T&E and SE Interactions – An Industry View

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T&E and SE Interaction

"To be clear, the system engineering approach used by the AF and our industry partners must focus on an end state that quickly delivers high quality, best value products (capabilities) that fully meet the warfighters' need, and are designed to easily and inexpensively accommodate growth of capabilities in subsequent increments."

Testimony of Dr. Marvin Sambur and
Lieutenant General Ronald E. Keys
before the House Armed Services Committee
Subcommittee Tactical Air and Land Forces
March 30, 2004

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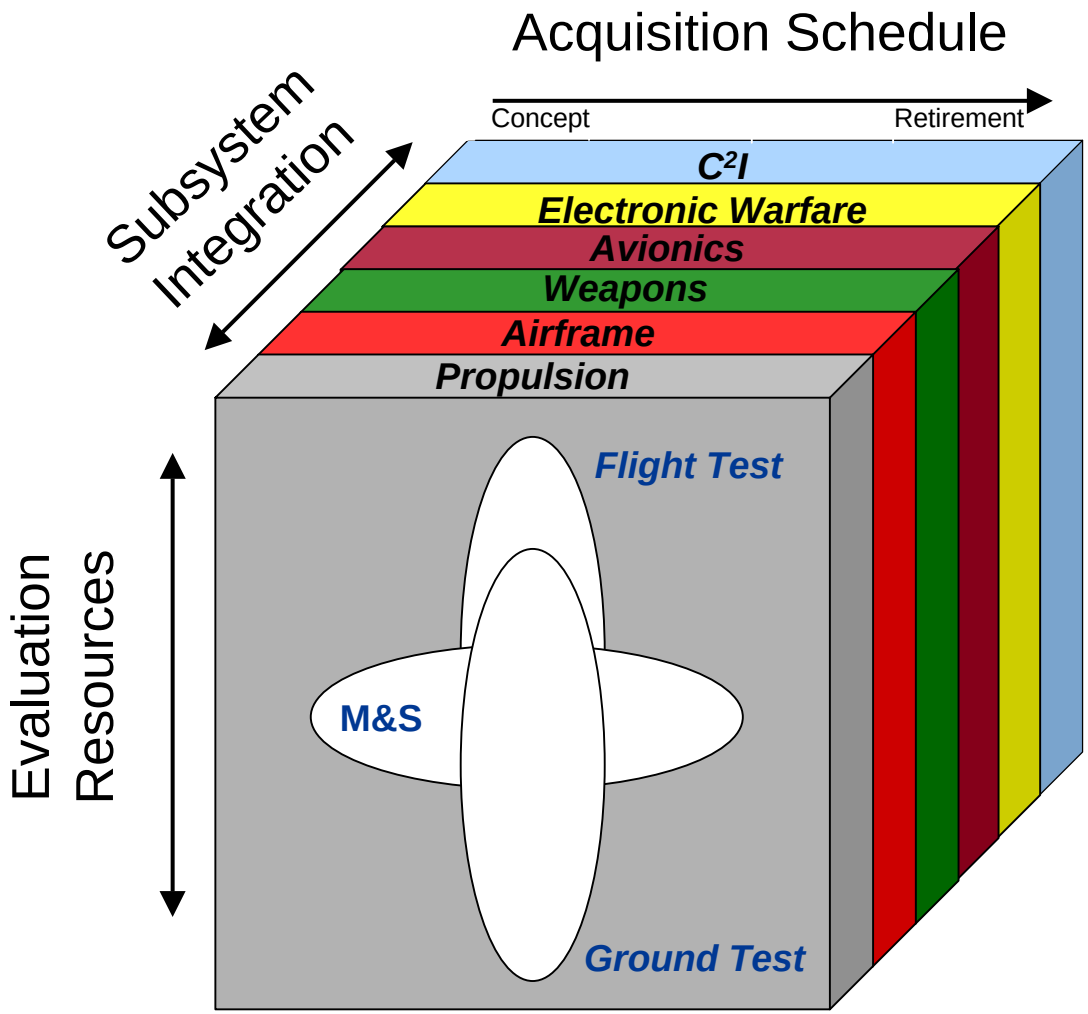
Systems Engineering Is…

"An interdisciplinary approach encompassing the entire set of scientific, technical, and managerial efforts needed to evolve, verify, deploy, and support an integrated and life-cycle balanced set of system solutions that satisfy customer needs."

T&E and SE Interaction

- A military “system” includes – in addition to the physical hardware and software of the weapon (or other) system –
  - Technologies development and application
  - Design rules and tools
  - Test and evaluation capabilities
  - Operations
  - Logistics support

T&E Role in Weapon System SE



- Integrate evaluation resources
- Integrate sub-systems ASAP and AWAP
- Reduce acquisition cycle time

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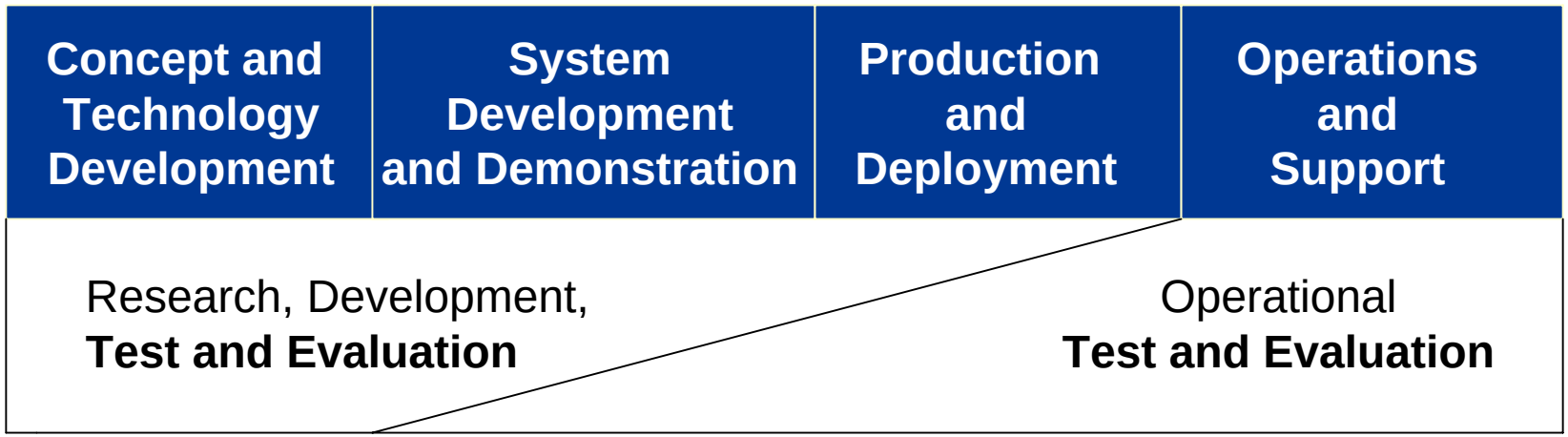
T&E and the Acquisition Process



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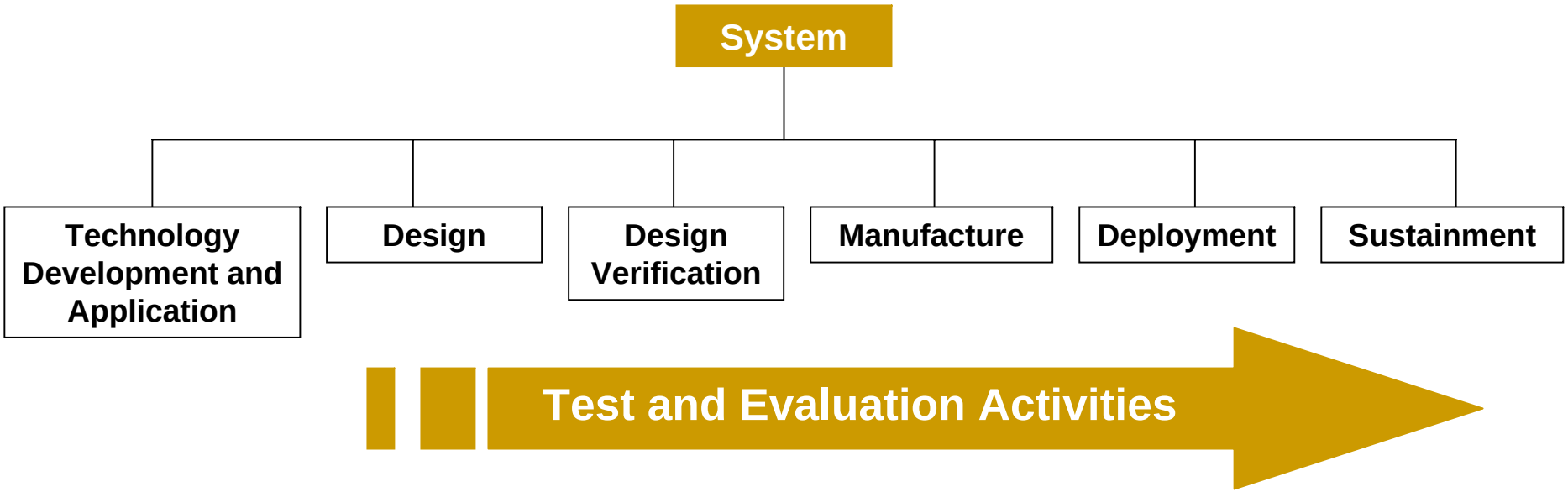
Event Driven Technical Elements of SE



Test plays a role in each of these elements

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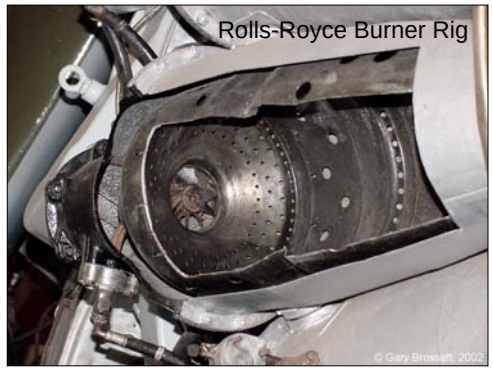
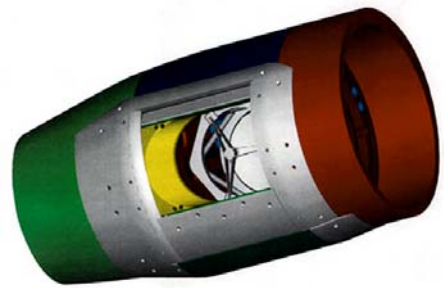
T&E and SE Interaction

- Technology development and application
  - “Simplified” test scenarios
  - Simulated boundary conditions
  - Heavy on diagnostic instrumentation
  - “Scaled” experiments
- Design
  - Trade studies





Finite elements structural models are used to ensure that the Stratospheric Observatory for Infrared Astronomy (SOFIA) design meeting strength and rigidity requirements.

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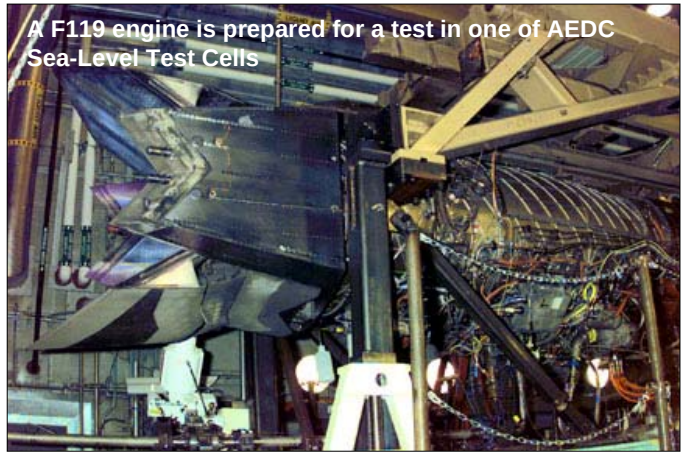
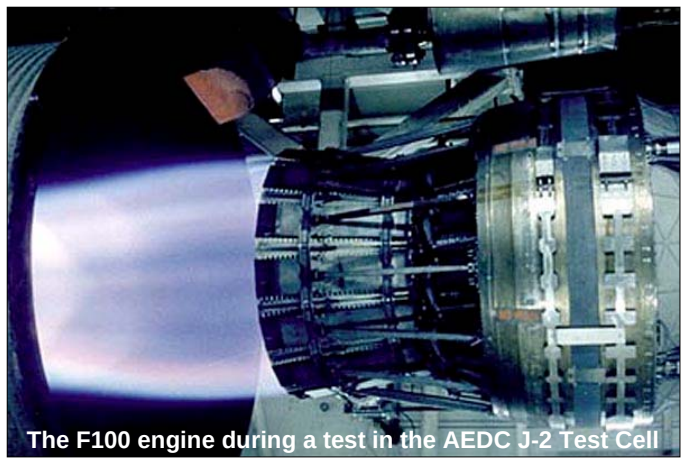
T&E and SE Interaction

- Design verification
  - Component tests
  - Rig tests
  - System tests
  - Ground tests
    - “Sea level”
    - Simulated altitude
  - Flight tests



A F119 engine is prepared for a test in one of AEDC Sea-Level Test Cells



The F100 engine during a test in the AEDC J-2 Test Cell

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T&E and SE Interaction

- Manufacture
  - Fabrication
    - Conformance to design characteristics
  - Assembly
    - Conformance to design characteristics
- Deployment
  - Operational T&E
  - Field verifications
- Sustainment
  - SLEP
  - CIP


Fuel nozzle flow bench

T&E and SE Interaction

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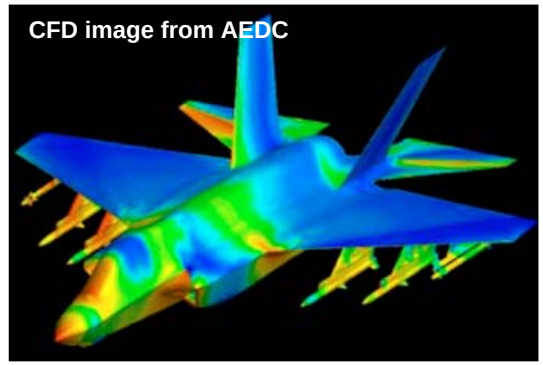
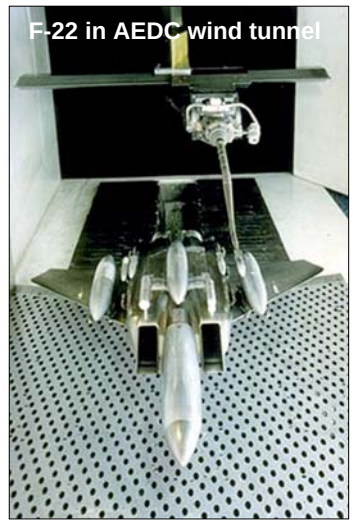
  - Technology development and application
  - Design rules and tools
  - **Test and evaluation capabilities**
  - Operations
  - Logistics support

T&E and SE Interaction

- Test and evaluation capabilities include
  - Modeling (typical)
    - First principles
    - CFD
    - One-dimensional
  - Component test (typical)
    - Compressor and turbine blades
    - Fuel and exhaust nozzles
    - Air frame (wind tunnel)





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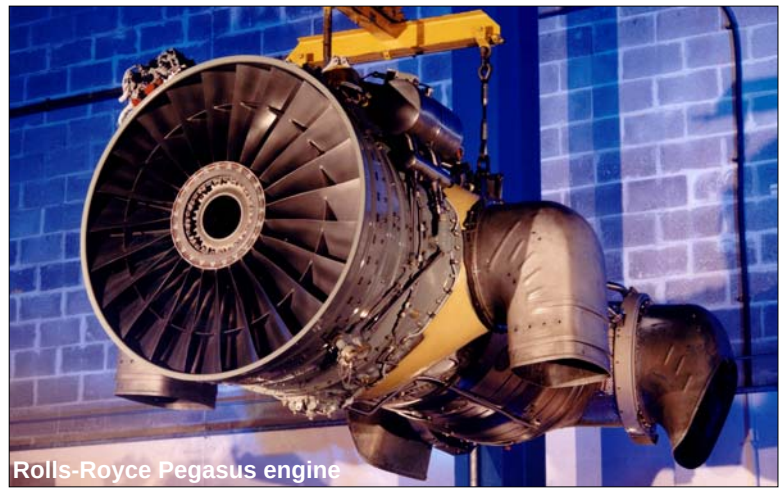
T&E and SE Interaction

- Test and evaluation capabilities include
  - Rig test (typical)
    - Fan and core compressors
    - Combustors
    - Turbines
    - Hydraulic system
  - System test (typical)
    - Air frame
    - Engine
    - Avionics
    - Flight controls
  - System of systems test


Rolls-Royce Pegasus engine


An F-22 in flight test

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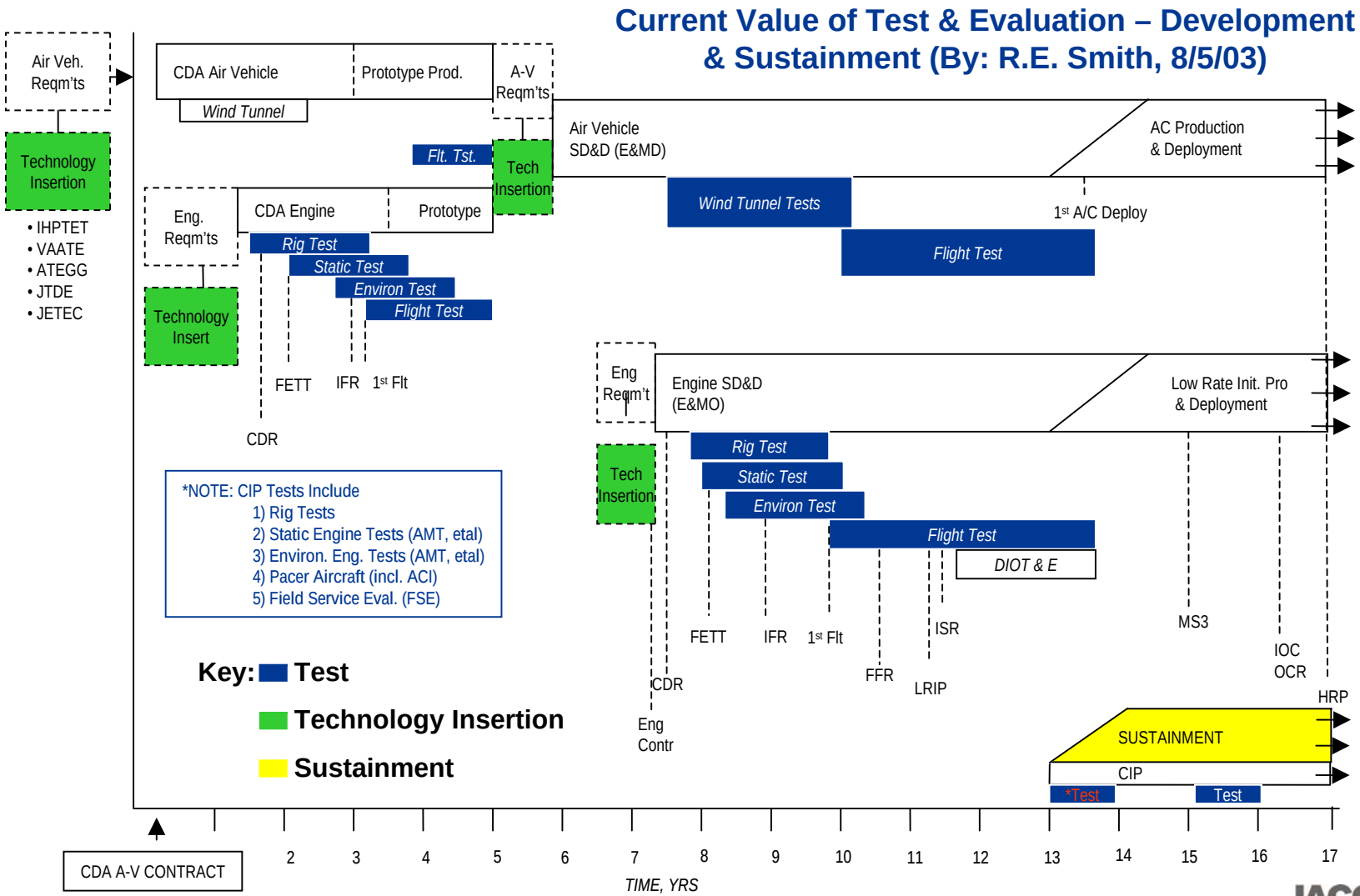
Turbine Engine Timeline



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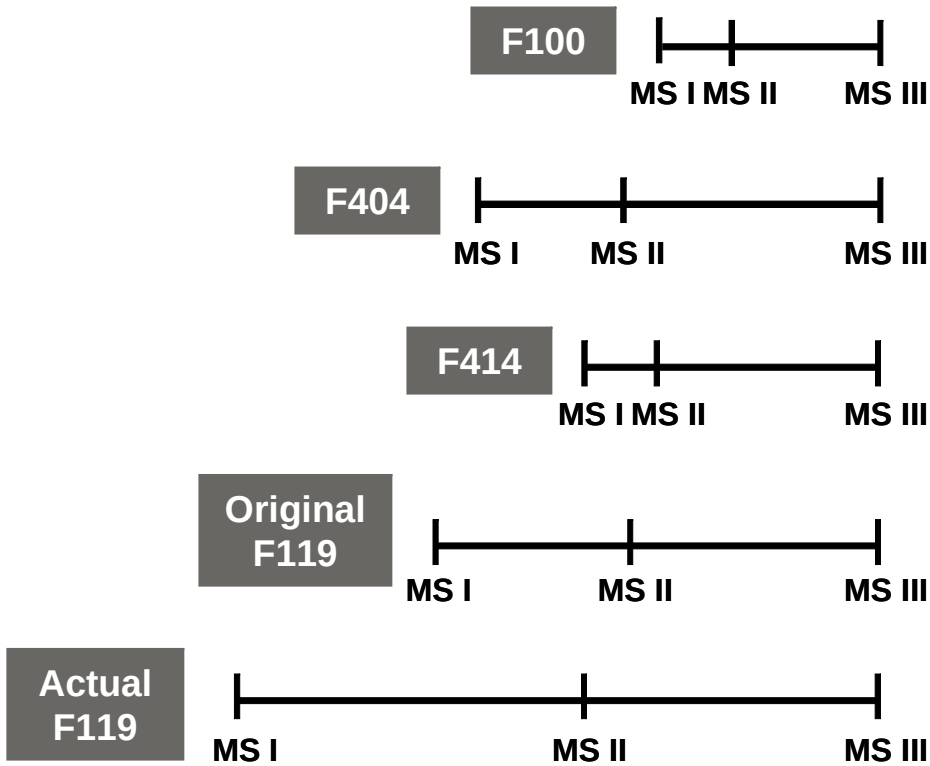
Engine Development Time and Complexity Increasing



	Develop. Time = Months	# Dev. Engines	Develop. Hours	FY96 Cost
F100	54	23	9,628	$1.4B
F404	98	15	15,000	$1.1B
F414	72	14	10,000	$1.0B
Original F119	108	11	9,683	$1.5B
Actual F119	156	9	8,677	$2.5B

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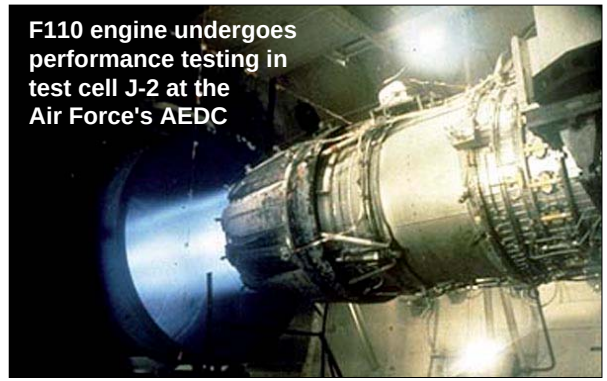
Typical Engine SLEP to Support Sustainment Phase (F110)

- Goals
  - 3X time-on-wing increase
  - 20% improvement in non-recoverable in flight shut down
  - 25% improvement in cost-per-flight-hour
  - 50% extension in engine phase inspections


F110 engine undergoes performance testing in test cell J-2 at the Air Force's AEDC

- Changes
  - Compressor
    - 3-D aero blisks
    - Reduced parts count
    - Increased efficiency
    - Increased rotor and structure life

Typical Engine SLEP to Support Sustainment Phase (F110)

- Changes (continued)
  - Combustor
    - 2X increase in service life
  - High-Pressure Turbine
    - Enhanced durability with advanced materials and cooling
  - Modernized Digital Electric Control (DEC)
    - Reduced maintenance
  - Augmentor
    - Increased durability and reduced maintenance

T&E Discovery of “Defects” Impacts System Development/Sustainment

	Aero Design	Rig Design	Rig Mfg.	Rig Build/Mfg.	Rig Install	Rig Test	Aero Report
Aero Design		X					X
Rig Design	X		X	X			
Rig Mfg.		X		X			
Rig Build/Instr.			X		X	X	
Rig Install		X		X		X	
Rig Test	X			X	X		X
Aero Report	X					X	

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Forward Feed of Information Can Reduce Execution Time

	Aero Design	Rig Design	Rig Mfg.	Rig Build/Mfg.	Rig Install	Rig Test	Aero Report
Aero Design		X					X
Rig Design	X		X	X			
Rig Mfg.		X		X			
Rig Build/Instr.			X		X	X	
Rig Install		X		X		X	
Rig Test	X			X	X		X
Aero Report	X					X	

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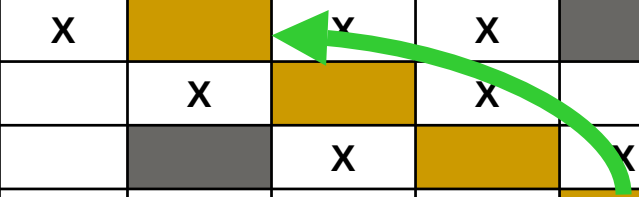
Rig Install		X		X		X	
Rig Test	X			X	X		X
Aero Report	X					X	



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	Aero Design	Rig Design	Rig Mfg.	Rig Build/Mfg.	Rig Install	Rig Test	Aero Report
Aero Design	16/1	X					X
Rig Design	X		X	X	.2/8		
Rig Mfg.		X		X			
Rig Build/Instr.		.1/12	X		X	X	
Rig Install		X		X		X	
Rig Test	X			X	X		X
Aero Report	X					X	

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Rig Install		X		X		X	
Rig Test	X			X	X		X
Aero Report	X					X	

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T&E Discovery of "Defects" Impacts System Development/Sustainment

Activity duration (weeks)

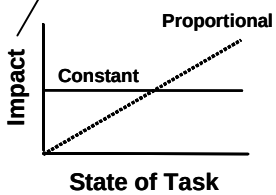
16/1

Activity start (week)

Probability of change

.1/12

Impact of change (weeks)



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Aero Report	X					X	

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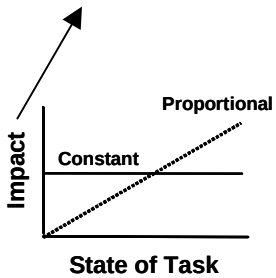
Impact of change (weeks)



Probability of defect requiring change

.2/8

Impact of changes (weeks)

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T&E Testing Contributions by Type

	Ground ("Sea Level")	Ground (Simulated Altitude)	Flight
Component	●	●	●
Rig	●	●	●
System	●	●	●

Key: ● Small ● Medium ● Large ● Very Large

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T&E – Yesterday, Today, Tomorrow Engines

50s → Performance {
- 50s → Test Protocol
- 60s → Modeling

T&E – Yesterday, Today, Tomorrow Engines

50s ➞ Performance
- 50s ➞ Test Protocol
- 60s ➞ Modeling

60s ➞ Operability

Compressor System
- 60s & 70s ➞ Test Protocol
- 70s & 80s ➞ Modeling

Augmentor
- ??? C&T vs. S&T

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- ??? C&T vs. S&T

70s & 80s → Durability

LCF
- 80s & 90s → Test Protocol
- 80s & 90s → Modeling

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HCF
- Currently being developed

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2000s → ?
- ?

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T&E – Yesterday, Today, Tomorrow Engines

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- 80s & 90s → Durability
  - HCF
    - Currently being developed
- 2000s → ?
  - ?

T&E *was*, *is*, and *will continue to be* vital to engine development

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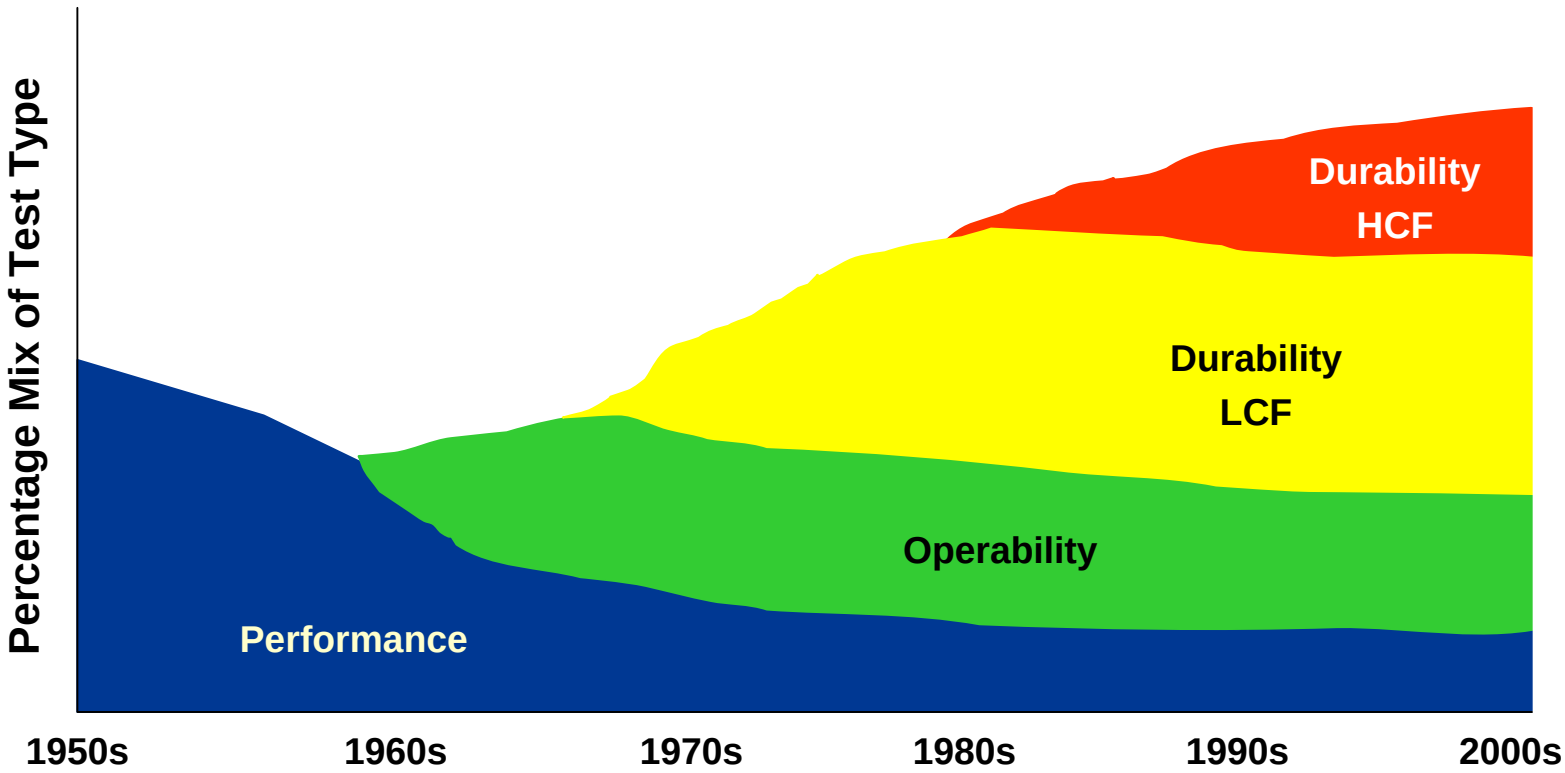
T&E Focus – Turbine Engines



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Summary

- T&E plays a vital role in SE
- T&E is critical from beginning to end of the weapon system cycle
- Attention must be given “up front” to sustainment T&E for
  - Successive spirals and
  - Service life extension efforts