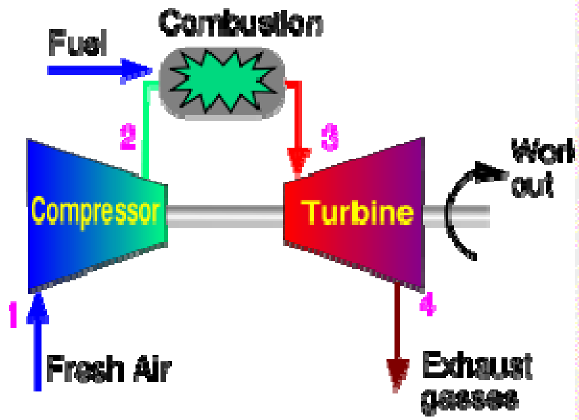


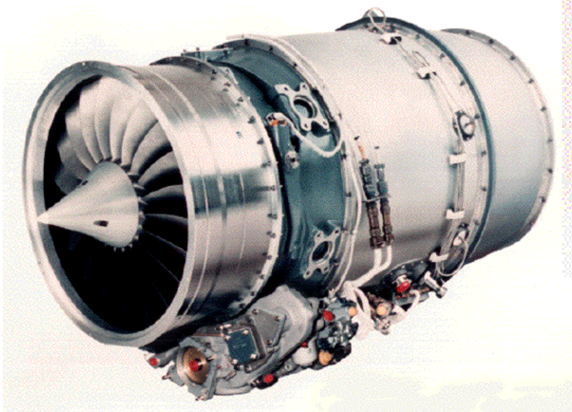


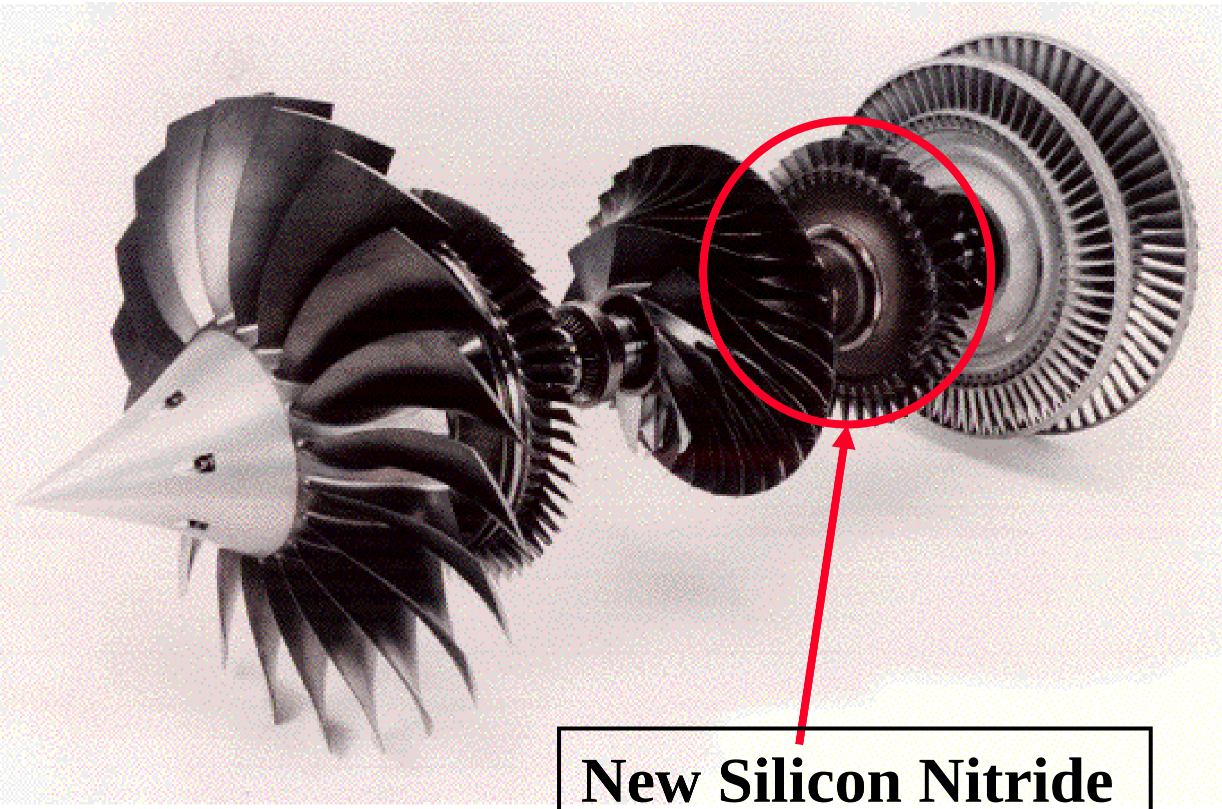


FJ44 for Illustration purposes only- FJ44 not the real example

Engine Example







New Silicon Nitride Turbine blades

FJ44 for Illustration purposes only- FJ44 not the real example

Turbine Component (C)

0	Idea!
1	Conceptual Design
2	Preliminary Design
3	Detailed Design
4	Subcomponent Rig Tests
5	Subscale Component Rig Test
6	Full Scale Component Rig Test
7	Demonstrator Engine Performance Test
8	Demonstrator Engine Durability Test
9	Demonstrator Engine Altitude Test

Component (C) Rating Criteria

<u>Conceptual Design Review (CDR) / Kickoff Meeting</u>

1. Engine/component-level goals/objectives defined (performance, efficiencies, cooling flows, pressure ratios, etc.)
2. Initial risk assessment.
3. New processes identified.
4. Tech Demo Systems Engineering (TDSE) deviations identified, evaluated and addressed.
5. Test facility, facility requirements, preliminary special test equipment and safety requirements identified.
6. Initial assessment of engine/component environment (pressure, temperatures and stresses).
7. Structural Audit format defined

Component (C) Rating Criteria

Preliminary Design Review (PDR)

1. Moderately detailed description of component and its materials.
2. Acceptable hardware reworks, changes, and refurbishment since previous use
3. Sufficient aerodynamic and mechanical design activity to allow all long lead hardware to be ordered.
4. Engine/component-level goals/objectives defined (performance, efficiencies, cooling flows, pressure ratios, etc.)
5. Risk assessment updated.
6. TDSE deviations identified, evaluated and addressed.
7. Preliminary manufacturing plan complete (long lead hardware identified).
8. Critical or new manufacturing processes/challenges identified.
9. Test facility, facility requirements, preliminary special test equipment and safety requirements identified.
10. Preliminary instrumentation and preliminary assembly plans complete.
11. Appropriate lessons learned identified and incorporated.
12. Initial Structural Audit.
13. Updated assessment of engine/component environment (pressure, temperatures and stresses).

Component (C) Rating Criteria

<u>Detailed Design Review (DDR)</u>

1. Pretest performance predictions cover all key test points .
2. Component predicted performance and operability is acceptable.
3. Final assessment of engine/component environment (pressure, temperatures and stresses)
4. Secondary flow analyzed was conducted at all key test points.
5. Acceptable data acquisition and safety monitoring, and all critical limits are defined.
6. Acceptable Instrumentation features/routing to include changes from previous builds.
7. Critical pieces of instrumentation have back-ups.
8. Yellow and red limits are defined for all safety critical parameters (speeds, vibration, temperatures, pressures, calculated parameters, etc).
9. All clearances (compressor & turbine tip, etc) are consistent with test points
10. Blade and vane vibratory responses (Campbells & Goodmans) are acceptable
11. High Cycle Fatigue test protocol has been applied).
12. Critical or new manufacturing processes/challenges identified.
13. Test facility, facility requirements, preliminary special test equipment
14. Instrumentation and assembly plans updated.
15. Appropriate lessons learned identified and incorporated.
16. Known risks have been addressed.
17. Appropriate TDSE deviations identified and addressed.

Silicon Nitride Material (M)

0	Unattainium!
1	Initial Coupon data
2	Coupon data with some extrapolation
3	Coupon data at relevant conditions
4	Subcomponent data with extrapolation
5	Subcomponent data with interpolation
6	Subcomponent data at relevant engine test conditions (1-2 data points)
7	Subcomponent data at relevant engine test conditions (3+ data points)
8	-1σ data
9	-3σ production values

Manufacturing Process (MP)

0	Idea!
1	Unproven process
2	Nonvalidated inspection of unproven process
3	Process feasibility demonstrated
4	Nonvalidated inspection of demonstrated process
5	Proof spin of demonstrated process at relative loads
6	Validated inspection of demonstrated process or cyclic life test of demonstrated process
7	Validated inspection and prior engine test of demonstrated process
8	Validated inspection of production process
9	Production inspection of production process

Turbine Assembly / Instrumentation Quality (AIQ)

0	No inspection and sign off (I&S O)
1	Third tier subcontractor component owner I&SO
2	Second tier subcontractor component owner I&SO
3	Subcontractor component owner I&S O
4	Original Engine Manufacture (OEM) component owner component I&S O
5	OEM component owner component and subassembly I&S O
6	OEM component owner component, subassembly and part I&S O or previously successful engine test if not disassembled or TDSE plan met and all CDR, PDR, DDR and TRR requirements are met
7	Successive build experience (second build)
8	Successive build experience (2+ builds)
9	Innovative quality control procedures to reduce risk (6σ process)

Turbine Part Quality (PQ)

0	No inspection and sign off (I&S O)
1	Third tier subcontractor I&SO
2	Second tier subcontractor I&SO
3	Part and process (casting, hole drilling, weld, braze etc.) level subcontractor component owner I&S O
4	OEM review of manufacturing inspection records
5	OEM visual review of parts and manufacturing inspection records
6	OEM component owner visual review of parts and manufacturing inspection records or previously successful engine test if not disassembled or TDSE plan met and all CDR, PDR, DDR and HDTOEM requirements are met
7	
8	
9	Innovative quality control procedures to reduce risk (6σ process)

Engine Assembly / Instrumentation Quality (EAIQ)

0	No inspection and sign off (I&S O)
1	Second tier subcontractor assembler / technician I&SO
2	Subcontractor assembler / technician I&SO
3	OEM assembler / technician I&S O
4	
5	OEM component owner I&SO of high risk components
6	OEM component owner I&S O or TDSE plan met and all CDR, PDR, DDR and TRR requirements are met
7	Successive build experience (second build)
8	Successive build experience (2+ builds)
9	Innovative quality control procedures to reduce risk (6σ process)

Test Plan (TP)

0	No requirements addressed
1	Some PDR requirements met
2	PDR requirements met
3	PDR requirements exceeded
4	PDR and DDR requirements met
5	PDR, DDR and TRR requirements are met
6	PDR, DDR, TRR and AEI requirements 1-17 met
7	PDR, DDR, TRR and AEI requirements 1-18 met
8	PDR, DDR, TRR and AEI requirements exceeded
9	Innovative test planning techniques to reduce risk

Engine Instrumentation (I)

0	No requirements addressed
1	Some PDR requirements met
2	PDR requirements met
3	PDR requirements exceeded
4	PDR and DDR requirements met
5	PDR and DDR requirements exceeded
6	PDR, DDR, and SMPTET requirements met
7	PDR, DDR, and SMPTET requirements exceeded
8	PDR, DDR, and SMPTET requirements exceeded with some first generation advanced instrumentation
9	PDR, DDR, and EI requirements exceeded with some second generation advanced instrumentation

Test Facility / Installation (TFI)

0	No requirements addressed
1	Some PDR requirements met
2	PDR requirements met
3	PDR requirements exceeded
4	PDR and DDR requirements met
5	PDR, DDR, and SMPTET requirements met
6	PDR, DDR, SMPTET, and AEI requirements met
7	PDR, DDR, SMPTET, and AEI requirements exceeded
8	Successive test facility experience (second build)
9	Successive test facility experience (2+ builds)

Special Test Equipment (STE)

0	No requirements addressed
1	Required STE identified (slip ring, oil cart, etc)
2	STE specifications identified (channels, flow, etc)
3	STE PDR complete
4	DDR requirements met
5	DDR requirements exceeded
6	DDR and SMPTET requirements met
7	DDR and SMPTET requirements exceeded
8	Successive build experience (second build)
9	Successive build experience (2+ builds)

TCR Calculation

Is risk at test acceptable?

Component Confidence Rating

Component	**= 5**
Material	**= 6**
Manufacturing Process	**= 5**
Assembly / Instrumentation Quality	**= 3**
Part Quality	**= 3**

$$CC = \sqrt[5]{C*M*MP*AIQ*PQ} = \sqrt[5]{5*6*5*3*3} = 4.2$$

Test Confidence Rating

Component Confidence Rating	**= 4.2**
Engine Assembly / Instrumentation Quality	**= 3**
Test Plan	**= 6**
Instrumentation	**= 6**
Test Facility / Installation	**= 9**
Special Test Equipment	**= 9**

$$TCR = \sqrt[6]{CC*EAIQ*TP*I*TFI*STE} = \sqrt[6]{4.2*3*6*6*9*9} = 5.8$$

TCR Evaluation

TCR=5.8 Not acceptable risk, need TCR>6

Action:

C=6 ~~Full scale turbine aero rig test~~

MP=6 Cyclic life spinpit testing

AIQ=6 Component owner is part of Component

PQ=6 Assembly, Inspection , and Engine

EAIQ=6 Assembly

$$CC = \sqrt[5]{C*M*MP*AIQ*PQ} = \sqrt[5]{5*6*6*6*6} = 5.8$$

$$TCR = \sqrt[6]{CC*EAIQ*TP*I*TFI*STE} = \sqrt[6]{5.8*6*6*6*9*9} = 6.8$$

TCR Evaluation

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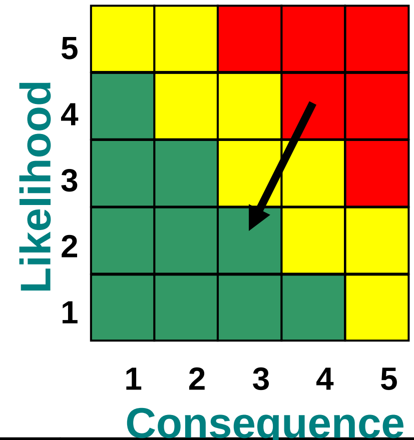
Engine TCR Can Quantify Risks*

Likelihood

Level	Likelihood	Probability of Occurrence
1	Not Likely	~10%
2	Low Likelihood	~30%
3	Likely	~50%
4	Highly Likely	~70%
5	Near Certainty	~90%.



Consequence

Level	Technical	Schedule	Cost
1	Minimal or no impact	Minimal or no impact	Minimal or no impact
2	Minor technical shortfall, no impact to high level technical requirements	Additional activities required, able to meet key dates.Slip <__ month(s)	Budget increase or unite production cost increases <__(1% of Budget)
3	Moderate technical shortfall but work around available which will eliminate impact to high level technical requirements	Minor schedule slip, no impact to key milestones. Slip < __month(s) of critical path. Sub-system slip > __ month(s).	Budget increase or unit production cost increase < __(5% of Budget)
4	Unacceptable, work arounds available which will eliminate impact to high level technical requirement	Program critical path affected, all schedule float associated with key milestone exhausted Slip < months	Budget increase or unit production cost increase < __(10% of Budget)

*Risk Management Guide For DOD Acquisition, Jun 03, DOD DAU

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Summary

TCR developed for Turbine Engines

- Applied at key program milestones
  - Program Award, PDR, CDR & test
- Evaluates test readiness of engine components, instrumentation, assembly and test facilities
- Establishes quantitative risk assessment
- Engine TCR is flexible and could be tailored to be applicable across many technical areas