DESIGN OF COCKPIT DISPLAYS FOR LIMITED DELEGATION OF SEPARATION ASSURANCE

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Abstract
The Evolutionary Air-ground Co-operative ATM Concepts (EACAC) study of the FREER-FLIGHT project investigates the delegation by the controller to the pilot, of some tasks related to separation assurance. Starting from the analogy of visual clearances, EACAC investigates the possibility of giving electronic clearances in managed airspace. One of the issues of the study deals with the appropriate assistance scheme to be provided to the pilot, considering the proposed concept of limited delegation. An initial design work has been done, leading to the definition of key elements for cockpit displays: three different levels of assistance are identified, with different representations. All these options will be evaluated by pilots, first through a cockpit environment in a stand-alone mode (end 1999), and then using a cockpit simulator in a real-time simulation with controllers (mid 2000).

Introduction
The Evolutionary Air-ground Co-operative ATM Concepts (EACAC) study of the FREER-FLIGHT project investigates the delegation by the controller to the pilot, of some tasks related to separation assurance. Starting from the analogy of visual clearances, EACAC investigates the possibility of giving electronic clearances by making use of the new CNS/ATM technologies soon to be available, in conjunction with new operational procedures. EACAC targets near term applications – typically 2005 – taking place in current ATC organisations, while at the same time proposing long-term developments. Expected gains are mainly a reduction of controller workload together with the improvement of safety and flight efficiency.

One of the issues of the study\textsuperscript{1} deals with the appropriate assistance scheme to be provided to the pilot, considering the proposed concept of limited delegation. An initial design work has been done, leading to the definition of key elements for cockpit displays: three different levels of assistance are identified, with different representations. The objective of this paper is to present all these elements and variants that compose the proposed enhanced cockpit display of traffic information (CDTI). The next step will be a pilot evaluation.

The paper is organised as follows: the following section outlines the concept of limited delegation. The next section presents an overview of existing CDTI. Final section derives requirements and presents some typical displays of the enhanced CDTI.

Outline of the Concept
Two major constraints are driving the EACAC study. The first one relates to human acceptability: respect roles and work methods of controllers and pilots, enable incremental practice and progressive confidence. Beyond, the issue is to overcome the acceptance dilemma: no human-centred system can be used without confidence, but no confidence can be

\textsuperscript{1} Please refer to [9] for a more detailed description.
obtained without practising the system in real operations. The second constraint relates to technology: rely on minimum assumptions for CNS facilities and equipment modification. In addition, to enable transition phases compatibility with stepwise fleet equipment should be guaranteed.

To meet these constraints, EACAC relies on a pragmatic and straightforward initial concept. Firstly, as for visual clearances, the concept is applicable for problems involving two aircraft: one aircraft (subject aircraft) receives the delegation with respect to the other aircraft (target aircraft). In addition, depending on the task delegated, conditions of applicability in terms of complexity of problems have been identified, and must be respected. Secondly, the concept relies on the following key points:

- **Limited delegation:** The task delegated to the pilot is limited to the monitoring and implementation of solutions. Thus, situation analysis, identification of problems, e.g. conflict detection, definition of solutions, and decision of transfer remain within role and responsibility of the controller. (However, the delegation requires pilot’s agreement.)

- **Flexible use of delegation:** The level of task delegated to the pilot can range from monitoring up to implementation of a solution, and the controller has the ability and responsibility to select for each problem the appropriate level of delegation.

EACAC aims at covering two major classes of application: crossing and overtaking, typically in en-route airspace, and sequencing, typically in TMA (Terminal Manoeuvring Area). For each of these applications, three levels of delegation have been identified: basic, intermediate, and advanced. For the basic level, the delegation is extremely limited, hence enabling early practice. Beyond, the higher the delegation level, the higher the expected gain. However, a higher level imposes more restrictive conditions of applicability.

For crossing and overtaking applications, the three following levels of delegation have been identified:

1. **Basic:** identification of the “clear of traffic”.
2. **Intermediate:** climb/descent or navigation resume.
3. **Advanced:** implementation of manoeuvre.

For sequencing applications, the three following levels of delegation have been identified:

1. **Basic:** identification of separation.
2. **Intermediate:** station keeping.
3. **Advanced:** sequence establishment and traffic merging.

In terms of surveillance information, position and velocity of the target aircraft transmitted through ADS-B or TIS-B are sufficient. Trajectory intent information (such as Trajectory Change Points) is not required since identification of problems and solutions is performed by the controller, but can be used to increase applicability domain. In addition, surveillance information on surrounding traffic is not required.

**Overview of Existing Cockpit Displays of Traffic Information**

A wide range of applications along with the appropriate on-board assistance scheme, has been investigated so far in the domain of air/ground co-operative ATM. Typically, applications investigated range from short term, e.g. station keeping and in-trail following, to longer term, e.g. autonomous aircraft under free-flight operations. A possible way to classify and characterise the various on-board assistance schemes thus defined is to consider the level of assistance provided. However, since some are used in a context of autonomous aircraft operations, they integrate not only “resolution” features, but also “alerting” ones [13]. In the context of limited delegation where the controller always performs conflict detection, only the “resolution” aspect will be
discussed. Three major levels of assistance can be identified:

- **“Actual”**: presents the situation based on current flight parameters of subject aircraft. It may include some predictive features, typically for displaying the point of loss of separation or the point of closest approach. The display proposed in [3] to support the “ASAS crossing procedure” is a typical example based on flight state information: the situation with respect to the target aircraft is presented through a relative speed line and a 8Nm circle centred on the subject aircraft position. A set of displays using different levels of intent information (flight state, commanded values and trajectory) to indicate conflict bands is proposed in [1].

- **“What-if”**: provides the capability to test potential manoeuvres. Typically, [2] has defined a predictive tool to assess a risk of conflict, which uses target values selected on the autopilot. The effect of potential changes of heading and/or speed can thus be tested before they are engaged. For an FMS based approach, [5] provides a graphic editing capability for the subject aircraft trajectory which is used in conjunction with “no-go” zones generated by both conflicting and surrounding aircraft.

- **“Red/green range”**: indicates the range of authorised and forbidden manoeuvres. The example is TCAS², which provides red and green arcs on the vertical speed indicator. (For heading or bank angle with the former TCASIII, similar principles were envisaged.)

- **“Advisory”**: indicates the manoeuvre to be performed. Again, TCAS is a typical example of a system providing advisories, as well as the system proposed by [8]. The pilot has to follow exactly the manoeuvre computed to solve the conflict (or to avoid the collision for TCAS). The solution trajectory automatically generated in [5] can also be seen as an advisory. In that case however, the pilot can ask for other solution trajectories by giving high level directives, e.g. pass to the left.

As stressed in [11], the on-board assistance scheme required is closely linked to the underlying operational concept and related procedures, e.g. what tasks are intended to be delegated to the pilot, and how? Typically, the level “actual” should be sufficient for a monitoring task, whereas a “what-if” should be the minimum level of assistance for implementing a manoeuvre. However, finding the appropriate manoeuvre with a “what-if” requires varying one (and possibly more) flight parameter. The “advisory” level could provide further assistance, but it should not be used alone. Indeed, it does not provide elements for the understanding of the situation, and thus imposes to rely upon automation [2]. In addition, no real interaction with the pilot can naturally take place. Finally, a strong limitation of the existing “advisory” based systems (at least TCAS and [8]) relies on two points. Firstly, the assistance scheme is switched-off when the “clear of traffic” is issued. Secondly, the “clear of traffic” only depends on proximity conditions typically when closest point of approach is passed, *without any considerations on where and how the pilot will resume his trajectory*. Whereas this is acceptable and somewhere consistent for collision avoidance, this may be highly critical for assuring separation in medium and low converging encounters: nothing prevents the pilot from getting back into conflict. (In other words, the notion of “clear of traffic” is not absolute, but is relative to a trajectory.) To deal with this issue, some preventive indications could be introduced after “clear of traffic”. Instead, a “what-if” naturally provides a simple way to do it: the “resume” manoeuvre can be tested before it is actually engaged.

Considering the possible limitations of the “what-if” on one side (multiple testing), and the

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² Regardless that TCAS is designed for collision avoidance, and not for separation assurance.
“advisory” on the other (mainly automation dependency), an intermediate assistance level has been envisaged: the “scale of separations” that indicates the separation value for a range of possible manoeuvres. The “scale of separation” can be seen as an extension of the binary “red/green ranges” towards an “analog” representation of the effect of different manoeuvres. In addition, it remains valid and meaningful even after “clear of traffic”.

Requirements for an Enhanced Cockpit Display of Traffic Information

The aim is to identify the main elements of an enhanced CDTI. Different aspects are considered: the functions required by the different levels of assistance, then, the type of representation, the level of information used, and the definition of the separation parameter.

The next sub-section outlines the underlying principles. Finally, typical displays for the different levels of assistance and types of representation are proposed.

Underlying Principles

To support operations of limited delegation as presented before, two assistance functions are required:

– Monitoring separations, including identification of specific events typically the “clear of traffic”.
– Implementation of solutions, i.e. capability to identify of an appropriate manoeuvre (provided that the type of manoeuvre has been specified by the controller).

For that purpose, the three following levels of assistance are proposed:

– “Actual”: indicates the separation value based on current flight parameters.
– “Target/what-if”: indicates the separation value based on the target values of flight parameters selected on the autopilot (heading, speed, or vertical speed). As a consequence, this also provides “what-if” assistance if a target flight parameter is in the HOLD mode of the autopilot (applicable for heading and speed).
– “Scale of separations”: indicates the separation value for a range of flight parameters (heading or speed). Knowing the desired separation, an advisory can easily be obtained.

Typically, it is thought that monitoring separations will require the first and possibly the second assistance level, while the implementation of solutions will probably require the second or the third.

The information used on the subject aircraft is the flight states and the target values of the autopilot. On the target aircraft only flight states information is required, though intent can be used if available.

The definition of the separation parameter depends on the application. It is based on:

– Closest point of approach (CPA) for high closure rate applications, e.g. lateral and vertical crossing.
– Sliding future point (SFP), i.e. predicted point \( x \) minutes in advance, for low closure rate applications, e.g. lateral and vertical low convergence and passing, longitudinal station keeping.

Typical Displays

Three typical set of displays are presented for lateral crossing (Fig. 1), vertical crossing (Fig. 2), and longitudinal station keeping (Fig. 3). For each figure, the PFD (Primary Flight Display) and the ND (Navigation Display) shown on the top represents the “baseline” CDTI. Below PFD and ND, each column represents a level of assistance, and each line a view or an item composing the enhanced CDTI. The first line shows the core zone of the

\[ \text{In a typical use however, only one flight parameter will be modified.} \]
ND, the second one shows the text box (typically located in the lower right corner of the ND), and the third line represents an item of the PFD. Finally, a full assistance scheme could be obtained by superposing the three levels (but some filtering may be needed to avoid cluttering, typically on the ND for lateral crossing).

Figure 1: Enhanced CDTI for lateral crossing. On the ND, closest points of approach (CPA) are displayed (along with a 8Nm circle - optional). These are current (col. 1) and target (col. 2) CPA. In (col. 3), two CPA configurations are presented for two typical heading changes (+/- 30°). Instead of heading changes, typical separation values could be used, e.g. 8Nm with passing behind and with passing ahead. Alternatively, a curve of CPA for subject aircraft can be displayed. The text box indicates (current and target) lateral distance at CPA (in Nm) and closest time of approach (CTA, in minutes). (The text box is not used for the third level.) The scale of separations is shown on the heading rose in (col. 3), indicating the lateral distance at CPA for different headings. (A scale of separations on the speed tape is also envisaged.) In this situation, turning to heading 110° will provide approximately 8Nm.
Figure 2: Enhanced CDTI for vertical crossing (at reduction of vertical speed, V/S). Closest points of approach are displayed, along with a “vertical scale” (typically ranging between +/- 4000ft) that indicates relative altitude of the target aircraft at CPA. (To avoid confusion with the existing VNAV deviation scale, it set on the left side.) The text box indicates (current and target) vertical separation (in FL) and CTA. On the vertical speed indicator (VSI), only current and target vertical separations at CPA are displayed. A scale of separations can hardly be displayed on the VSI, instead two V/S corresponding to the maximum values of the “vertical scale” (+/- 4000ft) are indicated. In this situation, as indicated on the VSI, reducing the V/S from 1000fpm to approximately 1100fpm increases the separation from 7FL (700ft) to 30FL (3000ft).
Figure 3: Enhanced CDTI for longitudinal station keeping. A “longitudinal scale” (typically ranging between +/- 1Nm) is displayed that indicates the difference of the along-track distance (ATD) (current or predicted in x minutes) with respect to the objective one. The text box indicates (current or predicted) ATD (here, the ATD in two minutes), plus some standard indications (e.g. closure rate, or ground speed or the target aircraft). A tape of ATD is indicated, which is linked to the speed tape, in order to provide the scale of separations for different speed values. A possible way to link these two tapes is to indicate the ATD that will be obtained in x minutes (typically 2 minutes) when going to the speed value (assuming that the prediction time applied allows complete acceleration or deceleration). Typically, when going to 280 knots, an ATD of approximately 11Nm will be obtained in 2 minutes.
Conclusion

In the scope of designing on-board assistance schemes for limited delegation of separation assurance, three levels of assistance in cockpit displays have been proposed, with different representations. An appropriate modelling is under investigation, and initial results will be presented in [10]. All these options will be evaluated by pilots, first through a cockpit environment in a stand-alone mode (end 1999), and then using a cockpit simulator in a real-time simulation with controllers (mid 2000).

References