Specific Range Solutions Ltd.
"Your partner in flight optimization"
omer.majeed@srs.aero / 1.613.883.5045
www.srs.aero

TBM 850 Cruise Performance Optimization Program

A Multi-Parameter Numerical Approach

1.0 Introduction

There has always been a need to obtain the best utilization of an aircraft in regards to time, cost or range. Awareness of the environmental impact of aircraft operation has also been increasing. The operation of any aircraft can be optimized for minimum time, minimum cost or minimum fuel burn, within the limits of its performance capabilities as defined by its Pilot Operating Handbook or Aircraft Flight Manual. Current flight planning software integrates various inputs such as departure, destination and alternate airports, upper winds and temperatures, payload and aircraft performance data to calculate the flight profile, flight time and fuel burn for a particular mission.

This study presents the results from a Windows-based application developed and validated by Specific Range Solutions Ltd that optimizes the cruise leg of the TBM 850 turboprop aircraft. The user inputs the departure and destination airports, aircraft weight, cruise leg distance, en-route upper wind and temperature data. The program includes adjustments for bleed flow, airframe drag and fuel flow, as well as a propeller model sub-routine that calculates the effect of two different RPM settings. The user then selects the parameter to minimize, either duration of the cruise leg, direct operating cost or fuel burn.

The program outputs the optimum altitude, the indicated temperature at that altitude, throttle setting, engine torque, fuel flow, as well as the indicated and true airspeeds. The total fuel burn, total time, total cost in dollars and specific range for the leg are also calculated.

The paper discusses the operational context for flight optimization, the development methodology and path, verification approach and initial results, followed by conclusions and proposed future developments. The results of this study were presented at the 18th CASI Propulsion Symposium on April 27th, 2011 in Montreal, Quebec.

2.0 Operational Context

"A commercial aircraft is a vehicle capable of supporting itself aerodynamically and economically at the same time."

William B. Stout, designer of the Ford Tri-Motor

Aircraft operations comprise the following four elements:

- *Flight Planning*: Activities related flight planning and preparation, including weather, route, flight profile, payload, weight and center of gravity calculations.
- *Ground Operations*: Pre- or post-flight activities at the gate or ramp with external electrical power and/or APU. Taxi out and taxi-in.
- *Flight Operations*: Activities from take-off to touch-down to safely and efficiently complete the mission.
- *Maintenance*: Airframe, avionics, systems, engine and APU maintenance tasks (on-wing and off-wing). On-condition, scheduled or preventative.

It is in the areas of flight planning and flight operations that an operational optimization program could be employed. Such a tool could also be useful for analysis of operational scenarios, i.e. as a fast and user-friendly "what-if" tool.

There are many flight planning product and service providers already in existence such as Lufthansa Systems Lido, Sabre, ARINC, FWZ, Jeppensen, Universal, SITA. AirData and Navtech, as well as some free flight planning providers such as flightaware.com. Notwithstanding, a program that is optimized for not only a specific type, but also for the current airframe and engine condition would have value to an operator.

The operational optimization of aircraft performance is complex due to the number of variables involved. No two flights are exactly the same due to the differences in flight conditions and aircraft configuration. The input elements for flight planning comprise:

- o *Mission*: Departure and arrival airports, heading, distance (range) and payload;
- o *Weather*: Temperature and upper winds (speed and direction);
- o *Aircraft Type, Condition and Configuration*: Aircraft specification performance, airframe drag, engine performance, system configuration, propeller setting and center of gravity;
- o *Operational Constraints/Objectives*: Minimum time, minimum cost, minimum fuel burn (maximum range) or a compromise between all three.

The aircraft selected for this study is the TBM 850, a light-turboprop aircraft with a Maximum Take-Off Weight (MTOW) of 7,394 lb. The TBM 850 is powered by the Pratt & Whitney Canada PT6A-66D engine, which has 850 shp (shaft horsepower) and 1,835 thp (thermodynamic horsepower) ratings. The aircraft has a 1,400 nautical mile (NM) range with NBAA IFR reserves (100 NM), zero wind, ISA and 658 lb of payload. It is certified per FAR Part 23.2006 and has a maximum payload of 1,876 lb.

The main aircraft performance parameters are:

- o Power setting
- o Altitude
- o Weight
- o Static Air Temperature (SAT)
- o Wind direction and speed
- o Center of gravity.

The TBM 850 was selected for the study because of the ready availability of a complete set of data as per the Performance Section of the TBM 850 Pilot's Operating Handbook Ref. [1]. The data was in PDF format and was manually digitized as a set of tables for use in the software program. The first four parameters are clearly seen in the POH extract shown in Figure 2.1. The center of gravity is not taken into account in the performance tables, likely due its small influence on an aircraft of that size.

TBM
850 PILOT'S OPERATING HANDBOOK

SECTION 5
PERFORMANCE

CRUISE PERFORMANCE
Normal (recommended) cruise

Conditions : ***ISA***
Landing gear and flaps UP
2000 RPM (*) - BLEED AUTO

NOTE :
- *Power recommended by PRATT & WHITNEY CANADA*
- *If BLEED HI selected,*
  torque reduced by 8 %
  above FL 240, airspeeds reduced by 4 KIAS+1 KIAS/2000 ft
  fuel flow increased by 2 % below FL 240

Pressure altitude (feet)	IOAT (°C)	TRQ (%)	Fuel flow			AIRSPEEDS (kt)					
						5500 lbs (2495 kg)		6300 lbs (2858 kg)		7100 lbs (3220 kg)	
			l / h	kg / h	us gal / h	IAS	TAS	IAS	TAS	IAS	TAS
0	+ 22	121	336	264	88.8	243	246	242	245	241	244
5000	+ 13	121	309	242	81.6	238	259	237	257	235	256
10000	+ 3	121	288	226	76.0	232	272	231	270	229	269
15000	- 6	121	276	216	72.8	227	287	225	285	223	283
18000	- 12	121	267	209	70.5	223	296	222	294	220	291
20000	- 15	121	261	205	69.0	221	302	219	300	217	298
21000	- 17	121	259	203	68.4	220	306	218	303	216	301
22000	- 19	121	257	202	68.0	219	309	217	307	215	304

Figure 2.1 – TBM 850 Pilot Operating Handbook Section 5 Performance Extract – Normal Cruise, ISA Conditions Ref. [1]

3.0 Software Development

3.1 Initial Development

The first iteration of the TBM 850 optimization program was completed in May 2010 and featured basic functionality based on the following inputs or selections:

- Weight;
- Temperature deviation from standard conditions (ISA);
- Length of the cruise leg in nautical miles (NM);
- Parameter to optimize: time, cost (owner or professional pilot operated) or fuel burn.

The program solved for the input conditions and output the following parameters: optimum altitude, temperature at that altitude, throttle setting, engine torque, fuel flow, indicated and true airspeeds, as well as total fuel burn, total time, total cost in dollars and specific range. The graphical user interface (GUI) or program screen including both input and output data is presented in Figure 3.1.

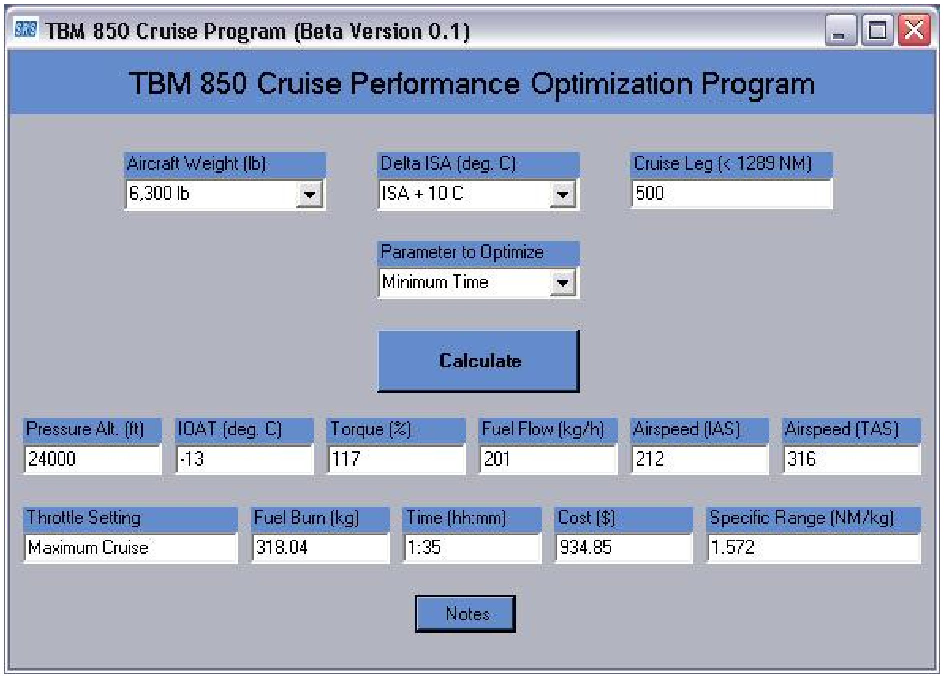

Figure 3.1 – TBM 850 Cruise Performance Optimization Program Screen (v0.1)

The development involved digitizing the performance data into tables, creating the graphical user interface and then designing, coding and testing the optimization engine along with the required calculations for output. The program backend is modular in that the optimization and calculation algorithms would be applicable to any aircraft type provided the performance data is structured in a similar way per the TBM 850's files.

Algorithms to calculate minimum cost, minimum fuel burn and minimum time for the cruise flight phase were developed.

3.2 Current Development

For the purposes of presenting at the 18th CASI Propulsion Symposium, the program was further developed by Specific Range Solutions Ltd. to include the additional functionalities:

- User selection of the departure and destination airports with automatic calculation of point-to-point distance in nautical miles and true course;
- User selection of ISA conditions or forecast en-route upper wind and temperature data with automatic calculation of average temperature deviation from ISA conditions;
- User selection of airframe drag penalty (with or without weather radar);
- User selection or powerplant wear decrement (0% to 3% in 1% increments);

- User selection of two propeller speed settings (2000 RPM or 1600 RPM);
- User selection of the Bleed System configuration (BLEED AUTO or BLEED HI).

Each of these new functions was added progressively using a building block or spiral development process and each function was designed, implemented and tested prior to adding the next function. The revised and annotated graphical user interface is indicated below in Figure 3.2.

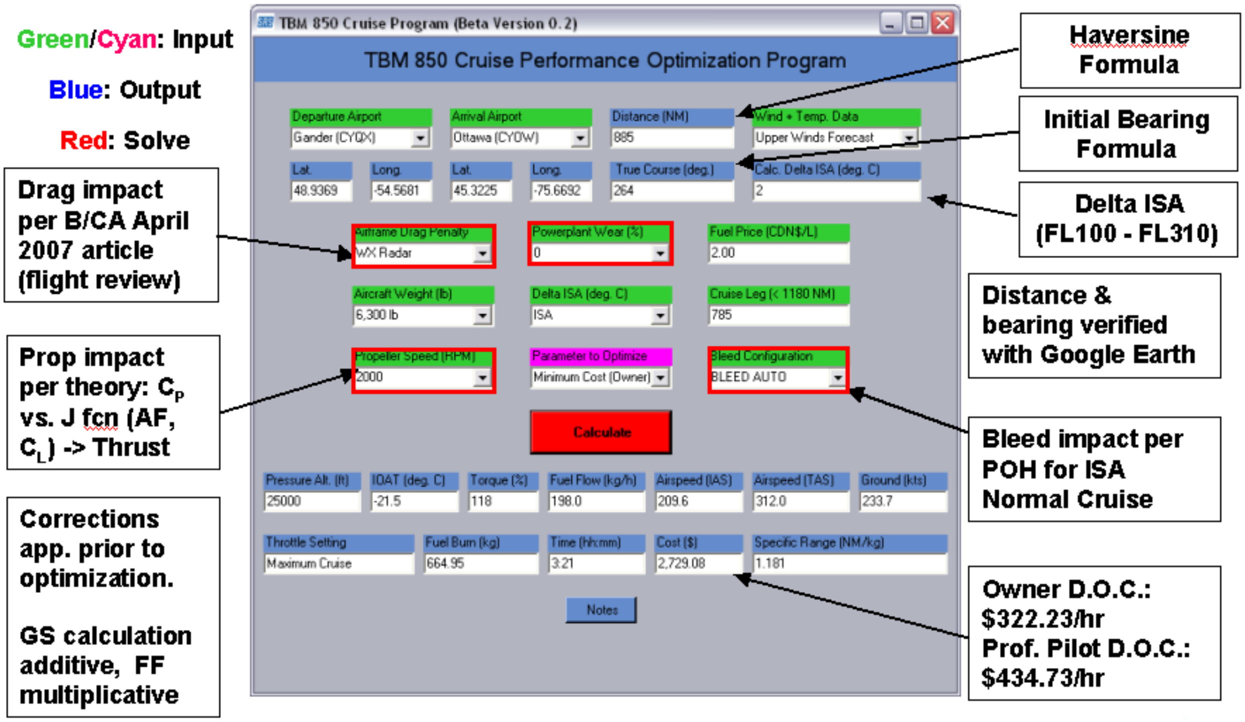

Figure 3.2 – TBM 850 Cruise Performance Optimization Program Screen (v0.2)

3.3 Forecast Upper Wind and Airport Surface Weather Data

The forecast Upper Wind (FD) and METAR data per Table 3.1 were obtained from the Aviation Weather Web Site of NavCanada (www.navcanada.ca) for the Ottawa Macdonald-Cartier International Airport (CYOW) weather station, which was selected as the sample en-route weather waypoint.

The weather data for converted into a structured file for use by the program for surface conditions up to the TBM 850's certified ceiling of 31,000 ft. A similar file was created for standard day (ISA) conditions with zero wind.

The weather data files were also checked for accuracy.

Upper Wind Data – April 24, 2011

Request Generated **04/24/2011 at 15:12:11 UTC** . Weather information available at that time is displayed.

STN YOW - OTTAWA. ONT	for use	3000	6000	9000	12000	18000
FDCN01 CWAO FCST BASED ON 241200 DATA **VALID 241800**	**17-21**	2807	2812-01	2729-04	2746-07	2673-16
FDCN02 CWAO FCST BASED ON 241200 DATA **VALID 250000**	**21-06**	2605	2714-03	2824-04	2743-07	2669-16
FDCN03 CWAO FCST BASED ON 241200 DATA **VALID 251200**	**06-17**	1907	2512-01	2825-03	2733-08	2764-17

STN YOW - OTTAWA. ONT	for use	24000	30000	34000	39000	45000	53000
FDCN01 KWBC DATA BASED ON 241200Z **VALID 241800Z**	**1700-2100Z.**	2577-29	269744	772952	763361	257259	264359
FDCN02 KWBC DATA BASED ON 241200Z **VALID 250000Z**	**2100-0600Z.**	2781-29	760744	762552	761560	267760	265158
FDCN03 KWBC DATA BASED ON 241200Z **VALID 251200Z**	**0600-1700Z.**	2780-28	761143	761553	772261	267761	275160

Request Generated **04/24/2011 at 15:33:01 UTC** . Weather information available at that time is displayed.

METAR/TAF

OTTAWA/MACDONALD-CARTIER INTL/ON

METAR CYOW 241500Z 29008KT 15SM BKN030 BKN180 BKN240 07/01 A3004 RMK SC5AS2CI0 SLP175=

Table 3.1 – Forecast Upper Wind (FD) and Surface (METAR) at CYOW on April 24th, 2011 @ 15:12:11 UTC.

3.4 Testing and Verification

The digitized performance tables were verified via a manual data review against the performance tables and then verified in v0.1 of the program via non-regression testing.

As mentioned in the previous section, each new function was tested as it was added using progressive non-regression and regression testing. A code review was also performed for each new sub-routine.

4.0 Preliminary Results

To evaluate the new version of the TBM 850 optimization software, two different flights (missions) from Gander to Ottawa were evaluated, one at zero wind, ISA conditions and the other with a strong westerly wind based on NavCanada forecast Upper Wind (FD) data as follows:

1. Gander (CYQX) to Ottawa (CYOW), ISA, 776 NM, WX Radar, 0% Engine Wear, 2000 RPM, BLEED AUTO, $2.00/L, 6,300 lb, ISA.
2. Gander (CYQX) to Ottawa (CYOW), FD Forecast, 776 NM, WX Radar, 05 Engine Wear, $2.00/L, 6,300 lb, ISA (ISA+2^{o}C).

The results are presented in Table 4.1 based on the four optimization parameters.

Optimized Parameter	ZA ft	IOAT deg. C	TRQ %	FF kg/hr	IAS kts	TAS kts	Gnd kts	Throttle	Burn kg	Time hh:mm	Cost $	SR NM/kg
Configuration 1												
Gander to Ottawa, ISA, 776 NM, WX Radar, 0 Eng. Wear, 2000 RPM, BLEED AUTO, $2.00/L, 6,300 lb, ISA												
Min Cost (Owner)	31000	-35.62	92	159	185	305	305	Norm	405.87	2:33	$1,827.78	1.912
Min Cost (P. Pilot)	31000	-35.62	92	159	185	305	305	Norm	405.87	2:33	$2,114.95	1.912
Min. Fuel (Owner)	31000	-38.62	62	116	151	250	250	LRC	360.06	3:06	$1,892.00	2.155
Min. Time (Owner)	26000	-25.52	115	198	209	315	315	Max	487.77	2:28	$2,001.91	1.591
Configuration 2												
Gander to Ottawa, FD Forecast, 776 NM, WX Radar, 0 Eng. Wear, $2.00/L, 6,300 lb, ISA												
Min Cost (Owner)	25,000	-21.5	118	198	210	312	234	Max	657.32	3:19	$2,697.79	1.181
Min Cost (P. Pilot)	25,000	-21.5	118	198	210	312	234	Max	657.32	3:19	$3,071.27	1.181
Min. Fuel (Owner)	30,000	-36.6	62	117	152	247	150	LRC	604.33	5:10	$3,161.17	1.284
Min. Time (Owner)	5000	7.9	121	242	232	252	242	Max	774.76	3:12	$2,950.52	1.002

Table 4.1 – Results for Gander (CYQX) to Ottawa (CYOW) Flight Under ISA and FD Conditions

A number of observations are readily made. For all optimization cases, Min Cost (Owner), Min. Cost (P. Pilot), Min Fuel (Owner) and Min. Time (Owner), the fuel burn, time and cost are all considerably higher for the forecast conditions. This is due to the strong westerly winds which are 7 knots at 280° True at 3,000 ft ASL and increase to 97 knots at 260° True at 30,000 ft ASL.

Another point is that for the forecast case, the minimum time of 3 hours and 12 minutes at 5,000 ft is only 7 minutes faster than the minimum cost solution at 25,000 ft, though both are flown at the Maximum Cruise power setting. Flying higher in an owner-flown configuration will save $252.73 and over 117 kg of Jet-A, in addition to having a less bumpy ride. Therefore, while optimization algorithms will produce many correct of solutions, as an operator it is nevertheless important to look at the big picture and take into account all the various operational considerations in the flight planning decision making process.

The results in terms of total cost, total fuel burn and total time as a function of the optimization parameter are shown in Figures 4.1, 4.2 and 4.3, respectively.

In Figure 4.1, the Min. Cost (Owner) solution is confirmed as the minimum cost solution for both ISA and forecast conditions compared to the Min. Fuel (Owner) and Min. Time (Owner) solutions.

The Min. Fuel (Owner) solution is confirmed in Figure 4.2 as the minimum fuel burn solution for both ISA and forecast conditions compared to the Min. Cost (Owner) and Min. Time (Owner) solutions.

In Figure 4.3, the Min. Time (Owner) solution is confirmed as the fastest solution for both ISA and forecast conditions compared to the Min. Cost (Owner) and Min. Fuel (Owner) solutions.

Therefore, based on the comparison of the results, the optimization algorithms are solving for the selected minima.

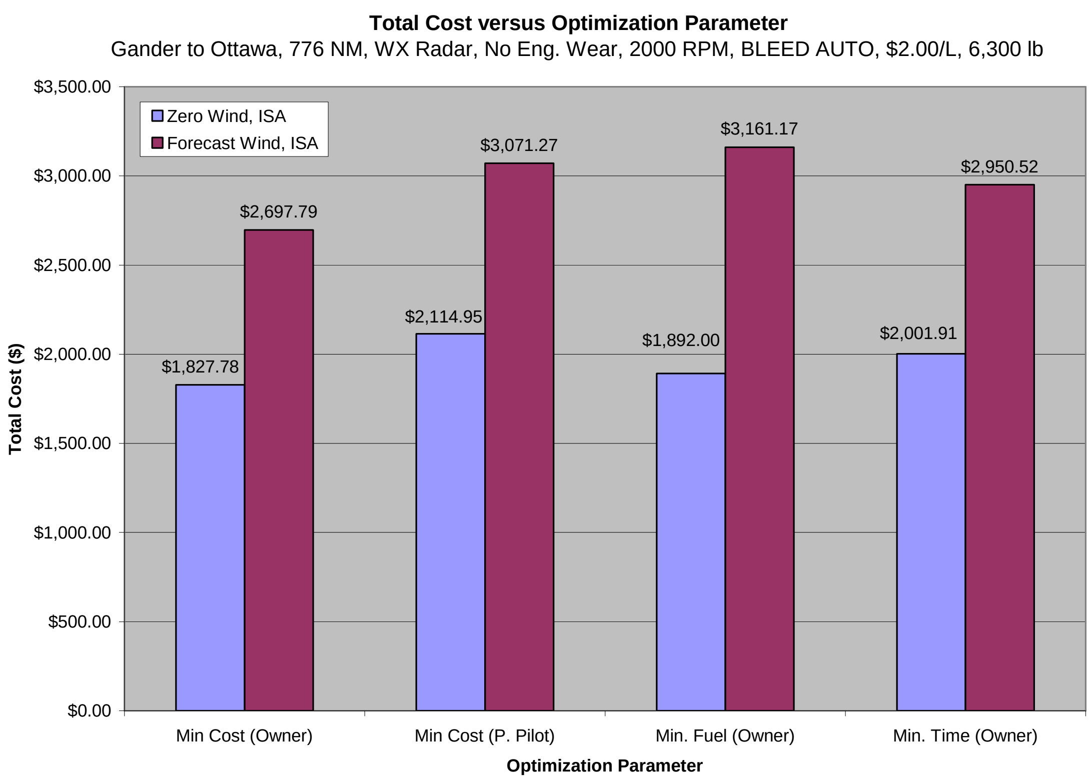

Figure 4.1 Total Cost versus Optimization Parameter

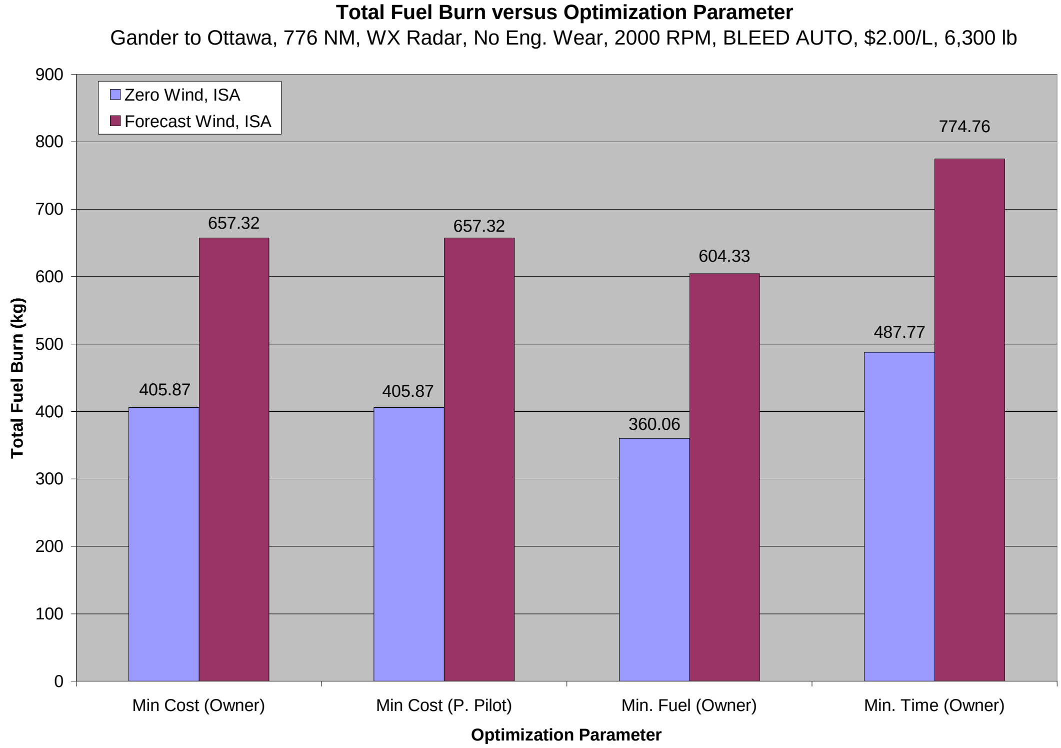

Figure 4.2 - Total Fuel Burn versus Optimization Parameter

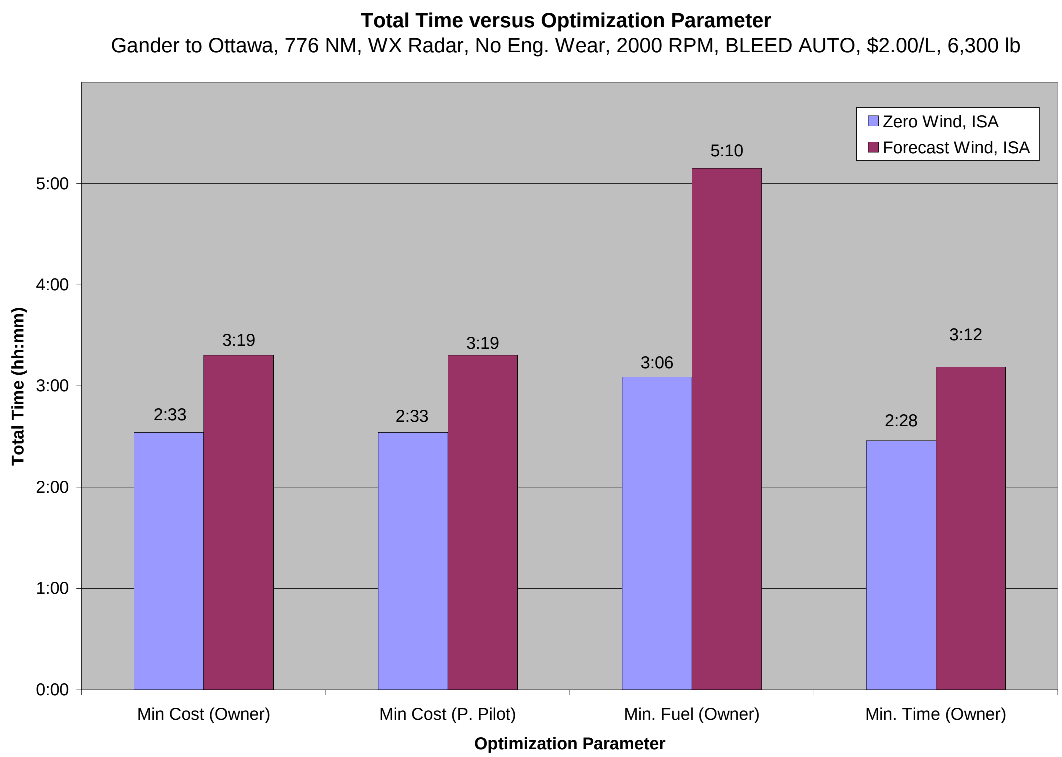

Figure 4.3 - Total Time versus Optimization Parameter

5.0 Conclusions

The conclusions that can be drawn from this paper are that:

- The TBM 850 Cruise Performance Optimization Program has been extended to a higher, more realistic and useful level of functionality compared to its previous iteration;
- The spiral development approach of incremental designing, coding and testing is an efficient and effective methodology for creating software applications;
- The optimization algorithms are calculating and identifying the user-selected minima;

Other reflections arising from this latest development effort are:

- Aircraft performance prediction should go beyond the specification data to better characterize performance with regards to aircraft condition and configuration, i.e. taking into account airframe drag and powerplant performance on a particular aircraft;
- Improved performance prediction means fuel uplift requirements will be more accurate, maximizing safety margin and minimizing “not required” fuel carried;
- The application could evolve in a real-time optimizer for use by pilots (as opposed to looking up data in tables) or into a type-specific flight planning tool, and finally
- The optimization program could be used for R&D investigations into flight operations.

6.0 Proposed Future Improvements

There are many opportunities to improve the TBM 850 Cruise Performance Optimization Program:

- Airspeed adjustments for drag, bleed, propeller as implemented were estimated and piecewise, they should be continuous as performance is a continuum;
- Fuel flow adjustments for engine performance and bleed as implemented were estimated and piecewise, again they should be continuous;
- It would be interesting to implement realistic engine wear characterization at component level and then assess the impact on overall aircraft performance;
- Verification of the program with actual flight test data to check propeller RPM modeling and Bleed System modeling;
- Create a complete flight planning capability by including climb and descent flight phases.

7.0 References

1. TBM 850 Pilot's Operating Handbook Section 5 Performance Rev. 0.
2. Teach Yourself Microsoft Visual Basic .NET 2003 in 21 Days, Steven Holzner, SAMS Publishing, 2003.
3. Aircraft Design: A Conceptual Approach, Daniel P. Raymer, American Institute of Aeronautics and Astronautics Inc., 1989.
4. Gas Turbine Theory, Sixth Edition, H.I.H. Saravanamuttoo, G.F.C. Rogers, H. Cohen & P.V. Straznicky, Pearson Education Limited, 2009.
5. Airplane Aerodynamics and Performance, Dr. Chuan-Tau Edward Lan & Dr. Jan Roskam, DARcorporation, 2008.
6. Business & Commercial Aviation, April 2007 Issue “EADS Socata TBM 850” by Fred George, pg. 62 – 69, McGraw-Hill Companies, 2007.7.
7. Flying, June 2006 Issue “TBM 850 Is Even Faster” by J. Mac McClellan, pg. 64 – 71, Hachette Filipacchi Media U.S. Inc., 2006.