Turboprop Engine Take-Off Cost Calculator

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Turboprop Engine Take-Off Cost Calculator: Why?

- The overhaul cost of a 2,000 shp turboprop aircraft engine valued new at $2 million is up to $750,000.
- Aircraft engine maintenance, repair and overhaul (MRO) is big business, which means it is a big expense to operators.
- Operators want best value. They need to understand the impact of engine use on maintenance costs, not just on a long term basis, but by flight phase.
- There are different ways to perform and pay for engine maintenance:
  1. In-house repair
  2. OEM or third party maintenance
  3. Power by the hour contract
- Engine maintenance can be managed on hard time basis or on-condition. Many rotating components are life-limited (LCF).

Turboprop Engine Take-Off Cost Calculator: Why?

- Calculator could be used as a pre-flight tool to help pilot decision-making .
- Could be used in Line Operations Flight Training (LOFT) to sensitize flight crews regarding maintenance costs.
- Cost models could be combined with FDM/FOQA data to estimate maintenance costs post-flight.
- Could be used by OEM's or third-party maintenance providers to evaluate costs for a power by the hour contract to de-risk the contract.
- Why focus on the take-off flight phase for analysis?
  - More manageable scope and significant impact in regards to engine wear.
  - Reduced Power, Assumed Temperature Thrust, FLEX Thrust are known to reduce engine wear/damage or extend engine life.
  - By how much ($) under specified conditions?
  - Safety is the first consideration in setting take-off power/thrust: Permitted by AFM or SOP? Performance calculations shall dictate minimum power/thrust.

Turboprop Engine Take-Off Cost Calculator

What is the impact on fuel and maintenance costs of a reduced take-off power setting compared to a normal power setting?

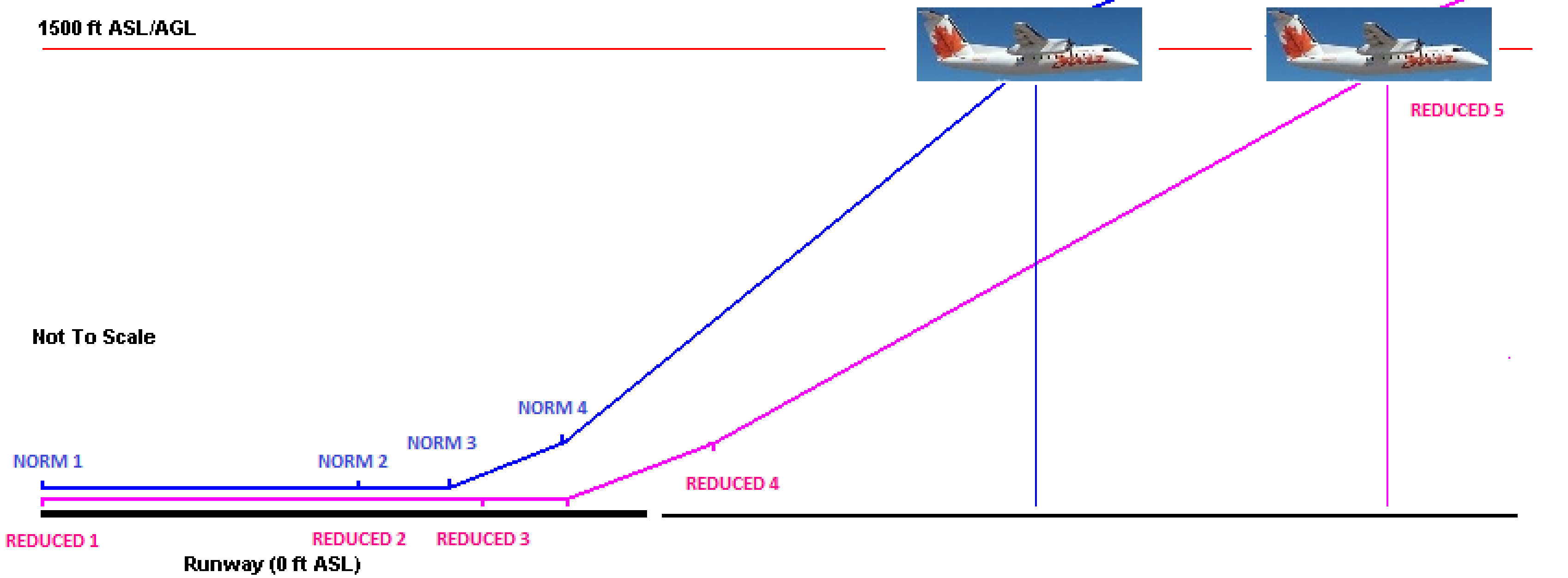
- This is a complex question because it includes elements of aircraft performance and engine duty cycle, thermodynamics, mechanical and thermal stresses, corrosion, etc. Yet, how the engine is used in all flight phases, including take-off, has economic consequences.
- A high-level combined aircraft performance and engine damage model approach is proposed.
- Operationally, safety is always the foremost consideration. However, if sufficient runway length is available, what are the cost savings of reducing the take-off power setting via reduced torque?
- This analysis first presents a classic take-off performance analysis with a fuel burn cost estimation for a Dash 8-100 (Q100) type aircraft powered by two PW120A turboprops.
- Then a maintenance cost analysis is performed based on a highly simplified engine damage model using cost and damage assumptions.
- Finally, a user interface of an application for a laptop or iPad-type device is proposed.

Take-Off Performance Calculations

First Principles Approach:

Four Segments:

1. Ground Roll to Rotation
2. Rotation to Lift-Off
3. Transition
4. Climb-Out to 1,500 ft AGL/ASL



Take-Off Performance Calculations: Fuel Cost Est.

Analysis Configuration								
Dash 8-100 equipped with two PWC PW120A turboprops								
Sea Level ISA Conditions: Baro: 29.92 in. Hg / 0 ft / 15 C								
Dry Runway Surface Condition Assumed								
Zero Wind								
Take-Off Weight = 24,250 lb								
Flaps = 15 deg.								
VR = 95 KIAS								
Analysis Points	**Total Time** (sec)	**Total Distance** (m)	**Total Distance** (ft)	**Altitude** (ft)	**Total Fuel Burn** (lb)	**Delta Fuel Burn** (lb)	**Delta Fuel Burn** (%)	**Total Fuel** ($)
Normal Take-Off (100%)								
1. Start of Ground Roll	0.0	0	0	0	0.0	0.0	0.0	$0.00
2. End of Ground Roll	19.0	485	1,592	0	10.1	0.0	0.0	$6.70
3. End of Rotation	22.0	638	2,094	0	11.7	0.0	0.0	$7.77
4. End of Transition	24.2	760	2,493	56	13.0	0.0	0.0	$8.63
5. Climb to 1,500 ft	55.8	2,301	7,549	1,500	29.8	0.0	0.0	$19.78
Reduced Take-Off (94%)								
1. Start of Ground Roll	0.0	0	0	0	0.0	0.0	0.0	$0.00
2. End of Ground Roll	20.0	517	1,697	0	10.3	0.0	0.0	$6.86
3. End of Rotation	23.0	672	2,206	0	11.9	0.0	0.0	$7.89
4. End of Transition	25.4	792	2,599	53	13.1	0.0	0.0	$8.71
5. Climb to 1,500 ft	57.7	2,402	7,882	1,500	29.8	0.0	0.0	$19.78
Delta Distance	101.4	m						
Delta Time	2.0	sec.						
Delta Burn	-0.22	kg						
Delta Cost	-$0.33	@ $1.20/L						

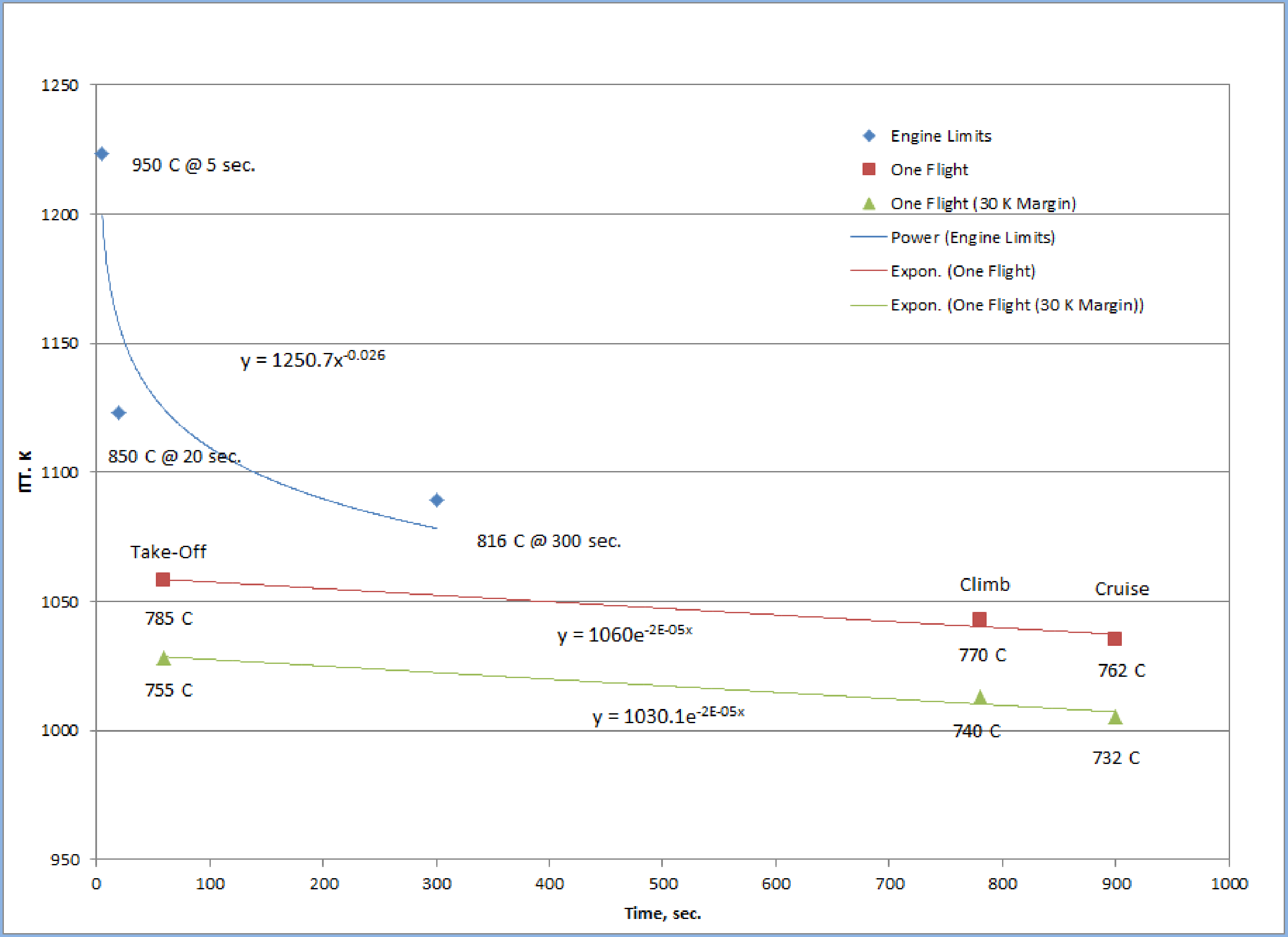
Aircraft Typical Flight Profile (Duty Cycle)

1. Bombardier Commercial Aircraft Update - September 2012					
Dash 8-100/Q200/Q300 Fleet statistics, May 2012					
Average flight time (mins.) 51					
2. Per Dash 8-100 ODM					
	Time (min)	*Fuel (lb)*	*Power*		
Taxi-Out	2	14	Idle		
Take-Off	1	31	Take-Off		
Circuit & Landing	2	24	Idle		
Taxi-In	2	14	Idle		
Totals	7	83			
3. Maximum Cruise Rating (20,000 ft)					
ISA, Zero Wind	Assume 24,250 lb			**Time (Min)**	**Power**
1. Climb - Type I (High Speed), 1050 RPM				13	Climb
2. Cruise - Max Cruise Setting, 1050 RPM				15	Cruise
3. Descent - Type I (High Speed), 300 fpm, 900 RPM				16	Idle
Block Fuel	1124	lb		44	
Block Time:	51	min			
Block Distance:	182	NM			

Factors Contributing to Engine Damage & Wear

- Static Failure
- Creep
- Low Cycle Fatigue (LCF)
- High-Cycle Fatigue (HCF)
- Thermomechanical Fatigue (TMF)
- Oxidation and Hot Corrosion
- Erosion
- Compressor and Turbine Fouling

PW120A ITT Temperature Limits and Duty Cycle



Estimate of Maintenance Cost for Take-Off

Replacement Cost of PW120A	$1,875,000			
Baseline			**On Condition**	
Overhaul Cost	$700,000.00		Overhaul Cost	$700,000.00
Hot Section Inspection Cost (1xHSI)	$100,000.00		Hot Section Inspection Cost (2xHSI)	$200,000.00
Total Cost	$800,000.00		Total Cost	$900,000.00
TBO	8,000		TBO	15,000
Flight Cycles (51 min/flight)	9412		Flight Cycles (51 min/flight)	17647
Cost per Hour	$100.00		Cost per Hour	$60.00
Cost per Cycle	$74.38		Cost per Cycle	$39.67
Cost per Take-Off	$22.31		Cost per Take-Off	$11.90
Maintenance Cost Allocation (Assumed):				
Take-Off	30%			
Climb	30%			
Cruise	30%			
Start-Up, Taxi, Descent	10%			
Total	100%			

Life limited parts include:

- LP/HP Turbine Disks
- LP/HP Centrifugal Impellers
- PT Stage #1/#2 Disks
- HP Turbine Blades

Engine Power Assurance Check verifies NH, NL, ITT/T6 and Wf.

Example of a Life Reduction Rule Based on TO Power

Larson-Miller equation for creep life for high temperature superalloys:

$$\text{LM Value} = \text{TEMP(K)}/1000 * (20 + \text{LOG10}(\text{LIFE(HRS)}))$$

Relates temperature exposure to creep life.

Objective is to develop and validate a rule that relates ITT and exposure time to permanent reduction in ITT margin: type design and engine S/N specific. Note that some reduction in ITT margin is due to compressor and turbine fouling, can be restored via washing.

Take Off Power (% TQ)	ITT (K)	ITT (^{o}C)	Larson-Miller Value	Creep Life (Hrs)	Life Ratio
100	1058	785	24.0	480	1.00
94	1043	770	24.0	1019	2.12
100	1058	785	25.0	4226	1.00
94	1043	770	25.0	9239	2.19
100	1058	785	26.0	37239	1.00
94	1043	770	26.0	84000	2.26

15 K/ 15^{o}C reduction in ITT doubles creep life at take-off temperatures. Therefore, maintenance cost is <u>theoretically</u> cut in half, excluding LCF contribution. However, creep is not the only damage mechanism.

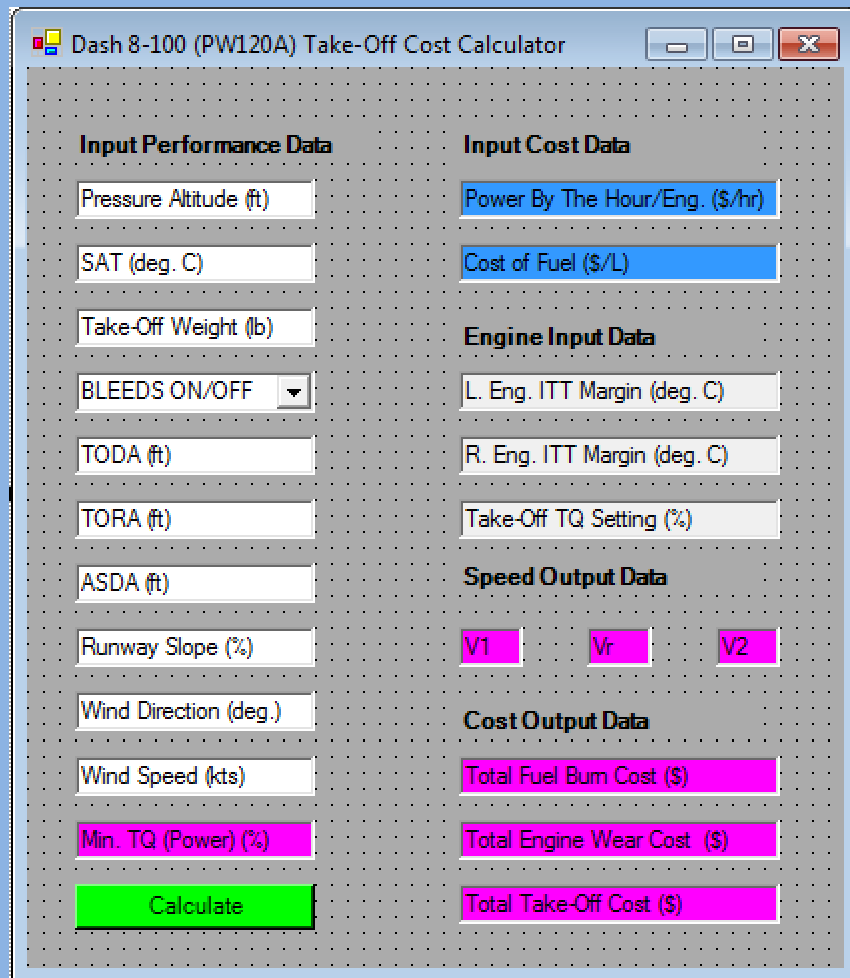
SRS

Total Cost Difference: Normal vs. Reduced Power TO

Difference in total engine costs (fuel and maintenance) per 8,000 TBO: $22.65

Engine Costs	100% TQ (1,800 shp)	94% TQ (1,700 shp)
Corrected Total Fuel Cost	$19.78	$19.45
Maintenance Cost (2 Eng.)	$44.63	$22.31
Total Cost	$64.41	$41.76

Take-Off Calculator Graphical User Interface



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Summary:

- Methodology to calculate total cost of fuel and engine maintenance has been presented.
- Fuel burn calculations validated.
- Maintenance cost calculations not validated and based on assumptions regarding damage ratio/flight phase and simplified damage rule based on ITT.

Way Forward:

- Life reduction rule development proposed based on:
  - Baseline condition of engine
  - Combination of classic engineering calculation and empirical data
  - Selection of most appropriate parameter: NH, NL, ITT/T6 or Wf
- Validation required based on in-service data
- Expansion to full flight envelope i.e. all flight phases

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Thank you

Questions?