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, Jeppesen, 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:

- **Mission**: Departure and arrival airports, heading, distance (range) and payload;
- **Weather**: Temperature and upper winds (speed and direction);
- **Aircraft Type, Condition and Configuration**: Aircraft specification performance, airframe drag, engine performance, system configuration, propeller setting and center of gravity;
- **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 23.22006 and has a maximum payload of 1,876 lb.

The main aircraft performance parameters are:

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

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

![TBM 850 Cruise Performance Optimization Program Screen (v0.1)](image)

**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);
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.

<table>
<thead>
<tr>
<th>STN YOW - OTTAWA, ONT</th>
<th>for use</th>
<th>3000</th>
<th>6000</th>
<th>9000</th>
<th>12000</th>
<th>18000</th>
</tr>
</thead>
<tbody>
<tr>
<td>FDCN01 CWAO FCST BASED ON 241200 DATA</td>
<td>17-21</td>
<td>2807</td>
<td>2812:01</td>
<td>2729:04</td>
<td>2746:07</td>
<td>2673:16</td>
</tr>
<tr>
<td>FDCN02 CWAO FCST BASED ON 241200 DATA</td>
<td>21-06</td>
<td>2605</td>
<td>2714:03</td>
<td>2824:04</td>
<td>2743:07</td>
<td>2696:16</td>
</tr>
<tr>
<td>FDCN03 CWAO FCST BASED ON 241200 DATA</td>
<td>06-17</td>
<td>1907</td>
<td>2512:01</td>
<td>2825:03</td>
<td>2733:08</td>
<td>2764:17</td>
</tr>
</tbody>
</table>

### 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°C).**

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Configuration 1</th>
<th>Configuration 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZA ft</td>
<td>31000</td>
<td>25000</td>
</tr>
<tr>
<td>IAS °C</td>
<td>35.62</td>
<td>38.62</td>
</tr>
<tr>
<td>THO %</td>
<td>92</td>
<td>92</td>
</tr>
<tr>
<td>FF kg/hr</td>
<td>159</td>
<td>116</td>
</tr>
<tr>
<td>TAS kts</td>
<td>185</td>
<td>151</td>
</tr>
<tr>
<td>TAS kts</td>
<td>305</td>
<td>250</td>
</tr>
<tr>
<td>Burn kg</td>
<td>305</td>
<td>250</td>
</tr>
<tr>
<td>Burn hr:mm</td>
<td>305</td>
<td>250</td>
</tr>
<tr>
<td>SR NM/kg</td>
<td>405.87</td>
<td>360.06</td>
</tr>
<tr>
<td>Norm</td>
<td>2:33</td>
<td>5:10</td>
</tr>
<tr>
<td>Max</td>
<td>657.52</td>
<td>774.76</td>
</tr>
<tr>
<td>Cost $</td>
<td>$1,827.78</td>
<td>$1,892.00</td>
</tr>
<tr>
<td>Cost $</td>
<td>$2,001.91</td>
<td>$2,950.52</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Gander to Ottawa, ISA, 776 NM, WX Radar, 0% Engine Wear, 2000 RPM, BLEED AUTO, $2.00/L, 6,300 lb, ISA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min Cost (Owner)</td>
<td>31000</td>
</tr>
<tr>
<td>Min Cost (P. Pilot)</td>
<td>31000</td>
</tr>
<tr>
<td>Min. Fuel (Owner)</td>
<td>31000</td>
</tr>
<tr>
<td>Min. Time (Owner)</td>
<td>26000</td>
</tr>
<tr>
<td>Min Cost (Owner)</td>
<td>31000</td>
</tr>
<tr>
<td>Min Cost (P. Pilot)</td>
<td>31000</td>
</tr>
<tr>
<td>Min. Fuel (Owner)</td>
<td>31000</td>
</tr>
<tr>
<td>Min. Time (Owner)</td>
<td>26000</td>
</tr>
</tbody>
</table>

### 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.

![Total Cost versus Optimization Parameter](image_url)

**Figure 4.1 Total Cost versus Optimization Parameter**

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**Figure 4.2 - Total Fuel Burn versus Optimization Parameter**

Gander to Ottawa, 776 NM, WX Radar, No Eng. Wear, 2000 RPM, BLEED AUTO, $2.00/L, 6,300 lb

<table>
<thead>
<tr>
<th>Optimization Parameter</th>
<th>Zero Wind, ISA</th>
<th>Forecast Wind, ISA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min Cost (Owner)</td>
<td>405.87</td>
<td>657.32</td>
</tr>
<tr>
<td>Min Cost (P. Pilot)</td>
<td>405.87</td>
<td>657.32</td>
</tr>
<tr>
<td>Min. Fuel (Owner)</td>
<td>360.06</td>
<td>604.33</td>
</tr>
<tr>
<td>Min. Time (Owner)</td>
<td>487.77</td>
<td>774.76</td>
</tr>
</tbody>
</table>

**Figure 4.3 - Total Time versus Optimization Parameter**

Gander to Ottawa, 776 NM, WX Radar, No Eng. Wear, 2000 RPM, BLEED AUTO, $2.00/L, 6,300 lb

<table>
<thead>
<tr>
<th>Optimization Parameter</th>
<th>Zero Wind, ISA</th>
<th>Forecast Wind, ISA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min Cost (Owner)</td>
<td>2:33</td>
<td>3:19</td>
</tr>
<tr>
<td>Min Cost (P. Pilot)</td>
<td>2:33</td>
<td>3:19</td>
</tr>
<tr>
<td>Min. Fuel (Owner)</td>
<td>3:06</td>
<td>5:10</td>
</tr>
<tr>
<td>Min. Time (Owner)</td>
<td>2:28</td>
<td>3:12</td>
</tr>
</tbody>
</table>
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.
5. Airplane Aerodynamics and Performance, Dr. Chuan-Tau Edward Lan & Dr. Jan Roskam, DARcorporation, 2008.