AN IN-FLIGHT AID TO NEGOTIATE A MORE EFFICIENT FLIGHT PATH

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Abstract

Rather than flying direct routes from origin to destination, pilots fly prescribed flight paths or "highways in the sky" defined by waypoints along the routes. These waypoints form pre-set "tracks" that can limit operational efficiency for many flights. There are ways to improve operational efficiency within these restrictions by negotiating a more advantageous vertical trajectory. Typically pilots do not negotiate with Air Traffic Control unless it is required to avoid heavy turbulence or weather. This methodology allows pilots to easily and frequently view a "what-if" scenario to assess the impact on fuel usage of a predicted change in flight trajectory. Not only does this method reduce operational cost to the airlines, but it also reduces the impact to the environment as it has the potential to significantly reduce fuel consumption for a given flight. An additional advantage is that this method can be applied to any aircraft currently in service and requires no modifications in the manufacturing process.

1 Business Case

Business case: Airline pilots, usually in close communication with and supported by their respective Airline Operations Center (AOC), are constantly trying to ensure their flights are flown in an economical way. Unfortunately, there is currently no available display the pilots can use to indicate what the change in fuel usage would be if an adjustment to their aircraft's speed or altitude is executed. Today's growing focus on flying as lean a flight track as possible provides the rationale for offering airlines a new in-flight decision support tool we call "LeanTrack." The focus on flying lean tracks is substantiated by Fig. 1, which compares typical fuel costs in the order of 30% to other direct operating costs for a typical commercial jet aircraft—reference 1.

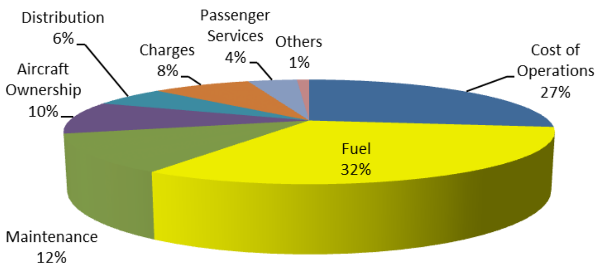

Fig. 1: Typical Airline's Direct Operating Costs -- Source: IATA Chief Economist / MCTF

IATA validated this cost ratio for fuel in Business News dated June 6, 2014. It predicted that fuel would comprise 30% of an airline's operating cost in 2014. The fact that a typical airline's fuel usage is a major cost driver is compelling! A solution seems necessary that would aid airlines to continuously monitor and be able to predict any savings of or additional fuel usage as a consequence of adjusting the aircraft's speed and/or altitude compared to an "ideal" reference trajectory calculated for the flight. The LeanTrack tool will help airlines assess flight trajectory alternatives by:

1. Displaying a predicted change in fuel usage (as compared with the fuel usage of the current trajectory) though "what-if" scenarios for flight trajectory changes
2. Displaying the selected adjustments in speed and/or altitude for "what-if" scenarios.

3. Offering options for use to negotiate with Air Traffic Control (ATC) more efficient flight trajectories, if available, by minutes and hours ahead of executing a change in trajectory

It is possible to seamlessly convey these trajectory options by using currently available technology and by staying within the current airspace operational infrastructure. This level of real-time information is precisely what the LeanTrack invention disclosure accomplishes and is described in detail below.

2. Display Example and a Systems View

Fig. 2 is an example display for flight crews and AOC to evaluate "what-if" scenarios offered by LeanTrack. Since the AOC generates a flight plan that consists of information that includes the speed (which translates into time), altitude and destination (which translate into distance) of the particular flight, LeanTrack uses these parameters in combination with unique airplane data to evaluate "what-if" scenarios. The output from "what-if" calculations display differential gallons of fuel usage if the new flight trajectory is executed for the remaining flight. This is a useful capability to rapidly evaluate, in real time, how negotiations with ATC might be conducted to agree on a better economic route and trajectory.

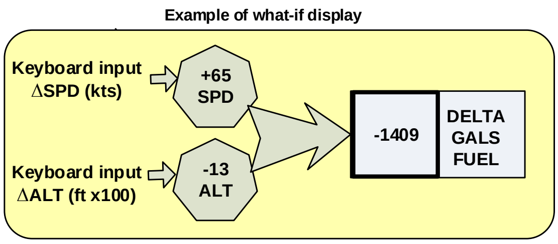

Fig. 2: A possible Display for Flight Crews and AOC to Evaluate What-if Scenarios

Fig. 3 illustrates the interconnection between the front end and back end of the LeanTrack system. The system uses information from a flight plan prepared by an Airline Operational Center (AOC). This information includes, among other data, a reference trajectory for the particular flight and for the specific aircraft while taking into account prevailing environmental conditions en route. LeanTrack uses these data in real time to aid in the decisions about predicted trajectory changes en route. When the flight crew wishes to evaluate the fuel usage change for a new trajectory before it is executed, they can type in a new speed and/or altitude for LeanTrack to calculate the energy comparisons between this desired trajectory and the current trajectory or original flight plan. LeanTrack converts the difference in energies into a display of a predicted change in fuel usage for flying an anticipated trajectory compared to flying the current of reference trajectory; and, LeanTrack displays the inputs that generated this result.

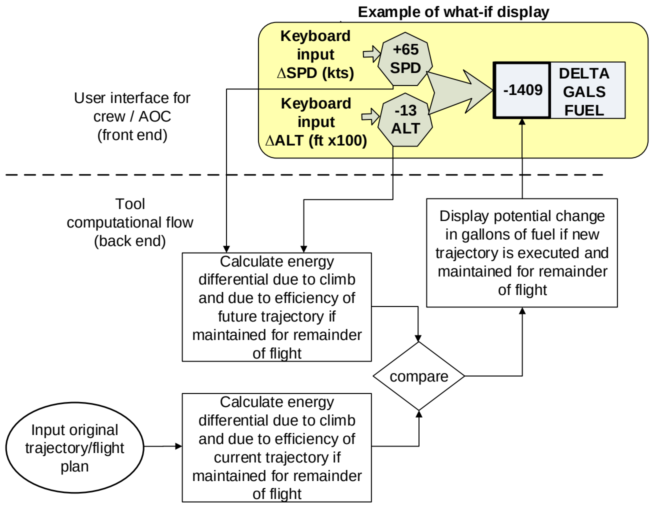

Fig. 3: A Systems View of LeanTrack

3. Method of Simulating the Tool

Simulated Flight Plan

The user defines the following characteristics of the simulated flight plan:

- Departure and destination elevations (starting and ending altitudes)
- Takeoff and landing speeds (starting and ending speeds)
- Departure and arrival time (starting and ending times)
- Climb end time and descent start time
- Optional rate of climb or descent factor

The user can then define a deviation from that simulated flight plan, namely altitude and speed

changes, with the desired time of command execution during the flight.
The tool then uses exponential functions to create a flight trajectory in the form of smooth speed and altitude v. time curves for both the original flight plan and the anticipated deviation from that plan.
Below is an example of a command to descend 1000ft two hours into the flight. Though there is no commanded speed change, the speed curve will adjust slightly to accommodate this anticipated execution of the command.

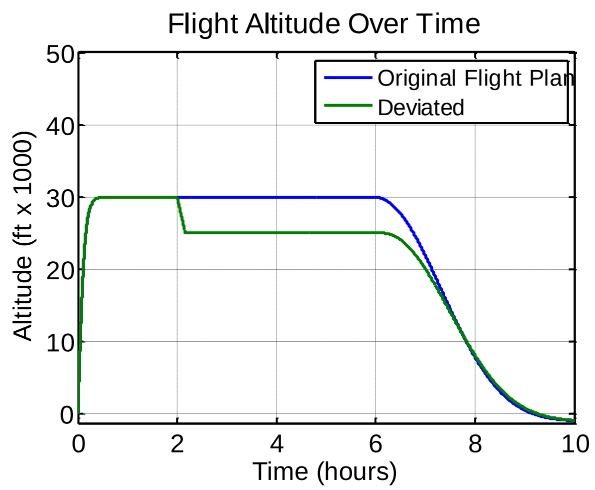

Fig. 4: Simulated Altitude Curves

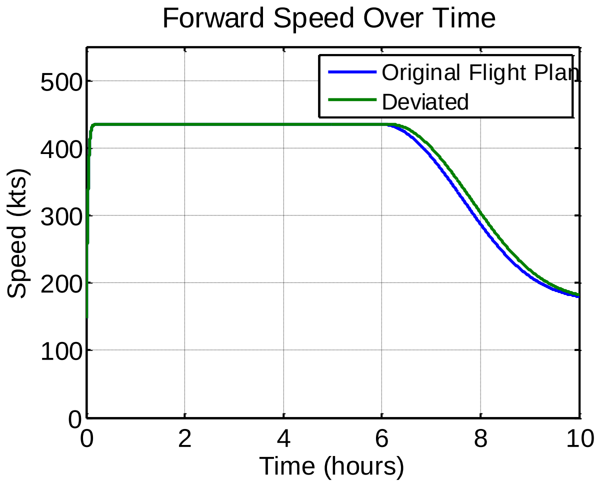

Fig. 5: Simulated Speed Curves

4. Energy Calculations

The simulation will output a value of fuel gained or lost as a result of this anticipated deviation. Carrying forward the example in the previous section, the command offered a **savings** of **1409 gallons** (MATLAB files that generated this value are not included). To arrive at this value, energy usage is calculated for the original and new trajectories by adding up the following components:

1. Excess energy due to climb
2. Excess energy due to the aircraft not flying its "ideal" altitude at each given speed

The two values are then compared to determine fuel savings or increases. Note that the total fuel burn for each trajectory is never calculated—only the differences that a speed and/or altitude deviation causes is calculated from an energy perspective and if the change is maintained for the remainder of the flight.

Excess energy due to climb

One component of excess energy spent is due to the physics of the plane climbing. This energy can be calculated using the generic formula $\int_{t_0}^{t_{end}} F \cdot ds$. The required differential force from cruising to climbing can be represented by excess thrust, or T_{excess} (called F_{ex} in Fig. 6). This quantity is defined by$(Thrust - Drag)$, which would be zero in cruise and nonzero in climb. The simulation assumes the plane will glide when descending and will therefore not require excess thrust when climb angle—not to be confused with angle of attack—is negative.
In the simulation, flight path is pre-defined and therefore climb angle and acceleration vectors are known. Takeoff weight is known, and it is assumed the weight will decrease as fuel is used according to a generic trend. By forming equations of motion, the simulation solves for T_{excess} at each time interval, e.g. as often as once per second. Flight path is known, so displacement is known as well. Excess energy/fuel due to climb is then calculated as $\int_{t_0}^{t_{end}} T_{excess} \cdot ds$.

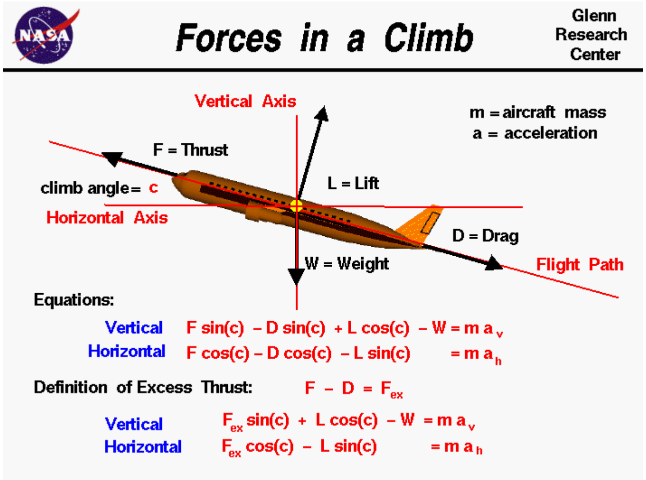

Fig. 6: Forces in a Climb – Source: NASA

Excess energy due to airplane not flying "ideal" efficiency curve

Fig. 7 shows a generic power curve which can be drawn for a particular airplane at each cruise speed. The least power would be required at the most efficient speed for the current altitude, at the minimum of the parabola.

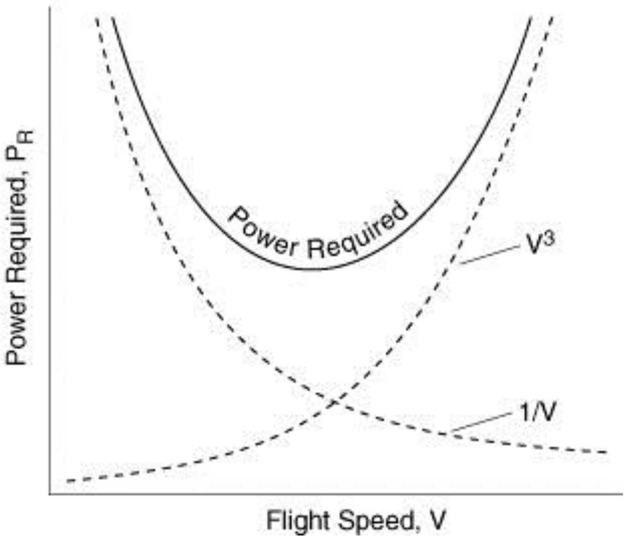

Fig. 7: Typical Airplane Power Curve

For any given altitude, airplane, and flying conditions, there exists a most efficient, theoretically "ideal" speed at which the least amount of fuel is burned. Fig. 7 shows a trend line derived from an airplane power curve over several speeds and applied to the simulation discussed previously.

Fig. 8 is derived from a set of such power curves for different speeds at specific conditions for the airplane in the simulation. The original AOC flight plan at cruise has the airplane flying at 30,000ft and 435 knots, shown on Fig. 8 as a red dot. When the deviation in flight trajectory occurs, in this case descending 5000ft, the plane is actually flying closer to its "ideal" altitude for that speed and weight as shown by the black dot. Thus, less fuel is burned over the remaining course of the flight. Note that fuel savings could also have been achieved by speeding up, or by performing a combination of descent and acceleration. LeanTrack gives pilots visibility of these options. Alternatively, if the plane were to move further away from the "ideal" line in altitude or speed, the simulation would show a fuel cost rather than savings.

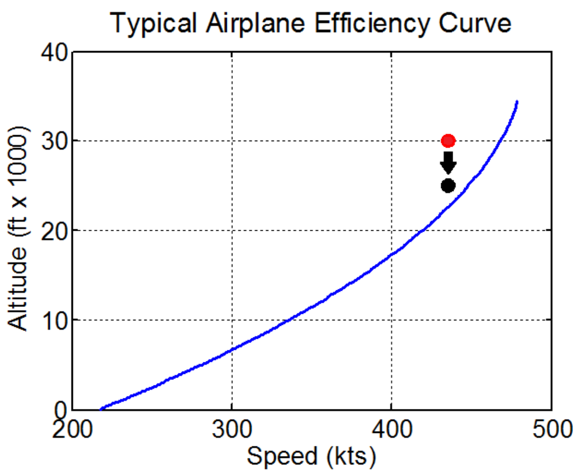

Fig. 8: Typical Airplane Efficiency Curve (derived from the power curve)

Since the simulation has already accounted for energy cost/savings due to climb with equations of motion, it uses this power curve to derive energy cost/savings due to speed changes throughout the flight. For this calculation, the simulation "converts" the altitudes of the original flight plan over time into "ideal" speeds using the curve from Fig. 8. It then uses a curve similar to Fig. 8 to derive power required for the speed differential. Energy due to flying off of the "ideal" curve can then be calculated from power, since $E = \int_{t_o}^{t_{end}} Power \cdot dt$.

The same calculation is replicated for the new flight path and takes this energy factor into account in the total comparison of the two trajectories.

Adding total energy

Total energy is then calculated for each trajectory and compared as follows:

$$Total\ Energy\ Differential\ (Joules) = \left(\int_{t_o}^{t_{end}} T_{excess} \cdot ds + \int_{t_o}^{t_{end}} Power \cdot dt\right)_{deviated} - \left(\int_{t_o}^{t_{end}} T_{excess} \cdot ds + \int_{t_o}^{t_{end}} Power \cdot dt\right)_{original}$$

Joules can be directly converted into gallons of fuel. If the above equation is positive, the deviation will require more fuel, and if negative, will result in a fuel savings.

References

[1] IATA's 9th Maintenance Cost Conference, Chairman's Report, Dublin 11-13.09.2013

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