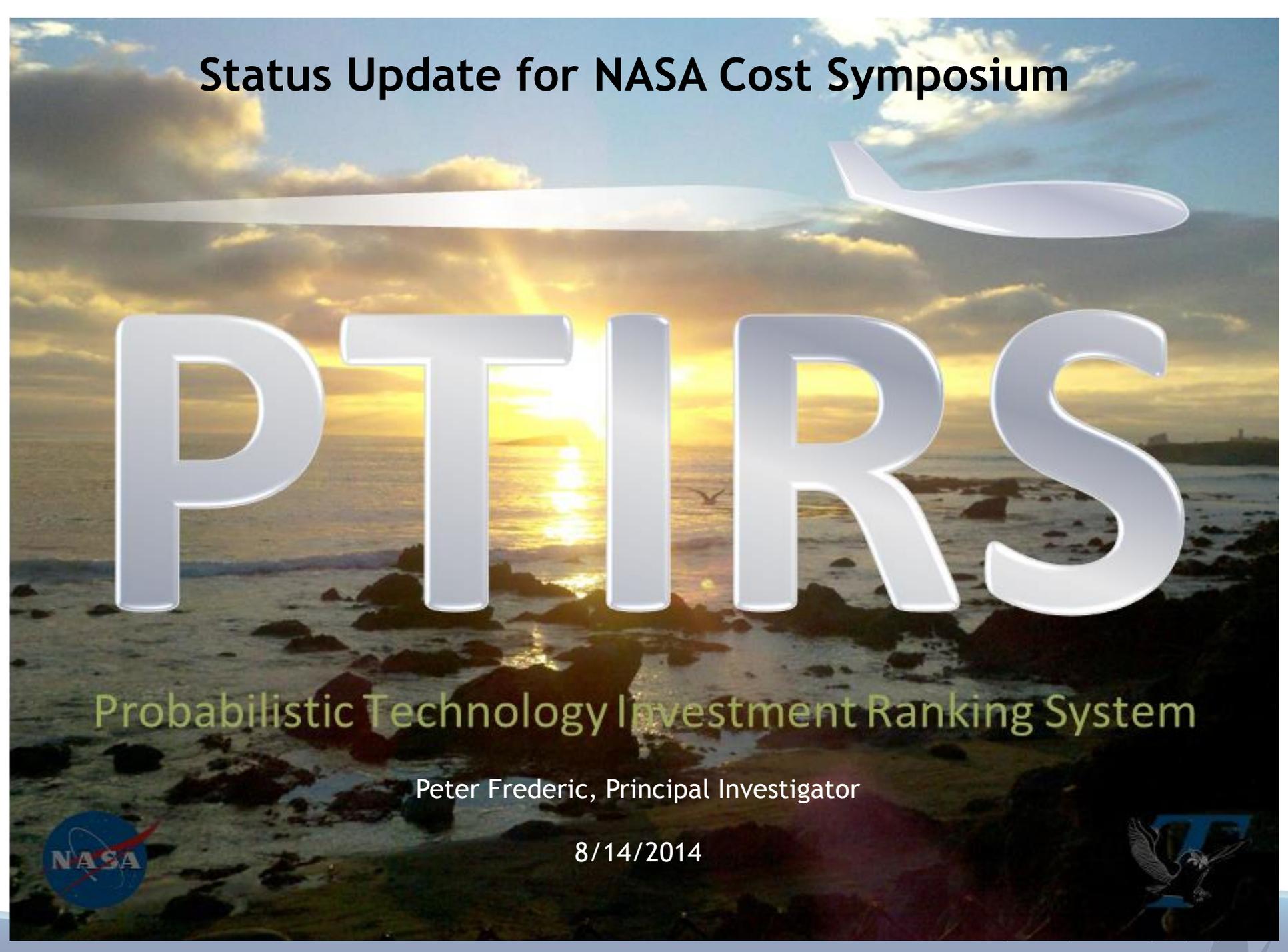


# Status Update for NASA Cost Symposium



# PTIRS

Probabilistic Technology Investment Ranking System

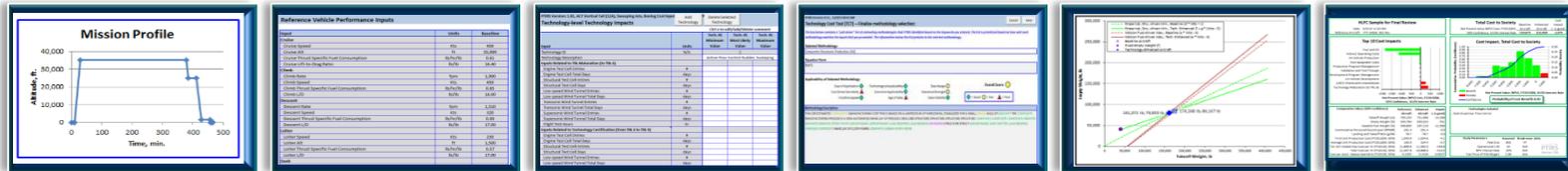
Peter Frederic, Principal Investigator

8/14/2014



- PTIRS is a tool that is used to build a business case for incorporating a technology or suite of technologies on a future aircraft
- Research topic
  - “An area of interest for development under this NRA solicitation is technology maturation and certification cost estimation and integration of cost analyses into the conceptual design process to have a systematic way of prioritizing investment in particular technologies.”
- Approach
  - Developed an Excel-based tool that combines a complete life-cycle economic analysis model, an infinitely flexible technology cost estimating tool, an integrated weight resizing tool, and pervasive Monte Carlo risk analysis capability

- **Sponsor: NASA Environmentally Responsible Aviation (ERA) Project, Integrated Systems Research Program, Aeronautics Research Mission Directorate**
  - ERA Project goals: simultaneous reduction of community noise, NOx emissions, and fuel consumption
- **NASA Research Announcement Topic: “Enhancement and Application of System Design and Analysis Tools”**
- **Period of Performance: May 2012 to May 2014, extended to Jan. 2015**
- **PTIRS Version 1.0 successfully delivered May 2014**
- **NASA COTR: Craig Nickol**
- **Principal Investigator: Peter Frederic**
- **Program Manager: Rey Carpio**



- Milestones
- Heritage Factors
- Fleet Size
- Flight Rate
- Mission Profile
- Payload
- Vehicle Config.

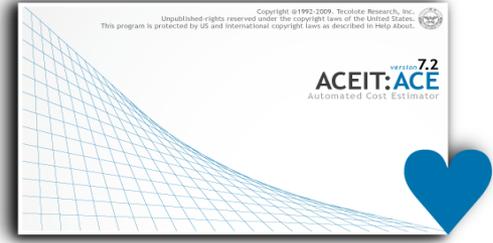
- Payload
- SFCs
- L/Ds
- Noise Footprints
- Emissions
- R & M Factors
- Mass Properties

- Impact Factors
  - Mass Properties
  - SFCs
  - L/Ds
  - Noise Footprints
  - Emissions
  - R & M Factors
  - New Components
- All impacts specified with uncertainty distributions

- Multi-category Dev't, Prod., O&S CERs
- Interfaces to COTS Estimating Tools

- Override Mass Properties

- Fundamental Transport Aircraft CERs (Tech. Matur., Dev't, Prod., O&S)
- Economic & Programmatic Wraps
- Inflation Factors
- Learning Curves
- Net Present Value Factors



# Selecting Reference Configuration

PTIRS 2013\_12\_12.xlsm - Microsoft Excel

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Reference\_Aircraft 737-800, 160 pax

**Session Description:**

Case Name	
Creation Date	12/12/13 10:05 AM
Modification Date	12/12/13 10:09 AM
Analyst	
Reference Aircraft	737-800, 160 pax
Retrofit	Box Wing, Pre-ERA, 224 Pax / 8000 NM 777-200LR, 301 Pax 1998 Tube and Wing, 224 Pax / 8000 NM Blended Wing-Body, 224 Pax / 8000 NM 737-800, 160 pax 787-8
Notes:	



Version: 0.52

Reference Design System-level Tech Impacts Technology-level Tech Impacts Asy-level Tech Adds Asy-level Tech Mods Re

Ready 100%

# Specifying Performance Impacts

PTIRS 0.95 HLFC 2 Fudged for Charts.xlsm - Microsoft Excel

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LDCrzModMin fx 19

PTIRS Version: 0.95, HLFC Sample for Final Review, 5/4/14 11:34 AM

### System-level Technology Impacts

*Ctrl-e to edit/add/delete comments*

Input	Units	Reference Baseline Value	Minimum Value	Most Likely Value	Maximum Value
<b>Cruise</b>					
Cruise Speed	Kts	485			
Cruise Alt	ft	35,000			
Cruise Thrust Specific Fuel Consumption	lb/hr/lb	0.54			
Cruise Lift-to-Drag Ratio	lb/lb	18.80	19	19.5	20
<b>Climb</b>					
Climb Rate	fpm	1,200			
Climb Speed	Kts	496			
Climb Thrust Specific Fuel Consumption	lb/hr/lb	0.56			
Climb L/D	lb/lb	18.00			
<b>Descent Speed</b>					
<b>Noise Footprint</b>					
Cumulative Perceived Sound Level (Approach + Cutback + Sideline)	EPNdB	291			
<b>Landing and Takeoff Oxides of Nitrogen</b>					
Characteristic mass of NOx emitted during the reference landing and take-off (LTO) cycle divided by rated thrust	g/kN	78.7			
<b>Airframe Intervals</b>					
C Check, months	mo	48			
D Check, months	mo	96			
Engine TBO, hours	hr	17,000			

Reference Mission Reference Configuration Reference Performance Factors Reference Design System-1

Ready 100%

# Describing Technology Implementation

PTIRS\_0\_95 HLFC 2 Fudged for Charts.xlsm - Microsoft Excel

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D6 Ducting

PTIRS Version: 0.95, HLFC Sample for Final Review, 5/4/14 11:34 AM

**Assembly-level Technology Impacts, Additions**

*Ctrl-e to edit/add/delete comment*

Input	Units	Assembly #1 Minimum Value	Assembly #1 Most Likely Value	Assembly #1 Maximum Value	Assembly #3 Minimum Value	Assembly Most Like Value
Assembly ID		1			3	
New Item Description	N/A	Ducting			Valves, Pur	
Technology ID	N/A	1			1	
WBS Number	<input type="button" value="Choose WBS"/>	P.4.7			P.4.7	
WBS Description	N/A	Environmental Control Subsystem			Environmental Contr	
Descriptive Keyword Codes	<input type="button" value="Choose Keywords"/>	17, 18, 40, 41, 62, 65, 68, 70, 388, 91			17, 18, 40, 41, 62, 63, 64, 6	
WBS Item Current Weight	lb	3,947.2			3,947.2	
New Item Weight	lb	1,900.0	2,000.0	2,100.0	1,100.0	1,150.0
WBS Item Current Software Code Size	SLOC	0.0			0.0	
New Item Software New Code Size	SLOC					
New Item Software Existing Code Size	SLOC					
Quantity Per Vehicle	#	1	1	1	1	1
Technology Maturation Equivalent Quantity	#	1.0	1.0	1.0	1.0	1.0
Certification Equivalent Quantity	#	1.0	1.0	1.0	1.0	1.0
EMD CER	<input type="button" value="Choose EMD CER"/>	ECS Nonrecurring \$/lb (138)			ECS Nonrecurring	

Reference Performance Factors | Reference Design | System-level Tech Impacts | Technology-level Tech Impacts

Select destination and press ENTER or choose Paste

100%

# Use Keywords to Describe New Assembly

PTIRS 0.95 HLFC 2 Fudged for Charts.xlsm - Microsoft Excel

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B7 fx 1

PTIRS Version: 0.95, HLFC Sample for Final Review, 5/4/14 11:34 AM

**Select Keywords:**

Select keywords describing hardware or software assembly. If applicable, type ad-hoc keywords separated by spaces.

Keyword ID	Keyword	Selected	Ad-hoc Keywords
1	Mechanical		
2	Structure		
55	Hydraulic		
62	Pneumatic	✓	
63	Pump		
64	Valve		
65	Duct	✓	
66	Line		
67	Actuator		
68	High pressure	✓	
69	Low pressure		
70	High flow	✓	
71	Venturi		
388	Orifice	✓	
508	Sweeping jet actuator		
509	Synthetic jet actuator		
72	Electromechanical		
83	Piezoelectric		
84	Cryogenic		
91	Environmental control system	✓	
110	Fuel		

System-level Tech Impacts Technology-level Tech Impacts Asy-level Tech Adds Key

Ready 100%

PTIRS 0\_95 HLFC 2 Fudged for Charts.xlsm - Microsoft Excel

File Home Insert Page Layout Formulas Data Review View Developer Add-Ins

G7

PTIRS Version: 0.95, HLFC Sample for Final Review, 5/4/14 11:34 AM

**Technology Cost Tool (TCT) -- Describe known cost drivers:** Cancel Next

*PTIRS has identified a list of candidate estimating methodologies based your keywords and will help you select a final methodology based on your ability to provide the inputs listed below. Enter Values for all inputs that are available to you. For values that are not immediately available, indicate the difficulty of obtaining those values by placing a check in the appropriate column. Indicate exceptionally important drivers by placing an "X" in the Key Driver column.*

Cost Driver	Units	Observed Low	Observed High	Most Likely Value	Easy	Hard	Impos- sible	Key Driver
Microprocessor IC feature size (0.022, Intel Core i7 4770K, c. 2013)	microns	0.000	0.000				X	
Operating Platform	1 = Fighter, 2 = Bomber, 3 = Ground, 4 = Cargo	1.000	4.000	4.000				
Weight	Wlb	6.000	3,108.000	2,000.000				
Airborne?	Yes=1, No=0	0.000	1.000	1.000				
Hardened?	Yes=1, No=0	0.000	1.000				X	
First Year of Prod	Pyr	1,975.000	1,983.000	2,023.000				
Number of Equivalent Ics	number	10.000	1,000.000				X	
Number of Elements	number						X	
Cost Unintegrated Hardware	Total Cost						X	
Antenna Aperture	sq ft	0.150	3.870				X	

Technology-level Tech Impacts Asy-level Tech Adds **Describe Known Cost Drivers** Asy-level Tech Mods Resizing Resized

Ready 100%

# Selecting Cost Methodologies for Unique New Components

PTIRS 2013\_12\_12.xlsm - Microsoft Excel

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Selected\_Methodology Composite Aerostructures, Weight Only, Production (108)

PTIRS Version: 0.52, , 12/12/13 10:38 AM

**Technology Cost Tool (TCT) -- Finalize methodology selection:** Cancel Next

*The box below contains a "pull-down" list of estimating methodologies that PTIRS identified based on the keywords you entered. The list is prioritized based on how well each methodology matches the inputs that you provided. The information below the list pertains to the selected methodology.*

**Selected Methodology**

Composite Aerostructures, Weight Only, Production (108)

- Composite Aerostructures, Weight Only, Production (108)
- PRODUCTION CER - Secondary Structures. (30)
- PRODUCTION CER - Structure Tanks. (32)
- Composite Frame Structures, Weight Only, Production (102)
- Composite Aerostructures, Weight + Part Count, Production (111)
- Composite Structures Production, Adjustable (63)
- Avionics Reliability Cost Trade-off Model, Recurring Portion (2)
- Manual Cost Entry (0)

Ease of Application	Technological Applicability	Data Range	<b>Overall Score</b>
Cost Driver Sensitivity	Economic Applicability	Statistical Strength	= Good            = Fair            = Poor
Intuitive Appeal	Age of Data	Data Visibility	

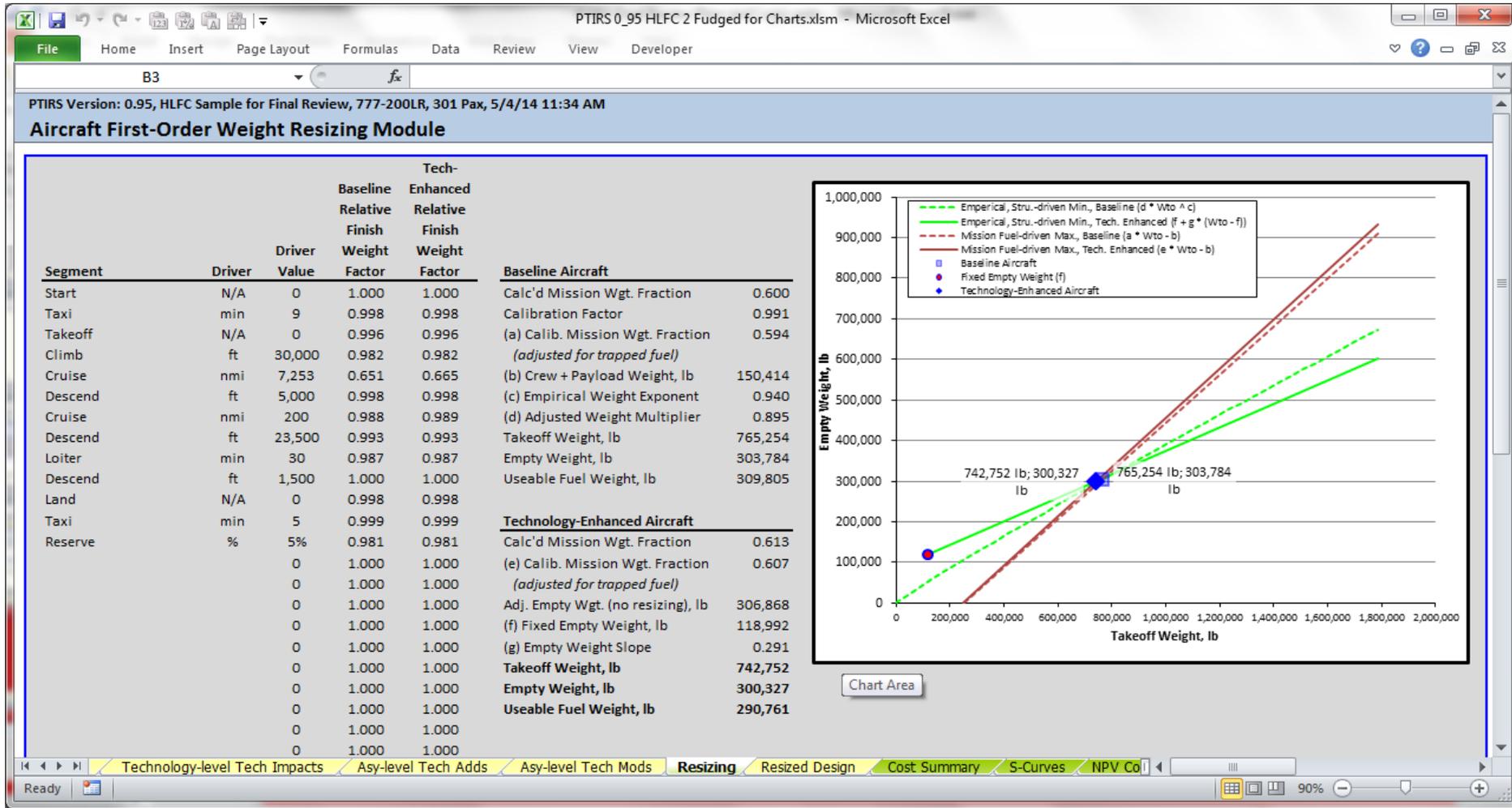
**Methodology Description**

THIS PRICE H BASED MODEL ESTIMATES THE PRODUCTION COST OF COMPOSITE AEROSTRUCTURES FOR COMMERCIAL AIRCRAFT BASED ON WEIGHT ONLY KEYWORDS STRUCTURE STRUCT AERODYNAMIC AERO WETTED LOAD BEARING STRESSED COMPOSITE HAND LAY UP CLOTH FABRIC GRAPHITE CARBON EPOXY RESIN

Asy-level Tech Adds **Finalize Selection** Asy-level Tech Mods Resizing Resized Design Cost Summary S-Curves NPV Compare

Ready 100%

# Viewing Resizing Results

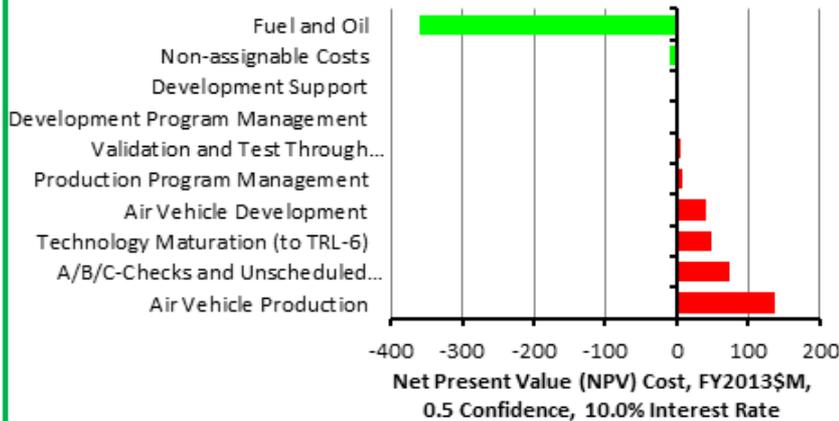


# Viewing Business Case Results

## HLFC Sample for Final Review

Date: 7/29/14 1:31 PM      Weight Resizing: Yes  
 Reference Aircraft: 737-800, 160 pax

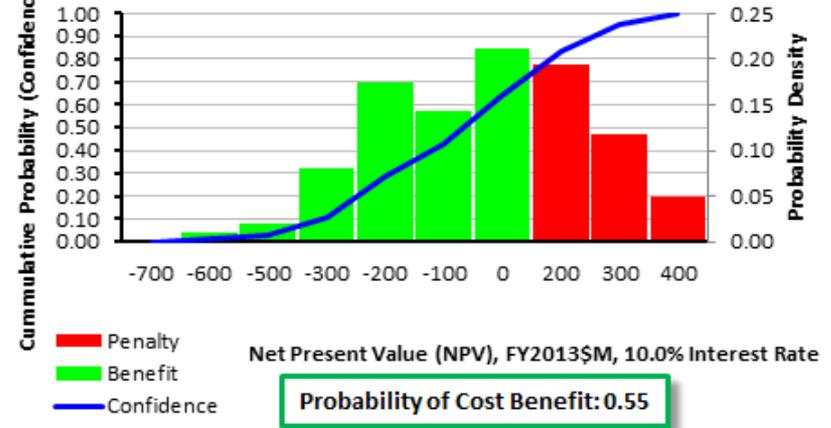
### Top 10 Cost Impacts



## Total Cost to Society

	Baseline Aircraft	Enhanced Aircraft	Cost Impact (- is good)
Net Present Value (NPV) Cost, FY2013\$M, 0.5 Confidence, 10.0% Interest Rate	48,814	48,819	-53

### Cost Impact, Total Cost to Society



### Comparative Values (0.5 Confidence)

	Reference Aircraft	Enhanced Aircraft	Impact (- is good)
Takeoff Weight (Lb)	174,248	174,491	243
Empty Weight (lb)	84,147	86,282	2,135
Useable Fuel Weight (lb)	46,766	44,858	-1,908
Cummulative Perceived Sound Level (EPNdB)	276.0	276.0	0.0
Landing and Takeoff NOx (g/kN)	34.8	34.8	0.0
First Unit Production Cost (FY2013\$M, 0.5)	162.5	165.4	2.7
Average Unit Production Cost (FY2013\$M, 0.5)	25.8	26.3	0.4
Tot. A/C-related Ops Cost per Hr (FY2013\$, 0.5)	5,160.6	5,091.2	-81.0
Total Cost per Hr (FY2013\$, 0.5)	12,941.2	12,886.0	-66.8
Cost per Avail. Statute Seat-Mile (FY2013\$, 0.5)	0.1764	0.1757	-0.0008

### Technologies Included

- Hybrid Laminar Flow Control

### Study Parameters

	Assumed	Break-even (0.5)
Fleet Size	855	645
Design Life	20	14
NPV Interest Rate	10.0%	11.4%
Fuel Price (FY2013\$/gal)	3.20	2.97

# Comparison of Predicted Costs with Published Prices

	737-800	777-200LR
<b>PTIRS Estimates, FY2013\$M</b>		
Development	6,348	17,361
Production	49,911	161,670
Flight Test Aircraft	10	9
Operational Fleet	855	855
Backup Aircraft	144	140
Development Years	8.6	8.6
Production Years	14.9	14.9
Production Start to Sale Lag, Years	1.3	1.3
Present Value Interest Rate	10%	10%
Sales Markup	25%	25%
Value of Development at End of Development	11,062	30,252
Total Payments on Development to End of Production	21,760	59,506
Production at Sale	56,671	183,565
Acquisition Total Cost with Finance Cost	78,431	243,071
Acquisition Unit Cost with Finance Cost	77.8	242.3
<b>Unit Cost Plus Markup</b>	<b>97.3</b>	<b>302.9</b>
<b>Boeing.com Price</b>	<b>93.8</b>	<b>306.5</b>
<b>PTIRS Estimate Divided by Boeing.com</b>	<b>104%</b>	<b>99%</b>

# Comparison of Predicted Operating Costs with Actual Operating Costs

777-200LR	PTIRS		PTIRS	
	2013\$M	2013\$/hr	Divided by Actual	Actual 2013\$/hr
Assignable Life Cycle (Development, Production, Operations)	1,385,222	22,403		
Development	17,361	281		
Production	161,670	2,615		
<b>Operations and Maintenance</b>	<b>1,206,191</b>	<b>19,508</b>	<b>100%</b>	<b>19,538</b>
Flight Operations	722,818	11,690	107%	10,968
Flight Crew	92,319	1,493	103%	1,450
Fuel and Oil	453,145	7,329	105%	6,980
Insurance	1,369	22	106%	21
A/B/C/D-Checks and Unscheduled Maintenance	117,484	1,900	127%	1,500
Vehicle Level	14,083			
Airframe	19,803	909	129%	703
Propulsion	61,302	991	124%	798
Subsystems	13,227			
Avionics Hardware	1,216			
Software	7,853			
Depreciation	58,501	946	93%	1,017
Passenger Services	42,974	695	60%	1,149
Flight-line Servicing	3,162	51	72%	72
Control	3,035	49	72%	68
Landing Fees	3,748	61	61%	99
Other Indirect Costs	430,454	6,962	97%	7,182

American Air Lines Inc.

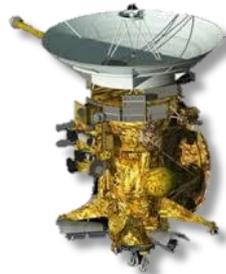
- Adaptive Compliant Trailing Edge (ACTE) - preliminary results
- Flap-edge and Landing Gear Noise Reduction - preliminary results
- Pull-truded Rod Stitched Efficient Unitized Structure - preliminary results
- High OPR Axially Staged Combustor - inputs collected from technical experts, results pending
- Highly Loaded Front Block Compressor - inputs collected from technical experts, results pending
- Large-scale GTF Soft Vanes and Over-The-Rotor Metal Foam Liners- inputs collected from technical experts, results pending
- Active Flow Control Vertical Tail - initial results briefed to ERA management

- Flight demonstration aircraft estimating capability
- Retrofit estimating capability
- Improvement of noise monetization methodology
- Public-friendly cost-effectiveness metrics
  - Aircraft sales price
  - Airline ticket price
  - Seat-miles per gallon

- PTIRS software and databases are modular allowing for extension to target platforms other than commercial transport aircraft
- For other aircraft platforms only minor WBS and Economic Analysis Module (EAM) modifications required



- For non-aero platforms, WBS, EAM, and Resizing Module modifications required, but little or no software modifications



- **PTIRS is a comprehensive tool for evaluating business cases for advanced commercial aircraft technologies from three perspectives:**
  - Manufacturer
  - Operator
  - World community
- **PTIRS Version 1.0 is a reliable tool, unique in its ability to provide logically rigorous data on which to make sound decisions in a rapidly advancing world.**
- **The PTIRS architecture is extensible to address other platforms in addition to commercial transport aircraft**