

Engine Workscope Optimization



**STANDARD
AERO**

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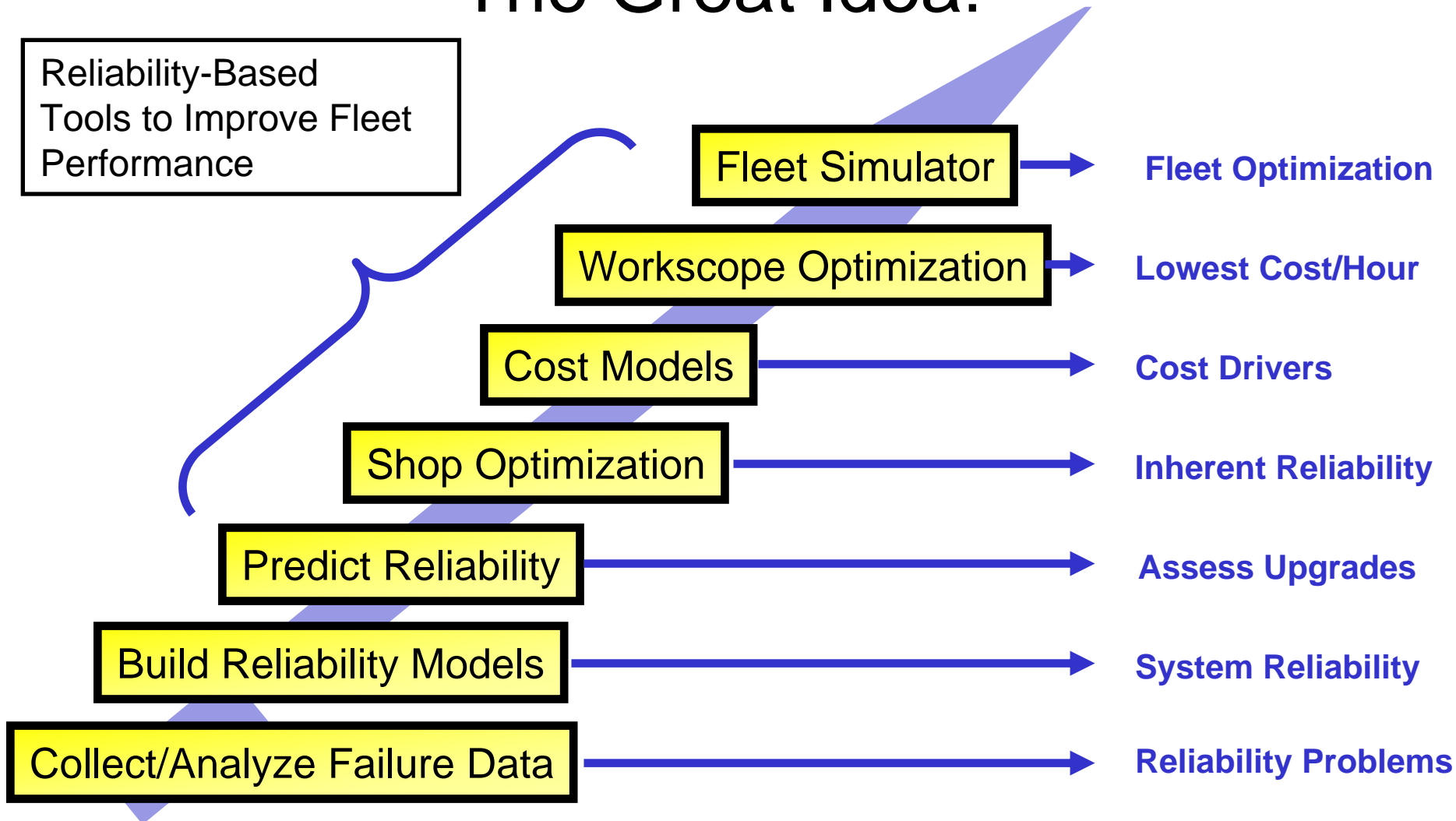
The Maintainer's Dilemma



What is the Optimum Workscope?

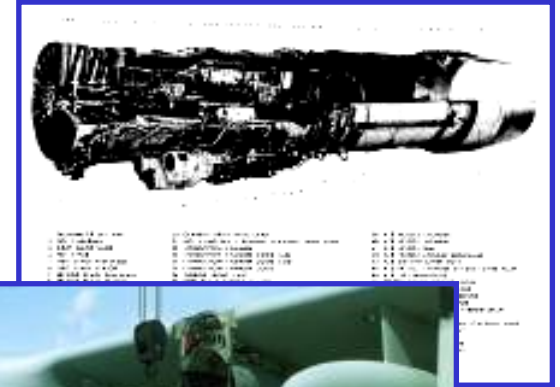
The Great Idea!

Reliability-Based
Tools to Improve Fleet
Performance

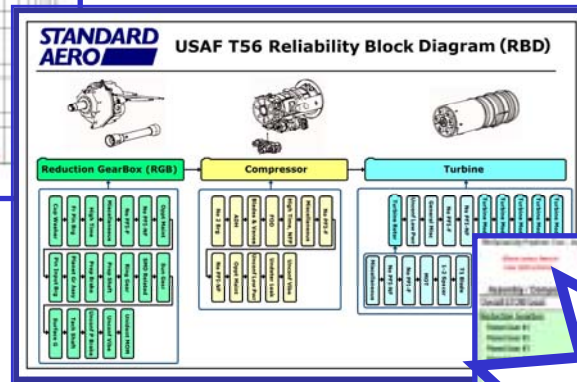


Why Focus on Gas Turbine Reliability?

- Very complex systems. Example: T56 has:
 - Over 3000 different parts
 - A fuel control with 740 parts
 - 108 identified failure modes
- Shop visits are very expensive and occur only every 4 to 5 years
- Engine reliability impacts aircraft availability and deployed labor needs
- Intuition & experience cannot account for all variables
- Easily adapted to other complex mechanical systems



Predicting Engine Reliability



Collect Data



Failure Database

Distributions

Reliability Analysis



Predictor Tool

Reliability Model

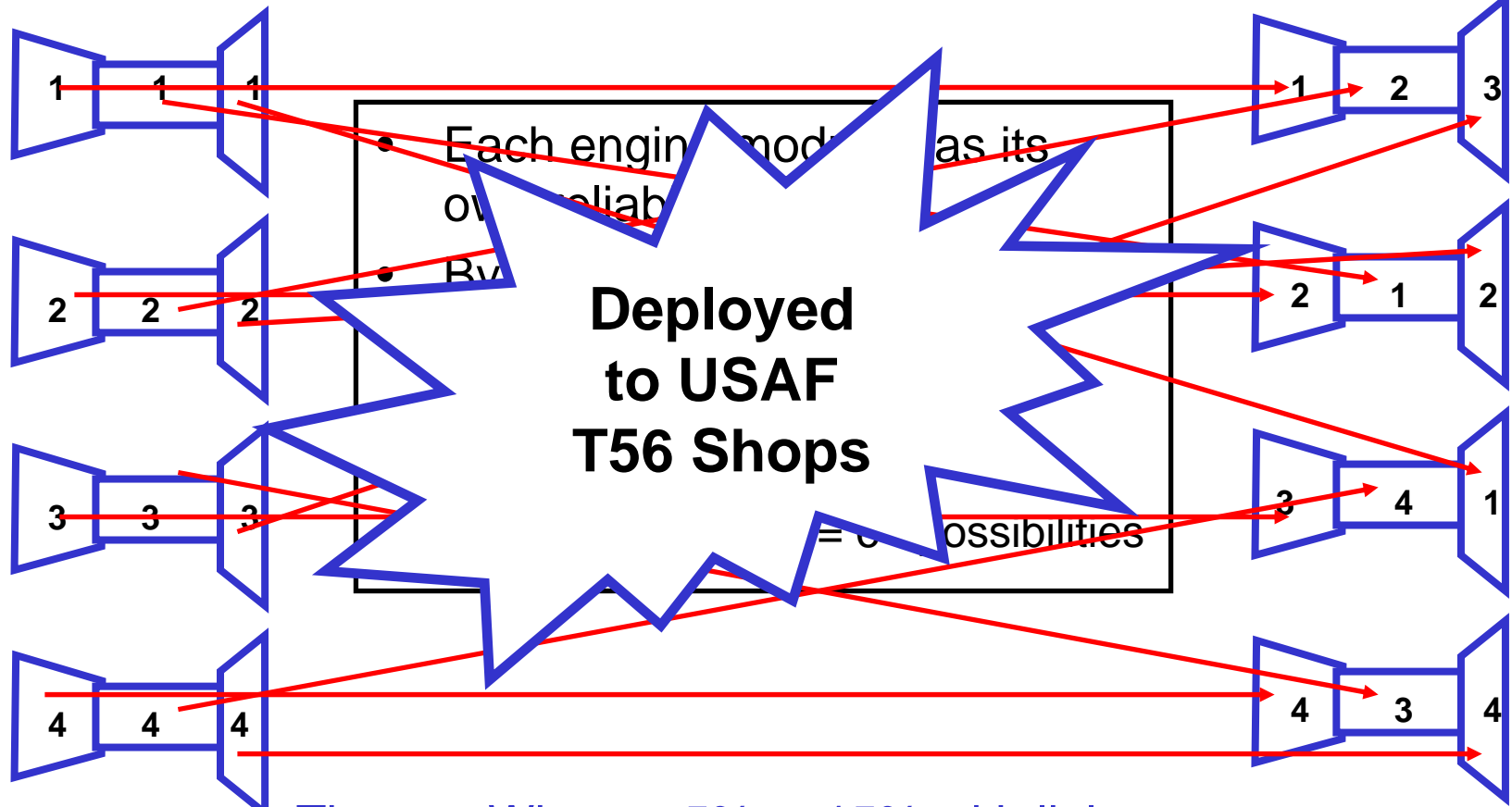
Deployed to USAF T56 Shops

Time On Wing Predictor

Shop Optimization

Current Engines in Shop

Optimized Engines



Time on Wing up 5% to 15% with little cost


Shop Optimization

Example

- 4 Engines, each with three modules
- Each module has own Time Since Overhaul (TSO)

Select SRAN(s)

SRAN	Location
4433	(Dyess AFB, TX)



T56 ETOW Shop Optimizer

Directions

CEMS Data Date: 01-Aug-06

Select Engines Clear

ESN	SRAN	E-TSO	Eng ID	I?	RGB		Comp		Turb		T-Rtr	Turb Type
					SN	TSO	SN	TSO	SN	TSO	TSO	
AD0E113453	4433	9582	E1	Y	00AG033008	489	AD0C513860	3320	AD0T513481	7251	3175	T56-A-15
AD0E113731	4433	7537	E2	Y	00AG023337	4973	AD0C701830	1256	AD0T508146	8689	373	T56-A-15
AD0E113844	4433	8703	E3	Y	00AG033501	2788	AD0C701705	2788	AD0T509255	10536	1	T56-A-15
AD0E114270	4433	6474	E4	Y	00AG032808	576	AD0C513008	576	AD0T506881	12472	2626	T56-A-15

Import CEMS Data

Select Spare Modules Clear

SRAN		
RGB	Comp	Turb

RGB		Comp		Turb		T-Rtr	Turb Type
SN	TSO	SN	TSO	SN	TSO	TSO	

Turb		T-Rtr	Turb Type
SN	TSO	TSO	

Add Non-Inventory 0 Time Mod(s) RGB(S) 0 Comp(s) 0 7B(s) 0 15(s) 0

Min ETOW Goal: 1000 Default Values Use T-Rtr TSO if Turb TSO exceeds: 6000

Status: Idle (Version 2.1) Optimize

Predict Reliability Shop Optimization Workscope Optimization Fleet Simulator

RESULTS				STANDARD AERO T56 ETOW Shop Optimizer				Average Percentage Gain			
SRAN	Location			CEMS Data Date: 01-Aug-06				12.07%			
4433	(Dyess AFB, TX)							Total Original ETOW Hours 4957			
								Total Optimal ETOW Hours 5637			
								ETOW Hours Gained 680			
								Average Hours Gained per Engine 170			

Original Engines					RGB		Comp		Turb		T-Rtr	Turb Type	ETOW	LLP Lim	LLP Mis
ESN	SRAN	E-TSO	Eng ID	I?	SN	TSO	SN	TSO	SN	TSO	TSO				
AD0E114270	4433	6474	E4	Y	00AG032896	576	AD0C513008	576	AD0T506881	12472	2626	T56-A-15	1406		
AD0E113844	4433	8703	E3	Y	00AG033501	2786	AD0C701705	2786	AD0T509255	10536	1	T56-A-15	1372		
AD0E113731	4433	7537	E2	Y	00AG023337	4973	AD0C701830	1256	AD0T508146	8689	373	T56-A-15	1147		
AD0E113453	4433	9582	E1	Y	00AG033098	489	AD0C513860	3320	AD0T513461	7251	3175	T56-A-15	1032		

Optimal Engines			RGB		Comp		Turb		T-Rtr	Turb Type	ETOW	LLP Lim	LLP Mis
SRAN	RGB	Comp	SN	TSO	SN	TSO	SN	TSO	TSO				
4433	4433	2059	00AG033098	489	AD0C513008	576	AD0T509255	10536	1	T56-A-15	2012		
4433	4433	4433	00AG032896	576	AD0C701830	1256	AD0T508146	8689	373	T56-A-15	1772		
4433	4433	4433	00AG033501	2786	AD0C701705	2786	AD0T506881	12472	2626	T56-A-15	1044		
4433	4433	4433	00AG023337	4973	AD0C513860	3320	AD0T513461	7251	3175	T56-A-15	810		

Add Non-Inventory 0	Time Mod(s)	RGB(s)	0	Comp(s)	0	7B(s)	0	15(s)	0
Min ETOW Goal:	1000	Use T-Rtr TSO if Turb TSO exceeds:	6000						

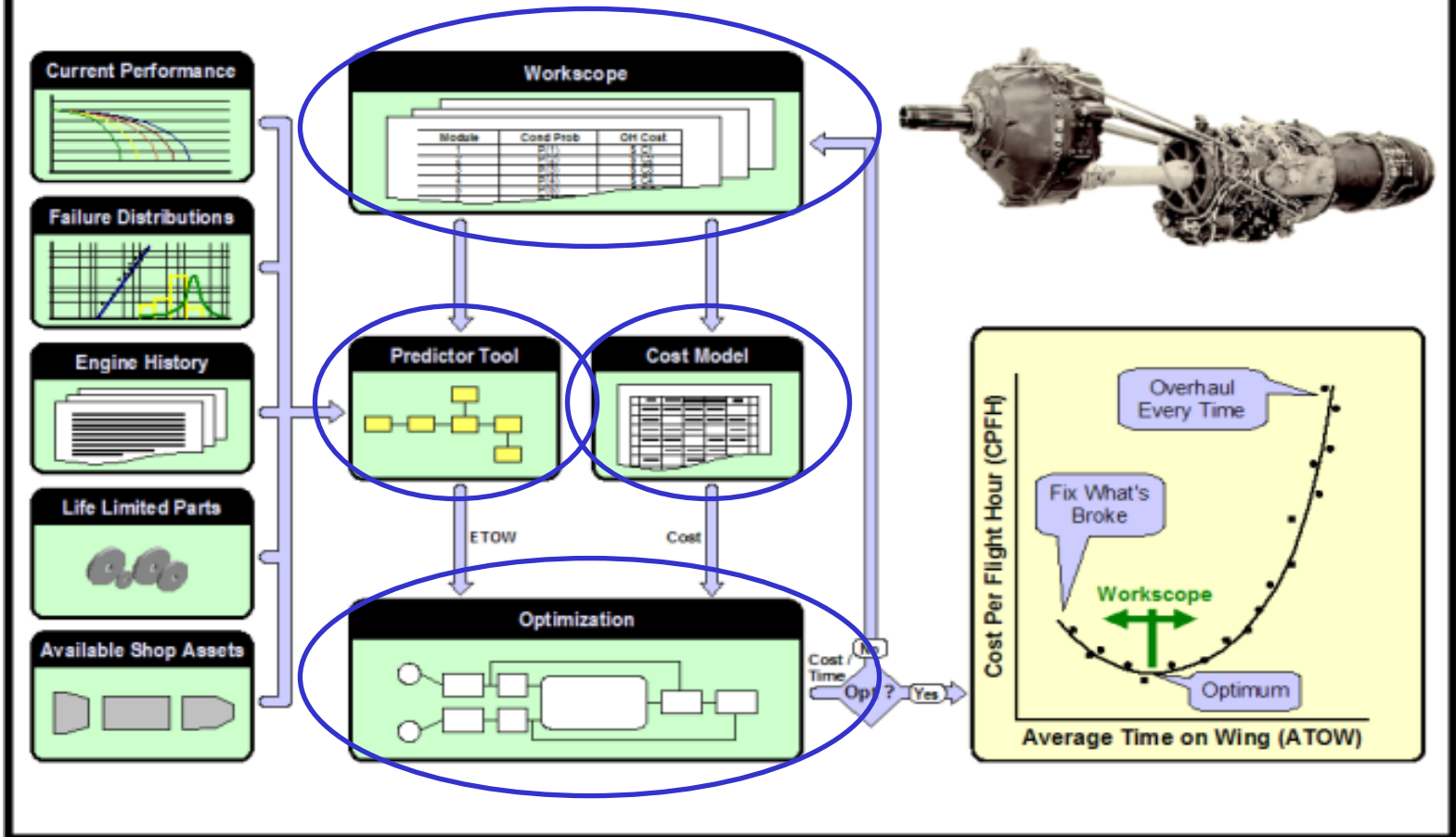
Shop Optimization Results

- Time on Wing increases 680 hrs or 12%

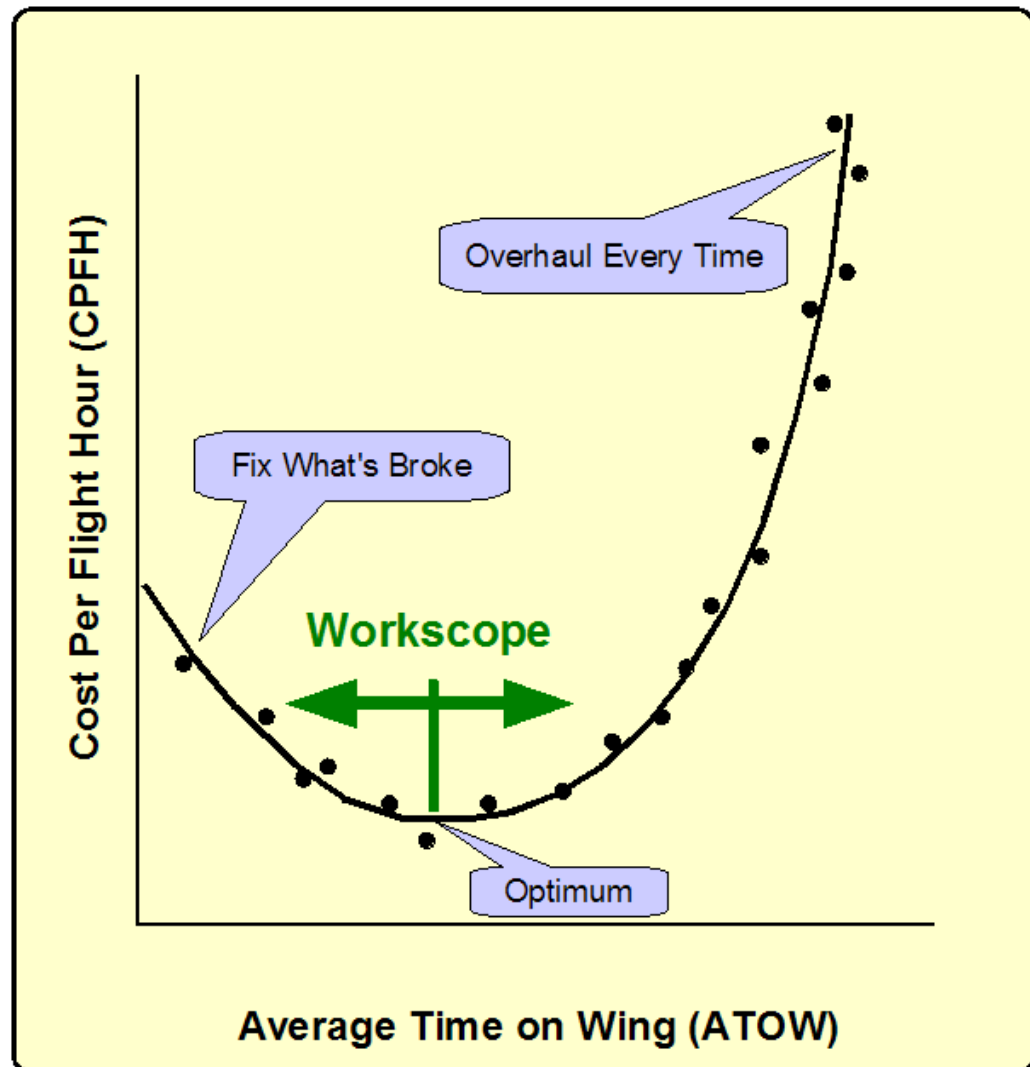
- Four Engines Optimized

- Aligns modules based on reliability - not time remaining

Workscope Optimizer

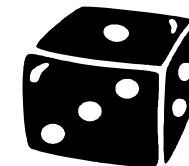
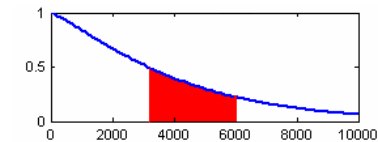
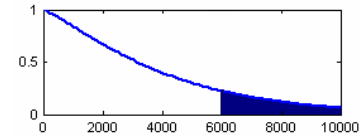


Solution to the Maintainer's Dilemma



Cost Model

- Residual value of life remaining on replaced parts
- Depreciate replaced modules over expected time on wing
- “Sunshine” costs
- Costs associated with risk (ie FOD)



Cost for Every Workscope

TF39 Workscoping Tool

- USAF employs to workscope TF39 engines
- Centralized team performs worksopes
- Currently building similar tool for USAF T56 fleet
- Computationally intensive
- Impact Technologies developing schemes to ease computational burden



13 Workscope Options

2^{13} or 8192 Possible Worksopes

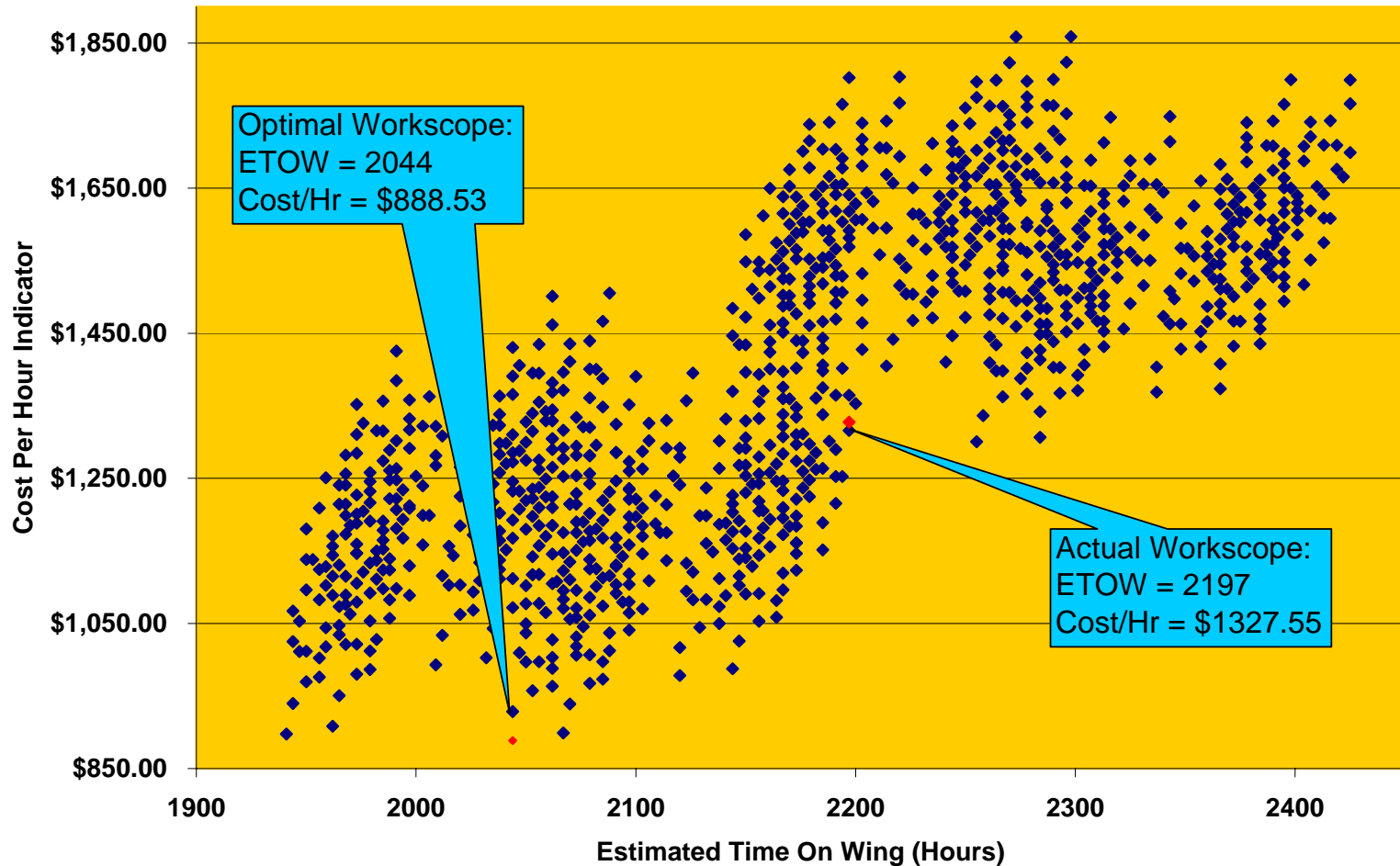
TF39 Workscope Optimizer

Example

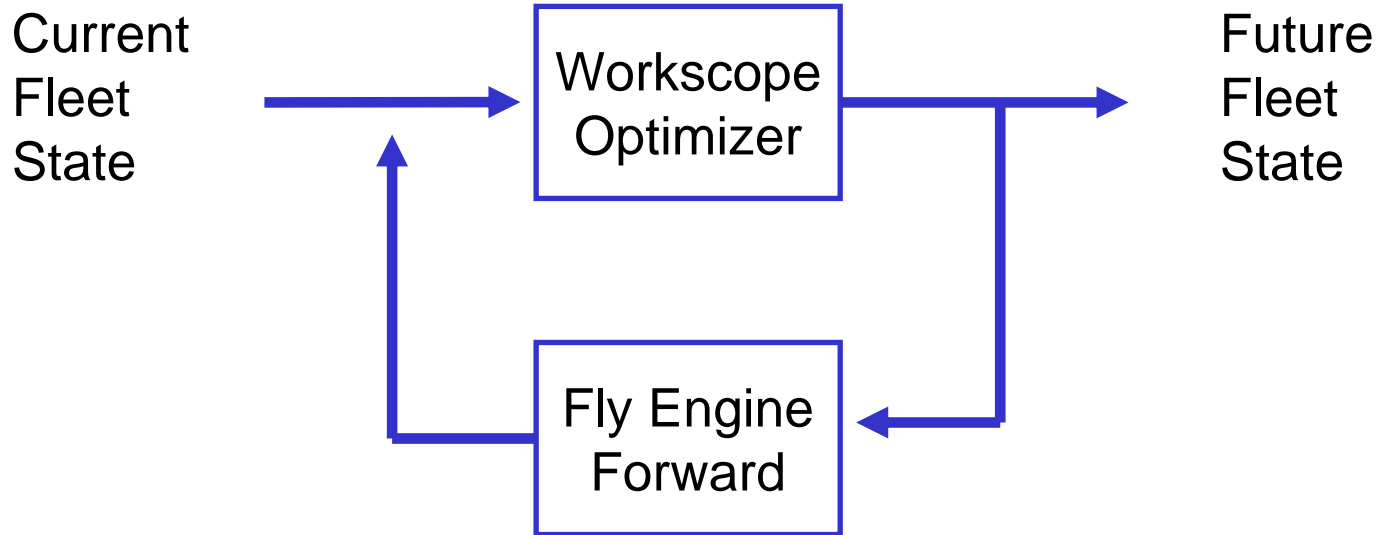
- 13 modules
- Operator selects mandatory requirements
- Software optimizes workscope for lowest cost per hour

PREDICTOR VERSION II - ETOW & SA CPEFH CALCULATION											REMOVED ENGINE STATUS	
Component	Config Option	Current TSO	Target TSO for Build Goal	Predicted (%) Success BUILD GOAL	Primary Failure or Condition	Predicted Number of SHOP VISITS	LCF Life Remaining	Module Availability	Component TSO at Engine Removal	Config Option - Removed Engine	Minimum ETOW	
Performance	N/A	0.0	2244	0.97		0.028	N/A	N/A	N/A	N/A	OCM	1500
Inlet OAD (1 pc per 3 y or less)	N	3000	5244				N/A	Yes	3,000.0	N	HSM	1950
Transfer OAD (Arbor Assy? y or less)	N	0	2244	0.99		0.010	N/A	Yes	5,500.0	N	D-M	2150
Fan Rotor	N/A	3228.7	5472.7	0.96		0.044	N/A	Yes	3,228.7	N/A	Over	
Stage 1 Stator	N/A	0	2244	0.99		0.012	N/A	Yes	2,160.7	N/A	Initialize	
Stage 2 Stator (F or 1E or 2E)	2e	0	2244	0.99		0.009	N/A	Yes	2,160.7	2e	Load ELLWS	
Fan Frame	N/A	3000	5244				N/A	Yes	3,000.0	N/A		
Compressor Rotor	N/A	0	2244	0.98		0.016	N/A	Yes	5,825.0	N/A		
Compressor Fwd Case	N/A	5625	7869				N/A	Yes	5,825.0	N/A		
Compressor Rear Case	N/A	5625	7869				N/A	Yes	5,825.0	N/A		
CRF (Type I or II)	N	0	2244	1.00		0.001	N/A	Yes	4,077.3	N		
Compressor Cover	N/A	0	2244	1.00		0.001	N/A	Yes	2,160.7	N/A		
Stage 1 HPT Nozzle	N/A	0	2244	0.98		0.018	N/A	Yes	2,160.7	N/A		
HPT Rotor (H1907 y or less)	y	0	2244	1.00		0.000	N/A	Yes	2,160.7	y		
Turbine Mid Frame	N/A	7213.3	9457.3	0.99		0.014	N/A	Yes	7,213.3	N/A		
LPT Rotor (9h & 8h T8007 y or less)	n	1500	3744	0.99		0.015	N/A	Yes	1,500.0	n		
LPT Stator	N/A	3000	5244				N/A	Yes	3,000.0	N/A		
Turbine Rear Frame	N/A	7213.3	9457.3	0.98		0.016	N/A	Yes	7,213.3	N/A		
Fan Shaft (M36001 Config? y or less)	N	3000	5244				N/A	Yes	3,000.0	N		
Thrust Reverser (OH? y or less)	y	0	2244	0.87		0.141	N/A	Yes	2,160.7	y	Long Opt	
Predicted Probability(Shop Visit Excluding Thrust Reverser)				0.83		ETOW	Optimize	Cost Data				
Predicted Probability(Shop Visit Including Thrust Reverser)				0.72		0.32		Total Cost	\$ 3,068,040			
Shop Visit Rate per 1000 EPH Excluding Thrust Reverser				0.08				Assigned Module Cost	\$ 1,169,550			
Shop Visit Rate per 1000 EPH Including Thrust Reverser				0.14	X	6915		Assigned Risk	\$ 140,345			
Total Shop Visit Rate per 1000 EPH Excluding Thrust Reverser				0.36				Residual Value of CDO Modules	\$ 988,271			
Total Shop Visit Rate per 1000 EPH Including Thrust Reverser				0.43		2244		Expected Sunshine Cost	\$ 759,873			
								Expected Cost Per EPH	1,362.76			

TF39 Workscope Optimizer



Fleet Simulation



- Able to use Workscope Optimizer to fly an entire engine fleet forward
- Assess impact of environment, upgrades and maintenance policy

Fleet Simulator

- Concept validated
- Prototype built
- Developing version 2.0
- Final version spring 07

STANDARD AERO Fleet Fly-Forward Simulator

Close Form

Simulation Input Parameters:

Customer: Canadian Forces
Engine Type: T56-A-15
Simulation Start Date: 7/1/2004
Simulation End Date: 6/30/2005
LLP Alignment Strategy: 5
Module Alignment Strategy: 1
Simulation Run Limit: 25

Prepare Simulation: Clean Out Old Data Run Simulation

Review Results: Open Form

Select Form to Open: Chart - Engine Removals

Export Data Table: Export Data to Excel

Select Table to Export: Simulation_Output

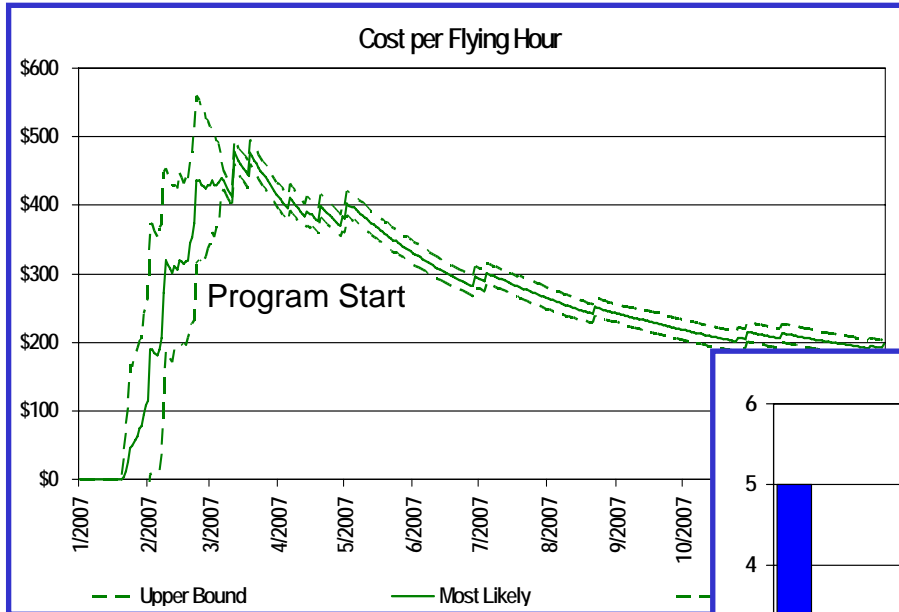
Simulation Output:

Line	Date	Message
0	7/1/2004	Starting 25 simulation runs for Canadian Forces T56-
1		... Simulation run # 1 ...
2	7/1/2004	-- Projected ETOW for 716498 = 2577.81153949058
3	7/1/2004	-- Projected CPFH for 716498 = 0
4	7/3/2004	200101, MOD001, ConfigCount = 1
5	7/3/2004	200102, MOD002, ConfigCount = 1
6	7/3/2004	200103, MOD003, ConfigCount = 2
7	7/3/2004	200105, MOD005, ConfigCount = 1
8	7/3/2004	200106, MOD006, ConfigCount = 1
9	7/3/2004	Engine SN = 716494, Model = 2037 pre-RTC, Config
10	7/3/2004	Module MOD001 unavailable for engine 716494
11		-- build postponed until 7/5/2004
12	7/5/2004	Engine SN = 716494, Model = 2037 pre-RTC, Config
13	7/5/2004	Module MOD002 unavailable for engine 716494
14		-- build postponed until 7/7/2004
15	7/7/2004	-- Projected ETOW for 716457 = 7446.14839268515
16	7/7/2004	-- Projected CPFH for 716457 = 0
17	7/7/2004	Engine SN = 716494, Model = 2037 pre-RTC, Config
18	7/7/2004	Module MOD003 unavailable for engine 716494
19		-- build postponed until 7/11/2004
20	7/8/2004	-- Projected ETOW for 716450 = 4627.63758294092
21	7/8/2004	-- Projected CPFH for 716450 = 0
22	7/8/2004	200101, MOD001, ConfigCount = 1
23	7/8/2004	200102, MOD002, ConfigCount = 1
24	7/8/2004	200103, MOD003, ConfigCount = 2
25	7/8/2004	200105, MOD005, ConfigCount = 1

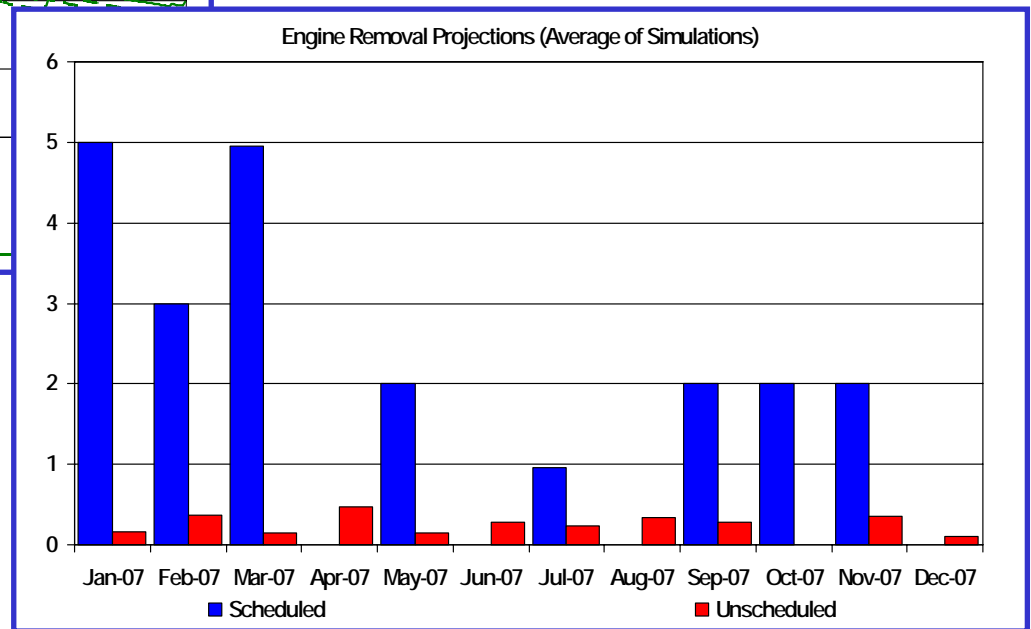
Form View

Fleet Simulator

Project Fleet Costs



Project Engine Removals



Conclusion



Questions?