Flight Trajectory Optimization for Operational Performance Analysis of Jet Passenger Aircraft

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Effective solutions are required to meet the ever increasing demands in the aviation industry. Flight trajectory optimization is considered one of the core technologies to improve the operational performance of conventional air transportation systems. This paper provides an in-depth quantitative evaluation on potential benefits achieved by performing flight trajectory optimization with respect to a series of flight data obtained by secondary surveillance radar data. Dynamic programming is used as the optimization tool to achieve optimal flight trajectories by considering the tradeoff between fuel consumption and flight time. Meteorological data of the Japan Meteorological Agency and the base of aircraft data (BADA) model data of the European Organization for the Safety of Air Navigation are utilized to evaluate the operational performance of both flight data and optimal trajectories. Operational performance results of flight data show a significant variation in the tradeoff between fuel consumption and flight time according to descent speed selection and vectoring in the terminal airspace. Optimal trajectories achieve a considerable reduction of fuel consumption while complying with arrival time constraints by adjusting the top of descent setting and descent speed.

Key Words: Optimization, Surveillance Data, Aircraft Performance, Fuel Consumption, Flight Time

Nomenclature

\[ C_{fuel} \] : fuel cost  
\[ C_{time} \] : time cost  
\[ CI \] : cost index  
\[ D \] : aerodynamic drag  
\[ FF \] : fuel flow  
\[ g \] : gravitational acceleration  
\[ H \] : geopotential altitude  
\[ J \] : performance index  
\[ L/D \] : lift-to-drag ratio  
\[ M \] : Mach number  
\[ MSL \] : mean sea level  
\[ m \] : aircraft mass  
\[ P \] : position of aircraft  
\[ R \] : Earth radius  
\[ r \] : position unit vector  
\[ S \] : wing area  
\[ T \] : engine thrust  
\[ t \] : flight time  
\[ V_{CAS} \] : true airspeed  
\[ W_x \] : zonal wind component  
\[ W_y \] : meridional wind component  
\[ \gamma \] : path angle  
\[ \eta \] : cross range angle  
\[ \theta \] : longitude  
\[ \mu \] : weighting parameter  
\[ \xi \] : downrange angle  
\[ \phi \] : latitude  
\[ \psi \] : azimuth angle  

Subscripts

\( 0 \) : initial  
\( a \) : with respect to airflow  
\( f \) : final  
\( j \) : arbitrary  
\( MO \) : maximum operating  
\( \text{min} \) : minimum  
\( \text{opt} \) : optimal  
\( \text{ref} \) : reference

1. Introduction

In recent years, jet passenger aircraft have become highly advanced in terms of technology, but eventually perform inefficient flight missions due to air traffic congestion which has rapidly increased in the last couple of decades. Departure/Arrival delays at major hub airports...
have a significant impact on the fuel requirements and overall flight planning implemented by ground dispatch computers and onboard flight management systems (FMS). At the same time, continuous rises in fuel prices, environmental concerns and economic instability in the aviation industry demand a futuristic air transportation system (ATS) with effective solutions to provide a reliable, safe and efficient service to customers. Long-term research projects such as NextGen from the United States, SESAR from Europe and CARATS from Japan are dedicated to finding plausible measures to improve the conventional ATS to meet the demands specific to their regions.\(^1\)\(^2\) Though various R&D programs are implemented to cope with the timeline of these projects, potential benefits achieved by these improvements are not yet clearly clarified. Therefore, a quantitative study on operational performance will be of great significance in understanding the critical loopholes in the conventional system which should be given priority and improved in the foreseeable future.

Hence, this paper focuses on the improvement of operational performance in the domestic airspace of Japan from the viewpoint of flight trajectory optimization. In particular, secondary surveillance radar (SSR) data measured at the Chofu ground station of the Electronic Navigation Research Institute (ENRI) is used to evaluate the operational performance of a series of aircraft which are bound for Haneda airport, Tokyo. A quantitative evaluation of flight trajectory optimization is then implemented in an assumed airspace of non-restricted air traffic control (ATC) with respect to corresponding flight cases to discuss the possible potential benefits, mainly regarding fuel consumption and flight time. To perform dynamic optimization, dynamic programming (DP) is applied as the optimization tool while utilizing meteorological data released by the Japan Meteorological Agency (JMA)\(^3\) and aircraft performance data from the base of aircraft data (BADA) model, developed and maintained by the European Organization for the Safety of Air Navigation (Eurocontrol).\(^4\)

The core contents of this paper are described according to the following structure. Section 2 describes the estimation of aircraft information, mainly air data and fuel consumption using SSR data. Utilized models to evaluate the aircraft performance are also introduced here. In section 3, mathematical formulation of flight trajectory optimization and the application of DP are thoroughly discussed. The analyzed results and achieved potential benefits are reviewed in section 4 while discussing the quantitative evaluation conducted for trajectory optimization followed by the conclusions of the study.

2. Estimation of Flight Information from SSR Data

The SSR system provides ground-based surveillance of transponder-fitted aircraft by transmitting a specific low energy signal towards a known target (interrogation) and receiving an analyzed signal from the aircraft’s transponder (reply).\(^6\) The system provides two types of services as follows.\(^7\)

1) Mode A/C: provides range and azimuth surveillance, identification codes and altitude reporting.

2) Mode S (Select): provides all Mode A/C services, selective addressing, specific services and full two-way data link, both uplink and downlink.

ENRI conducts R&D projects of SSR in order to prepare for future deployment of SSR Mode S with the downlink aircraft parameters (DAPs) function in Japan.\(^8\) To perform a quantitative evaluation on operational performance, we acquire position data measured at the experimental SSR Mode S ground station located in ENRI headquarters in Chofu, Tokyo, which has a rotation period of 10 sec with a maximum coverage radius of 250 NM.\(^8\)

In this evaluation, we consider a series of flights performed by several medium-to-heavy types of aircraft which

1) perform arrival flights to Haneda airport, Tokyo, and

2) fly over ARLON fix (35°15’23.5” N 139°58’59.8” E) which is located on the ARLON standard arrival (STAR) route.\(^9\)

Acquired surveillance data are given in Table 1 and are illustrated in Fig. 1. These selected data correspond to surveillance data measured for a day in February 2012.

<table>
<thead>
<tr>
<th>Aircraft type</th>
<th>No. of flights</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-1</td>
<td>20</td>
</tr>
<tr>
<td>A-2</td>
<td>6</td>
</tr>
<tr>
<td>B-1</td>
<td>54</td>
</tr>
<tr>
<td>B-2</td>
<td>46</td>
</tr>
<tr>
<td>B-3</td>
<td>36</td>
</tr>
<tr>
<td>B-4</td>
<td>5</td>
</tr>
</tbody>
</table>

Fig. 1. Arrival trajectories over ARLON fix.

Type A and Type B represent two different aircraft manufacturers, where “1” refers to medium-sized twin-engine aircraft and the rest refer to heavy wide body, twin-engine aircraft.

2.1. Estimation of air data

Initial steps of the evaluation are similar to the analysis conducted to estimate flight trajectories using GPS data measured in an airborne airliner cabin.\(^10\) Air data such as true airspeed (TAS) and air temperature are required to estimate the fuel flow from surveillance data. Inertial speed is estimated from surveillance data and meteorological data is utilized to estimate the required air data. The next subsection introduces the meteorological data used in this analysis.
2.2. Meteorological data

The Japan Meteorological Agency provides a variety of weather data on global and domestic atmospheric conditions. These are known as numerical weather prediction (NWP) models and periodically updated weather data are available online for commercial use. Physical variables mentioned in Table 2 are provided by two main NWP models; namely the global spectral model (GSM) and Mesoscale model (MSM) in a grid point value (GPV) format on a coordinate system defined by longitude, latitude and barometric pressure level. The precision of these data is reviewed by referring to an airline’s onboard flight data. Analyzed results show that the GSM model data are more precise and suitable to be applied in operational performance analysis. Hence, in this study we use data from the GSM for the Japan region and its fundamental properties are given in Table 2.

2.3. Estimation of fuel consumption

The onboard FMS enables the airline companies to operate in a cost-effective way. Along with increasing demands in the industry, airline companies are trying to improve their system and reduce operational cost by any means. The most obvious costs related to a flight are those of fuel and direct operations associated with maintenance and crew. The ability to perform fuel-efficient flights would provide airliners with great advantage in a highly competitive market. Therefore, estimating the fuel usage of an aircraft gives an understanding of its operational performance.

2.4. Aircraft performance model

The BADA aircraft performance model, developed and maintained by Eurocontrol is regarded as a significant asset in evaluating aircraft performance. It includes numerous performance data of a large variety of aircraft. According to the BADA model, fuel flow is a function of engine thrust and TAS where the thrust is evaluated by aerodynamic drag, path angle and vertical acceleration. The BADA model consists of several sub models such as the aerodynamic model, fuel flow model and maximum thrust model which provide useful equations to evaluate each required parameter. It also consists of operational limitations for each aircraft which are applied in this study to sustain the validity of calculated values. The accuracy of this model is confirmed via numerical analysis. Results show that the numerical error of evaluating the fuel consumption is ±5% compared to an airliner’s onboard flight data. By applying this model in both operational performance analysis and trajectory optimization we can neglect the model error.

3. Optimal Trajectory Design

We propose a flight trajectory optimization tool in this section with the objective of discussing the tradeoff between fuel consumption and flight time with respect to estimated flight information in the previous section. A futuristic ATC system is assumed where aircraft are able to perform on optimal flight trajectories until they are bound to STAR procedures. The proposed flight trajectory optimization model is briefly introduced here. A detailed explanation of this tool is given in previous studies.

3.1. Mathematical formulation

The usual 6DOF motion of an aircraft is simplified by point mass approximations and omitting the state variables which represent the aircraft’s attitude to enable the application of DP. Equations of motion introduced in Eqs. (1) - (4) are solved with respect to the state variables of \( \phi, \theta, H \) and \( V_{TAS} \). The control variables are given as \( \gamma_a, \psi_a \) and \( T \) by considering the aircraft’s 3D-translational motion which is illustrated on Fig. 2.

\[
\frac{d\phi}{dt} = \frac{1}{R_0 + H \cos \phi} \left( V_{TAS} \cos \gamma_a \sin \gamma_a + W_a \right) \tag{1}
\]

\[
\frac{d\theta}{dt} = \frac{1}{R_0 + H} \left( V_{TAS} \cos \gamma_a \cos \psi_a + W_a \right) \tag{2}
\]

\[
\frac{dH}{dt} = V_{TAS} \sin \gamma_a \tag{3}
\]

\[
m \frac{dV_a}{dt} \cos(\gamma_a - \gamma) \cos(\psi_a - \psi) = T - D - mg \sin \gamma_a \tag{4}
\]
3.2. Dynamic programming (DP) approach

A dynamic optimization is required to achieve a fuel-minimum or a fixed arrival time flight trajectory by considering the effect of weather conditions on an assumed steady or quasi-steady flight. Therefore, we apply the dynamic programming method in our optimization analysis. Trajectory optimization has been extensively studied in the past few decades as an optimal control problem and dynamic programming has been proved as an effective tool for trajectory optimization for its unique qualities which are thoroughly discussed in our recent studies.

As shown in Fig. 3, state variables $\phi$ and $\theta$ are transformed to $\xi$ and $\eta$ in the polar coordinate system to provide a feasible calculation platform for the proposed optimization model. The independent variable $\xi$ and state variables $\eta$, $H$ and $V_{CAS}$ are discretized by an equidistant orthogonal grid system. The downrange angle, which increases monotonously with time, depicts the progress along the great circle route (GCR). The cross range angle defines the lateral deviation from GCR.

The Boeing company has proposed a definition for cost index $CI$ as the ratio between $C_{time}$ and $C_{fuel}$ with their units given as dollars/hour and cents/lb., respectively. In this study, the performance index is defined in Eq. (5) for the optimal selection of cost index for airline fleet hub operations by considering the tradeoff between fuel consumption and flight time.

\[
\text{Minimize } J = \int_{t_0}^{t_f} \left( C_{fuel} \cdot FF(t) + C_{time} \right) \, dt \tag{5}
\]

To simplify the analytical calculations, the definition of performance index in Eq. (5) is rewritten as Eq. (6) by applying $\mu$ as the weighting parameter for flight time.

\[
\text{Minimize } J = \int_{t_0}^{t_f} \left( FF(t) + \mu \right) \, dt \tag{6}
\]

The global optimum is obtained by solving the combinatorial optimization problem for all transitions between grid points in the defined state space grid. In this study, both fuel-minimum optimal trajectories ($\mu = 0$) and optimal trajectories with fixed arrival time are subject to comparisons with results obtained in section 2 to understand the potential benefits achieved. Techniques are introduced to improve the analytical platform by reducing the calculation time and avoid the disadvantages of using the logic of DP.

4. Analytical Results

In this section, a review of results obtained from a quantitative evaluation on conventional operational performance discussed in section 2 is followed by a quantitative evaluation on trajectory optimization for corresponding flight cases.

4.1. Conventional operational performance

The evaluation method in section 2 is applied to the flight cases given in Table 1. Operational performance results of Type B-3 aircraft are shown in Figs. 4 - 7 as the representative examples. Each color represents a specific flight case measured by the surveillance system. Initial and final points of each flight case are derived as the first measured data point of that specific flight case and the closest data point to ARLON fix, respectively.

As illustrated in Figs. 4 and 5, it is understood that most aircraft perform descent flights with high speeds above 10,000 [ft]. We could also understand that during descent operations, the speed schedule of aircraft flying above 32,000 [ft] is controlled according to the Mach number and the speed schedule of aircraft flying below 30,000 [ft] is controlled according to the calibrated airspeed (CAS). This transition altitude range is usually defined as the crossover altitude. Furthermore, $V_{CAS}$ is reduced to approximately 250 [kt] due to the restriction which compel aircraft to operate at an indicated airspeed less than 250 [kt] at 10,000 [ft] MSL or below in the approach control area according to the Civil Aeronautics Law.

Due to high descent speeds, aircraft do not achieve high lift-to-drag ratio values as shown in Fig. 6. Results in Fig. 7 confirm the trend that selected descent airspeed at most flight cases is not optimal.

A typical descent flight headed to Haneda airport is extracted and a detailed description is given with results depicted in Figs. 8 and 9. The flight begins its descent phase at 39,000 [ft] with a measured total flight time of 1,253 [sec] along a flight range of approximately 325 [km]. Due to strong tailwinds (downrange wind), the aircraft gains a high ground speed value at its initial descent phase. The Mach controlled flight mode with idle thrust settings results in an increase in CAS until the aircraft transits to CAS controlled flight mode at approximately 31,000 [ft].

Furthermore, an increase in the TAS component occurs with the decrease in the tailwind component. Hence, the aircraft pitches upwards in order to maintain the flight within speed limits. Idle thrust shows a value of approximately zero along the descent phase and records negative thrust markings at approximately 10,000 [ft]. This could be considered as applying speed brakes to maintain the aircraft within its speed constraints (less than 250 [kt]) before entering the terminal airspace and to perform a shortcut from the predefined route entered in the FMS. Lift-to-drag ratio varies in a broad range due to various flight maneuvers and the fuel flow results show a considerable amount of fuel use during the flight as a
result of current flying procedures.

Next, we propose a futuristic ATS where pilots are allowed to perform optimal flight trajectories up to the initial fix on STAR route as they are bound to ATC vectoring and other approaching restrictions afterwards. In order to achieve realistic optimal trajectories, we have provided the proposed model with the following calculation conditions which are extracted from the BADA model. Representative results are used to discuss the quantitative evaluation implemented for Type B-3 aircraft and understand the achieved benefits.

4.2. Calculation conditions

The state space grid, applied in the optimization tool and its grid resolution for each flight case are defined in Table 3. The discretization is selected to provide the aircraft with a plausible physical motion by considering its total energy transition. As previously mentioned, calculation techniques are applied to reduce the calculation time.

<table>
<thead>
<tr>
<th>State space grid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downrange</td>
</tr>
<tr>
<td>Altitude</td>
</tr>
<tr>
<td>Calibrated airspeed</td>
</tr>
<tr>
<td>Cross range</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Grid resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δζ</td>
</tr>
<tr>
<td>Δζ</td>
</tr>
<tr>
<td>ΔH</td>
</tr>
<tr>
<td>ΔV_{CAS}</td>
</tr>
</tbody>
</table>
Additionally, in order to perform a fair comparison between conventional and proposed optimal flight procedures, the initial and terminal points are made identical along with initial and terminal 3D position and calibrated airspeed. Furthermore, SSR data do not include the aircraft mass. Hence, we utilize the reference mass provided by the BADA model as the initial mass for each specific aircraft. Only the operational limitations for Type B-3 aircraft are shown here.

Fig. 10. Flight time versus fuel comparison (fuel-minimum).

Fig. 11. Flight time versus flight range (fuel-minimum).

In the next subsection, we discuss the potential benefits obtained by performing a quantitative evaluation where the optimal flight trajectories are generated with respect to type B-3 aircraft flight data.

### 4.3. Performance optimization with free arrival time

First, we allow the aircraft to fly in a fuel-optimal trajectory with no arrival time restrictions. Results from the quantitative evaluation for Type B-3 aircraft are illustrated in Figs. 10 and 11. From Fig. 10, it is clear that in most cases a reduction of flight time in the order of 100 seconds can be achieved along with a reduction of fuel consumption in the order of 100 kilograms for all flight cases. From Fig. 11 it is also understood that the reduction of flight time is relatively smaller compared to the reduction of flight range. The gradient of Fig. 11 depicts that, if the flight range is identical for both reference and optimal flight cases, the optimal flight would perform approximately five minutes longer than its corresponding reference flight. The aspects of flight performance for fuel-minimum optimal trajectories are discussed by illustrating the results of a representative example. The results for main variables of both surveillance data flight (refers to as reference) and optimal flight (refers to as optimal) trajectories are compared in Figs. 12 - 20. All figures are plotted with respect to flight time. Upper row figures represent results for flight route, flight altitude and calibrated airspeed. Middle row figures represent fuel usage, fuel flow and lift-to-drag ratio. Bottom row figures are the true airspeed, applied engine thrust and flight range. This is a relatively long and an easy-to-compare flight case from the fuel consumption point of view, as no excessive flight range is consumed in the optimal flight as shown in Fig. 12. According to the results provided in Table 4, fuel consumption is reduced in spite of performing at a longer flight time. This is due to the difference of top of descent (TOD) setting and the selection of airspeed at descent. Optimal flight begins descending from the initial point with minimum thrust and has achieved a long flight range by choosing an airspeed which provides a high lift-to-drag ratio. This also decreases the cruise flight range which requires a high amount of thrust. As the initial point is fixed according to the reference flight, the latter part of optimal flight is adjusted by increasing the flight speed and decreasing the lift-to-drag ratio to correspond with the terminal point of the reference flight. We can assume that the optimal flight would set the TOD earlier if the reference flight was recorded for a longer period of time including a longer cruise flight phase. Furthermore, as depicted in Fig. 19, the reference flight results reveal negative thrust markings which could be considered as using speed brakes during the descent. The reason for optimal flight over a large flight range with minimum thrust is the existence of strong tailwinds.

### 4.4. Performance optimization with fixed arrival time

Next, we provide the optimization model with an arrival time constraint and study how the optimized results would alter against the free arrival time results we obtained in the previous subsection. The same representative flight case discussed earlier is subjected to examination and the obtained results are depicted in Figs. 21 - 29. Referring to the numerical results given in Table 5 and comparing them with results in Table 4, an increase in fuel consumption occurs in accordance with decreasing the flight time. Flight time is reduced according to the time constraint provided in the model. Compared to the fuel-minimum optimal flight, the flight time has to be reduced in order to deal with the constraints. Hence, the optimal flight performs a cruise phase to maintain a safe margin to reduce the flight time. Therefore, excessive fuel
Table 4. Analytical results for state parameters with fuel-minimum trajectory optimization.

<table>
<thead>
<tr>
<th></th>
<th>Reference flight (A)</th>
<th>Optimal flight (B)</th>
<th>B-A</th>
<th>(B-A)×100/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flight time [sec]</td>
<td>1,464</td>
<td>1,677</td>
<td>213</td>
<td>14.51%</td>
</tr>
<tr>
<td>Fuel consumption [kg]</td>
<td>1,147.2</td>
<td>620.13</td>
<td>-527.07</td>
<td>-45.94%</td>
</tr>
<tr>
<td>Flight range [m]</td>
<td>365,790</td>
<td>356,512</td>
<td>-9,278</td>
<td>-2.54%</td>
</tr>
</tbody>
</table>

Fig. 12. Flight route.
Fig. 13. Flight altitude.
Fig. 14. Calibrated airspeed.
Fig. 15. Fuel consumption.
Fig. 16. Fuel flow.
Fig. 17. Lift-to-drag ratio.
Fig. 18. True airspeed.
Fig. 19. Engine thrust.
Fig. 20. Flight range.

Fig. 21. Flight route.
Fig. 22. Flight altitude.
Fig. 23. Calibrated airspeed.
Fig. 24. Fuel consumption.
Fig. 25. Fuel flow.
Fig. 26. Lift-to-drag ratio.
consumption occurs accordingly with the high amount of thrust used in the phase. Selection of relatively high airspeed during the latter part of flight is also necessary to satisfy the constraint conditions while conserving the total energy of the aircraft. This results in a lower lift-to-drag ratio compared to the latter part of fuel-minimum optimal flight. Furthermore, the optimal flight performs along the GCR to minimize the flight time. This is due to the existence of strong tailwinds without any wind shear along the direction normal to the direction of flight. We can assume that if the wind shear did exist, the optimal flight would use its advantage by performing a lateral deviation from GCR. The weighting parameter is applied as $\mu = 1.34$ in this flight case. It could also be considered that providing the model with negative $\mu$ value, we could extend the flight time with a tradeoff of additional consumption of fuel.

Results in Fig. 30 reveal the tradeoff between flight time and fuel consumption obtained from the quantitative evaluation for trajectory optimization with fixed arrival time for Type B-3 aircraft. Compared to the results in Fig. 10, we could understand that an overall increase of fuel consumption occurs while satisfying the boundary constraints (fixed arrival time for each flight case) provided in the model. Optimal results with negative weighting parameters cause more fuel consumption due to the additional flying time period compared to the corresponding fuel-minimum optimal flight. Optimal results with positive weighting parameters also cause more fuel consumption with the selection of high cruise and descent speeds as the aircraft tends to arrive at the destination earlier than its corresponding fuel-minimum optimal flight. These results confirm the theory behind the tradeoff between fuel consumption and flight time which has been a topic of significant interest since jet passenger transportation was introduced to the aviation industry.\textsuperscript{12, 19-22}

5. Conclusions

In this study, we reviewed the effect of flight trajectory optimization on operational performance analysis of jet passenger aircraft by performing a thorough quantitative evaluation. The conventional operational performance was evaluated by a series of flight data which were acquired as SSR data. From the obtained results, we could understand that conventional flight operations are planned according to various ATC constraints, and therefore, modern highly advanced aircraft are not capable of performing efficient flight missions.

A new set of flight procedures were assumed to achieve the maximum operational performance of aircraft and generate fuel-minimum optimal trajectories using the proposed model along with the understanding of utilized models’ validity. Fuel minimum optimal trajectories acquire the following strategies to reduce fuel consumption with the tradeoff of longer flight time.

1. Early setting of TOD.
2. Selection of low descent speed.

In order to achieve more plausible solutions corresponding to conventional flight procedures, a fixed arrival time constraint was provided in the model and the alternative strategies used in reducing the fuel reduction were reviewed while satisfying the applied constraints. From the obtained results, we could understand that the tradeoff between flight time and fuel consumption is a major factor from the operational performance point of view and the proposed model is very capable of performing fuel-efficient optimal trajectories while
satisfying the provided constraints. This study focused on a designated partial airspace of Japan because the SSR ground station has its own coverage area. From our previous studies, we could understand that 3 - 20% of total fuel consumption reduction could be achieved with respect to a series of flight data based on several main domestic flight routes.\textsuperscript{14} \textsuperscript{23} We could also conclude that if we could acquire the SSR surveillance data covering the national airspace and expand this quantitative evaluation, a full study on the operational performance and potential benefits from the proposed model could be evaluated. Furthermore, we could conclude that flight trajectory optimization with fixed arrival time could be a plausible solution to implement concepts such as calculated fixed departure time (CFDT) applications.\textsuperscript{20} By providing arrival time not only for arrival at airport, but also at specified waypoints, we could extend this study to perform an overall optimization which would greatly contribute towards a futuristic ATS system and also towards the development of CARATS to achieve its primary goals.

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