15th Triennial World Congress, Barcelona, Spain

CONFLICT RESOLUTION BY NEGOTIATION

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Abstract: The increase in air traffic, forces the current centralized air traffic control systems to be replaced with more decentralized control systems. The idea of *free flight* is developed with this consideration. In free flight aircrafts communicate and cooperate with each other to solve the conflicts. Each aircraft has its own separate optimization criteria, and aircrafts have to modify their paths considering these criteria. There should be a compromise in the amount of concession that aircrafts make in order to solve the conflict. In this research negotiation is introduced to achieve an agreement on the deviations from the optimal paths. Aircrafts negotiate on the amount of deviations they will perform to modify their paths. A frame for negotiation is developed, negotiation principles are determined, and simulations are performed. *Copyright © 2002 IFAC*

Keywords: Air traffic control, conflict resolution, negotiation, fuzzy logic, game theory.

1. INTRODUCTION

The air traffic load whole around the world is estimated to double in the year 2025 (Perry, 1997). The increasing demand of airspace due to the increase in air traffic forces the current Air Traffic Management Systems (ATMS) mainly relying on human to be replaced with safer and more efficient intelligent control systems. In today's ATMS, the air-traffic controllers (ATC) take the whole load in both arranging the paths and solving the conflicts between aircraft paths, however the increase in number of the flights makes the system so complicated that it is impossible for a centralized controller to manage the control in an efficient way. Besides a collapse in the centralized controller would lead to the collapse of whole system. The increasing technology, such as Center-TRACON (Terminal Radar Approach Control) Automation System for trajectory calculations and Automatic Dependent Surveillance (ADS) making use of Global Positioning System (GPS) for navigation information, lead to a new system in air traffic control, namely the 'free flight'. The idea of free flight is based on more autonomous aircraft capabilities that are only possible with the currently developed communication, navigation, guidance and artificial intelligence technologies. One of the major problems to be solved in free flight is conflict resolution that will avoid the collapse of aircrafts.

This study is accomplished to develop a communication and computation frame that enables introducing negotiation in conflict resolution. The methods developed to solve the conflicts are mostly based on optimal control techniques, potential field modeling, or structured maneuvers to be followed in a situation of conflict. What differs conflict resolution by negotiation from those is that it enables both airplanes to decide on the maneuvers cooperatively, without having to obey a predefined path structure or a path that will be generated by predefined algorithms. In this way, airplanes will choose their way according to their self-determined preoccupations, namely objective functions. These objective functions may be subject to change according to pilot needs, conflict situation, flight needs, etc. Consequently, what needs to be done in this method to generate a non-conflicting path in accordance with special considerations is to include these considerations into the rule base of the negotiation protocol. Examples of these considerations may be about turning radii, timing considerations, fuel consumption, minimum deviation from the optimum path, etc. Then each aircraft will make its offerings in negotiation, considering its own performance factors. A compromise between the performance criteria of each aircraft will be achieved without each aircraft knowing the other's preoccupations.

2. LITERATURE REVIEW

Perry (1997), gives a good presentation of current general air traffic control structure, presents the problems, and introduces the free flight idea. Wangerman, *et al.* (1998), suggests a structure for air traffic management appropriate for principled negotiation between intelligent agents. Two kinds of agents, namely aircraft and central controller, are suggested and their functions are defined as 'declarative, procedural, and reflexive' functions. A rule based structure for communication and for negotiation that is based on offer and counter offer is proposed. Serkhavat, *et al*, concentrates on the task of the ATC in free flight. Cell-decomposition architecture is proposed to make the timing arrangements. Each aircraft's path is considered to be within a safe tube and any conjunction of these tubes is considered to be conflicting. Timing problem is formulated as a quadratic programming problem, to minimize the fuel consumption. In (Tomlin, *et al.*,a), the structure of the airplane agents is modeled in a hierarchical manner as 'strategic planner, tactical planner, trajectory planner, and regulation', and each part's functions are described. Petrick, *et al.* (1998), presents a dynamic programming approach for on-line trajectory optimization of an aircraft in 4-dimentional space.

Tomlin, *et al.* (a), considers conflict resolution in two different ways as non-cooperative and cooperative. Non-cooperative conflict resolution is based on zero-sum pursuer-evader game theoretical modeling. The optimal control techniques and Hamiltonian formulation are utilized. In the case of cooperative conflict resolution the maneuvers generated by potential field approach are performed. In (Mesterton-Gibbons, 1992), a detailed introduction to game theoretical modeling is given with many examples. Potential field approach is used also in (Tomlin, *et al.*, 1998; Tomlin and Ghosh, 2000) for conflict resolution. In (Bosc and Dean, 1997; Ebby and Kelly), approaches based on charged particle, which can again be considered as potential field approaches, are used. Genetic algorithm is applied to conflict resolution in (Alliot, *et al.*, 1992). In all these only algorithmic solutions for conflict resolution are developed, but nothing is said on a negotiation based structure to solve the conflict. In (Clements, 1999; Bicchi and Pallottino, 2000), optimal control techniques are utilized to solve the conflicts. In (Clements, 1999), the situation of two conflicting aircrafts with constant velocities is considered. Only one of the planes make extra maneuver to solve the conflict and the other does not change its direction. This is performed in an optimum manner with Hamiltonian formulation.

Faratin, *et al.* (1998), presents a detailed study of negotiation. There, negotiation is taken as an offer-counter offer process, and the associated principles are introduced. The tactics dependent on time, resource, and behavior are proposed and the strategies as a combination of these tactics are pointed. Bui, *et al.* (1999), outlines an agent-based framework for building decision support systems and suggests structures for different kinds of software agents. In (Özdemir, 2001), a fuzzy rule based negotiation system is developed. The modified form of this scheme is utilized in applications of this research.

3. CONFLICT AND CONFLICT RESOLUTION

Each aircraft in the airspace has its optimized fly-paths. These paths are optimized according to the goals of each agent, in a global manner. The optimization criteria can be based on fuel consumption, atmosphere conditions, maneuverability of the aircraft, timing considerations, passenger comfort, etc. The structure of the plane, the pilot preferences, the task to be accomplished, or any other thing may affect the weight of cited criteria in the cost function of the optimization. As a result each aircraft has different optimization functions for path construction, and even an aircraft's cost criteria may change from time to time and situation to situation. Although the aircraft paths in certain areas may be constructed by optimization, it is impossible to foresee all the air-traffic in an aircraft's flight. Hence, there is always the possibility of any two flight-paths cross each other at a point at the same time and the aircrafts may crash each other, which is called *conflict*.

The accepted formal definition of the conflict is given in terms of the accepted minimum separation criteria between aircrafts. This criterion is 1000 feet vertically and 3 miles horizontally around airport, 5 miles horizontally elsewhere in the en route environment. Since the free flight is to be applied mostly in the en route the concern for the free flight conflict resolution techniques is the 5 miles limit. In fact this 5 miles standard comes from the technical limits of the radar, which completes a scan every 12 seconds (Perry, 1997). When the satellite-based ADS technology is implemented on a large scale, this 5-miles separation standard can be significantly reduced, and hopefully the free flight system will have much less separation standards. However, currently this standard is in order and the applications here will assume 5-miles separation. Furthermore in (Tomlin, *et al.*,b), the detection zone defined by the radius of aircraft's sensing capability is suggested to be 100 miles. This range could be of concern for the conflict resolution algorithms to operate in general applications.

As mentioned before general conflict situation formalizations and resolution techniques for free flight are mainly concerned with the en route flight. The en route flights of aircrafts are generally constant speed, linear, constant level cruise flights. The solutions of concern are preferably maneuvers that change the direction of the flight, in the same level, with constant speed. This is what pilots prefer for flight quality and passenger comfort. Henceforth, the conflict formulation and resolution techniques in this research are in accordance with this preference: constant speed, level maneuvers to come over the conflict, and catching the previously planned route again.

Two conflicting aircrafts have their preplanned, probably linearly directed, routes that cross each other at the same time. In order to solve the conflict, at least one of them should change its route in near region of the conflict. But it will be fairer if both of them deviate from their routes. Of course, each one will want to deviate less from its path. Then the conflict resolution problem can be considered and modeled as a zero-sum game (Mesterton-Gibbons, 1992), competing on the airspace. This is the point where negotiation is in effect. Negotiation is used to reach an agreement on the amount of deviations from optimal paths.

4. NEGOTIATION

In an autonomous multi-agent system it is frequently required that the agents cooperate to accomplish a task. This is necessary "either because they do not have sufficient capabilities or resources to complete their problem solving alone or because there are interdependencies between agents" (Faratin, *et al.*,1998). In situations of competition between agents for some resources or, in order to spend less energy or time, negotiation is used to solve the problem in a fair way. Agents make negotiation on the resources, try to persuade each other, and the problem is solved when an agreement is achieved. A quotation in (Faratin, *et al.*,1998) describes negotiation as, "a process by which a joint decision is made by two or more parties. The parties first verbalize contradictory demands and then move towards an agreement by a process of concession making or search for new alternatives".

Negotiation is generally processed by iterative rounds of offer and counter offer, and it stops when an agreement is achieved between two parties. Then, in a situation of negotiation the following should to be considered - both for building the structure of the agents and for constructing the negotiation domain:

- The issue over which negotiation takes place.
- The reasoning model for making new offers.
- The agreement criteria (acceptance and rejection criteria).
- The protocol for negotiation (the structured communication module for sending and receiving new offers and informing about acceptance and rejection of previous offers).

5. APPLICATION OF NEGOTIATION TO CONFLICT RESOLUTION

5.1 The conflict resolution domain for negotiation.

In this application it is assumed that both aircrafts subject to conflict have their optimum paths to follow, however they have to modify their paths because of the conflict. It is assumed that each aircraft desires to make the modification with minimum deviation from its optimum path. Modifications will be made with incremental clockwise deviations from the path that directs to the target position from the instant position. The subject of the negotiation will be the deviation angles of each aircraft.

Clock-wise turning is forced to define the 'rule of the road'. When the direct head-on conflict is considered (Fig. I), the clockwise turning of directions of both aircraft will result in increasing the distance from the other one. Since a minimum predefined distance should be sustained, the more one of the aircrafts deviate, the less will the other deviate. Hence this situation can be considered as a zero sum game modeling. This underlies the modeling of the presented conflict resolution domain for negotiation. However, the zero-sum game situation is not valid for all conflict situations, when each clock-wise turning is considered. In Fig. II., aircraft 1 will approach to aircraft 2 if it makes the indicated α turning, and this will increase the necessary angle β that aircraft 2 should turn. As a result concession of aircraft 1 does not result in a less concession of aircraft 2. Hence the situation is not a zero-sum game, when the turnings are considered one by one. However, when the whole maneuvers are considered as the sum of all deviations, it is valid that the more one aircraft deviates from its optimum direct path, the less will the other deviate from its optimum direct path. Hence, the zero-sum game modeling is still valid if the whole action is considered, and this gives way to application of negotiation for conflict resolution.

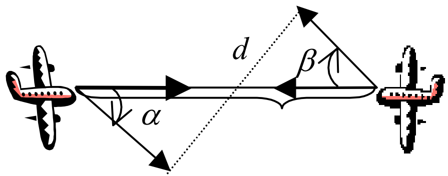

Fig. I. Direct head-on conflict situation.

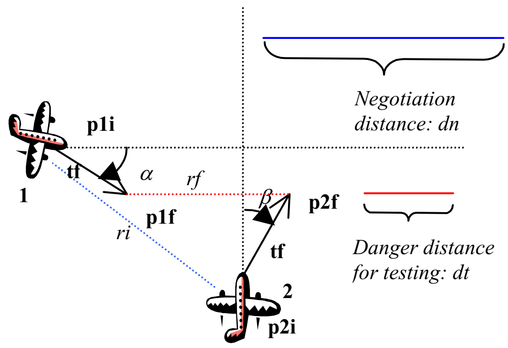

Fig. II. Variables used in negotiation and testing phases.

Negotiation starts when two aircrafts enter a predefined region of negotiation, which is determined by the distance between the aircrafts. Which aircraft will start negotiation first is determined randomly in simulations. It is assumed that in real applications it would be possible to choose the starter as the one that is first to send the necessary signal to the other. The algorithm, considering aircraft 2's offering process, can be summarized as below. Figure 2 shows the variables used in the negotiation process.

1. If the distance between the two aircrafts is less than the negotiation distance, negotiation starts. (Start negot iation if **ri<dn.)**
2. Each aircraft determines the direction from its instant position to its target position.

3. Aircraft1 makes an offer of α degrees deviation. Calculates its final position it will arrive after a predefined time range, **tf,** with this deviation (**p1f**). Sends these to aircraft 2.
4. Aircraft2 calculates its new offer considering the other aircraft's and its own previous offerings. Comes up with β and **p2f.**
5. Tests the other aircrafts offering, namely compares **p1f** and **p2f**.
6. If the distance between **p1f** and **p2f** is smaller than the danger distance it rejects aircraft1's offering, sending its own offering β and **p2f.** If the distance is larger, then it accepts the other's offering and negotiation stops with agreement on α and β.
   - Reject if $rf<dt$.
   - Accept if $rf \geq dt$.
7. If aircraft1's offering is rejected aircraft1 takes the offering of aircraft2 and makes its new offering increasing its previous offering. Tests it and rejects or accepts aircraft1's offering. This negotiation goes on till an agreement is achieved.
8. At the end of an agreement, it is guaranteed that after navigating in the agreed directions the distance between the aircrafts will not be less than the danger distance. The aircrafts navigate in the agreed directions and come to their new positions to begin a new negotiation.

5.2 The rule based negotiation model.

The negotiation model used in conflict resolution is based on a fuzzy rule based system (Özdemir, 2001). Each aircraft has its rule base relating its new concession to previous concessions of each aircraft. In other words, it increments its angle according to the previous increment each aircraft has made (Fig. III .).

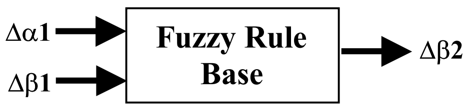

Fig. III. Determination of new concession depending on the previous concessions, from the view of aircraft 2.

The logic underlying the rules is as follows:

- If the previous own concession of the aircraft *(Δβ1)* is small, make a large concession *(Δβ2)*.
- If the previous own concession of the aircraft *(Δβ1)* is large, make a small concession *(Δβ2).*
- If the concession of the other aircraft *(Δα1)* is small, make a large concession *(Δβ2).*
- If the concession of the other aircraft *(Δα1)* is large, make a small concession *(Δβ2).*

With these logic the rule table is as in Table 1. The membership functions are shown in Figure IV.

This rule based offering model needs two previous offers of the negotiators. Hence the first and second offers should be made externally. In the simulation these two initial offerings are done using two different functions. These first offers should be considerably small in order not to exceed the initial offerings of the rule base, besides they should take the positions of the aircrafts into account for the initial offers. The functions used are as follows:

$$\Delta\beta 2 = \left(\frac{ri}{(dn-dt)}\right)^2 \times \frac{\pi}{200} \quad \text{, for the first offer} \quad (1)$$

$$\Delta\beta 2 = \left(\frac{ri}{(dn-dt)}\right) \times \frac{\pi}{200} \quad \text{, for the second offer} \quad (2)$$

Table 1 Rule table for the offering process.

Δβ1 \ Δα1	**Z**	**S**	**M**	**B**
Z	VB	B	M	S
S	B	M	S	VS
M	M	S	VS	Z
B	S	VS	Z	Z

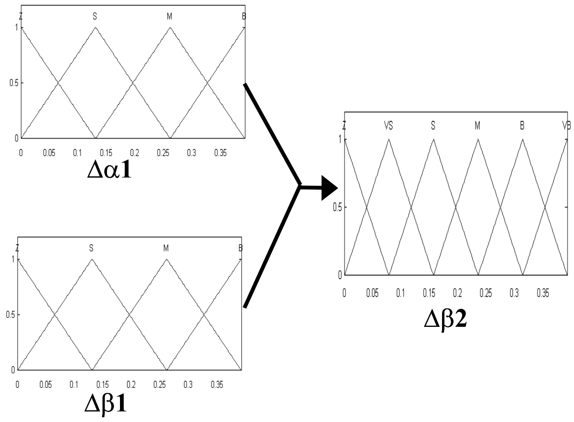

Fig. IV. Membership functions for the variables of offering process.

5.3 Mathematical formulation of negotiation based conflict resolution for the direct head-on conflict.

Here will not be given a general mathematical proof of the negotiation based conflict resolution described above. Rather will be given a mathematical formulation of the special case of direct head-on conflict for the negotiation domain. This formulation gives idea about the principles that the negotiation model is based on. It would be possible to generalize the formulation to any conflict situation following similar approaches, but then occurs massy mathematics that could be handled with computers. Since the aim here is to give the underlying idea rather than a full analytical proof, it is contented with the special case formulation.

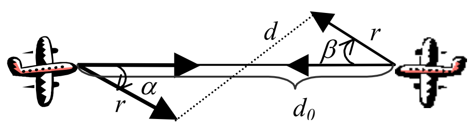

Fig. V. Direct head-on conflict for formulation.

Consider the direct head-on conflict in Figure V. Here the worst case is considered such that the aircrafts have already approached as much as the minimum distance, hence $d_0=d_{min}$. α and β turnings should satisfy that $d>d_{min}$. The problem is to show that the negotiation algorithm is able to find such α

and β couples.The distance between the aircrafts after the turnings is given by,

$$d = \left[r^2 \left(2 + 2\sin(\alpha+\beta) \right) + d_{\min}^2 - 2 d_{\min} r \left(\cos\alpha + \cos\beta \right) \right]^{1/2} \quad (3)$$

where r is the distance with which the next position is determined. It is assumed that both aircrafts are flying with the same velocity, v. If the negotiation is made for the positions that aircrafts will reach after t_n seconds, then $r = v \times t_n$. The algorithm requires $d > d_{min}$. When Eq.69 is considered this corresponds to $\frac{r}{d_{\min}} \geq \frac{\cos\alpha + \cos\beta}{1 + \sin(\alpha+\beta)}$. Let's define the right hand side as,

$$g(\alpha, \beta) = \frac{\cos\alpha + \cos\beta}{1 + \sin(\alpha + \beta)} \quad (4)$$

The function $g(\alpha, \beta)$ is monotone decreasing with respect to the increase in both α and β, with a maximum value of 2 and minimum value of 0.

The negotiation is based on iterative rounds of offer and counter offer where offers are increased iteratively according to the rule base based on previous concessions. As a result the negotiation module generates monotone increasing (α, β) couples at each iteration. If it is assumed that $0 < \alpha, \beta < \pi/2$ this can be formulated as follows,

$$\begin{matrix} \beta_{k+1} = f_\beta(\beta_k, \beta_{k-1}, \alpha_k, \alpha_{k-1}) \\ \alpha_{k+1} = f_\alpha(\alpha_k, \alpha_{k-1}, \beta_{k+1}, \beta_k) \end{matrix}, \quad \left\{ \begin{pmatrix} \alpha \\ \beta \end{pmatrix}_k \right\}_{\begin{pmatrix} 0 \\ 0 \end{pmatrix}}^{\begin{pmatrix} \pi/2 \\ \pi/2 \end{pmatrix}} : \textit{monotone increasing} \quad (5)$$

The negotiation module produces increasing α and β in the range (0,0)-(π/2, π/2). This will result in the decrease of $g(\alpha,\beta)$ from 2 to 0 monotonically. Then it is assured that (by the mean value theorem of calculus) the requirement $g(\alpha,\beta) < r/d_{min}$ will be achieved somewhere for some (α,β) generated by the negotiation module whatever the initial suggestion is.

5.5 Simulation results.

Simulation results for three conflict situations are given in Fig. VI.

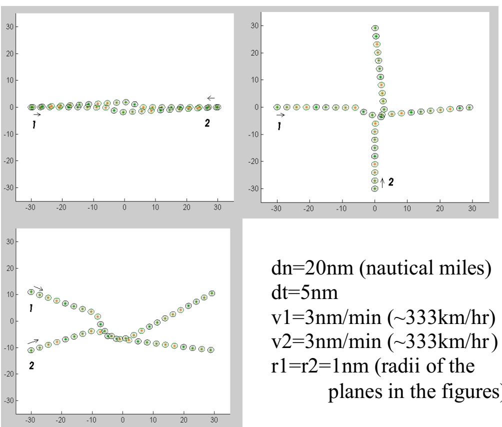

Fig. VI. Simulation results of the negotiation based conflict resolution for three different conflict situations.

In these figures small arrows and numbers indicate the aircrafts and the paths they fly through. All the conflicts are resolved successfully with the minimum separation criteria of 5nm satisfied. The circles in the figures indicate the positions of aircrafts at each minute starting from their initial positions. The parameters used in these simulations are also depicted near the figures.

5.6 Generalization of negotiation based conflict resolution for three aircraft conflicts

In generalizing the algorithm to three aircraft case the basic idea is determining the angle of deviation from the direct path by negotiating with the other two aircrafts. There are three aircrafts negotiating. Since the negotiation process is based on taking offer and making new offer, the negotiation between three aircrafts should be turn by turn. At each step an aircraft should take the offers of the other two, make its new offer and accept or reject the situation of current offers comparing the others' offers with its new offer. It should be noted that what it rejects or accepts is not the offer of any of the aircrafts but the situation that would result with the current offers of all three. Hence, in the rejection case, all the offers should be updated regardless of their being the problematic one or not.

In section 5.2 a fuzzy-rule based reasoning is used considering the other aircraft's previous concession with current aircraft's previous concession (Fig. III). In the three aircraft case the same reasoning will be used. But this time there will be two 'other' aircrafts. Therefore, the maximum of the two other aircrafts' concessions will be used as the 'other concession', with aircraft's own previous concession.

Regardless of the points mentioned above, three aircraft conflict resolution algorithm is similar to the two aircraft case given in section 5.1. Fig. VII is a modified version of Fig. II, for three aircrafts. It shows the variables used in the negotiation process.

In Fig. VIII, the simulation results for three different three aircraft conflict situations are given. In the first two figures three aircrafts are conflicting at the same time and the algorithm has overcome the situation. In the bottom figure the three aircrafts are not conflicting at the same time, but still the three aircraft negotiation is used to show that it covers the two aircraft negotiation case. Aircraft 1 is in conflict with aircraft 2 first, and later with aircraft 3. As it is seen aircraft 3 is not affected by the resolution of the conflict between aircraft 1 and 2 although it is involved in the negotiation. The parameters used in the simulations are depicted on the figures. The parameter dn in these figures should be taken as the distance that the negotiation starts when the distance between any two of the aircrafts is less than that.

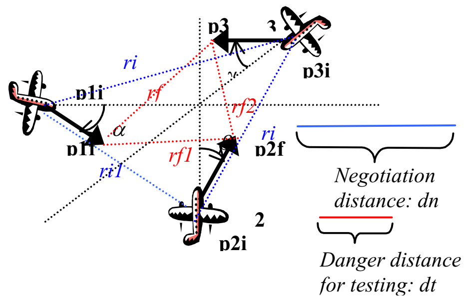

Fig. VII. Variables used in negotiation and testing phases of the three aircraft conflict resolution.

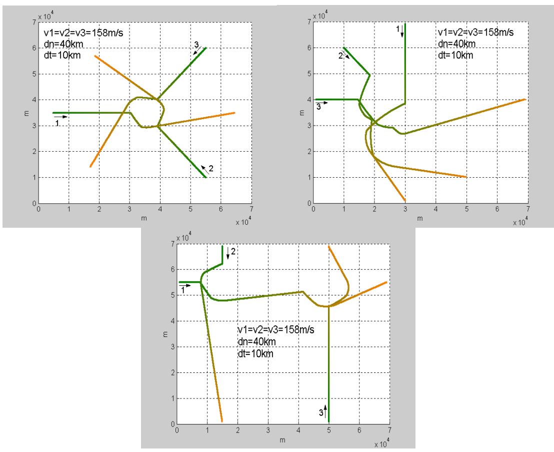

Fig. VIII. Solutions generated by the negotiation algorithm for three aircraft conflict situations.

6. CONCLUSION

Current air traffic control systems are forced to be replaced with more decentralized and autonomous control systems where each aircraft is defined as a separate autonomous agent. Cooperative conflict resolution is one of the basic problems to be solved for such a free flight system. It is important for conflict resolution algorithms to pay attention to different optimization criteria of aircrafts. In this research negotiation is proposed for such a cooperative conflict resolution. Aircrafts negotiate to achieve an agreement on how much concession each will make for resolution. The conflict resolution problem in free flight and negotiation are described. Then a domain of handling conflict is introduced for application of negotiation to conflict resolution. After presenting the simulation results for two aircraft conflicts the technique is generalized for three aircraft conflicts. The method proposed is successful in solving both two and three aircraft conflicts.

The advantages of the proposed algorithm over the other techniques mentioned in the section 2 are that the algorithm has a testing facility, and it enables considering different criteria of aircrafts. Any path constructed by the negotiation based conflict resolution is guaranteed to be non-conflicting at each iteration of the algorithm. Otherwise an agreement wouldn't be achieved and the algorithm would have failed to solve the conflict. The reasoning module for making the offers is a rule-based system, in which the rules can be modified easily according to different criteria. The thing to be done is to determine the rules relating the new offer with the parameters of diverse criteria.

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