HIPS and its Application to Oceanic Control

Andy Price

Head of ATM Systems Development

Department of ATM Systems Research

R&D Directorate, NATS

Colin Meckiff

Head of Innovative Support Tools

Eurocontrol Experimental Centre, Brétigny

Abstract:

The Highly Interactive problem Solver (HIPS) is a graphical planning tool, originally developed by Eurocontrol for future domestic en route applications within the Programme for Harmonised ATC Research in Eurocontrol (PHARE). As part of a project to upgrade the existing Oceanic Flight Data Processing System (FDPS) at Prestwick, Scotland, a prototype version of HIPS has been developed to assess its applicability for Oceanic Control purposes. This paper presents the basic HIPS concepts, and then describes how the technique has been adapted for the particular oceanic application at Prestwick. The results of the Oceanic HIPS trial are presented, and the paper concludes by exploring further work which would need to be undertaken to develop Oceanic HIPS to an operational standard and examining other potential ATM applications for the approach.

HIPS and its Application to Oceanic Control

1. Introduction

The Highly Interactive Problem Solver (HIPS) is a graphical planning tool developed under the Programme for Harmonised ATC Research in Eurocontrol (PHARE) (Ref 1), involving participation by the Eurocontrol Agency and Member States. It was aimed initially at enabling an en route planning controller to generate a conflict−free clearance through his or her sector in domestic European airspace.

During the requirements phase of a UK National Air Traffic Services (NATS) project to upgrade the current Flight Data Processing System (FDPS) at the Scottish Oceanic Area Control Centre (OACC) at Prestwick, HIPS was identified as a candidate tool to provide an effective display of traffic information, and to support conflict resolution requirements for FDPS2, the new system.

In order to evaluate the benefit of the HIPS approach in an oceanic context, a study was undertaken by NATS, supported by the Eurocontrol Experimental Centre (EEC) Brétigny, during the latter half of 1996. HIPS was modified to reflect oceanic separation standards and operational concepts and a prototype was developed in order to undertake real time trials on the NATS Research Facility (NRF) at the Air Traffic Management Development Centre (ATMDC) at Bournemouth.

This paper presents the basic HIPS concepts, and then describes how HIPS has been adapted for the particular oceanic application at Prestwick. A detailed treatment of oceanic separation standards is provided, with particular emphasis on longitudinal separation standards which differ significantly in concept from the domestic en route separation standards, for which HIPS was originally designed. The results of the Oceanic HIPS trial are presented, and the paper concludes by exploring further work which would need to be undertaken to develop Oceanic HIPS to an operational standard and examining other potential ATM applications for HIPS.

2. HIPS Concept

2.1 Background and context

Many attempts have been made to model and thus automate conflict resolution using methods ranging from knowledge−based and geometrical techniques through to more exotic approaches such as genetic algorithms and force fields. These approaches take the view that it is, or will soon be, possible to entrust computers with complete responsibility for producing solutions to air−traffic problems. This does not necessarily imply human−free operation, since there is generally the suggestion that solutions could be presented to the controller in the form of ‘advisories’ to be accepted or rejected according to his own judgement. One cannot, however, bypass the fact that in such cases it is actually the computer which is working to ‘understand’ and solve the problem.

A simpler level of automation has been developed using ‘what−if’ processes which generally involve trial and error techniques − these often have the advantage that they are more or less compatible with current operational practice, with the controller himself working to find solutions. They share a common drawback, however, in that the presence or absence of conflicts in any proposed solution is definitively confirmed only ***after*** the proposal has been inserted. In other words, there could be several trial and (literally) error cycles before a conflict−free solution is found.

The HIPS approach uses a system of geometrical projections and transformations of trajectories in 4D to show aircraft−free manoeuvre space ***a−priori***, so that the controller can see where solutions are to be found before trying a new proposal. The advantages of the approach include:

- The search process is speeded up since suitable solutions can generally be found at the first attempt.
- By explicitly showing free airspace, controllers are made aware of solutions which they may not have previously considered, and some of these solutions could be significantly better than those they are in the habit of applying.
- It becomes possible to insert better solutions, for example to minimise deviations or leave aircraft at their preferred cruise level for longer.

2.2 The concept of no−go zones

As a starting point this technique requires that each aircraft in the system has a predicted 4D trajectory with known (or estimated) uncertainty. In principle this requirement is sufficiently loose that basic flight plan information can be used as a ‘trajectory’, and this is the case for the oceanic application described in this paper. However for radar environments (for which the technique was originally developed) large uncertainties in trajectory predictions can render the approach ineffective for conflict resolution purposes. This is not, in fact, a shortcoming implicit to HIPS itself − it is an evident consequence of trying to apply automation in a situation of high uncertainty. One of the features of the HIPS approach is that the explicit nature of the graphics tends to show up difficulties in the assumed scenarios, particularly with respect to elements such as the quality of trajectory prediction, separation standards etc.

Using the trajectory information, HIPS provides the controller with a simple picture to enable him or her to rapidly assess the possibilities available in a given problem situation, and to simulate alternative manoeuvres for aircraft. These manoeuvres result in a dynamic update of the display as necessary. Three picture types may be generated:

- a conventional horizontal (plan) view,
- a vertical view, corresponding to a vertical 'slice' along the route, and
- a view generated in an abstract (and less intuitive) speed/time dimension.

To get an idea of how this works in plan view, consider Figure 1(a). The aircraft of interest, EEC123, is traversing our airspace from west to east. Unfortunately, its trajectory is predicted to be in conflict with that of another aircraft, EEC456, which is travelling in a northerly direction. The portion of trajectory for which there is a loss of separation (according to the chosen standards) between EEC123 and EEC456 is marked with a thicker line. If it is now decided to solve the conflict by changing EEC123's course, various options could be tested assuming a certain point as our start of turn, and for each one a conflict check could be made, with any loss of separation marked in bold as before. This process could correspond to a set of trial plans.

The essence of the HIPS approach is to eliminate the need for such a process by effectively performing a series of trials, and presenting the results *a−priori* in the form of 'no−go' zones, which correspond to the grouping together of all the bold lines, as shown in Figure 1(b). This provides a visual device by which the controller can see, in this case, that the conflict can be solved by a relatively small southward, or larger northward deviation to EEC123.

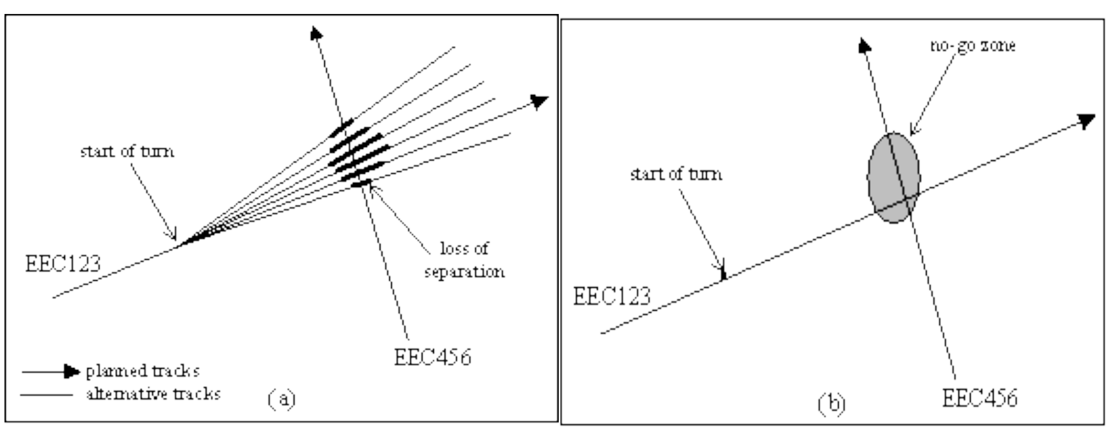


Figure 1 : Derivation of no−go zone

2.3 Practical implementation of no−go zones

The type of technique shown in Figure 1 illustrates the principle of no−go zones, but in practice it needs to be improved for at least three reasons:

- It generates zones based upon a heading change from a known start−of−turn point, which in practice means that a controller must first choose this point. This requirement could significantly increase the number of interactions required to operate the tool.
- The no−go zones can only be calculated relative to a single trajectory segment. Any change of aircraft heading requires that assumptions be made as to the subsequent intentions of the aircraft and the possible manoeuvres which may be applied to it.
- The example given above is linear, whereas in reality aircraft change speed, heading and altitude, rendering this simple example rather unrealistic.

This section will briefly outline some of the techniques that have been developed to solve these problems with, in particular, an introduction to the concept of manoeuvre surfaces.

2.3.1 The use of manoeuvre surfaces

A manoeuvre surface may be defined as the future locus of points a particular aircraft may sweep out for a given type of manoeuvre. With the simple heading change type of manoeuvre shown in Figure 1, the manoeuvre surface in a horizontal (2−dimensional) plane is a disc whose centre is the start of turn. In the 3 dimensions of x, y (the horizontal plane) and time, it is a cone whose origin is the start of turn. Figure 2 illustrates this: Consider a subject aircraft describing a linear path in the horizontal (x, y) plane. When a third (time) dimension is added, the path becomes a rising arrow. Both the 2D (x, y), and the 3D (x, y, t) arrows are shown on the diagram in bold. If the subject aircraft turns, with the origin as the starting point for the turn, the range of possible new trajectories will describe a cone, which is referred to as the manoeuvre surface.

Now consider a second (environmental) aircraft. This is shown as a trajectory in the same 3D space, and is surrounded by a separation ‘tube’ which, for the purpose of this example, is of constant radius. A no−go zone for the subject aircraft, created by the presence of the environmental aircraft, is then defined by the intersection of this tube with the manoeuvre surface. In the example of Figure 2, if the subject aircraft is turned to the right by 30−40 degrees, it would find itself in conflict at some point in the future with the other aircraft. In order to produce a display useable by a controller, it is possible to project the 3D no−go zone from the 3D manoeuvre surface down onto a conventional 2D plan view display as shown.

Note that, as before, the illustration assumes that the aircraft involved are in stable flight, at constant speed and can turn instantaneously. Any deviation from this will have the effect of distorting each of the drawn objects to give, for example, an irregular ‘cone’ for the manoeuvre surface.

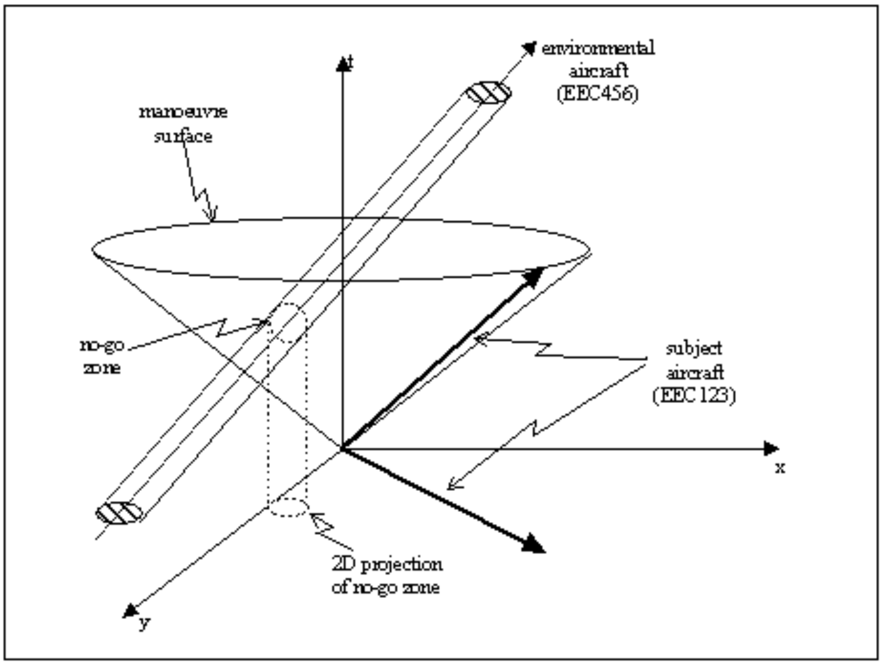


Figure 2 : Cone−shaped manoeuvre surface

To solve problems of start−point dependency and complex routes, the use of an abstract ‘bilinear’ manoeuvre surface is proposed. This is an alternative to the disc (2D) or cone (3D) surface introduced above. Instead of defining the surface using a turn from a given start−point, it is produced by generating a set of alternative trajectories by offsetting from the subject trajectory according to a set of rules (Ref 2). Figure 3 shows a bilinear parametric surface in 2 dimensions for one segment of a trajectory, with two alternative trajectories shown at displacements *s* and *2s* from the subject. Alternative trajectories produced in this way can then be used in tests for loss of separation.

In 3 dimensions (x, y, t) the surfaces take the form of a connected sequence of planes rising up in the time axis. A major difference between the case of a cone−shaped surface and the bilinear surface is that discontinuities in the trajectory can be handled more smoothly in the case of the bilinear approach − Figure 4(a) shows the case of a sequence of ‘cone’ surfaces, where the cones are disconnected, and the start point of each cone is fixed to that foreseen in the original trajectory prediction. Any editing activity on the trajectory will invalidate the second or subsequent cones. Figure 4(b) shows the bilinear surface approach, where the surfaces are connected, and where edits can be made without discontinuous changes in the surfaces.

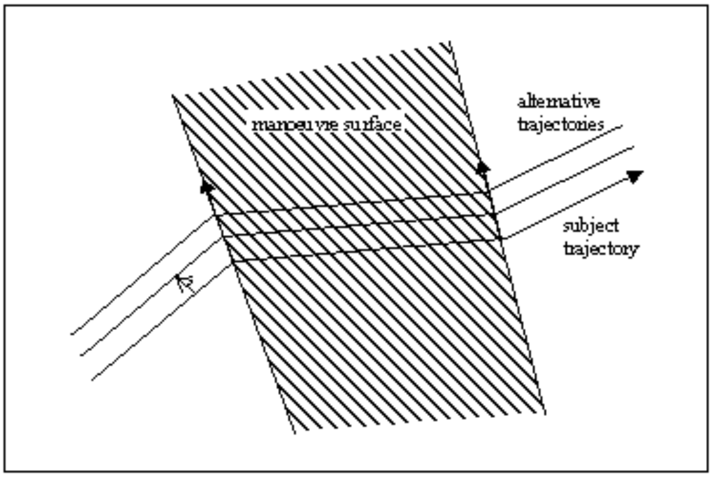


Figure 3 : Bilinear manoeuvre surface

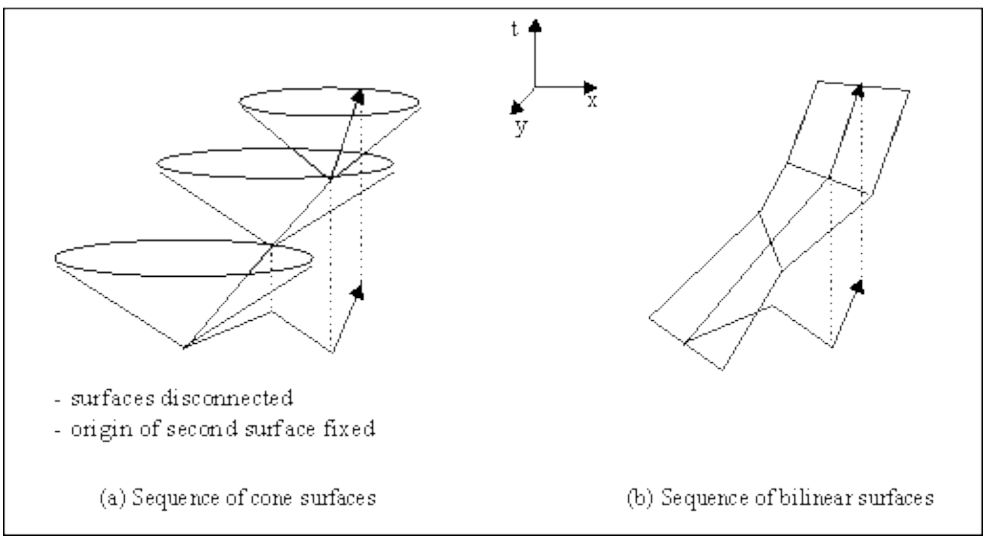


Figure 4 : Sequencing of manoeuvre surfaces

Having produced a manoeuvre surface for a subject trajectory, generation of no−go zones becomes a problem of intersecting the ‘tubes’ (made up of the trajectories of environmental aircraft, separation standards and error components) with this surface. See Ref 2 for a description of some of the techniques used for this.

2.3.2 Conflict detection and separation standards

As with any resolution tool, the objective is evidently to find a solution which is conflict−free, so the definition of a conflict is key. For this tool we define a conflict as an infringement of minimum separation standards. That is, wherever the distance between the predicted trajectories falls below the specified minima at a given future moment in time, there will be a conflict. Current versions of en route HIPS incorporate a comprehensive model of separation comprising four elements:

1. Horizontal separation defined as a circular exclusion ‘disk’ (5Nm radius) around the aircraft.
2. Vertical separation, normally 1000ft, above and below the aircraft.

These two elements correspond to standard radar separations, and their combination gives the appearance of a cylindrical volume around the aircraft.

3. Thirdly, temporal separation is implemented by effectively ‘sweeping’ the cylinder forward and backward along its trajectory. The volume swept out by this method defines an exclusion zone. The amount by which the volume is swept is defined by parameters which may be set to zero.
4. Finally, longitudinal errors are modelled using a similar process of sweeping back and forth, total swept distance being a sum of these errors and the temporal element. Longitudinal errors for pairs of trajectories are combined and normally incorporate a simple time dependency, so that the value of the error will increase with time into the future consistent with Ref 3.

The effect of uncertainty can be explicitly shown on the HIPS diagrams: Extending the example of Figure 1, we could perform a similar exercise to develop no−go zones at two different look−ahead times. Figure 5 shows the situation 20 minutes and 5 minutes ahead of a predicted conflict.

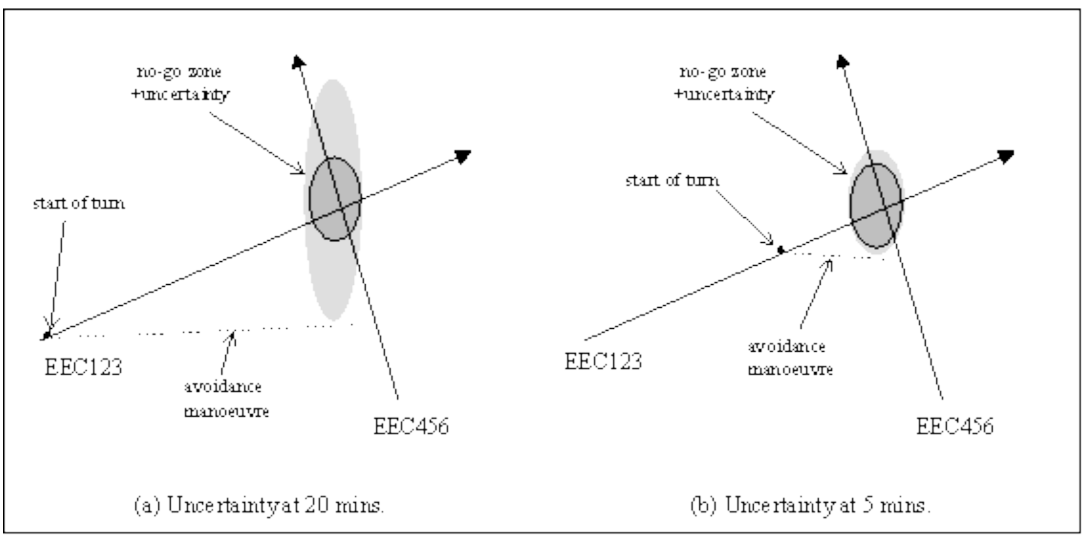


Figure 5 : Effect of uncertainty on no−go zones

The conflict zone calculated without longitudinal error is shown by the darker ellipse, and the contribution of the longitudinal uncertainty is shown as a lighter ‘cloud’. In Figure 5(a), the uncertainty is quite large. meaning that to be sure of finding a conflict−free solution, the controller would need to send aircraft EEC123 significantly off−track, whereas in Figure 5(b), the uncertainty is somewhat reduced, so the manoeuvre can be much smaller. (Note, however, that the overall route length increase is not necessarily less in the second case). Thus HIPS can give an explicit illustration of the principle of an optimal manoeuvre time, which is a trade−off between prediction uncertainty and the severity of the manoeuvre which needs to be applied.

In programming terms separation standards are implemented as external (callback) procedures, which allows an easy switch to different sets of standards according to the application. This feature was used to redefine the separations for the oceanic application as described later in this paper.

2.4 Trajectory editing

Once the no−go zones are displayed in an appropriate way, it is a relatively simple matter for the controller to edit the subject trajectory using simple mouse click and/or drag operations. In general editing functions would allow for adding, deleting and moving constraint points, insertion of doglegs etc. in horizontal, vertical or speed/time dimensions. It is possible to combine manoeuvres in all three dimensions for one or several aircraft − the diagrams are always updated in real−time to maintain an up to date picture. An example of a combined manipulation would be to increase the speed of one aircraft involved in a conflict, and reduce the speed of another, the diagrams providing the visual cues to allow instant assessment of the consequences of the joint manoeuvre.

3. Oceanic Operation

3.1 Oceanic airspace

Oceanic airspace falls outside the sovereignty of individual states. By international agreement, ICAO has authority for ATC within oceanic airspace. Responsibility is then contracted to specific national administrations for the provision of ATC services within specific oceanic regions.

UK NATS has responsibility for the provision of ATC in the Eastern part of the North Atlantic in the Shanwick Flight Information Region (FIR), which stretches north to 61N, west to 30W and south to 45N. The Shanwick FIR is controlled from the NATS' Scottish Oceanic Area Control Centre (OACC) located at Prestwick. Bordering FIRs over the North Atlantic are controlled by the USA, Canada, Portugal and Iceland.

The majority of the traffic within the Shanwick region flies between Europe and North America, generally being handed over between the Shanwick and Gander FIRs, as shown in Figure 6. However, a proportion of flights take other routes, for example Portugal to Iceland, or Scandinavia to South America.

3.2 Organised Track Structure

To facilitate efficient ATC for aircraft flying between Europe and North America a system of organised tracks has been devised which extends across the entire oceanic airspace. These tracks are redefined every 12 hours to take account of forecast meteorological conditions and the 'tidal' flow of traffic over the Atlantic (ie eastbound in the early morning (UK time) and westbound in the afternoon). Prestwick is responsible for drawing up the optimum westbound tracks, while NAV Canada handles the eastbound track system. The organised track structure (OTS) will typically consist of 4 or more routes, each with a pre−defined set of flight levels as shown, for example, in Figure 6.

The bulk of westbound flights controlled from Prestwick use the OTS. However, a significant number do not, and these are termed 'random' tracks. There is an increasing pressure from airlines to permit a greater proportion of random tracks, thereby allowing greater operational flexibility by the operators. It is likely that, over time, the proportion of random traffic in oceanic airspace will increase significantly.

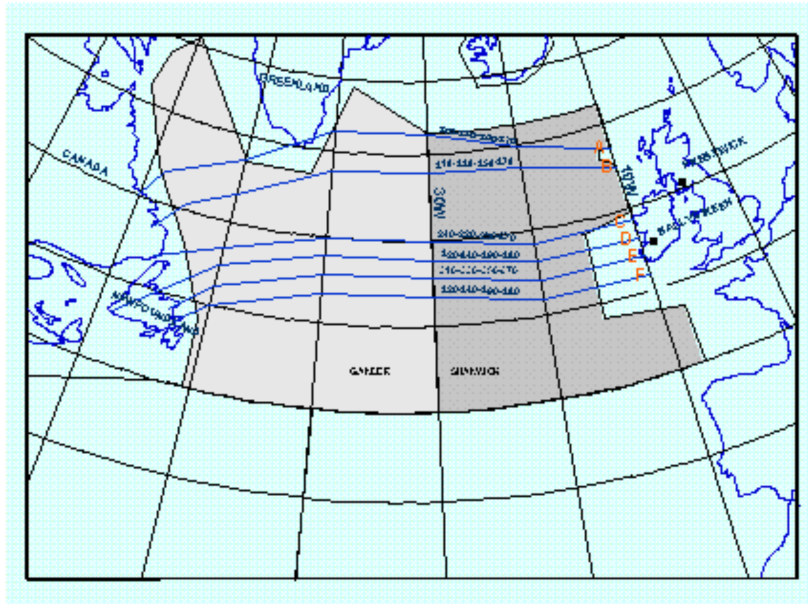


Figure 6 : Oceanic Airspace and the Organised Track Structure

3.3 Controller Roles

3.3.1 Planning Controller

Prior to entering oceanic airspace, an aircraft must be in receipt of an oceanic clearance. The planning controller is responsible for issuing such clearances, typically 40 minutes prior to oceanic entry time. The oceanic clearance will cover the entire oceanic transit from oceanic entry to landfall, including those portions of the flight through adjacent FIRs. Before issuing a clearance, the planning controller will assess the requested clearance against aircraft already cleared to enter the system. If the requested clearance is conflict free, then the requested clearance will be issued. However, it is likely that, in order to issue a conflict free clearance, amendments to the requested clearance will be required such as the use of a different track, a different flight level, or a change to the oceanic entry time.

3.3.2 En route Controller

En route controllers monitor the aircraft during their passage through Shanwick airspace. As there is no radar surveillance over the bulk of oceanic airspace, procedural control is used. Each aircraft transmits reports at regular intervals during its oceanic passage, providing position, time and flight level information. Any differences between the reported and expected information are reported to an en route controller who takes the appropriate action, which might include issuing a new clearance. The en route controller also handles any requests for changes from the pilot, for example a request for a higher level once fuel has been burnt off.

3.3.3 Support Roles

The planning and en route controllers are supported by a number of other ATC staff. The Clearance Delivery Officer (CDO) is responsible for communicating with aircraft over VHF to transmit the clearances issued by the controllers, and pass requests from the aircraft back to the controllers. This organisation effectively frees up the controllers to consider clearance requests without getting involved in real time R/T communication with the aircraft.

Once over oceanic airspace, aircraft are generally out of VHF radio range. R/T communications are then handled over HF radio via the HF radio station at Ballygireen in Ireland. Communications between Prestwick and Ballygireen are handled by telex.

3.4 Separation Standards

Separation standards within oceanic airspace are fundamentally different from domestic radar separation standards in two ways.

Firstly, there is a very much greater significance attached to longitudinal separation in oceanic flight. The required longitudinal separation is (typically) 10 minutes for aircraft following the same track and 15 minutes for aircraft following intersecting tracks. Changes in the angle of approach between intersecting aircraft tracks may result in changes to the separation standards required.

Secondly, the lateral separation standards required are very much larger than domestic radar separation standards. A radar separation standard of 5Nm is typical in domestic airspace, whereas in oceanic airspace, the basic lateral separation standard is 60Nm. The larger separation standard is required, basically because there is no independent check on aircraft position as there is no radar coverage in oceanic airspace, and thus significant allowance needs to be made for navigational inaccuracy and errors by the aircraft.

There are a number of complexities in the above simple statements of separation standard. For example, the separation standards vary depending on navigational equipment fit, in particular whether or not the aircraft conform to Minimum Navigational Performance Standards (MNPS) requirements. Also, the practical application of longitudinal separation standards varies depending on whether the preceding aircraft is slower or faster than the succeeding aircraft. Deemed lateral separation may be applied in some circumstances, and there are various other examples which illustrate the complex nature of a detailed expression of oceanic separation standards.

4. Mapping of HIPS to the Oceanic Concept

The HIPS concept outlined in Section 2 maps, in principle, very readily to the oceanic operation concept described in Section 3, more so, in fact than to the current domestic radar environment.

The HIPS concept is geared towards generating a single conflict−free trajectory, in advance, through a controller’s airspace sector. This is precisely the role of the oceanic planning controller, who generates a clearance for an aircraft’s entire oceanic transit prior to entry into oceanic airspace. This is in contrast to the current role of a domestic sector planner controller, who will typically clear an aircraft into his or her sector at a specific level and will agree the exit level with the next sector, but will leave tactical control of the aircraft within the sector to the tactical controller. Of course, HIPS was originally designed to satisfy a future PHARE concept which envisages a modified role of the domestic planner controller who, supported by datalink, would generate conflict free clearances through the sector, leaving the tactical controller to deal, principally, with non−datalink equipped aircraft, and any deviations from the planned trajectories.

HIPS allows modifications to a trajectory using any of the current operational practices used to modify requested clearances procedurally. These include modifications to speed, entry time, route and flight level. The graphical nature of HIPS operation allows the controller to create more complex clearances than would be possible with a conventional flight data display. HIPS therefore seems to be particularly suitable for generating clearances for aircraft following random routes, the proportion of which, as stated in Section 3.2 are expected to increase significantly.

HIPS is also readily compatible with the current sequential message processing oceanic operational concept. When a request for clearance message (RCL) is received from an aircraft, the planning controller assesses whether the requested clearance is acceptable, and may identify possible alternatives. Using HIPS, when a RCL message is selected for processing the requested clearance is displayed in HIPS as the current trajectory. All other aircraft with oceanic clearances would then be treated as environmental aircraft resulting in the display of no−go zones in the HIPS windows. By manipulating the aircraft trajectory in HIPS to generate a conflict−free trajectory, the controller would, in effect, be generating an alternative oceanic clearance which could be transmitted to the aircraft in the normal way via the CDO or, in a future development, via datalink.

5. Oceanic Separation Standards

5.1 Separation Standards Documentation

ATC procedures and standards in the UK are laid down in a CAA document, the Manual of Air Traffic Services (MATS). MATS Part 1 contains instructions which apply to all UK ATC units. Instructions which apply to a particular ATC unit are contained within MATS Part 2 for that Unit. The local definitions of the separation standards for the oceanic area are therefore laid down in MATS Part 2 for Prestwick.

The definitions and procedures in MATS Part 2 are derived from, and are intended to clarify, the relevant ICAO documentation, namely PANS−RAC (ICAO Doc 4444) and Regional Supplementary Procedures (ICAO Doc 7030/4). Additional guidance is provided in the North Atlantic Systems Planning Group’s (NATSPG’s) Document entitled ‘Application of Separation Minima (North Atlantic Region)’ Fourth Edition.

The reason for this apparent wealth of documentation is to clarify the interpretation of the (rather simply stated) basic separation standards in, as far as possible, all possible circumstances.

The definitions provided in these documents describe the separation required between aircraft in three dimensions: vertical, lateral and longitudinal. In principle, they should define whether, in any particular set of circumstances, two aircraft are separated. Unfortunately, from a HIPS implementation point of view, a number of uncertainties still remain, in particular relating to longitudinal separation.

The most significant issue is that the documentation states the required longitudinal separation standards in terms of time between aircraft, but without defining precisely what is meant by time between aircraft. When aircraft are ‘in trail’ on the same track, the definition of time between aircraft is trivial, but in many other circumstances, the precise definition of time between aircraft is open to considerable interpretation, but obviously, for any automatic system, such as HIPS, a precise definition of time between aircraft is required to determine reliably the boundary between what is acceptable separation and what is not.

5.2 Implementation of Oceanic Separation Standards in HIPS

5.2.1 Vertical Separation

In principle, the mapping of vertical separation standards to HIPS is straightforward. The basic vertical separation criteria of 1000’ below FL290 or 2000’ at or above FL290 are identical to the domestic en route criteria previously implemented in HIPS.

The one area of complexity relates to climbing and descending aircraft. In contrast to domestic HIPS, where vertical trajectories are modelled relatively precisely, for oceanic purposes, all flight levels encompassing the climb or descent need to be blocked for the maximum likely duration of the climb.

For implementation purposes, a climbing aircraft is modelled with a climb rate of 400 ft/min. Waypoints define the start and end of the climb region. All the flight levels involved in the climb, together with those corresponding to the vertical separation minima are blocked from the start of the climb until 10 minutes flying time after the anticipated time of climb completion. The additional 10 minutes flying time is included to allow for uncertainty in when an aircraft begins its climb.

5.2.2 Lateral Separation

The separation standards documentation permits lateral separation to be applied in degrees rather than nautical miles. This facilitates mapping of the separation standards to the OTS but, due to the spherical geometry involved, does, in some circumstances, allow an applied lateral separation less than the corresponding distances of 60Nm, 90Nm or 120Nm.

For implementation purposes in HIPS, this reduction in standard separation is expressed directly as a reduced required lateral separation. So, for example, in situations nominally requiring 60Nm separation, a separation standard of 54.5Nm is applied, corresponding to the minimum separation achieved using the degrees approach.

This approach also has the beneficial side effect that when no−go zones are displayed corresponding to adjacent OTS tracks either side of a requested track, a narrow corridor between the adjacent no−go zones is apparent, graphically confirming that the requested track is, in fact, conflict free.

One further difference between the interpretation of oceanic and domestic lateral separation standards relates to the distinction between separation between aircraft and separation between tracks. In domestic use, the lateral separation standard refers to separation between the continuously varying aircraft positions expressed as a point. For oceanic purposes, the lateral separation standard applies to the separation between the entire route portion over which lateral separation is applied (i.e. where longitudinal or vertical separation are not available). So, for example, in the case of crossing tracks, lateral separation could not be used, even if the actual distance between the was greater than 60Nm throughout the crossing manoeuvre. In this case, longitudinal separation as discussed in Section 5.2.3 below would have to be applied.

5.2.3 Longitudinal Separation

The situation for longitudinal situation is rather complex as outlined in Section 5.1 above. Longitudinal separations are expressed as times between aircraft, but in order to apply the required minima it is necessary to establish how the time between two aircraft should be measured.

A number of interpretations are possible, whilst still remaining compliant with the intent of the separation standards. The implementation used for the demonstrator version of Oceanic HIPS is described fully in Ref 4, with further detail concerning the relationship between temporal uncertainty and longitudinal separation standards being explored in Ref 5. Separations standards are defined for the following cases:

◊ Same Track
◊ Intersecting Track
◊ Diverging Tracks
◊ Parallel Tracks, Not Laterally Separated
◊ Reciprocal Tracks

Analysis of the separation standards suggested that an appropriate way to capture the required separation standards in all the above cases would be to address situations in which one aircraft was ‘following’ another independently from cases where the aircraft had not yet passed and were ‘approaching’ each other.

The following discussion, reproduced from Ref 4, illustrates the approach taken, which is then applied in detail to the cases listed above.

Separation for Following Aircraft

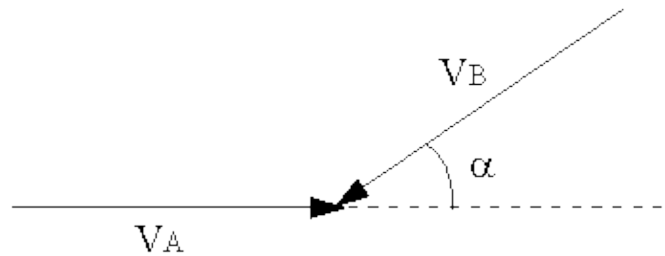
For the situation in which one aircraft "follows" another, the method is based on determining which aircraft is "following", and applying the separation based on the speed of that following aircraft. The following aircraft can be determined by identifying the change of heading required to turn each aircraft towards the other − the aircraft for which the smaller turn is required is deemed to be following. Note that if the following aircraft is travelling faster, then it may at some point "pass" the leading aircraft, causing a change (reduction) in separation requirement. However, the precise location of this point may be unclear during the planning phase, and hence it is appropriate to maintain the greater separation.

The required separation for following aircraft is the distance travelled by the following aircraft during the time period specified in the prescribed minima.

Separation for Approaching Aircraft

For the situation in which two aircraft approach each other the method is based on determining an appropriate weighted sum of the speeds of the two aircraft, and applying separation based on this speed. Ideally this weighted sum may be determined by resolving the speeds of the two aircraft towards each other, however the angle between the aircraft, and hence the required separation between them would change continually. Instead the speeds of the aircraft are resolved in a constant direction between them, this heading being selected to maximise the separation required, as described below.

Consider two aircraft heading "towards" each other on intersecting tracks, with headings $\alpha°$ away from being opposite, and with speeds V_A and V_B respectively:



An angle θ is selected as shown below, along which the speeds of the two aircraft will be resolved in order to determine the speed at which the aircraft are heading towards each other.

The relative speed of the aircraft along this heading is given by the equation below:

$V = V_A \cos\theta + V_B \cos(\alpha - \theta)$

$= V_A \cos\theta + V_B \cos\alpha \cos\theta + V_B \sin\alpha \sin\theta$

The value of θ for which V is maximal can be determined by differentiation.

$dV/d\theta = -V_A \sin\theta - V_B \cos\alpha \sin\theta + V_B \sin\alpha \cos\theta$

V is maximal for derivative equal to 0.

$0 = -V_A \sin\theta - V_B \cos\alpha \sin\theta + V_B \sin\alpha \cos\theta$

$V_B \sin\alpha \cos\theta = V_A \sin\theta + V_B \cos\alpha \sin\theta$

$\tan\theta = V_B \sin\alpha / (V_A + V_B \cos\alpha)$

The required separation for approaching aircraft is the distance travelled at speed V, calculated as above, during the time period specified by the prescribed minima.

Required Separation

The required separation applied in HIPS between any two aircraft is then the larger separation obtained from using both the above ‘following’ and ‘approaching’ methods. For aircraft on the same track, it is easy to see that this higher of the two values yields the ‘correct’separation for both ‘following’ and ‘approaching’ cases. For other cases, it is easier, in practice, to calculate both values and use the higher, rather than determining whether the situation is ‘following’ or ‘approaching’ and only calculate one value using the ‘correct’ method. This is because the angle between aircraft at which their closing speed becomes lower than the "following" speed depends on the relative speeds of the aircraft.

6. Oceanic HIPS Demonstrator

6.1 System Description

The NATS Oceanic HIPS Prototype is shown in Figure 7. The three HIPS windows are shown on the right hand side of the display. These comprise (from top to bottom): the Route Display, Speed Display and Altitude Display. On the left of the display are shown the three components designed to support demonstration of the HIPS functionality. These comprise (again from top to bottom): the Flight Strip Display , Oceanic Plan Display and Message List. Also available, but not shown in Figure 7, is an In Progress List. These four latter elements were designed solely to support an assessment of HIPS functionality. They are based on current Prestwick Flight Data Processing System (FDPS) functions, but are not intended to be fully representative of an operational system. Each of these components are described in turn below.

HIPS Route Display

The HIPS Route Display shows a plan view of the aircraft trajectory under consideration, together with no−go zones representing areas of conflict with other aircraft. To provide context, an oceanic map is also displayed showing the OTS, coastlines, sector boundaries, reporting points, airspace reservations. No−go zones are annotated with the callsigns of conflicting aircraft, and it is possible to switch the HIPS displays between aircraft by clicking on the displayed callsign labels. By selecting an alternative OTS track via a pop−up menu, or by dragging constraint points with the mouse, creating new constraint points or deleting constraint points a conflict−free trajectory can be generated.

HIPS Speed Display

The HIPS speed display presents a longitudinal view of the aircraft's trajectory through oceanic airspace. The vertical axis represents delay or advancement of time, while the horizontal axis represents progress of the flight across the ocean, annotated with time of day. Trajectories may be modified by moving constraint points vertically, thereby changing the required time at that point (and by implication, the speed flown to reach that point). By dragging the entry point, the time of entry to the sector is adjusted, and by dragging the exit point, the speed of the aircraft across the whole sector is adjusted. It is also possible to drag added constraint points horizontally, thereby changing the geographical position of speed changes.

HIPS Altitude Display

The HIPS altitude display allows controllers to adjust the vertical profile of a clearance. The vertical axis represents flight level, and the horizontal axis represents progress across the ocean in exactly the same way as shown on the speed display. It is possible to move a constraint point vertically to change the flight level, and horizontally to adjust the climb/descent rate. Moving the entry point will result in the planned flight level being adjusted for the entire oceanic transit. When a climb or descent is initiated, the system will automatically insert a new constraint point at the top of descent or start of climb, assuming a climb/descent rate of 400ft/min. This new constraint point can subsequently be adjusted if required to change the assumed rate of climb or descent.

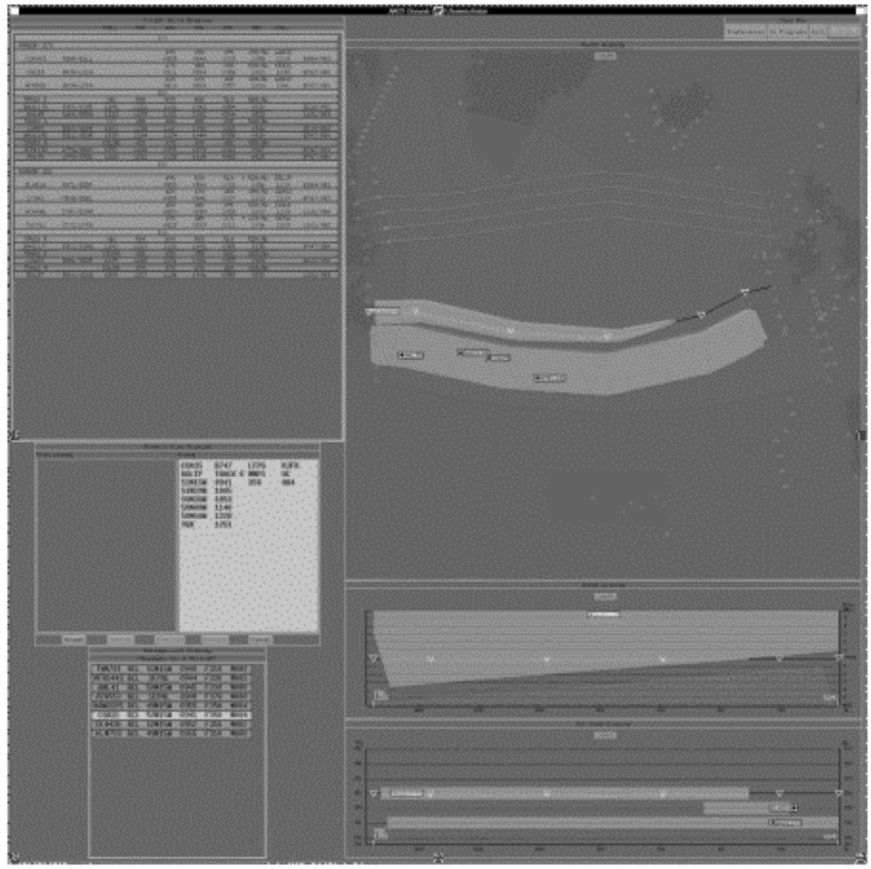


Figure 7 : The Oceanic HIPS Demonstrator

Flight Strip Display

The flight strip display shows a flight strip for each currently cleared aircraft in a very similar way to the existing FDPS. Flight strips are colour coded − blue for westbounds and buff for eastbounds. Flight strips are ordered by flight level and track, with coloured markers between each block, pink for flight level and violet for track.

Oceanic Plan Display

The oceanic plan display shows prime and provisional flight plans for the aircraft under consideration. The prime plan shows the requested, or currently issued clearance. The provisional plan shows the corresponding clearance following editing of the trajectory using HIPS.

The Oceanic Plan Display also contains the buttons required to progress the message through the various stages of clearance (see Section 6.2 below).

Message List

The message list shows pending requests for clearance (RCL) and revised position estimate (RPE) messages received. Obviously, for an operational system, a comprehensive catalogue of messages would need to be processed, but RCL and RPE were the only messages required for this evaluation of HIPS.

In Progress List

The In Progress List shows a list of aircraft for which the requested clearance has been modified, but not yet finalised. The In Progress List can be displayed or not, as required by the controller.

6.2 Generation of Clearances using HIPS

To put the system description above into context, it might be helpful to consider the process of generating a clearance using HIPS from receipt of a clearance request from an aircraft.

When a RCL or RPE message is received, it is put into a time ordered queue of messages and displayed in the (scrollable) Message List.

To process a message, the controller clicks on the appropriate message in the Message List. This action displays the requested clearance in the Oceanic Plan Display and displays the aircraft’s trajectory and consequential no−go zones in the HIPS windows. The controller can then edit the trajectory as required in HIPS to produce a conflict free trajectory.

By clicking on the ‘Confirm’ button, the provisional plan corresponding to the edited trajectory is displayed in the Oceanic Plan Display. In an operational system, this action might also cause the provisional clearance to be submitted to an independent conflict probe, as currently implemented in FDPS.

At this stage, the controller can choose to accept the provisional clearance by clicking the ‘Accept’ button. This will cause the message to be removed from the Message List, and a flight strip to be inserted in the Flight Strip Display.

Alternatively, the controller can click ‘Restart’ which will delete the provisional clearance and restore the HIPS displays to the requested clearance, or ‘Cancel’ which will cancel all edits and remove the aircraft from HIPS displays.

At any stage the controller can switch to another aircraft for editing by clicking on another message, another aircraft callsign in the HIPS displays, or an entry in the In Progress list. The current state of editing of the current aircraft is then saved and can be returned at a later stage.

7. Oceanic HIPS Trial

7.1 Trials Overview

In order to assess the effectiveness of the Oceanic HIPS system described above, a real time trial was carried out in December 1996. This trial is fully reported in Ref 6, and is summarised in the discussion below.

The objectives of the trial were to make a subjective assessment of the useability and effectiveness of HIPS for oceanic use, and to compare results using the Oceanic HIPS system with equivalent results using the existing FDPS at Prestwick. In particular, assessments were made of changes resulting from the use HIPS in measures of controller workload and quality of service to the airlines.

The trial was conducted in two phases. The first phase was carried out using the existing FDPS simulator at Prestwick, and the second phase was carried out using Oceanic HIPS implemented on the NATS Research Facility (NRF) at the ATM Development Centre (ATMDC) at Bournemouth. The same four controllers took part in both phases of the trial, and each phase used the same set of traffic samples.

Six traffic samples were used, three of which were based on the existing traffic mix of random and OTS tracks, and three of which were based on random tracks only. The purpose of the random based track samples was to enable an assessment of the performance of HIPS in an environment of increasing demand for random tracks, as discussed in Section 3.2 above.

7.2 Trials Results

7.2.1 Summary

The results of the Oceanic HIPS trial were very positive in favour of HIPS. For random tracks, very significant improvements were demonstrated in both controller workload and quality of service measurements. For OTS tracks, small improvements were demonstrated, but of a lower significance than for random tracks. Subjectively, controllers were very positive about HIPS, and felt that it would be a useful system when fully developed. These results are discussed in more detail in the remainder of this section.

7.2.2 Controller Workload

Two different subjective assessment methods were used to measure workload, Instantaneous Self Assessment (ISA), where controllers indicate there own perceived workload on a periodic basis by pressing one of a set of colour−coded buttons, and NASA’s Task Load Index (TLX), a PC−based questionnaire administered immediately at the end of each run which asks the controllers to rate their workload over five separate factors such as mental demand, time pressure and frustration experienced.

Using ISA, all the controllers responded with a lower perceived workload for random traffic when using HIPS compared to the current FDPS. For the track−based samples, two out of three controllers responded with lower perceived workload values when using HIPS. The overall TLX score also indicated significantly lower workload using HIPS for random aircraft but, in this case, did not indicate a significant difference for track−based samples.

To supplement the subjective measures described above, an objective measurement of the time required to plan each aircraft was made. This indicated a reduction in planning time for random aircraft of 25% using HIPS. There was no significant difference between FDPS and HIPS for planning track−based aircraft.

7.2.3 Quality of Service

As meteorological data was not used in the trial, it was not possible to make absolute measurements of quality of service metrics such as fuel burn. Instead, it was assumed that the requested clearance represented the ideal trajectory, and statistics were collected of the number of aircraft receiving their requested clearance and, for those that did not, the deviation from the requested clearance.

Again, for random tracks, very significant performance benefits were demonstrated from the use of HIPS. The number of aircraft which received their requested clearances using HIPS increased by some 45%, and for those that did not, the differences between the requested routes and the issued clearances were smaller using HIPS. For track−based aircraft, small, but significant benefits were demonstrated in deviation from requested clearances using HIPS but, in this case, there was no significant difference in the number of aircraft given a clearance exactly as requested.

7.2.4 Subjective assessment

It is vital, in developing new computer assistance tools for ATC, that controllers have a positive perception of those tools. The tools should be seen as, not only, effective in that they support a useful and necessary ATC function, but must also be seen as easy to use, presenting the impression that they were designed for controllers, rather than by engineers.

In general terms, Oceanic HIPS was very well received in the trial, in terms of both effectiveness and ease of use. Inevitably, many detailed comments were received on individual design aspects, and these are reported in Ref 6. For example, the granularity of ‘snap to grid’ functions was considered too fine when dragging constraint points, and some text fonts were considered too small. However, despite these detailed comments, the controllers were generally impressed with the HIPS concept and felt that it could be developed to be a very useful operational system.

8. Operational Implementation Issues

8.1 Implementation Plans

At the time of writing, contractual discussions are in progress between NATS and EDS for implementation of HIPS−like functionality in FDPS2, the replacement FDPS at Prestwick, scheduled for operation by the end of 1999. Notwithstanding these negotiations, a number of areas for further work were identified during the development of Oceanic HIPS and these are discussed briefly below.

8.2 Further analysis of separation standards

As discussed in Section 3.4 above, considerable work was undertaken during the Oceanic HIPS prototype development to analyse the interpretation of separation standards for representation within HIPS for evaluation purposes. Nevertheless, for operational implementation further work would be required including, inter alia:

- ◊ Implementation of a comprehensive ‘set’ of separation standards to address requirements not defined in the prototype, such as supersonic aircraft.
- ◊ Subtleties relating to relaxation of the basic separation standards in some circumstances, such as reduced longitudinal separation at the entry point for aircraft following the same track if the preceding aircraft is travelling faster.
- ◊ Implementation of deemed lateral separation between aircraft on adjacent tracks where specified parts of the tracks are not actually separated by the required 60Nm.
- ◊ Further work on representation of longitudinal separation where the clearance may be broken down into a number of route segments, with potentially different relative headings between aircraft for each route segment.

A recurring theme within this paper relates to the currently documented oceanic separation standards which do not lend themselves readily to automation. Consequently, the work on separation standards for HIPS implementation has required basic interpretation of the laid down separation standards. Validation of the HIPS implementation would therefore need to be carefully considered prior to operational use. Consideration also needs to be given as to whether ICAO approval for their implementation is required. It could be considered that if clearances generated using HIPS are subsequently submitted to an independent conflict probe which itself uses ICAO approved algorithms, then separate approval for the HIPS tool per se is not required.

8.3 Integration of HIPS with other ATC Tools

The evaluation of HIPS was carried out in a relatively simple environment, in order to ensure, as far as possible, that any performance benefits demonstrated during the trial were, in fact, a consequence of the use of HIPS. However, in an operational environment, HIPS would also need to interact with other ATC tools and systems. Further work is required to look at the performance of HIPS in a ‘total’ ATC system environment.

8.4 Operational issues

If HIPS were to be introduced operationally, it is likely that more complex clearances would be issued than is currently the case. This might well provide a direct business benefit to the operators by providing clearances closer to those actually requested by the aircraft, but also raises a number of operational issues which would need to be considered. Such issues include: difficulties in the controller ‘maintaining the picture’, difficulty of manual reversion were the FDPS to fail, the ability of other centres (for example Gander run by NAV Canada) to accept complex HIPS−type clearances, and the safety of passing these clearances over HF.

8.5 Future Technological Developments

A number of technological developments are currently being investigated for use within oceanic ATC systems. Some, such as Controller Pilot Datalink Communication (CPDLC) and Automatic Dependent Surveillance (ADS) are already at an advanced stage of development. HIPS seems to be naturally compatible with the emergence of these systems. CPDLC would ensure that complex clearances could be received accurately, and ADS would make it easier to check that clearances were being followed. In addition, if the introduction of new technologies such as ADS were to result in smaller separation standards, then HIPS could readily be adapted to the new standards, automatically taking into account aircraft equipment fit, and presenting smaller no−go zones where appropriate.

9. Other Potential HIPS Applications

HIPS should not be regarded as a tool, but rather a concept of which a particular implementation has been discussed in this paper. Use of the concept of no−go zones in other areas is under investigation, and this section summarises current thinking on some of these.

9.1 En−route domestic planning

This was the original target application for HIPS, where the tool was integrated and tested as part of PHARE Demonstration 1 (PD/1). The PHARE scenario assumed that accurate aircraft trajectories were available around 20 minutes into the future, and therefore that sector planners could perform de−confliction before the aircraft were assumed under tactical control.

Feedback and results from PD/1 were very positive (Ref 7), and showed that for this application HIPS was appreciated by controllers, and fully satisfied the requirement for conflict resolution support while keeping the human in the loop.

9.2 Tactical radar control

Initial investigations have been undertaken to look at the use of HIPS at tactical level. The requirements of a tactical tool differ from those of a planner for at least two reasons: First, interaction processes must be rapid and simple, and second, the tactical controller should not be required to look away from his radar display to work in another window.

A proposal has been made for a ‘vectoring aid’ to give support for simple heading change operations. It works on the basis of an elastic vector functionality, which allows the controller, using a pointing device, to ‘stretch’ out a vector either from the aircraft’s current position or from any other point on the trajectory (elastic vectoring was available in both ODID and PD1, and operates in a similar way to a standard bearing−and−range line). Since this is an application of the concept to a single trajectory segment, it has been developed using the original ‘cone’ model of manoeuvre surface. The consequence of this is that the zones are calculated without using the abstract manoeuvre surface, so are accurate and static.

9.3 In−the−cockpit

The current free−flight discussion is suggesting that pilots (or more particularly airlines) would like a greater say in how their aircraft are conducted from departure to destination. Since the HIPS approach is, by definition, a view from the perspective of one aircraft ‘against’ the rest, it seems reasonable to consider inserting it into the aircraft cockpit for use by the pilot. In the first instance this could allow a form of direct negotiation between air and ground by providing ‘mirrored’ displays to the pilot and air−traffic controller. Requests from the pilot (e.g. for direct routeing or level changes) could then be made intelligently, rather than ‘blind’ as is today’s practice.

Another approach is being studied by the FREER project (Ref 8), which is looking at autonomous aircraft separation. In this case aircraft are responsible for assuring their own separation with other aircraft, with no intervention from ground systems. This project has incorporated a customised version of HIPS into its CDTI (Cockpit Display of Traffic Information).

10.Conclusions

Originally developed by Eurocontrol as part of the PHARE project, HIPS combines a sophisticated display of air situations with a simple to use trajectory editor. The display is generated using geometric techniques to derive the positions of aircraft in 4 dimensions, and then project the results onto a useable 2−dimensional image.

A prototype of HIPS has been developed by NATS, with support from Eurocontrol, to assess its applicability to oceanic control at the Oceanic Area Control Centre (OACC) at Prestwick.

The study involved: adapting the HIPS concepts to the requirements of oceanic control; reviewing oceanic separation standards and developing an acceptable representation of separation standards in HIPS; developing a software prototype; and conducting trials with the prototype on the NATS Research Facility (NRF) at the ATM Development Centre at Bournemouth.

The results of the Oceanic HIPS trial were very positive. For random tracks, very significant improvements were demonstrated in both controller workload and quality of service measurements. For OTS tracks, small improvements were demonstrated, but of a lower significance than for random tracks. Subjectively, controllers were very positive about HIPS, and felt that it would be a useful system when fully developed.

Further work identified for oceanic application includes: analysis of aspects of longitudinal separation standards not addressed in the prototype system and validation of the proposed separation standards implementation; development of a strategy to integrate HIPS with other tools in a ‘total ATC’ environment and analysis of operational issues such as the transmission of complex clearances generated using HIPS.

HIPS appears to be particularly amenable to ongoing development and integration with future technological developments in the oceanic environment such as ADS and CPDLC. In addition, a number of other ATM applications for HIPS have been identified, and investigation is on−going in a range of such applications. These include domestic (i.e. radar) en route planning and tactical control, and use by pilots in the cockpit.

11. References

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