Risk-capacity Tradeoff Analysis of an En-route Corridor Model

Bojia Ye, Minghua Hu
College of Civil Aviation,
Nanjing University of Aeronautics and Astronautics
Nanjing, China
yebojia2010@gmail.com

John Shortle
Center for Air Transportation Systems Research
George Mason University
Fairfax, U.S.A
jshortle@gmu.edu

Abstract**—*A corridor is one of the new classes of airspace introduced with Next Generation Air Transportation System (NextGen). A well-designed corridor may reduce the airspace complexity, increase airspace capacity and decrease controller workload. This paper develops a computer simulation model for constructing risk-capacity tradeoff curves of en-route corridor concepts.*

Keywords-corridor; simulation, risk-capacity tradeoff

I. *Introduction*

A corridor is defined as a long "tube" of airspace, in which groups of flights fly along the same path in one direction and accept responsibility for separation from each other [1]. Multiple (parallel) lanes, self-separation and dynamic activation rules are three of the prominent attributes of corridors. A well-designed corridor may reduce the airspace complexity, increase airspace capacity and decrease controller workload.

Previous research has looked at the initial design concept, optimal placement of corridors, and the topology of the network. Alipio et al. [2] initially proposed and evaluated the conception of Dynamic Airspace Super Sectors (DASS). Yousefi et al. [3] conducted a statistical analysis of city-pair traffic and the placement of a network of High-Volume Tube-Shape Sectors (HTS). Sridhar et al. [4] grouped airports into regions, and modeled a series of tubes connecting major regions. Hoffman et al. [5] constructed a tube network and made an estimate of capacity-enhancing effects of tubes for airspace. Xue et al. [6] studied the complexity of traffic in a selected corridor by using simulation. Zadeh et al. [7] proposed a flow-based modeling approach to cluster 4DTs into potential corridors. Yousefi et al. [8] developed an initial operational procedure to implement flow corridor operations.

The objective of this research is to develop models and methods for constructing risk-capacity tradeoff curves in the corridor.

II. *Model Description*

Figure 1 illustrates an example two-dimensional parallel corridor structure [8] for en route and cruise operations. The route is 80 nm length and 16 nm width. With the route centerlines 8 nm apart, two corridors are placed in a similar area of airspace.

An aircraft usually enters the corridors on the left and leaves on the right. In the corridor, an aircraft may adjust its speed and the separation with its leading aircraft, switch the corridor for overtaking, or in extreme cases exit the corridor befor the exit, along paths that are offset by 30 degrees.

In our model, we assume the aircraft behaviors in the corridor as follows: 1) arrivals initially enter corridors with random velocities and separations 2) the aircraft fly along the middle line of each corridor and self separates with aircraft in front according to a self-separation model by adjusting its acceleration and speed 3) any time the speed of an aircraft is larger than the average speed of the leading aircraft by speed threshold, it attemps to switch corridor 4) any time an aircraft gets within minimum separation of aircraft in front, it switches corridor or breaks out 5) the first aircraft in each corridor and the aircraft whose separation with it leading aircraft is larger than a threshold value, it flies at the initial velocity.

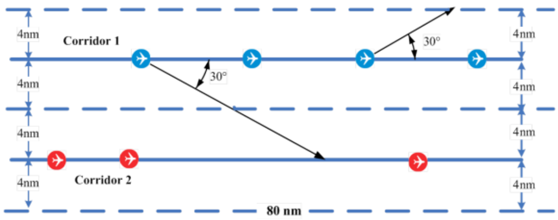

Figure 1. *Parallel corridors*

A. *Aircraft Performance Model*

This section defines an aircraft performance model used in simulation.

1) *Algorithm:*

In order to determine the throughput of the corridors, we use an aircraft performance model based on computer simulation to capture the stochastic range of the problem.

Figure 2 shows pseudo code for the main algorithm. We briefly describe the core outline of the algorithm. Specific details will be explained later. Table 1 defines some key variables in the main algorithm.

In the loop, the algorithm checks the velocity difference and separation between each aircraft and its leading aircraft. If the velocity difference is equal to or greater than the *velocity threshold*, and also the separation is less than *region separation*, then the *corridor switch requirement* will be checked. This represents a scenario where the trailing aircraft is traveling faster than the leading aircraft and the leading aircraft is not too far in front of the trailing aircraft, so the trailing aircraft wants to pass. If the *corridor switch requirement* is satisfied (i.e., the other lane is sufficiently clear), then the trailing aircraft will *switch corridors* to pass the leading aircraft. If the trailing aircraft cannot switch lanes due to congestion, the trailing aircraft will choose to *fly at the target velocity*, *adjust velocity* or *breakout* on the basis of different separations.

If the velocity difference is smaller than the *velocity threshold*, and also the separation is larger than the *region separation*, the trailing aircraft will *fly at the target velocity*. Or else, the trailing aircraft will *adjust velocity* when the separation is between *region separation* and *minimum separation*. This represents a case where the trailing aircraft is traveling at a speed that is either slower or only slightly faster than the leading aircraft. If the leading aircraft is sufficiently far in front, the trailing aircraft simply flies at its target velocity, but otherwise the trailing aircraft adjusts its speed to maintain separation with leading aircraft.

When the separation is less than the *minimum separation*, the aircraft will *switch corridors* if the *corridor switch requirement* is satisfied, or else *breakout* of the corridor.

```
INPUT
        Number of aircrafts, time step, corridor switch angle etc;
INITIALIZE
        Aircraft attributes, metrics and flying states;
LOOP
        WHILE not all aircrafts passed the corridors
        If (V_T(t) - V_L(t) > V_threshold )
                If(Sep(t) > Sep_threshold)
                        Fly at the target velocity;
                Else if (Sep(t) > MS + B)
                        If(Corridor switch requirement is satisfied)
                                Switch corridor;
                        Else
                                Adjust velocity;
                Else
                        If(Corridor switch requirement is satisfied)
                                Switch corridor;
                        Else
                                Breakout;
        Else
                If(Sep(t) > Sep_threshold)
                        Fly at the target speed;
                Else If (Sep(t) > MS + B)
                        Adjust velocity;
                Else
                        If(Corridor switch requirement is satisfied)
                                Switch corridor;
                        Else
                                Breakout;
END OF LOOP
```

Figure 2. *Pseudo code about main algorithm*

TABLE I. PARAMETERS FOR ALGORITHM

Variables Name	***Description***	***Parameters***	***Value Type***
Current time	The current clock time in simulation	t	Independent variable
Aircraft number	Number of aircraft used for simulation in each corridor	i	Independent variable
Buffer	Addition separation added between aircraft-pair for safety performance	B	Constant
Velocity threshold	The threshold value of velocities difference between adjacent aircraft for surpassing	$Vel_{threshold}$	Constant
Region separation	The threshold value of longitudinal separation between adjacent aircraft for flying state changing	$Sep_{threshold}$	Constant
Minimum separation	The minimum safety longitudinal separation between adjacent aircraft for flying state changing	MS	Constant
Current velocity	The speed of the target aircraft at current time	$V_i(t)$	Dynamic variable
2D position	The longitudinal and latitudinal position in the corridor at current time, function of current time	$X_i(t),Y_i(t)$	Dynamic variable
Current separation	The longitudinal separation with leading aircraft (i-1) at current time, function of current time,	$Sep_i(t)$	Dynamic variable
Aircraft states	It represents the current movement of target aircraft in the corridor, function of current time	$S_i(t)$	Dynamic variable

2) *Aircraft States:* Aircraft states are used for describing the movements of the aircraft in the corridors. Five flying states are defined in the aircraft performance model: *target velocity flying state*, *velocity adjusting state*, *corridor changing state*, *breakout state and locking state*.

a) Target velocity flying state: In this state, an aircraft attempts to fly at its preferred target velocity without regard to the position or velocity of the aircraft in front of it. An aircraft is in this state if either (a) it is the first aircraft in the corridor, or (b) its leading aircraft is sufficiently far ahead so that it does not *currently* need to adjust its velocity to maintain separation. The speed, acceleration and position equations are given below (the parameters and variables are defined in Tables 1 and 2). This state can transfer from/to the velocity adjusting state and the locking state.

$$A_i(t)=0,\quad V_i(t+\Delta t)=V_{i,\,target}$$

$$X_i(t+\Delta t)=X_i(t)+\Delta t * V_i(t)$$

b) Velocity adjusting state: In this state, an aircraft attempts to adjust its speed to maintain separation with its leading aircraft. An aircraft is in this state if the separation is less than the *region separation* (that is, the leading aircraft is not too far in front) but larger than the minimum separation. In this state, an aircraft adjusts its velocity, acceleration and separation with the leading aircraft according to the self-separation model below. This state can transfer from/to the target velocity flying state, the corridor changing state, the breakout state and the locking state.

$$A_i(t)=\begin{cases} C_1 * V_i(t-T)+C_2 * [Sep_i(t-T)-D]+\sigma N(\Delta t) \\ C_1 * \Delta V_{i,target}(t) \end{cases}$$

$$V_i(t+\Delta t)=V_i(t)+\Delta t * A_i(t)$$

$$X_i(t+\Delta t) = X_i(t) + \Delta t * V_i(t)$$

In the acceleration equations, when the current separation of target aircraft is smaller than the region separation, the first acceleration equation is used, or else the second one will be used. During this time, the aircraft state will be set as velocity adjusting state. The parameters are described in Table II.

TABLE II. PARAMETERS FOR ACCELERATION EQUATION

Variables Name	***Description***	***Parameters***	***Value Type***
Time step	The length of time interval in simulation	Δt	Independent variable
Time-lag	The time lag of the flight response to the velocity adjustment	T	Constant
Coefficients	The parameters in acceleration equations, relative to separation differences, velocity differences and noise	C_1, C_2 and σ	Constant
Target separation	The target separation of each flight with its leading aircraft, equaling to buffer add minimum separation (B+MS)	D	Constant
Target velocity	The target velocity of each flight, initialized when entering the corridor	$V_{i,target}$	Random variable
Current acceleration	The acceleration of the target aircraft at current time, function of current time	$A_i(t)$	Dynamic variable
Velocity difference	Velocities difference between the target aircraft and the leading aircraft, function of current time	$\Delta V_i(t)$	Dynamic variable
Target velocity difference	Velocities difference between the current velocity and the target velocity, function of current time	$\Delta V_{i,target}(t)$	Dynamic variable
Noise	The noise in acceleration equations, function of time step	$N(\Delta t)$	Dynamic variable

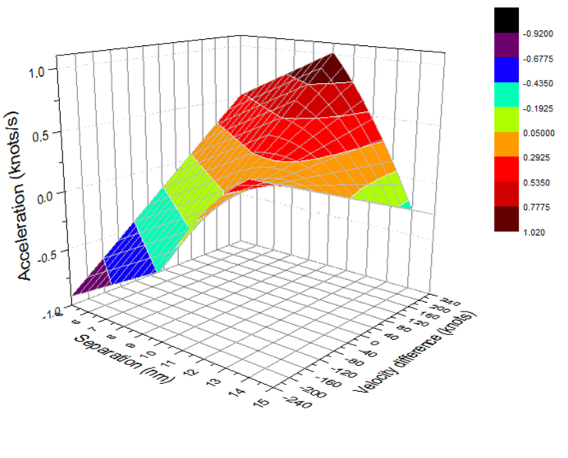

Figure 3. *3D acceleration equation model*

Figure 3 shows the acceleration equation model in three dimensions. The acceleration of an aircraft is a function of the velocity difference and separation. When the separation is smaller than the region separation (e.g. 12 nm), the acceleration increases with the velocity difference. When the separation is larger than the region separation, the acceleration is only proportional to the velocity difference with its target velocity.

c) Corridor changing state: Before introducing the corridor changing state, we first introduce the *corridor switch requirement*. The content of the *corridor switch requirement* is as follows: (a) The potential corridor-switch flight must be in either the target velocity flying state or the velocity adjusting state. (b) Make a projection of the target flight onto the other corridor (assuming a 30 degree path) to find its new leading and trailing aircraft in the other corridor (Figure 4). Both the distances between the new leading and the new trailing aircraft must be larger than half of the corridor-switch separation. (c) The trailing aircraft in the new corridor must also be in velocity adjusting state or target velocity flying state.

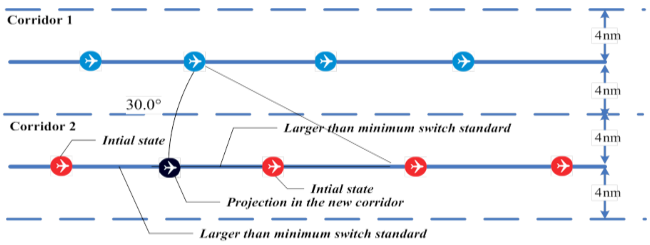

Figure 4. *Corridor switch requirement*

In the corridor-changing state, the target aircraft flies a 30-degree path to the other corridor. The aircraft adjusts its velocity using its projected position in the new corridor as if it were flying in that corridor and maintaining separation with the leading aircraft. An aircraft switches lanes under the following two situations: (a) the separation with its leading aircraft is less than the minimum separation and also the corridor switch requirement is satisfied (b) the velocity is larger than the average velocity of its leading aircraft by velocity threshold, the separation with its leading aircraft is less than the *region separation* and also the corridor switch requirement is satisfied. This state can transfer from/to velocity adjusting state.

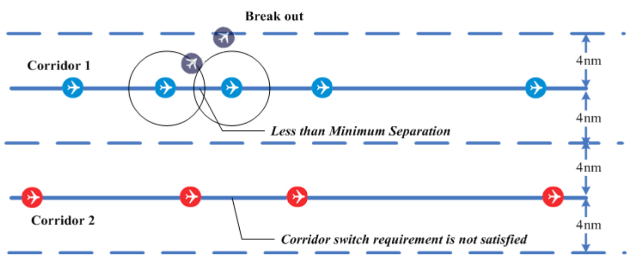

Figure 5. *Breakout*

d) Breakout state: An aircraft breaks out of the corridor if the separation with its leading aircraft is less than the minimum separation, and also the corridor switch requirement is not satisfied. In this state, the target aircraft follows a route to breakout to the side of a corridor (as Figure 6). The breakout aircraft keeps its velocity and adjusts its 2D position until out of the corridor region. The trailing aircraft in the original corridor is set to a locking state for one time step to avoid two consecutive aircraft changing to the breakout state or the corridor changing state at the same time. This state can transfer from the velocity adjusting state.

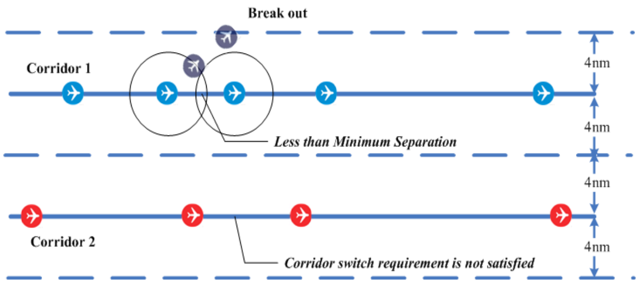

Figure 6. *Breakout*

e) Locking state: In this state, an aircraft cannot change to the corridor changing state or the breakout state until the locking time is over. This state is used to prevent simultaneous lane changes or breakouts. For example, when an aircraft is in the corridor changing state, the trailing aircraft in the original corridor is locked for one time step in order to avoid two consecutive aircraft changing to the corridor changing state or breakout state at the same time. Further, the trailing aircraft in the new corridor is locked until the corridor switch procedure is finished. This is to prevent two aircraft from "crossing" in the middle while changing lanes.

Figure 7 shows the distance relationships between aircraft pairs. Figure 8 shows the relationships between aircraft states.

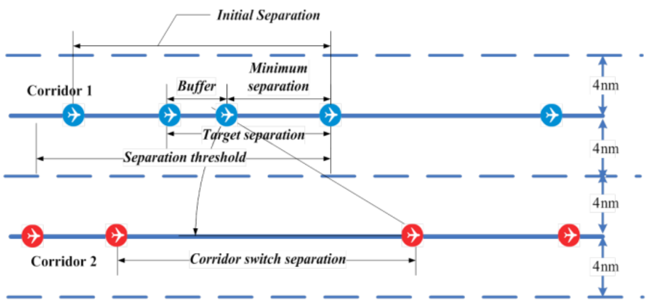

Figure 7. *Distance relationships*

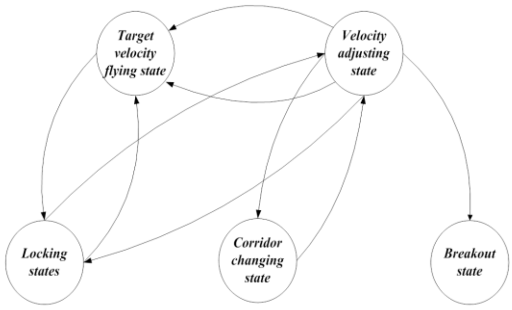

Figure 8. *Aircraft states relationship*

3) *Variables:* Tables III, IV and V define various parameters, metrics, and variables associated with the model.

a) Input Parameters: These are static parameters that the user selects to run the simulation (Table III). Note that additional input parameters such as the target separation and buffer separation are defined in Tables I and II, and not shown here.

TABLE III. INPUT PARAMETERS

Variables Name	***Description***	***Parameters***
Corridor-switch separation	The minimum spacing gap in the opposing corridor needed to switch lanes	*SD*
Minimum velocity	The minimum velocity an aircraft can fly in the corridor (a function of aircraft type)	*MinV*
Maximum velocity	The maximum velocity an aircraft can fly in the corridor (a function of aircraft type)	*MaxV*
Minimum acceleration	The minimum acceleration (i.e., maximum deceleration) an aircraft can use in the corridor (a function of aircraft type)	*MinA*
Maximum acceleration	The maximum acceleration an aircraft can use in the corridor (a function of aircraft type)	*MaxA*
Average time	Time interval for calculating average velocity of leading aircraft	*AT*

*b) Output Metrics:*These variables are the measures of system performance. Currently, the throughput, conflict rate, breakout rate and corridor switch rate are selected as outputs (Table IV).

TABLE IV. OUTPUT METRICS

Variables Name	***Description***	***Parameters***
Capacity	The number of aircraft that can pass the parallel corridors in one hour	*CA*
Breakout rate	The fraction of aircraft that breakout from the corridor	*BR*
Corridor-switch rate	The fraction of aircraft that switch from one corridor to another	*SR*
Conflict rate	The fraction of aircraft that either breakout or switch corridors.	*CR*

c) Internal Variables: Table V lists some dynamic variables used internally by the simulation. Note that some internal variables, such as current velocity, have been introduced previously in Tables I and II.

TABLE V. INTERNAL VARIABLES

Variables Name	***Description***	***Parameters***	***Value Type***
Initial separation	The initial separation of aircraft *i* with its leading aircraft, initialized when entering the corridor	IS_i	Random variable
Aircraft type	The type of aircraft *i* (determines the maximum and minimum velocity and acceleration)	TY_i	Random variable
Average velocity	The average velocity of the flight in front of aircraft *i*, averaged over the interval $[t - AT, t]$	$AV_{i-1}(t)$	Dynamic variable
Velocity history	The velocity history of the aircraft in front of aircraft i	$HV_{i-1}(t)$	Dynamic variable
Acceleration history	The acceleration history of aircraft i.	$HAV_i(t)$	Dynamic variable

III. *METHODOLOGY*

The Monte Carlo simulation is used here to test the stochastic range of the corridor model. We built a continuous-discrete hybrid model. The position, speed and acceleration etc. of each aircraft change continuously over time while the state of each aircraft changes at a countable number of points in the time.

In the simulation, 10,000 aircrafts are created for each corridor. Two types of aircraft with different minimum and maximum speed are randomly initialized with the same chance. The initial speed is normally distributed and independent from aircraft to aircraft. The initial separation equals to the sum of minimum separation and random cushion. The cushion is created as exponential distribution with buffer as it mean. All accelerations of each aircraft in the corridor are stochastic and subject to random fluctuations based on the acceleration equations in section II. The equations are functions of the velocity and separation difference.

The time step, separation threshold, time lag, minimum and maximum acceleration etc. are created as constants. Sample values [9] in the experiment can be found in appendix. The program is written in C++ and Figure 9 shows the simplified flow chart.

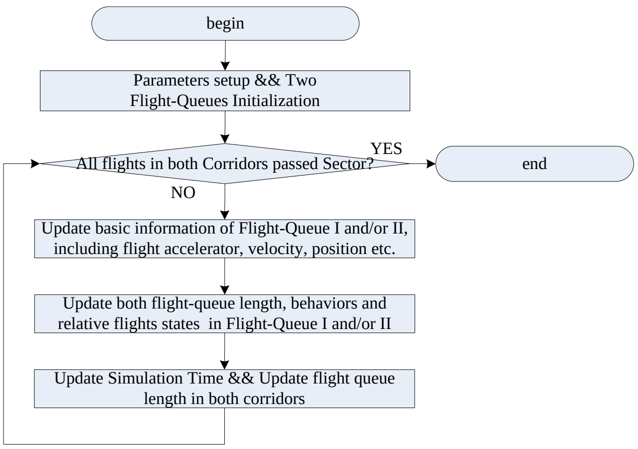

Figure 9. *Simplified flow chart*

Also the simulation includes a mechanism to output simulated flight trajectories in KML format, which can be read by Google Earth and displayed in an animated fashion. Figure 10 shows several example screen snapshots of this feature.

Figure 10. *Simulation snapshot*

IV. *PRELIMINARY RESULTS*

Figure 11 shows the sample results of two aircraft in the corridors. The maximum and minimum true speeds of the two kinds of aircraft are 470/330 knots and 420/280 knots separately. The maximum and minimum accelerations of both aircraft are set as 1.186 knots/s and -1.5 knots/s. The *x*-axis corresponds to the time horizon when each aircraft is in the corridor. The *y*-axis corresponds to the speeds and accelerations during this time. The right top graph is a speed sample of the aircraft with 420/280-knot limitations. The maximum speed of 420 caps the speed profile in the top right graph. In the bottom right graph, the second drop in acceleration is caused by a change in the leading aircraft during flight phase (e.g. a new leading aircraft due to a corridor switch).

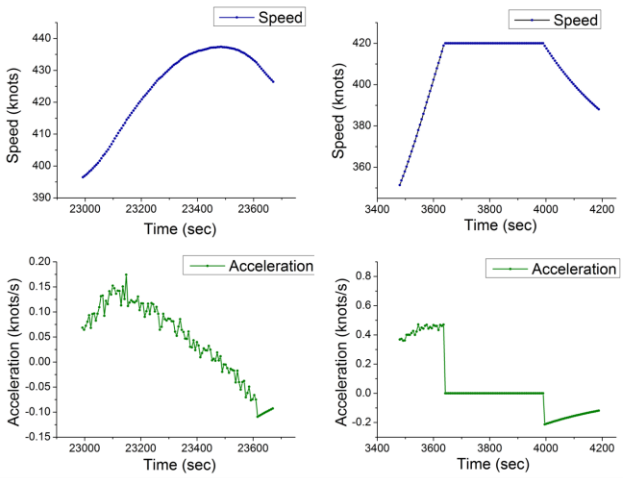

Figure 11. *Speeds and accelerations samples*

Figure 12 shows the sensitivity of the system to the separation buffer. We conduct a set of experiments by varying the buffer from 0 nm (target separation equals the minimum separation) to 5.5 nm. In the experiment, 10,000 aircraft are simulated to pass the two corridors ten times in the model, then the 95% confidence interval are calculated for each of the values.

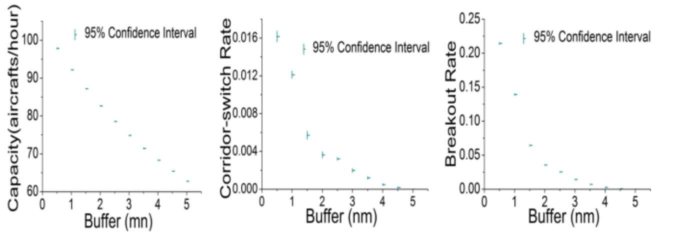

Figure 12. *Buffer sensitivity analysis*

In the figure, the capacity values are monotone decreasing as the buffer is increasing. That is, the highest capacity is achieved when the buffer is zero. However, more conflicts occur when the buffer is smaller. In addition, the percentage of breakouts is high, because the corridor-switch requirement is often not met due to congestion on the corridor. As the buffer increases to 2 nm, the breakout rate drops rapidly from more than 20% to about 4%, after that it reduces slowly until 0.

The corridor-switch rate decreases quickly at first, followed by a sharp decrease from 1 nm to 1.5 nm and then levels off slightly to 2.5 nm. After that, a steady decrease continues until the rate reduces to zero. The shape of the curve is due to the changing of the corridor-switch demand and requirement. When the buffer is very small, the demand of corridor-switch is very large. There is also a large number of breakouts, which allows for the corridor switches to be executed. As the buffer increases, fewer aircraft need to breakout from the corridors, but more and more aircraft-surpass requirements can be satisfied due to separation increasing between adjacent aircraft. This may be the reason of fluctuation. When the buffer increases to some threshold, aircraft begin to fly at their target velocity, so the corridor-switch rate slowly decreases to zero in the end.

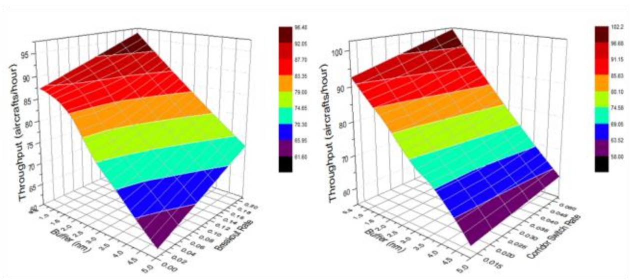

Figure 13. *Buffer sensitivity analysis(3D)*

Figure 13 shows the same information, but in three dimensions. We may see the tradeoff between buffer, capacity and corridor-switch rate and breakout rate. Figure 14 shows the Corridor-switch separation sensitivity to the corridor capacity, conflicts rate, corridor-switch rate and breakout rate. Here, the buffer is set as 2 nm and the corridor-switch separation changes from 7.5 nm to 12 nm.

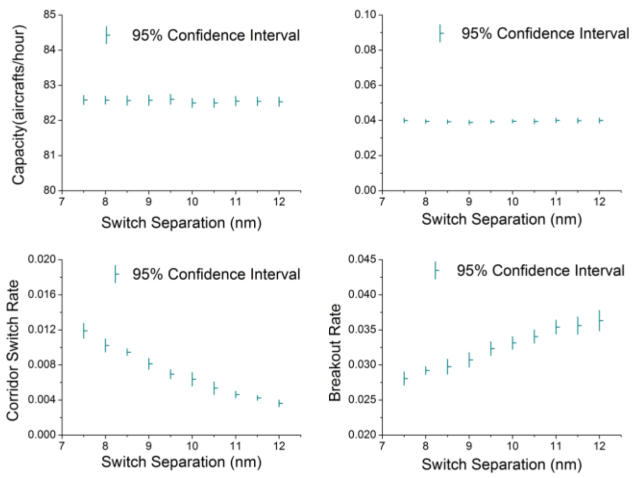

Figure 14. *Corridor-switch separation analysis*

The capacity values and the conflict rates remain stable during the changes in corridor-switch separation. From the simulation, it can be found that the capacity values keep in about 82.5 aircraft per hour while the conflicts rate (corridor-switch rate plus breakout rate) fluctuates slightly around 4 percent under current parameters. However, though the conflict rates change little, the proportion of conflicts vary a lot during this time period. The corridor switch rate decreases more than 60% with increased corridor-switch separation from 1.2 percent to 0.4 percent. The breakout rate increases with switch separation from 2.8 percent to 3.6 percent.

We can see from the figure that the corridor-switch separation can change the proportion of the conflict rate but has not so much relationship with the capacity and conflicts rate.

V. *Conclusions*

This paper conducted a computer simulation model of aircraft in parallel corridors. Key insights from the model are:

1) The corridor throughput decreases as the separation buffer increases. However a large percentage of aircraft may breakout when the separation buffer (the excess separation applied above the minimum) is low.

2) The corridor-switch separation (the minimum gap needed to switch lanes) has little impact on the capacity and conflict rate, but can change the relative proportion between the corridor-switch rate and the breakout rate.

3) The corridor switch rate depends on both the corridor switch demand and the corridor switch requirements. Buffer and corridor-switch separation are two important factors in the experiment.

The corridor structure presented in this paper is relatively simple. Future work includes extending the corridor structure to two or more levels, introducing more types of aircraft, improving relative aircraft behaviors and obtaining more accurate parameter values to use in the model.

APPENDIX

List of key parameters				
Metric name	***Parameters***	***Value type***	***units***	***Sample value***
Aircraft number	*i*	*Independent variable*	*aircraft*	*10,000*
Current time	*t*	*Independent variable*	*sec*	*600*
Time step	*Δt*	*Independent variable*	*sec*	*6*
Target velocity	*V i ,target*	*Random variable*	*knot*	*Norm(400,20) Norm(350,20)*
Initial separation	*ISi*	*Random variable*	*nm*	*5+exp(2)*
Aircraft type	*TYi*	*Random variable*	-	*Large*
Aircraft states	*Si(t)*	*Dynamic variable*	-	*breakout*
Current velocity	*Vi(t)*	*Dynamic variable*	*knot*	*380*
Current acceleration	*Ai(t,)*	*Dynamic variable*	*Knot/sec*	*0.8*
Velocity difference	*ΔV i (t)*	*Dynamic variable*	*knot*	*100*
Target velocity difference	*ΔV i ,target(t)*	*Dynamic variable*	*knot*	*50*
Noise	*N(Δt)*	*Dynamic variable*	-	*0.01*
2D position	*Xi(t),Y i(t)*	*Dynamic variable*	*nm*	*45, 4*
Current separation	*Sep i(t)*	*Dynamic variable*	*nm*	*5.5*
Average velocity	*AVi*-1 *(t)*	*Dynamic variable*	*nm*	*388*
History velocities	*HVi*-1 *(t)[AT]*	*Dynamic variable*	*knot*	*[420, 424, 430]*
History accelerators	*HAVi(t)[AT]*	*Dynamic variable*	*knot*	*[0.8, 0.6, 0.7]*
Capacity	*CA*	*Dynamic variable*	*Aircraft /hour*	*85*
Breakout rate	*BR*	*Dynamic variable*	*%*	*4*
Corridor-switch rate	*SR*	*Dynamic variable*	*%*	*3*
Conflicts rate	*CR*	*Dynamic variable*	*%*	*7*
Velocity threshold	$Vel_{threshold}$	*Constant*	*knot*	*40*
Separation threshold	$Sep_{threshold}$	*Constant*	*nm*	*8*
Buffer	*B*	*Constant*	*nm*	*2*
Time-lag	*T*	*Constant*	*sec*	*12*
Coefficients	*C1, C2 and σ*	*Constant*	-	*0.003,0.07,0.005*
Minimum separation	*MS*	*Constant*	*nm*	*5*
Target separation	*D*	*Constant*	*nm*	*7*
Corridor-switch separation	*SD*	*Constant*	*nm*	*12*
Average time	*AT*	*Constant*	*sec*	*30*
Minimum velocity	*MinV*	*Constant*	*knot*	*420/280*
Maximum velocity	*MaxV*	*Constant*	*knot*	*470/330*
Minimum accelerator	*MinA*	*Constant*	*knot/s*	*1.186*
Maximum accelerator	*MaxA*	*Constant*	*knot/s*	*-1.5*

REFERENCES

[1] "Concept of Operations for the Next Generation Air Transportation System", Joint Planning and Development Office, Washington, DC, 2010.

[2] J. Alipio et al., "Dynamic airspace super sectors (DASS) as high-density highways in the sky for a new US air traffic management system", in 2003 IEEE Systems and Information Engineering Design Symposium, 2003, pp. 57- 66.

[3] G. L. D. A. Yousefi, "High-volume tube-shape sectors (HTS): a network of high capacity ribbons connecting congested city pairs", Digital Avionics Systems Conference, 2004. DASC 04. The 23rd, vol. 1, pp. -3.1-7 Vol.1, 2004.

[4] B. Sridhar, S. Grabbe, K. Sheth, and K. D. Bilimoria, "Initial study of tube networks for flexible airspace utilization", in AIAA Guidance Navigation and Control Conference, Keystone, Colorado, 2006, pp. AIAA-2006-6768.

[5] R. Hoffman and J. Prete, "Principles of Airspace Tube Design for Dynamic Airspace Configuration", in AIAA-ATIO Conference, Anchorage, Alaska, 2008.

[6] M. Xue and S. J. Zelinski, "Complexity Analysis of Traffic in Corridors-in-the-Sky", History, no. September, pp. 1-9, 2010.

[7] A. Yousefi, A. N. Zadeh, and A. Tafazzoli, "Dynamic Allocation and Benefit Assessment of NextGen Flow Corridors", Metronaviation, 2010.

[8] A. Yousefi, J. Lard, and J. Timmerman, "Nextgen flow corridors initial design, procedures, and display functionalities", in Digital Avionics Systems Conference (DASC), 2010 IEEE/AIAA 29th, 2010, pp. 4.D.1-1-4.D.1-19.

[9] "Europen Organization For the Safey of Air Navigation", Eurocoontrol Experimental Centre, USER MANUAL FOR THE BASE OF AIRCRAFT DATA (BADA) REVISION 3.6, 2004.