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Abstract

A quantitative model is under development to assess the safety and efficiency of commercial aircraft operations under the Free Flight Program proposed for air traffic control for the US National Airspace System. The major objective of the Free Flight Program is to accommodate the dramatic growth anticipated in air traffic in the US. However, the potential impacts upon aircraft safety from implementing the Program have not been fully explored and evaluated. The model is directed at assessing aircraft operations at high altitude over the continental US airspace since this action is the initial step for Free Flight. Sequential steps with analysis, assessment, evaluation, and iteration will be required to satisfactorily accomplish the complete transition of US commercial aircraft traffic operations.

1 Introduction

Because of the steady growth of US air traffic, the Federal Aviation Administration (FAA) has proposed a Free Flight Program [1] to increase the air traffic capacity and flexibility of the US National Airspace System (NAS). The Free Flight Program concept is a bold innovation, which essentially allows commercial aircraft crews to set their own course and speed from aircraft departure to arrival. Implementing the Free Flight Program will require the development of new technology and result in major organizational and operational changes in the NAS. This paper presents the current air traffic control situation, a description of the Free Flight Program, and the development of a model for assessing risks of high altitude commercial aircraft operations under the Free Flight Program [2].

2 Background

The rapid rise of commercial air traffic in the United States has prompted the U.S. FAA to propose a novel program called "Free Flight" to accommodate future commercial air traffic safely and efficiently for the foreseeable future. In the Free Flight concept, pilots would be free to choose their own altitude and route from departure to arrival without the intervention or guidance of central traffic authority. The central traffic authorities, be they the Air Traffic Control Towers (ATCTs), the Terminal Radar Approach Controls (TRACONs), or the Air Route Traffic Control Centers (ARTCCs) would act as traffic monitors and would intervene only if flight safety was compromised. In its broadest form, Free Flight is defined as any move to remove restrictions on any air traffic flow. This would include all categories of aviation, i.e., air carriers, air taxis, general and military, in virtually all classes

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of airspace. However, the U.S. NAS in its present state is not configured to fully implement Free Flight. Many studies must be performed and tools developed and incorporated in the U.S. NAS in order to implement Free Flight to its fullest potential. This time period between the present U.S. NAS and the full implementation of Free Flight can be considered a transition period when appropriate air traffic tools will be developed and incorporated into the U.S. air traffic control system. Undoubtedly, many changes will occur in the process of controlling air traffic. Some of these changes will be very significant and could have a profound effect on safety and efficiency of U.S. air traffic.

3 Current US Traffic Control Situation

Currently, the US NAS is organized into three major components. Beginning with departure from the airport, the first component are the ATCTs which are located at the major airports and control air traffic from the runway out to 8 km to 32 km from the runway depending upon local topography, air traffic density and patterns and other considerations. The busiest US airports, of which there are 32, are surrounded by Class B airspace. Airports with less air traffic are defined as Class C airspace. The second component of the NAS are the TRACONs currently numbered at 28. These facilities are often collocated with the ATCTs but are separate facilities and control air traffic from 8 to 80 km or more from the runway depending upon local topography, air traffic and other considerations. The third component of the NAS are the ARTCCs currently numbered at 20 in the Continental US. These major NAS components control all air traffic in Class A airspace which consists of all airspace from 5.5 km to 13.7 km. The ARTCCs also control all Instrument Flight Rule (IFR) air traffic below 5.5 km as required and some Visual Flight Rule (VFR) air traffic as necessary.

The operations of commercial aircraft in the high altitude airspace which is essentially Class A airspace are the focus of this study. While general aviation and military aviation represent important components of high altitude air traffic, they are not considered here. Expanded models will include this traffic component later. The airspace controlled by the ARTCCs is not uniform and air traffic settings and flight activities vary greatly between ARTCCs. Important factors affecting the air traffic control include current and changing spatial and temporal traffic flow patterns between ARTCCs, types and characteristics of aircraft operating within the NAS, navigational features and protocols between ARTCCs such as administrative restrictions [e.g., international borders, restricted flight zones, Military Operation Areas (MOAs), etc.] and typographical, spatial, and temporal meteorological conditions prevailing at high altitude.

To summarize as of 1997, the U.S. National Airspace System consists of the following:
__20 Air Route Traffic Control Centers (ARTCCs)
__28 Terminal Radar Approach Controls (TRACONs)
__32 Class B Airspace's (formerly Terminal Control Areas or TCAs)
__Over 100 Class C Airspaces (formerly Airport Radar Service Areas or ARSAs)

The air traffic settings and flight activities currently vary greatly from center to center. Important factors affecting ATC include the following:
__Current and changing spatial and temporal traffic flow patterns between ARTCCs
__Types and characteristics of aircraft operating within NAS
__Navigational features and protocols between ARTCCs such as administrative restrictions, i.e., international borders, restricted flight zones, MOAs, etc.
__Topographical, spatial, and temporal meteorological conditions at high altitude

ATC control policy for the Free Flight Program is anticipated to allow increasing discretion within ARTCC airspace as individual aircraft and airlines select their own preferred routing. This trend will continue as the Free Flight Program unfolds and national air traffic increases if acceptable levels of aircraft safety can be maintained.

Specific, quantitative models which address the site specific critical factors affecting ATC are desirable and essential to accurately portray and quantitatively evaluate the traffic situation in sufficient detail to account for the effects and consequences arising from implementing the Free Flight Program.

ARTCCs are the central authority for issuing Instrument Flight Rules (IFR) clearances, and provide nationwide monitoring of each IFR flight in Class A Airspace for all airspace over the Continental U.S. from 18,000 feet Mean Sea Level (MSL) to 60,000 feet MSL. This paper develops a model to estimate the number of potential conflicts, which may occur in Class A airspace in the Free Flight Program.

4 The Free Flight Program

The Free Flight Program has been defined as the safe and effective flight operating capability under IFR in which aircrews have the freedom to select their flight path and speed in real time. Any activity which removes flight restrictions represents a move toward "free flight". The goal of free flight is not only to optimize the system for maximum capacity but also to open the system to permit aircrews to self-optimize their flight in terms of time, fuel efficiency, elevation, and flight path. Air traffic restrictions would be limited in duration and degree and would only be employed to ensure separation and safety of the flight and to accommodate to airport capacity and prevent unauthorized flight through restricted airspace.

The Free Flight Program has been proposed to accommodate to increasing NAS capacity requirements, permit more flight plan discretion and maintain or even enhance aircraft safety. To accomplish these goals will require the development of advanced technology and organizational changes and improvements in the NAS. These changes will be implemented as the technology is developed and qualified. However, rapid and unproved implementation of Free Flight could be disruptive of the NAS and prove inefficient and even unsafe. Initially the FAA will explore User Preferred Aircraft Routing above a certain altitude, which is essentially the Free Flight Concept for aircraft operations from about 10 km to 13.7 km.

5 Risk Assessment Model Development for Free Flight in Class A Airspace

5.1 Theory

Let Pi(x,y,z,t) be the probability density function for the ith airborne aircraft to be at position x, y, z at time t. The function Pi is a real, bounded, nonnegative function for all values of space and time. Since the aircraft is airborne the integral of the probability density function over all space and time must be unity.

$$\int_{\text{all } x,y,z,t} Pi(x,y,z,t)\, dxdydzdt = 1 \qquad (1)$$

Now the probability that two aircraft Pi and Pj are within the airspace volume dxdydz during the time increment dt is given by

$$Pi(x,y,z,t)\; Pj(x,y,z,t)\; dxdydzdt$$

The Interference probability Iij for these two aircraft is then given by

$$I_{ij} = \int_{\text{all } x,y,z,t} P_i(x,y,z,t)\, P_j(x,y,z,t)\, dx\,dy\,dz\,dt \qquad (2)$$

Now if the interference zone is defined as follows for the ith and jth aircraft as the following impulse (delta) functions

$$P_i(x,y,z,t) = \text{delta}\,(x-x_i,\ y-y_i,\ z-z_i,\ t-t_i)$$
$$P_j(x,y,z,t) = \text{delta}\,(x-x_j,\ y-y_j,\ z-z_j,\ t-t_j)$$

then we can express equation (2) as follows

$$I_{ij} = \Delta x_{ij}\, \Delta y_{ij}\, \Delta z_{ij}\, \Delta t_{ij} = \Delta V_{ij}\, \Delta t_{ij} = \begin{cases} 1 & \text{if } \Delta x_i \_ \Delta x_j, \Delta y_i \_ \Delta y_j, \Delta z_i \_ \Delta z_j, \Delta t_i \_ \Delta t_j \\ 0 & \text{otherwise} \end{cases}$$

where

$\Delta x_{ij} = \Delta x_i \ \Delta x_j$ with similar definitions for Δy_{ij}, Δz_{ij}, Δt_{ij}

The total number of interferences, IT, arising from all airborne aircraft interactions is given by summing over all intersecting flight paths as follows

$$IT = \sum_{\text{all } i,j} I_{ij} \qquad (3)$$

The collision zone $\Delta V_{ij}\ \Delta t_{ij}$ is defined as that high altitude, temporal airspace cylindrical volume (nominally 150 m radially in the horizontal plane and 100 m vertically) in which intercepting aircraft would likely experience damage from physical contact or air or engine turbulence sufficient to impair the air worthiness of at least one of the aircraft. The model can be employed to project the number and location of both interference and collision zone occurrences and compare these projections to existing data for assessment of risk levels and validation with operational data.

5.2 Model

The model under development for studying Free Flight operations at high altitude will use a Geographical Information System (GIS) to map the major airports in the continental US. High altitude flight operations are defined as aircraft operations at 5.5 km to 13.7 km altitude. The model assumes that aircraft flight paths at high altitude will be along the great circle connecting the departure and arrival hub for the flight. Obviously, variations from the nominal flight path may occur because of weather and navigational changes, emergency operations, and other factors. Initially the major 100 departure and arrival hubs or nodes will be identified and flight paths or links drawn on the GIS map of the continental US. Current (1995) data from the FAA shows about 22,000 commercial departures per day in the US. Chicago O'Hare (ORD), Dallas/Ft Worth (DFW) and Atlanta Hartsfield (ATL) average about 1000 departures daily. Los Angles (LAX) has about 650 daily departures and all other major airport hubs are below 500 daily departures. However, this air traffic volume is expected to increase significantly in the future.

Risk for this model is defined as potential conflicts between aircraft in the high altitude airspace. Two types of conflicts are defined and modeled [3]. Alert conflicts are the intersection of two or more flight paths in the high altitude horizontal alert plane for about 2 minutes of horizontal aircraft travel within a specified vertical zone. The nominal radius of the horizontal alert plane may be varied to test various alert zones and their effectiveness. Collision conflicts are the intersection of two or more flight paths in the high altitude horizontal alert plane within 5 seconds or less at speeds typically flown at high altitude. Such collision conflicts have the potential for midair collision, loss of aircraft airworthiness, or may require violent evasive maneuver to avoid such damage.

The model assumes that the flight path of high altitude commercial aircraft is distributed horizontally in a normal distribution for the flight path heading and is log normal in elevation since aircraft are usually operated at the lowest practical or allowable altitude to conserve fuel. However, this option is often altered by the flight crew to avoid air turbulence, minimize noise, or meet other navigational requirements. The temporal flight path distribution is lognormal with the distribution mean set as the scheduled hub departure time.

The model will then determine the event of an aircraft being within an interference zone which is defined as the intersection of two or more flight paths in the high altitude horizontal plane within a specified vertical zone. The model employs an interference zone defined as $\leq$ 3 minutes of horizontal aircraft travel at high altitude (approximately 20 km radially from the aircraft) and 300 m above and below the aircraft (600 m total vertical zone)

6 High Altitude Free Flight Risk Assessment

To initially test and assess the model, two intersecting high altitude flight paths which could exhibit aircraft interferences were selected. The flight paths and major carriers involved were the flight path between Atlanta and Salt Lake for Delta Airlines and the flight path between Chicago and Dallas for American Airlines. Departure time data was extracted from current published flight schedules for each respective airline, and a 15 minute time period for taxiing, takeoff, and accession of flight altitude was assumed for each flight. Imposition of the model for determining interferences given in Section 5 above to determine potential interferences as specified yielded the following results_2 interferences within a 1 minute flight path (13.4 km diameter interference zone)
_4 interferences within a 2 minute flight path (26.8 km diameter interference zone)
_3 interferences within a 3 minute flight path (40.2 km diameter interference zone)

Thus, a total of 9 interference occurrences was determined for the current air traffic schedules published by these two carriers. No consideration was made for altitude differences within the interference zone which would undoubtedly reduce the number of actual aircraft interferences. Nevertheless, it is apparent that the occurrence of potential interferences exists for even two intersecting flight paths along high traffic routes within the US. Furthermore, when the total number of interferences arising from multiple intersections of numerous high altitude flight paths that exist within the US are assessed, the number will be large and demand that concern and consideration for potential high altitude collisions be recognized. This concern will increase as Free Flight is implemented and air traffic increases.

7 Summary and Conclusions

A quantitative model of aircraft traffic over the continental US is being developed to study and evaluate the potential risks of high altitude aircraft collisions as the US NAS Free Flight Program is implemented. The model provides the ability to quantitatively compare the current levels of safety and capacity of the National Airspace with that level of safety and increased capacity anticipated with the Free Flight Program.

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