MALAYSIA-JAPAN CONFLICT FREE AIR-TRAFFIC ASSIGNMENT USING HEURISTIC METHOD

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ABSTRACT

Initial 4D trajectory management, corridor flow and airstream are concepts currently being studied to improve the air traffic management worldwide. This paper evaluates the viability of assigning aircraft into preferred flight path or trajectory within airstream inside a corridor flow. By following flight maneuver in lateral motion within airstream, each aircraft needs to be assigned before reaching a waypoint inside a corridor flow. The airspace is considered within the Asia Pacific region especially between Malaysia and Japan. Two assignment cases with space constraint (waypoint), Case A and B were generated and heuristic method is chosen for the aircraft assignment in both cases. Trajectory data for this study was obtained from the real flight path from Malaysia to Japan. The results show that the assignment method for case B ensure the aircraft can still reach the second waypoint. However, case A requires the first aircraft to be at two earlier slot in order to reach the second waypoint. By being able to have multiple airstream and the ability to assign aircraft it is expected that traffic flow can be increased and managed.

KEYWORDS: *i4D concept, Corridor Flow, heuristic assignments, greedy method*

1. INTRODUCTION

As the traffic demand continues to grow within the National Airspace System (NAS), the need for long-range planning (30 minutes plus) of arrival traffic increases greatly (Rhonda et al., 1994). The restriction on the capacity of runway, airspace and airport has caused congestion within the expanded terminal area which resulted in an increase of controller's workload, inefficiency due to more fuel burning by the aircraft as well as increasing in air traffic delay. In order to sustain the stipulation of increasing air traffic, the accuracy level of aircraft flight path or route is required to be increased in accordance with flight navigation and planning (Eurocontrol,2012 and JPDO,2012). Two main concepts, Initial 4D Trajectory Management and Corridor Flow has been developed. Initial 4D Trajectory Management creates ground and air stakeholders to share their common perspective of aircraft trajectory within time constraints (SESAR,2010, Laurence et al, 2013). Therefore, any flight can be controlled as close as possible within airspace and the flow of air traffic can be optimized. At first, 4D trajectory is used among Air Navigation Service Providers (ANSP), airport operators and other airspace users, it was then progressively enhanced by taking into account restraints in airport as well as airspace capacity. 4D trajectory is concurred to be a reference by airspace users to fly where it is facilitated by Air Navigation Service Providers (ANSP). Along the flight, the exchange between specific information on future aircraft projected-position and all service providers on route occurs where the arrival and departure airport times are agreed in advance. According to [JPDO,2012], the flow corridor concept is a proposed route structure in en-route airspace to increase en-route capacity. It is like a long tube-shaped volume of airspace while to make sure the aircraft cruise within the flow corridor region 99.995% of time, the aircraft are capable of Required Navigation Performance (RNP) [Yimin et al,2013, Xuejun et al,2015]. By using this technology, the main gap between aircraft can be reduced in lateral axis compared with the present flight path. The selfseparation ability of aircraft in flow corridor leads to avoid conflicts as well as maintaining the separation of the aircraft along the track in which the aircraft outside the corridor flow region are prohibited to enter the corridor flow boundary. According to (Noboru et. al,2015) analysis from the implementation of flow corridor using actual flight data in Japan, it was found that the Flow Corridor introduction enables both the flight time and fuel consumption reduction, and that the fuel consumption reduction is remarkably large in both the cruise and descent trajectories.

The main idea in implementing both Initial 4D Trajectory and Corridor Flow concepts are to reduce flight delay by adding multiple flight path in the same route with the additional time constraints on each flight path. In this paper, application of the airstream concept for flight assignment is used to facilitate these two concepts. A common maneuver trajectory was developed where the aircraft can change between lanes while following their assigned slots. This common maneuver trajectory will be used in this research to see the application of airstream for flight between Malaysia and Japan. From the current data of flight information of aircraft flying from Malaysia to Japan, the flight is replicated for multiple aircraft to see whether these aircraft can maneuver before reaching certain waypoint where the air traffic controller might other constraint to manage traffic flow after that waypoint. For the lane change assignment by an aircraft within the corridor flow, greedy heuristic assignment method is applied as it is found to be simpler in this operation either in space or time strategy where both can be adopted. Hence, flight duration from one point to another can be reduced where the faster aircraft are able to cruise on certain paths without having any conflict with the slower aircraft. In turn, the number of flight can be increased greatly on the same route in airspace.

2. GREEDY HEURISTIC ASSIGNMENT METHOD

Greedy method or greedy algorithm is assigned for the lane change assignment method on this study because this algorithm is an optimization algorithm which makes a locally optimal decision at each step. The decision is locally optimal, for the immediate step, but not necessarily for all the future steps. Each aircraft is moving along a slot within the airstream. Let the slot size be *ds* in nm. The *min-time* heuristic ranks of the aircraft in set J_t increasingly with respect to m_j^f and d_j^f given by:

$$m_j^f = \arg\min\{t_{dj}^m\} \quad \text{where} \quad m \in M_j \qquad (1)$$

The index of the first flight to be assigned *j**, is given by:

$$j^* = \arg\min\left\{m_j^f\right\} \text{ and } \exists d_j{}^f > ds \quad where \quad j \in J_t \qquad (2)$$

where flight *j** is assigned to be merging trajectory, m_j^f, and the distance to the waypoint, d_j^f must be more than a slot size, J_t is then updated by deleting *j**. Note that J_t must be incremented any time a new flight enters the airstream. The set of conflict free trajectories M_j are updated for $j \in J_t$.

The risk with this heuristic is that the trajectory assignment of several flights may be delayed frequently, making these flights support additional operations costs. Otherwise, the *max-wait* heuristic ranks the aircraft in set J_t decreasingly according to their waiting time within this set and assigns to the first of them, *j**, its earliest conflict free merge trajectory $m_{j^*}^f$. In order to perform the assignment of the free slots to the standard shift maneuvers, a greedy heuristic based on the min-time approach is developed. The main procedures of the resulting assignment algorithm are shown below:

1. Rank increasingly the transient flights according to their minimum final maneuver time, m_j^f. Let *j** be the first in the list.
2. If distance to waypoint $d_{j^*}^f > ds$, *a*ssign to flight *j** the maneuver associated to $m_{j^*}^f$ and update the sets J_a, J_t : $J_a = J_a \cup \left\{j^*\right\}$ and $J_t = J_a / \left\{j^*\right\}$
3. If $J_t = \emptyset$ then Exit
4. Update the sets M_j with $j \in J_t$, if $\forall j \in J_t : M_j = \emptyset$ then Exit otherwise return to step 1

Observe that when $M_j = \emptyset$, flight *j* has no opportunity on its target lane and must remain on its original lane.

3. MANEUVERING TRAJECTORY

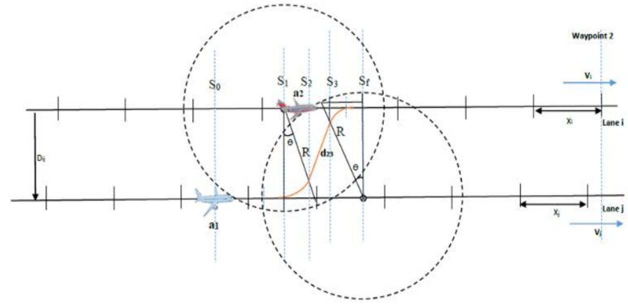

Fig 1. Standard shift maneuver between lanes

The standard flight maneuver as in Figure 1 is parameterized using the abscissa along the airstream as independent parameter. From S_0 to S_1, the aircraft $\boldsymbol{a_1}$ is cruising a straight segment at constant speed v_j. The maneuver starts at S_1, the aircraft begins with constant speed v_j and a left equilibrated turn of angle Θ ($<90^0$) and radius, R such as:

$$R = \frac{V_j^2}{g \tan \emptyset}$$

Θ is a standard turn bank angle such as $\Theta \leq \Theta_{max}$, where Θ_{max} is a maximum bank angle value and $R \geq R_{min}$ with $R_{min} > \frac{V_j^2}{g \tan \theta_{max}}$

Then, section S_2 is given by:

$$S_2 = S_1 + R \sin \theta$$

In order to merge safely into lane i, the aircraft performs a nominal change of speed from v_j to $v_i = v_j + \Delta v$ from S_2 to S_3. It is supposed that the nominal change speed characterized by a constant space rate, a [m/s/m], such as:

$$a = \frac{\Delta v \sin \theta}{D - 2(\mathrm{R})(1 - \cos\theta)}$$

Where a_{min} and a_{max} are the minimum and maximum speed space rate of change. Therefore, S_3 is given by:

$$S_3 = S_2 + \frac{D - 2(R)(1 - cos\theta)}{tan\theta}$$

From S_3 to the final maneuver segment, S_f, the aircraft performs at a constant speed v_i a right turn angle Θ and radius R. S_3 is given by:

$$S_3 = S_F + R \sin \theta$$

with $R \geq R_{min}$ with $R_{min} > \frac{V_j^2}{g \tan \theta_{max}}$

Then S_f is parameterized by S_1, D_{ij}, Δv, v_j, R and Θ, R and S_1 are design parameters to be chosen. Therefore, S_f is given by:

$$S_F = S_1 + D_{ij} - 2R \frac{(1 - cos\theta)}{\tan \theta} + 2R.\sin \theta$$

with $\alpha = \frac{\sin \theta}{D_{ij} - 2(\mathrm{R})(1 - \cos\theta)}$

$$t_1 = t_0 + (S_1 - S_0)/v_j$$

$$t_2 = t_1 + R \frac{\theta}{v_j}$$

$$t_3 = t_2 + \alpha \cdot \Delta v \cdot ln \frac{(cos\theta \cdot \Delta v)}{v_i}$$

Hence, the final time to reach the merging position is given by:

$$t_f = t_3 + R \frac{\theta}{v_j}$$

The distance between waypoint and final aircraft position, $d_j^{\,f}$ is given by: $d_j^{\,f} = WP - S_f$. WP is the waypoint position. Since the lanes are parallel along the constant flight level, the reference azimuth angle remains constant and equal to 90^0. Let X_k be the set of free slots on lane i, an efficient management of the airstream will make the aircraft to merge at the center of the earliest free slot k_m on lane i such as : $k_m = min\{k \in X_k\}$ and $\exists d_j^{\,f} \geq ds$ where, $\exists R \geq R_{min}$ and $\exists \Theta \in [0, 90^0]$ such as $S_f(S_1, R, \Theta) = x_i^{k_m}$

4. CASES CONSIDERED

The cases considered here are flights between Malaysia and Japan. The data that was used to generate the assignment problem was taken at 39,000 feet flight level, and from ALDAS (N10° 57.23'; E112° 12.72')to AZAMA (N26° 9.42'; E127° 47.66') waypoints. The chosen waypoints were taken since it is the longest nearly straight line in the real flight path. There are two cases considered in this study which are case A and case B. Both cases will have the same number of aircraft where some of the aircraft are assigned to make a lane change while the remaining aircraft are said to remain cruising on their own lanes and in their specific slots. Aircraft are all represented as alphabet from A to E. The assigned speed for each lane is lane i = 230 m/s, lane j = 260m/s and lane k =290 m/s

Some parameters have also have been set in order to know which aircraft will arrive the preferred slot earlier as well as to know the time taken for each of them to reach waypoint 2. From having different number of parameters, the earliest maneuvered aircraft can be chosen by assigning heuristics assignment greedy method.

The time separation between preceding aircraft and distance separation on each lanes is set to be 10 minutes and 8NM respectively due to safety purpose. The velocity of each aircraft and each slot on each lane has been discussed previously. Turning angle for maneuvered aircraft is set to be either 30^0 or 45^0 depending on the speed as well as the distance between the aircraft and the targeted slot. Turning radius must be greater than the distance separation between aircraft.

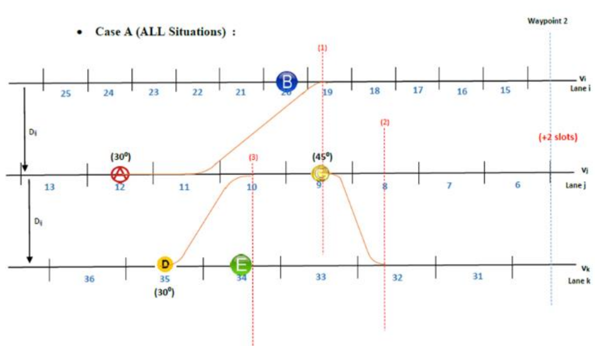

Fig2. Overall case A situations

Figure 2 shows the overall situations for case A where 5 aircraft involved in which 2 aircraft are cruising straight and level while another 3 aircraft are expected to make a lane change within the time before reaching waypoint 2. In this case, aircraft B and E are said to cruise on their own lane until reaching at waypoint 2 while aircraft A, C and D are going to make a lane change in sequence.

Figure 3 depicts the overall situations for case B where 5 aircraft involved in which 2 aircraft are cruising straight and level on lane i and j respectively while another 3 aircraft are expected to make a lane change within the time before reaching waypoint 2. In this case, aircraft C and E are said to cruise on their own lanes until reaching waypoint 2 while aircraft A, B and D are going to make a lane change in sequence.

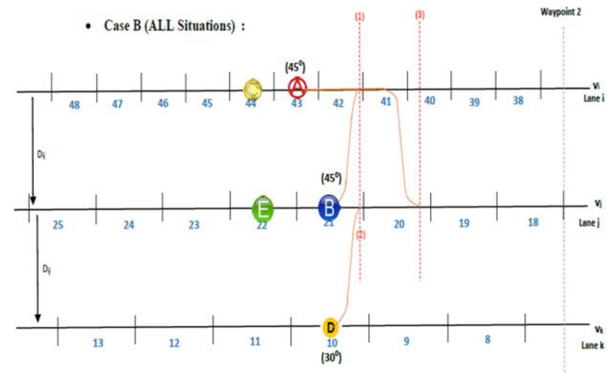

Fig 3. Overall case B situations

This case is more complicated where lane j and k comprised of 2 flying aircraft which close to each slot where more consideration shall be taken in determining the lane change assignment for transient flight. The distance for each aircraft in Case 2 is closer to the targeted waypoint 2.

Table 1. Final ranking between transient flights for case A

i	Initial starting time (Hr:M:S)	Maneuver Starting time (Hr:M:S)	Aircraft	Delay (s)	J_t Rank	Arrival Time (WP2) (Hr:M:S)	Initial Distance from WP2 (nm)
1	04:00:00	04:00:00	A	-	1	05:02:00	716.04
2	04:00:00	04:11:20	D	679.86	2	05:34:00	629.80
3	04:00:00	04:32:31	C	1951.08	3	04:57:00	463.32
4	04:00:00	04:12:31	E	-	-	04:52:00	535.81
5	04:00:00	04:00:00	B	-	-	05:25:00	521.92

In table 1, it shows the final ranking and maneuver time in Case A. The first situation involving 2 aircraft which are aircraft *A* and aircraft *B*. Both aircraft are said to be cruising at the same starting time which is at 04:00:00 and flying at different lanes next to each other. Aircraft *A* is going to make a lane change right after flying at certain distance from its initial position where the targeted slot for this aircraft is on slot 19. Meanwhile, aircraft *B* will continue to fly within its own slot on lane i. Therefore, consideration shall be taken on both aircraft to make sure aircraft *A* will not be in any conflict with aircraft *B* after lane change is made on lane i. For this case, the turning angle of aircraft *A* has been chosen to be 30^0 at t_A right before the lane change started. The banking angle of aircraft *A* is calculated right at t_C which is 16.2^0 just before it reaches on lane i.

Situation 2 in case A involved 2 aircraft which are aircraft *C* and aircraft *D*. Both aircraft are said to be cruising at the same starting time which is at 04:11:00

and flying at different lanes next to each other. Both aircraft are considered after 11 minutes from starting time because these 2 aircraft have to hold(delay) before making any turn as they have to wait for the earlier maneuvered aircraft (aircraft *A*) to make a complete lane change. Only then Aircraft *D* is able to make a lane change right after flying at certain distance from its initial position where the targeted slot for this aircraft is on slot 10. On the other hand, aircraft *C* will continue to fly within its own slot on lane *j*. Therefore, consideration shall be taken on both aircraft to make sure aircraft *D* will not be in any conflict with aircraft *C* after lane change is made from lane *k* to lane *j*. For this case, the turning angle of aircraft *D* is chosen to be 30^0 at t_1 right before the lane change started. The banking angle of aircraft *D* is calculated right at t_C which is 20.4^0 just before it reaches on lane *j*.

Situation 3 in case A involved aircraft *C* and aircraft *D*. Both aircraft are said to be cruising at the same starting time which is at 04:17:31 right after aircraft *D* completely made a lane change in situation 2. Aircraft *E* is considered after 17 minutes and 31 seconds from starting time because it has to hold (delay) before making any calculation as it has to wait for the previous maneuvered aircraft (aircraft *D*) to make a complete lane change. Only then Aircraft *E* is able to be taken into account right after flying at certain distance from its initial position where this aircraft will have to pass through the targeted slot or position made by aircraft *C* on the other lane. Hence, aircraft *C* will have to hold till 04:32:31 which is around 15 minutes to ensure it is able to make a lane change safely without any conflict with aircraft E on lane *k*. For this case, the turning angle of aircraft *C* is chosen to be 45^0 at t_1 right before the lane change started. The banking angle of aircraft *C* is calculated right at t_C which is 24^0 just before it reaches on lane *k*.

The first calculation of the assignment can be done for flight *A*, *C* and *D*. From this table, the maneuver duration of each transient flight to reach their targeted slot is determined. Then, the time arrival for every flight to the time-constraint which is at waypoint 2 is also identified before all of the aircraft merge into a lane to perform landing at the airport. Here, aircraft *C* will arrive at waypoint 2 the earliest followed by aircraft *E*, *B*, *D* and *A*. Therefore, the earliest aircraft that reaches waypoint 2 will be chosen to land first at the airport followed by the other aircraft behind.

Situation 1 in case B involving 4 aircraft which are aircraft *A*, *B*, *C* and *E* cruising at the same starting time which is at 04:00:00 and flying at lane *i* and *j*. Aircraft *B* is chosen for the lane change assignment as it has the earliest possibility in making lane change.

Table 2: Final ranking between transient flights for case B

i	Initial starting time (Hr:M:S)	Maneuver Starting time (Hr:M:S)	Aircraft	Delay (s)	J_t Rank	Arrival Time (WP2) (Hr:M:S)	Initial Distance from WP2 (nm)
1	04:00:00	04:00:00	B	-	1	04:50:00	294.84
2	04:00:00	04:02:00	D	119.18	2	05:10:00	282.00
3	04:00:00	04:03:11	E	-	-	04:52:00	379.08
4	04:00:00	04:32:10	A	1740.14	3	04:45:00	447.36
5	04:00:00	04:00:00	C	-	-	04:32:00	521.92

Meanwhile, the other aircraft will continue to fly within their own slots and lanes. Therefore, consideration shall be taken on aircraft *A* in order to make sure there will not be in conflict between aircraft *A* and *B* after the lane change is made on lane *i*. For this case, the turning angle of aircraft *B* is 45^0 at t_1 right before the lane change started. The banking angle of aircraft *B* is calculated right at t_B which is 16.2^0 just before it reaches on lane *i*.

Situation 2 in case B involved aircraft *D* and aircraft *E*. Both aircraft are said to be cruising at the same starting time which is at 04:02:00 and flying at different lanes next to each other. Both aircraft are considered after 2 minutes from starting time because these 2 aircraft have to hold(delay) before making any turn as they have to wait for the earlier maneuvered aircraft (aircraft *B*) to make a complete lane change. Only then Aircraft *D* is able to make a lane change right after flying at certain distance from its initial position where the targeted slot for this aircraft is on slot 20. On the other hand, aircraft *E* will continue to fly within its own slot on lane *i*. Therefore, consideration shall be taken on both aircraft to make sure aircraft *D* will not be in any conflict with aircraft *E* after lane change is made from lane *k* to lane *j*. For this case, the turning angle of aircraft *D* is chosen to be 30^0 at t_1 right before the lane change started. The banking angle of aircraft *D* is calculated right at t_C which is 20.4^0 just before it reaches on lane *j*.

In situation 3 in case B, aircraft *A* and aircraft *E* are said to be cruising at the same starting time which is at 04:03:11 right after aircraft *D* completely made a lane change in situation 2. Aircraft *E* is considered after around 3 minutes and 11 seconds from starting time because it has to hold (delay) before making any calculation as it has to wait for the previous maneuvered aircraft (aircraft *D*) to make a complete lane change. Only then Aircraft *E* is able to be taken into account right after flying at certain distance from its initial position where this aircraft will have to pass through the targeted slot or position made by aircraft *A* on the other lane. Hence, aircraft *A* will have to hold till 04:32:10 which is around 29 minutes to ensure it is able to make a lane change safely without any conflict with aircraft *E* on lane *j*. For this case, the turning angle of aircraft *A* is chosen to be 45^0 at t_1 right before the lane change started. The banking angle of aircraft *A* is calculated right at t_C which is 20.4^0 just before it reaches lane *k*.

From table 2, it is found that flight *A* supposed not to be able to make a turn since the delay time for this aircraft is quite long and after the lane change is done, this flight is said to be very close with the time-constraint in which around 8NM from waypoint 2.

5. CONCLUSIONS

This paper has illustrated in detail assignment that has been done. In the assignment, at least two slots are required in case A to make sure that the last maneuvered aircraft will have enough time to reach waypoint 2. On the other hand, there is no additional slots required for case B since all maneuvered aircraft will arrive at waypoint 2 after the lane change made. But, the last maneuvered aircraft will have very short distance from waypoint 2 right after reaching the targeted slot. It is well agreed that the more deterministic the traffic is; the higher density traffic can be managed with a given guaranteed level of safety. By being able to have multiple airstream and the ability to assign aircraft it is expected that traffic flow can be increased and managed. and e flight delay can be reduced.

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PHOTOS AND INFORMATION

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