AVIATION FUEL CONSUMPTION STUDIES - HAL BANGALORE AIRPORT SCENARIO

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Abstract

Air traffic density in India and the world at large is growing fast. The challenging problems encountered are flight delay and increased aviation fuel consumption. The method used for quantifying is by simulation for the selected aerodrome and air space. This paper presents the modeling, simulation and analysis of HAL Bangalore International Airport which has been carried out as part of the feasibility studies towards optimal aviation fuel consumption. Aviation Fuel consumption studies use concepts of minor rescheduling of flight times for ground operations and allowing aircraft to cruise at fuel optimal altitudes for air operations. Results presented in this paper are encouraging as it leads to fuel conservation during ground and air operations.

Keywords: Modeling, Aerodromes, Simulation, Ground and air delay, Aviation fuel consumption, Minor rescheduling, Base of aircraft data

Abbreviations

ATF = Aviation Turbine Fuel
ATC = Air Traffic Control
AAI = Airport Authorities of India
SIMMOD = Modeling and Simulation of Airport
BADA = Base Aircraft Data
TAS = True Air Speed (knots)

Introduction

Air traffic is increasing rapidly in India as well as world. The increase in air traffic causes the increase in consumption of ATF and hence an increase in the cost. The demand for ATF is leading to a shortage of Aviation Turbine Fuel supply and the cost of ATF is escalating. We are already observing that the increase in air traffic is making ATF very expensive. ATF prices become an important expenditure for the airliners. Hence, aircraft fuel consumption becomes a relevant issue for the planning and analysis for aviation operations.

The key parameters that affect the fuel consumption are aircraft design and maintenance procedures. For the existing aircraft, it is possible to conserve fuel by taking care of maintenance procedures. Another important parameter that affects the aircraft fuel consumption is ATC procedures. Aircraft will be waiting near the departure queues for the clearance from ATC especially when there are arrivals. Similarly aircraft will be waiting for ATC clearance for landing. These waiting times of aircraft would result in increased fuel consumption. It is necessary to minimize these waiting times of aircraft for the fuel conservation.

Some strategies for fuel conservation, from the Airlines, Airport Authorities and ATC perspective:

Airliners should consider

• rescheduling the flights
• and flying at optimum cruise altitudes than to fly at lower cruise altitudes for optimal fuel consumption.

All the airliners in India can save fuel by optimising routes and adopting modern navigation procedures.
AAI / ATC should try to minimise the ground waiting times with engines running. An aircraft should be able to depart within a maximum of 10 minutes of taxiing for fuel conservation.

It is expected that the studies on optimal aviation fuel consumption would lead to an improvement of air transport economics. Hence, it has been decided to carry out the feasibility studies for optimal aviation fuel consumption by adopting some of the above mentioned strategies with HAL Bangalore International Airport as an example. Some analysis and results on flight delay, air traffic controller workload pertaining to HAL Bangalore International Airport have already been presented in ref.[1].

This paper presents the feasibility studies carried out towards the fuel conservation, from the perspective of Airports, Airliners and ATC. The feasibility studies presented in this paper correspond to HAL Bangalore International Airport [2] and carried out by modeling of airfield and airspace scenario and simulation with realistic flight schedules. These feasibility studies include minor rescheduling of flight times to reduce waiting times at departure queues for ground operations and allowing the aircraft to fly at fuel optimal altitude levels for reduced fuel consumption for air operations. Since, the typical minor rescheduling duration is around 5 sec -10 sec for most of the cases; this may not alter the total flight duration much. Hence, landing at the destination airports may not be an issue.

In the following section, airfield and airspace modeling of HAL Bangalore International Airport (henceforth referred as HBIA) and simulation with realistic flight schedules is explained.

**Modeling and Simulation Methodology**

The four main functions are: i) Modeling of airfield and airspace structure, ii) Creating a schedule for the air traffic, iii) Simulating airports with air routes connecting them to other airports, and iv) Visualizing the flights by running an animated simulation. The following section describes the methodology of modeling of airfield and airspace scenario and simulation of air traffic using fast-time simulation software SIMMOD PLUS! [3].

The fast-time simulation has a discrete-event stochastic model in the software. It is a gate-to-gate simulation model. The inputs to the fast-time simulation are airfield and airspace models, ATC procedures and the flight schedules. Using the flight schedules, the simulation is carried out using point mass flight simulation to obtain the results as outputs. The study of air traffic generally spans 24 hours each day. It is convenient to have time scaled simulation where the time scale can range from 1 to 100. This enables seeing the reality of one hour happening in one minute or less and hence the term fast-time simulation is used.

**HBIA Simulation Studies**

The realistic flight schedules of HBIA during April 2008 for a busy day (Wednesday) are supplied by 5 and incorporated in the fast time simulation software. The flight operations include regional airlines viz. Air India, Indian Airlines, Deccan, GoAir, Paramount, SpiceJet, Indigo, Kingfisher, Air Sahara (JetLite) for commercial and air cargo purposes as well as international airlines viz. Lufthansa, Emirates, Malaysian Airlines, Singapore Airlines, Thai Airways, British Airways, Gulf Airways, American Airlines and SriLankan Airlines. Traffic scenario is simulated for HBIA with 351 movements including arrivals and departures. Simulation studies have been conducted for the realistic flight schedules and the corresponding results are discussed next.

**Analysis and Results**

Analysis and results presented in this section comprise of the delay studies and studies on optimal aviation fuel consumption.
Delay Studies

Prediction of possible ground delay and airspace delay has been carried out and presented in Table-1. These studies have been carried out for a normal case where the flight schedules are taken as it is and for a case where the concept of minor rescheduling of flight times has been adopted. The minor rescheduling has been carried out for departures only.

From Table-1, it can be seen that average ground delay has been reduced from around 1min to 14sec with the minor rescheduling of flight times. Similarly the air space delays have been reduced from 4min to about 3min.

The average delay is well within the stipulated maximum value of 4-5 minutes [6, 7]. The 4 minute average was chosen because its distribution is such that the maximum delays will not exceed about 20 minutes and some aircraft will in fact have only a few seconds delay. Since the peak air delay is more than 20min, it is necessary to reduce this delay. It is observed that, using the concept of minor rescheduling of flight times, ground delays have been reduced significantly (by 80%) and air delays have been reduced by 50%.

Studies on Optimal Aviation Fuel Consumption

Fuel burn is the total amount of fuel consumed by an aircraft during the course of its flight. Feasibility studies have been carried for aviation fuel conservation with ATC/AAI/Airliners perspective. These studies have been carried out for the Ground operations and Air operations. For the Ground operations, the concept of minor rescheduling of flight times has been used for the reduction of ground waiting times especially at Departure Queue. This concept would help in reducing the ground delays and also reducing the fuel consumption during ground operations. For the Air operations, the concept of allowing the aircraft to fly at higher cruise altitudes based on their performance data for has been used for the reduction in fuel consumption.

The EUROCONTROL Experimental Centre has published aircraft performance data for 91 basic types of aircraft [8]. The screenshot of ground node-link structure for the HBIA. Similarly, Fig.3 gives the screenshot of airspace scenario depicting the air node-link structure. This Base of Aircraft Data was derived from ATC surveillance radar data of actual flight operations acquired for seasonal atmospheric conditions during the summer and winter months and analyzed in terms of a Total Energy Model. It provides characteristic aircraft performance data including typical climb and descent speeds and vertical speeds (climb rates) as well as cruise speeds for operations within the ATC environment.

For turbojet and turbofan engines, fuel flow is a function of two factors, altitude and velocity. General observation from BADA3.6 is that the fuel consumption rates would decrease with higher altitudes (Flight Levels). This can be justified by the fact that, an increase in altitude would result in a decrease in atmospheric parameters like air density, temperature and speed of sound and thereby thrust and TAS. Thrust can be represented in terms of fuel consumption rate by an empirical relationship based on which it has been noticed that with a decrease in thrust, fuel consumption rate also will decrease. As observed from BADA3.6, fuel consumption rate has been defined as a function of speed (TAS) and altitude (Flight Level). The fuel consumption rate of B737 as a function of altitude and speed (TAS in knots) for cruise phase is shown in Fig.4.

From Fig.4, it can be seen that the fuel consumption rate is decreasing significantly for the marked region with

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Before Rescheduling</th>
<th>After Rescheduling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Scenario (En-route separations 10 NM)</td>
<td>4 min 12 sec</td>
<td>2 min 57 sec</td>
</tr>
<tr>
<td></td>
<td>50 min</td>
<td>25 min</td>
</tr>
<tr>
<td></td>
<td>1 min 4 sec</td>
<td>14 sec</td>
</tr>
<tr>
<td></td>
<td>9 min</td>
<td>3 min</td>
</tr>
</tbody>
</table>

Table-1 : Comparison of Air and Ground Delays Before Rescheduling and After Rescheduling
cruise speed 0.78M for FL270 to FL410 i.e. TAS ranging from 418 to 447 knots.

Fuel consumption rates, speed and altitudes for the different phases of a flight (Ascending, Cruise and Descending) are defined for the airspace using BADA3.6 data and data taken from ref.[5]. For airfield scenario, fuel consumption rate and speed information are taken from ref.[5]. SIMMOD Reporter tool of Visual SIMMOD Suite is used to generate Fuel burn reports.

**Ground Operations - Rescheduling of Flights**

Due to arrival-departure separations, aircraft will be waiting at departure queue for ATC clearance. Once the arriving aircraft exits runway and taxies towards parking bay, the aircraft at departure queue will get clearance for take-off. As discussed earlier, the concept of minor rescheduling of flight times has been adopted for ground operations to demonstrate the reduction in waiting times at departure queues and hence reduction in fuel consumption. Out of 351 movements, arrivals are 172 and departures are 179. The minor rescheduling has been carried out for only departures for about 114 cases i.e. ~64% cases. Out of 114 cases, rescheduling duration is less than 6min for 77% cases. For the rest, rescheduling duration ranges from 7min to 15min. Table-2 shows the reduction in total duration for ground operations and fuel consumption. From this Table, it can be seen that the rescheduling duration ranges from 3min to 10min. Cases 1 to 3 correspond to rescheduling durations about 6min.

Case 4 shows the maximum rescheduling duration of about 10 min and also the reduction in fuel consumption by about 50%. For this case, it has been noticed that before rescheduling, ground waiting time is around 588 sec and extra fuel consumption due to this waiting is 410 lb. After minor rescheduling for about 10 minutes, this waiting time has been reduced from 588 sec to 46 sec and the fuel consumption has been reduced from 410 lb to 107 lb. In concise, with rescheduling duration of 10 minutes, total duration for ground operations has been reduced by 10min and total fuel consumption for ground operations have been reduced by 300 lb.

**Air Operations - Sensitivity Studies on Optimal Cruise Altitude**

For air operations, sensitivity studies have been carried out at different cruise altitudes based on their performance data for the chosen aircraft. The following aircraft are chosen for the study.

- B737 and A320 (Medium jet)
- F2TH (Heavy)

For these aircraft, speed definitions and fuel consumption rate definitions for airspace and airfield scenario have been incorporated to the Fuel Burn Reporter of SIMMOD Reporter Tool.

Based on the cruise altitude (Flight Level) taken from Flight Plan, fuel consumption has been obtained using the Fuelburn Reporter. Sensitivity studies have been carried out for domestic and international flights, from the Cruise Altitude taken from the Flight Plan to the altitude limit provided in the BADA3.6 performance data of A320/B737/ATR and F2TH aircraft. The sensitivity study has been explained with an example of B737 in this section. For B737 aircraft, from Fig.4, it can be seen that the cruise altitude limit is FL410. The Flight Plan of Bangalore-Delhi flight is taken from [5]. The cruise altitude is FL270 as read from the Flight Plan. The sensitivity studies are carried out from FL270 to FL410.

The amount of fuel consumption for different cruise altitudes is shown in Table-3. From the study, it can be see that, if the B737 aircraft is allowed to fly at FL410, there

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Before Rescheduling</th>
<th>Rescheduling Duration</th>
<th>After Rescheduling</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Ground Operations Duration and Fuel Consumption</td>
<td></td>
<td>Ground Operations Duration and Fuel Consumption</td>
</tr>
<tr>
<td>1</td>
<td>9.3427 min / 448.5 lb</td>
<td>(6.0833 hr to 6.17 hr ~ 5 min)</td>
<td>6.6 min / 328.5 lb</td>
</tr>
<tr>
<td>2</td>
<td>7 min / 345.8 lb</td>
<td>(6.25 hr to 6.358377 hr ~ 6 min)</td>
<td>5 min / 280 lb</td>
</tr>
<tr>
<td>3</td>
<td>7.6 min / 336 lb</td>
<td>(12.25 hr to 12.3 hr ~ 3 min)</td>
<td>7 min / 325 lb</td>
</tr>
<tr>
<td>4</td>
<td>17 min / 653.6 lb</td>
<td>(9.833 hr to 10.0 hr ~ 10 min)</td>
<td>7 min / 350.5 lb</td>
</tr>
</tbody>
</table>
will be a maximum reduction in the fuel consumption (around 50%).

SIMMOD is 2D software; airspace links can represent air routes. An airspace link defines path between two airspace nodes. These airspace links are defined for different phases of flight like ascending, cruise, descending etc. Flight levels are defined with respect to these airspace nodes. Hence, even if the cruise altitude flight levels are changed for sensitivity studies, the total airspace link distance to be traveled will not change and hence no change in the flight duration. In a practical situation, this is not true. If the cruise altitude flight level is increased, aircraft has to travel more distance and hence more flight duration.

However, for fuel consumption calculations, cruise altitude change is taken into consideration by properly defining fuel consumption rates with respect to the cruise altitude flight levels. This will result in different fuel consumptions. As mentioned earlier, fuel consumption rate data as a function of flight level is taken form BADA3.6.

All these studies are carried out at cruise speed 0.78M as mentioned in BADA3.6 data.

From the above study, it can be concluded that the airliners may be requested to fly at different cruise altitude ranges as shown in Table-4 (based on the performance data of respective aircraft taken from BADA3.6) for optimal fuel consumption during air operations. These are cruise altitude ranges at which fuel consumption rate decreases at a faster rate. The highlighted values indicate the altitude limit of the respective aircraft. Also these cruise altitude ranges would ensure a good vertical separation with respect to different categories of aircraft.

Conclusions

Modeling, Simulation and Analysis of HBIA has been carried out. For the optimal aviation fuel consumption, feasibility studies have been carried out for HBIA with,

- aircraft cruising at fuel optimal altitudes for optimal fuel consumption
- minor rescheduling of the departure times to reduce the ground waiting times with engine/s on (especially at Departure Queue)

From fuel consumption studies, it has observed that by minor rescheduling of flight times, ground waiting times with engine/s have been significantly reduced and thereby the fuel consumption also. It has also been observed that if aircraft are allowed to fly at higher cruise altitudes, fuel consumption will be reduced. The sensitivity studies have been carried out for B737, A320, ATR and F2TH aircraft to recommend altitude range where fuel consumption is less.

Observations from these studies would form an input for Airliners, ATC and AAI to achieve optimal aviation fuel consumption.

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References


4. Jeppesen JeppView Software (Terminal Charts and En-route charts)


Fig.1 HBIA - Runways, Taxiways and Aprons

Fig.2 Screenshot of HBIA Airfield Scenario
Fig. 3 Screenshot of HBIA Airspace Scenario

Fig. 4 Fuel Consumption Rate of B737 as a Function of Altitude and Speed