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Beechcraft 1900D: Fuel, Emissions & Cost Savings Operational Analysis

by Omer Majeed, P.Eng.

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

Introduction

The Ford Tri-Motor flew for the first time in 1926, so the requirement for economy in aircraft design and operation is far from a recent phenomenon in commercial aviation. Continual advances in aerodynamics, propulsion and aircraft systems technologies have made flying ever more efficient, as well as the safest mode of transportation per passenger distance travelled. However, rising and increasingly volatile jet fuel prices, growing concerns over the impact of greenhouse gas emissions on climate change, the climbing cost of labour and maintenance, as well as the relentless pricing pressure brought to bear by competition and the Internet, are all serving to drive the entire industry—from large airlines to small operators—towards maximizing operational efficiency.

It has been estimated in the Intergovernmental Panel on Climate Change (IPCC) Special Report on Aviation that operational improvements can reduce fuel consumption and associated emissions between 2% and 6%, although fuel savings of up to 18.4% have been demonstrated in simulations of short flights, per David Learmount's November 5th, 2009 posting on flightglobal.com.

This article presents the results of a case study of a popular small airliner, the Beechcraft 1900D, flying a representative profile using actual data from an unidentified Canadian operator, and then comparing that flight to a more optimized one using a few well-established flight operations optimization techniques.

The overall objective of the article is to estimate fuel burn, emissions and cost savings using optimized procedures; and, it is hoped by the author, that the results will be both revealing and useful for the readers of this article, many of whom operate this aircraft..

Aircraft Background

The Beechcraft 1900D is a regional airliner seating up to 19 passengers and powered by two PT6A-67D Pratt & Whitney Canada turboprops, each with a 1,279 engine shaft horsepower (SHP) rating. The aircraft has a 17,120 lb maximum takeoff weight (MTOW) and has a range of 680 nautical miles (NM) with a full passenger load, while cruising at 25,000 ft in ISA conditions at High Speed Power. However, flights are more typically 220 to 260 NM in distance and on average 60 minutes in duration.

This type was selected for this case study as it is used by a large number of Canadian operators.

Description and Analysis of the Representative Flight

A survey of FlightAware.com data filtered for 1900D aircraft was conducted and the representative flight was selected based on the following criteria:

- Canadian operator flying only within Canadian airspace;
- Unrestricted climb and descent profile without steps or holding patterns;
- Flight of 40 to 60 minutes in duration;
- Complete set of latitude, longitude, pressure altitude, groundspeed and time data available starting and ending from 5,000 ft Above Sea Level (ASL) or below;
- Close to weather stations for which Nav Canada provides upper wind and temperature (FD) forecast data. Note that surface conditions were per reported METAR data.

The chosen and de-identified flight is presented in Figure 1 which shows pressure altitude versus track distance, 226.1 NM total, and in Figure 2 which shows the ground track plotted as longitude versus latitude.

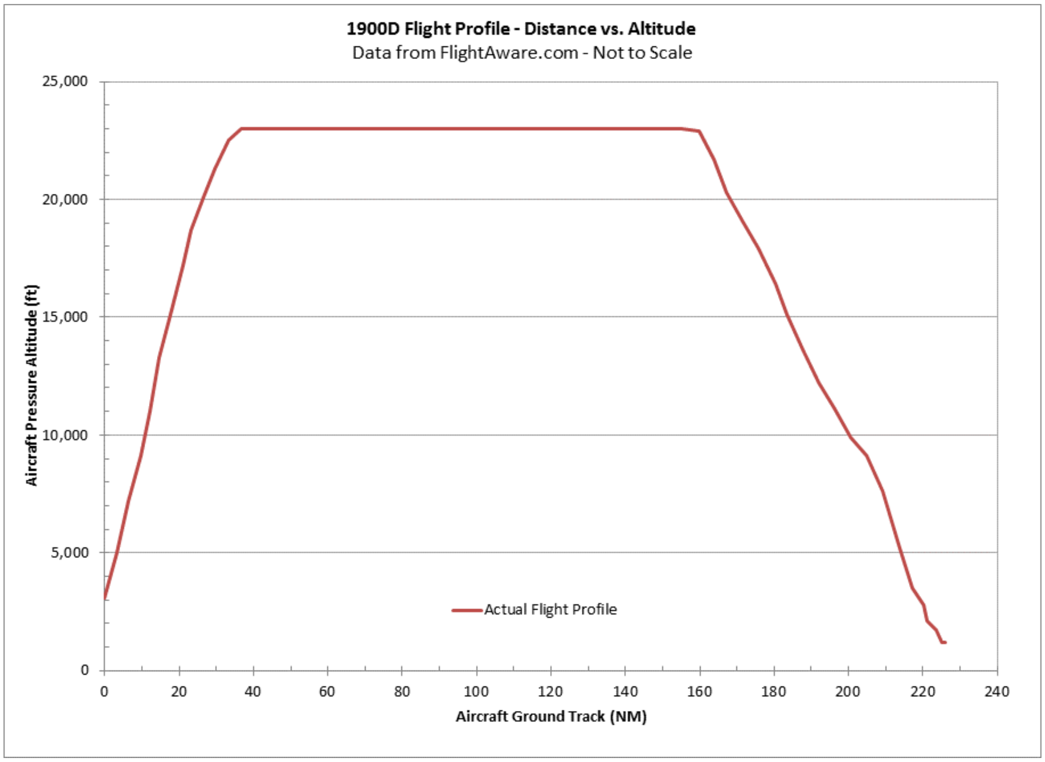

Figure 1 – 1900D Actual Flight Pressure Altitude vs. Ground Track Distance, Courtesy of FlightAware (flightaware.com)

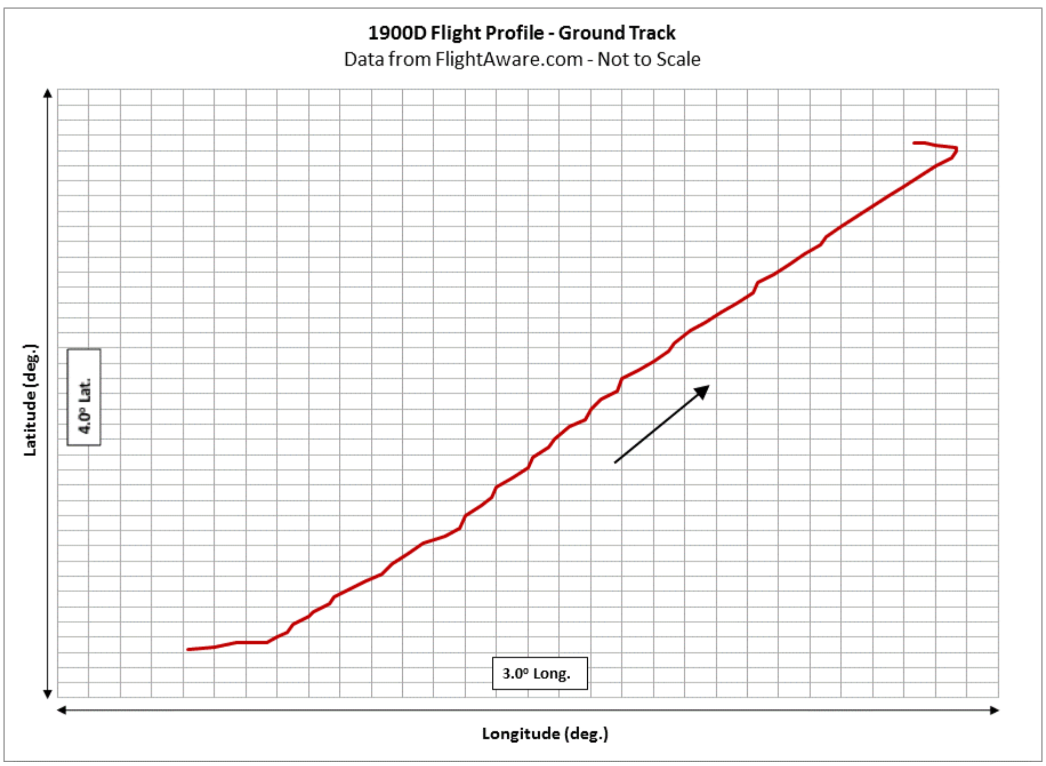

Figure 2 – 1900D Actual Flight Ground Track (Northeast Direction / 226.1 NM), Courtesy of FlightAware (flightaware.com)

The flight looks efficient from its altitude profile in Figure 1, as there are no level-offs during climb nor in descent and the aircraft is cruising at a relatively high altitude of 23,000 ft, which is favourable for reduced fuel burn. The cruise ceiling of the aircraft is 25,000 ft. The ground track also appears to be efficient in that the flight to the northeast is essentially point to point with a turn to the west for approach and landing. It should be noted that the FlightAware.com data has a sample period of one minute, a groundspeed accuracy to within 10 knots and a position accuracy of ±0.2 NM in latitude and ±1.0 NM in longitude when plotted on Google Earth.

Therefore, the crew flew a good profile with a continuous climb, as well as an uninterrupted descent. The question is, can this well-flown flight be made more even efficient with one simple operational improvement per flight phase? First, some background on the methodology employed.

The fuel burn and aircraft performance data were obtained from the 1900D Pilot's Operating Manual Ref. 129-590000-73. A number of assumptions were made to calculate the fuel burn, emissions and costs:

- Nav Canada short-term forecast upper winds and temperature data at departure and arrival airports were assumed to be representative of the actual flight conditions, upper winds at the cruise altitude were forecast from the northwest and averaged 78 knots. METAR data employed was as reported;
- True Air Speed (TAS) in cruise was reverse calculated from groundspeed and forecast upper wind data to be an average of 281 knots. This suggested for the 23,000 ft altitude and ISA-6^{o}C outside air temperature that the crew was operating an aircraft with a 14,000 lb weight at a High Speed Cruise setting;
- Climb was performed with Engine Anti-Ice OFF;
- To calculate CO_2 emissions in pounds (lb), a constant factor of 3.125 was applied to the fuel burn;
- Fuel cost was assumed to be $1.70/L; all cost figures are presented in Canadian dollars (CDN$);
- Variable costs include maintenance labour, parts & miscellaneous, but do not include crew costs, hull insurance, Nav Canada air navigation fees, landing fees, etc;
- Variable costs were estimated based on the operating costs for the King Air 300 presented in the August 2011 issue of *Business & Commercial Aviation,* scaled up for MTOW and corrected for the Canadian and U.S. dollar exchange rate.

The fuel burn, CO_2 emissions and cost results are presented by flight phase in Table 1 below.

1900D Actual (Typical) Flight @ 14,000 lb Avg. Weight, 226.1 Track NM, ISA-6C, Anti-Ice OFF

Flight data from FlightAware.com. Forecast upper winds & temperatures from NavCanada. Performance data per Pilot's Operating Manual

Flight Phase	Time (min)	Fuel Burn (lb)	CO_2 Emissions (lb)	Fuel Cost @ $1.70/L ($)	Variable Costs @ $594.66/HR* ($)
Start, Taxi-Out & Take-Off	10	110.0	343.8	$105.50	$99.11
Climb to 23,000 ft @ Avg. IAS = 156 KTS	12	236.0	737.6	$226.39	$118.93
High Speed Cruise @ 1550 RPM/IAS = 198 KTS	29	397.5	1242.3	$381.28	$287.42
Descent from 23,000 ft @ Avg. IAS = 223 KTS	19	230.9	721.4	$221.41	$188.31
Taxi-In & Shut-Down	10	70.0	218.8	$67.14	$99.11
	80	1044.4	3263.8	$1,001.72	$792.89
*Variable Costs include maintenance labour, parts & miscellaneous				**Total:**	**$1,794.61**

Table 1 – 1900D Actual Flight Fuel Burn, CO_2 Emissions and Cost Data ($1.70/L)

The flight time is 60 minutes and the block time is 80 minutes, with 10 minutes assumed on the ground at both the start and the end of the flight. The total fuel burn is estimated at 1,044 lb and total CO_2 emissions arte 3,264 lb. The fuel cost based on $1.70/L is $1,002 and the variable costs are $793 for a total cost of $1,795. These figures from the actual flight are therefore the baseline for comparison.

Description and Analysis of the More Optimized Flight

The more optimized flight uses the same ground track as the actual flight, the same reported METAR data, forecast winds and temperature data and the same cruising altitude. It is important to note that a full optimization of fuel burn or costs via altitude and cruise power analysis, as well as ground track minimization, has not been performed. In the case of optimization of the entire flight for a given aircraft type, weight and weather conditions, there will typically exist unique solutions in terms of cruise altitude and cruise power setting to achieve minimum cost, minimum burn (maximum range) and minimum time.

The approach used in this case study was to make one straightforward operational improvement by flight phase and compare the new, more optimized flight to the baseline flight.

For the start, taxi-out and take-off phase, it is proposed to use single engine taxi-out. While there was no procedure defined in the B1900D Airliner Flight Manual, nor in the Pilot's Operating Manual, other operators using turboprop aircraft such as the Dash 8-100 do use single engine taxi in normal operations. A separate procedure would be required for single engine taxi and the procedure could be permitted based on aircraft configuration, ramp weight, ramp and taxiway conditions, minimum warm-up time for the second engine and crew workload. The PT6A-67D engines of the Beechcraft are rather thirsty at ground idle, consuming approximately 210 lb/hr each or 420 lb/hr total, so there is incentive to reduce ground running time to a safe and reasonable minimum.

It should be noted that if single engine taxi is not operationally feasible, the same fuel burn benefits can be derived by reducing total engine ground running time by 2.5 minutes on departure and also on arrival.

In this analysis, a 5-minute delay has been incorporated for the start-up of the second engine e.g. right engine, with a 25% fuel burn credit allocated during the total 10 minute ground phase. Furthermore, assuming engine maintenance is time based and is assumed to constitute half of variable costs, therefore a 25% variable cost credit is also allocated for starting the second engine 5 minutes later.

The climb phase is flown per the Pilot's Operating Manual with Engine Anti-Ice OFF :

- SL to 10,000 ft: 160 KIAS
- 10,000 ft to 15,000 ft: 150 KIAS
- 15,000 ft to 20,000 ft: 140 KIAS
- 20,000 ft to 25,000 ft: IAS = 130 KIAS

The cruise phase was calculated with Intermediate Speed Cruise power at 1,550 RPM as compared to High Speed Cruise power at 1,550 RPM for the actual flight. No maintenance cost credit was taken for operating the engines in cruise at a reduced power setting, although there would be a benefit in terms of reduced engine wear.

Descent was an optimal Continuous Descent Approach (CDA) conducted at 200 KIAS at a rate of -1,500 ft/min from 23,000 ft per the Pilot's Operating Manual from an optimal Top of Descent (TOD) point calculated based on upper winds data.

Finally, single engine taxi-in was employed, in this case the opposite engine e.g. left engine is shutdown 5 minutes prior to the remaining engine. Again, for the 10 minute end of flight ground phase, a 25% fuel burn and a 25% variable cost credit were allocated.

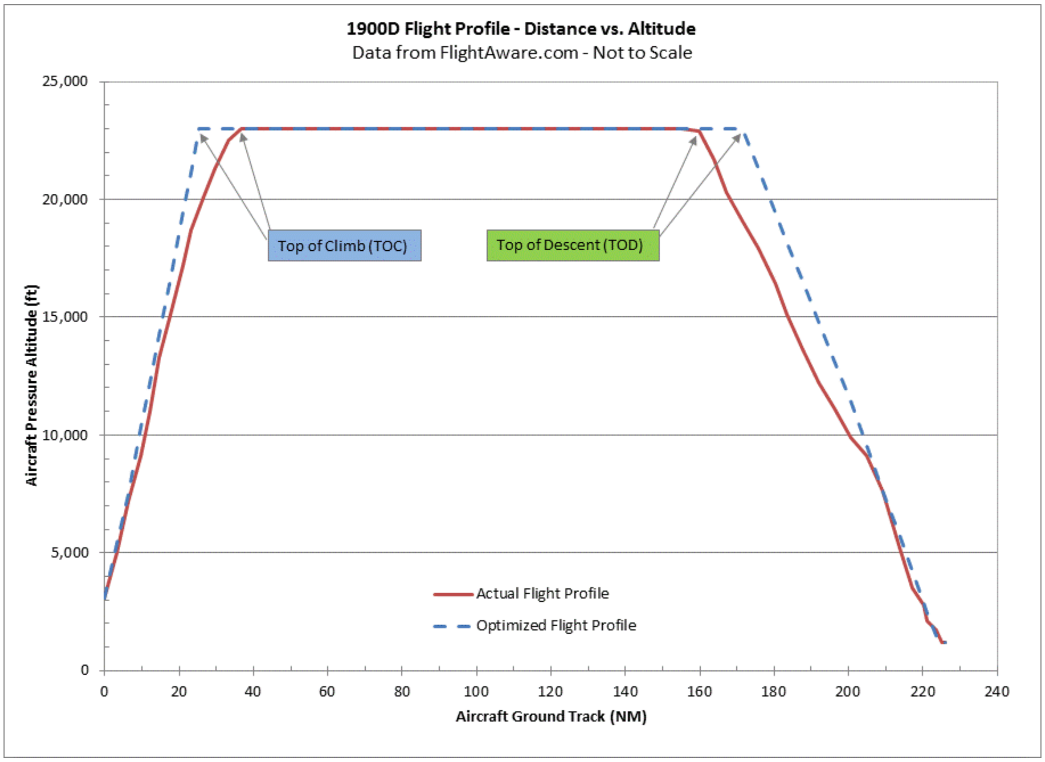

Figure 3 – 1900D Optimized vs. Actual Flight Pressure Altitude Profile

The optimized flight altitude profile is presented in Figure 3 with the ground track identical to Figure 2.

It is worth noting that the Top of Climb (TOC) point for the optimized flight profile occurs 11.5 NM sooner compared to the actual flight and the Top of Descent (TOD) point for the optimized flight profile occurs 16.1 NM later compared to the actual flight. The extended 27.6 NM cruise flight phase is more efficient in regards to fuel burn.

The fuel burn, CO_2 emissions and cost results for the optimized flight profile are presented by flight phase are presented below in Table 2.

1900D Optimized Flight @ 14,000 lb Avg. Weight, 226.1 Track NM, ISA-6C, Anti-Ice OFF

Track per flight data & weather data per NavCanada data. Performance data per Pilot's Operating Manual

Flight Phase	Time (min)	Fuel Burn (lb)	CO_2 Emissions (lb)	Fuel Cost @ $1.70/L ($)	Variable Costs @ $594.66/HR ($)
Start, Single Engine Taxi-Out & Take-Off	10	92.5	289.1	$88.72	$74.33
Climb to 23,000 ft @ IAS per POM Schedule	9	177.0	553.1	$169.76	$89.20
Int. Speed Cruise @ 1550 RPM/IAS = 183 KTS	38.9	454.9	1421.7	$436.33	$385.54
Descent from 23,000 ft @ 200 KTS	14.7	149.0	465.6	$142.91	$145.69
Single Engine Taxi-In & Shut-Down	10	52.5	164.1	$50.35	$74.33
	82.6	925.9	2893.5	$888.07	$769.10
*Variable Costs include maintenance labour, parts & miscellaneous				**Total:**	**$1,657.17**

Table 2 – 1900D Optimized Flight Fuel Burn, CO_2 Emissions and Cost Data

The revised flight time is 62.6 minutes and the block time is 82.6 minutes, both are 2.6 minutes longer than for the actual flight. However, the total fuel burn is estimated at 926 lb and total CO_2 emissions at 2,894 lb, or 118 lb and 370 lb less respectively compared to the actual flight. The fuel savings of 11.3% are amplified due to the sort duration of the flight. Finally, the total cost of the flight is estimated to be $1,657. This represents a savings of $137 or 7.7% less than the actual flight.

The cost savings on a per flight basis compared to the actual baseline flight are dependent on the price of the fuel as shown in Table 3. The price range is representative of the range currently paid at FBOs in Canada as a function of geographic location.

Cost of Fuel ($/L)	Savings per Flight ($)
$1.40	$117.38
$1.70	$137.44
$2.00	$157.49

Table 3 – 1900D Cost Savings of Optimized vs. Typical Flight as a Function of Jet-A Price

Where the results become very interesting is when they are applied fleet-wide over the course of a year as shown in Table 4. Estimates have been made for cost savings, fuel burn savings and CO_2 emissions savings based on the following assumptions:

- Analyzed flight was representative of typical operations
- 10 aircraft fleet of Beechcraft 1900D's
- 8.0 block hours of utilization per day
- 350 days flown per year
- Average price of Jet-A of $1.70/L
- Three different levels of operational implementation: 100%, 75% and 50%

Parameter	100% Implementation	75% Implementation	50% Implementation
Annual Fleet Cost Savings ($)	$2,795,390	$2,096,542	$1,397,695
Annual Fleet Fuel Savings(lb)	2,410,169	1,807,627	1,205,085
Annual Fleet CO_2 Savings (lb)	7,531,525	5,648,644	3,765,763

Table 4 – 1900D Annualized Cost, Fuel and Emissions Savings for Ten Aircraft Fleet

So even if it is only possible to achieve over the course of a year a modest 50% implementation efficiency due to operational constraints, using the aforementioned procedural improvements, the savings amount to almost $1.4 million less in expenditures based on a fuel price of $1.70/L, 1.2 million pounds less fuel burned and almost 3.8 million pounds less CO_2 emitted into the atmosphere based on a fleet of 10 Beechcraft 1900D airliners. The fuel burn and emissions savings would both be in the order of 5.7%.

Those savings are not, however, entirely free in that the 80-minute block time in the example was extended by 2.6 minutes. While various key time-dependent costs were taken into account, flight crew costs were not, as these are more complex and uncertain to estimate. There is also a cost and effort associated with implementing and monitoring more efficient procedures.

Conclusion

By the application of the single engine taxi-out and taxi-in procedure, closely adhering to the climb speed schedule indicated in the Pilot's Operating Manual to reach Top of Climb quickly and efficiently, reducing the cruise power setting slightly from High Speed Power at 1,550 RPM to Intermediate Speed Power at 1,550 RPM and starting the descent at the optimal Top of Descent point, maintaining 200 KIAS and -1500 ft/min, significant fuel burn, emissions and cost savings can be achieved on a short haul turboprop flight with less than a 3 minute increase in block time. Alternatively, reducing dual engine running time on the ground may compensate for reduced cruise speed, resulting in similar block times for flights of short duration.

The proposed procedural modifications to the flight should be feasible to implement normal flight operations. Of course, Air Traffic Control (ATC), traffic, weather and other considerations will impact flight planning and operations, but proper use of best practices will ensure more efficient and ultimately, more profitable aircraft operation without adversely impacting safety or schedule.

Disclaimer: The proposed single engine taxi procedure presented in this article does not replace the procedures contained in the Beechcraft 1900D Airliner Flight Manual (AFM) and the Pilot's Operating Manual (POM), nor in your company's existing Standard Operating Procedures (SOP). This article is presented for information only in regards to potential savings and operational impacts. Please consult with your airframe and powerplant OEM's, as well as with the appropriate authorities when procedural modifications are considered.

About the author: Omer Majeed, P.Eng. is an aerospace engineer practicing in the areas of flight operations optimization, as well as aircraft air systems analysis and design. He has supported flight testing of the Bombardier Challenger 300 and Airbus A380 aircraft, plus holds a Transport Canada CPL and multi-engine rating. He is the owner of Specific Range Solutions Ltd. (www.srs.aero).