Abstract

The work presented is the paper is part of a project whose objective is to investigate the limited delegation of separation tasks to the flight deck. Whereas delegation is initially aiming at increasing controllers availability, it is essential to assess potential impact on the flight deck. An holistic approach has been selected: simulations integrating both ground and air components are conducted in order to assess acceptance and potential benefits. In this context, to support flight crews in the separation tasks, dedicated interfaces were designed and implemented on a cockpit simulator. The objective of the user-centred design approach illustrated here is to provide the flight crew with appropriate information support, enabling them to efficiently and safely perform separation tasks. Whereas a large part of the elicited requirements were expected, some surprising requests emerged along the process. The pilots’ evaluation confirmed the need for a visual display of the required separation and for a system advisory of the most appropriate manoeuvre. However, the display of additional symbols had not been anticipated. Issues listed in this paper which served as design constraints, can be used as guidelines to assess the applicability of the proposed delegation of tasks.

1 Introduction

Delegation of separation assurance is foreseen as one possible option to allow the air traffic management system to cope with increasing traffic. It takes advantage of emerging CNS/ATM technologies in pre-operational state [17] along with additional avionics such as a Cockpit Display of Traffic Information [16] or an Airborne Separation Assurance System [21]. Beyond the technological aspects, the delegation can be seen as one possible task allocation between controller and flight crews. It thus raises the general question of identifying the appropriate allocation of tasks. From a flight crew perspective, one of the main issues is a risk of workload increase in the flight deck. This raises the question of identifying the appropriate level of assistance onboard. As stressed in [13][28], the level of assistance required is closely linked to the underlying operational concept and related procedures, e.g. what tasks are intended to be delegated to the flight deck, and how? For pure autonomous operations (free-flight), full conflict detection and resolution capabilities may be provided [10]. On the opposite, for limited delegation, e.g. station keeping [11][22][25], crossing [5], since only very specific tasks, e.g. speed or heading adjustments, are delegated, the assistance needed on board may be reduced.

The work presented here is part of a project whose objective is to investigate the limited delegation of separation tasks to the flight deck. Whereas delegation is initially aiming at increasing controllers availability, it is essential to assess potential impact on the flight deck. Although part-task simulations could provide insight on specific aspects, e.g. detailed display format, guidance cues [1][11][22][25], a more holistic approach has been selected: simulations integrating both ground and air components are conducted in order to assess acceptance and potential benefits. In this context, to support flight crews in the separation tasks, dedicated interfaces were designed and implemented on a cockpit simulator.

The paper is composed of five sections. Section 2 describes the method followed to design cockpit displays, focusing on the process of eliciting and evaluating user needs. Section 3 introduces the principles of delegation. Section 4 reports the elicited user requirements and discuss arisen issues. In Section 5, the design choices are illustrated with the proposed interfaces. The paper concludes with a discussion on the design process, in terms of expected
and surprising requirements and with a presentation of the next steps of the study.

2 User-centred design

As stated by SAE in [19], “The information a pilot needs to perform new tasks must be determined as well as how to present the subsequent information on CDTI. New procedures for the new tasks must incorporate the expanded role of CDTI.”

The design of interfaces for a new airborne separation assurance system can be characterised by four basic principles, described in [9], that are early and continuous focus on users, integrated design, early and continuous user testing and iterative design.

In the study reported here, the focus was put on the future users (air-traffic controllers and flight crews) from the initial step of defining the basic principles of the method. In line with user-centred design [12][8], our approach took as starting point current situation and users practices, to identify the existing actors, supports, tools and organisation. Typically, limited delegation was built upon an analogy with an existing practice (visual clearance). The participative approach (in the sense described by [20]) followed in this study did not limit the users involvement to the elicitation of needs, nor to the validation of final products, but covered the whole cycle of design. Indeed, future users (flight crews and controllers) were involved in the whole design, from early description of their practices, to the design activities themselves (i.e. the proposition of potential design options).

The design is integrated in the sense that the definition of the concept itself (and its associated procedures) considered from the start the systemic dimension, proposing applications, procedures and support for both air and ground sides. It is worth noting that the method described here was actually applied to the investigation and design of the overall air-ground system [29].

The evaluation of the concept and the associated user testing started even before any interface was actually envisaged, through collective discussions involving controllers and flight crews. Design options were initially envisaged on the basis of existing literature and standards [2][3][16][17][18][19][23] and turned into paper-based sketches used as a support for discussion with pilots. Interfaces were then specified on the basis of resulting requirements. Up to five pilots (both test pilots and airlines pilots) took part in a co-operative evaluation conducted over two days on a cockpit simulator. A representative set of tasks was defined (fly aircraft, communicate with controllers, set up delegation, monitor a designated traffic- later referred to as a target- on information displays) and a realistic working environment was provided (including radiotelephony communication with controllers, continuous updating of the aircraft and target parameters on displays). Moreover, various supports were used to collect users feedback, through continuous observations, collective debriefing and questionnaires.

Over the past two years, successive iterations were conducted, following the steps described on Figure 1, from the definition of users needs to specifications (of systems, procedures, phraseology), then to implementation (paper based then actual) and finally the evaluation of implemented prototypes. At each iteration, this evaluation enriches the elicited users requirements, which lead to new specifications and new prototypes to be tested. The process is evolutionary (defined by [7] as overall design changes through series of cycles of design, implementation, and evaluation) rather than incremental (defined as stepwise implementing of a pre-specified overall design).

Figure 1. Iterative design process.

3 Limited delegation

3.1 Principles

In the scope of defining a task distribution between controllers and flight crews, from the onset of the project, two key constraints were identified and adopted. The first one is related to human aspects and can be summarised by “minimise change in current roles and working methods of controllers and flight crews”. The second one is related to technology and can be expressed by “keep it as simple as possible”.

The proposed task distribution was actually designed around the human actors involved – controllers and flight crews. Taking as its starting point existing human roles and activities, and more specifically the analogy with visual clearances, it is based upon the following key elements:

- Some separation assurance related tasks are delegated to flight crews. Delegation is always initiated by the controller, but requires flight crew agreement.
The delegation is limited since the controller can only delegate “low level” tasks (implementation and monitoring) as opposed to “high level” tasks (definition of strategy). In addition, only one flight parameter is delegated at a time.

The delegation is flexible since the controller has the ability to select for each situation the level of task to be delegated from monitoring up to implementation.

This form of task distribution is expected to maintain unchanged core roles and working methods of controllers and flight crews. The delegation does not impose any change of responsibility since it can be considered as a new instruction. Thus, the controller would be responsible for providing the appropriate instruction (i.e. which ensures the separation and is flyable for the flight crew) while the flight crew would be responsible for following it (unless they reject it, if unable to comply).

Major benefits are expected from controllers perspective, mainly in terms of increased availability [29]. From a flight crew perspective, the delegation is expected to allow for more anticipation (less time-critical instructions to follow), to increase situational awareness, and to enable an optimisation of trajectories. It is also expected that safety would be improved (or at least maintained), through a better organisation of tasks and a redundant separation monitoring ensured by controllers and flight crews.

In terms of technology, no controller-pilot data-link communication, no intent information from aircraft, no automation on-board, no coupling to the autopilot nor to the flight management system are expected at this point – although they could be of interest. Only the knowledge of a subset of the air traffic situation is needed on board aircraft along with appropriate display cues.

### 3.2 Example of delegation procedure in sequencing situation

The delegation covers two classes of applications: sequencing operations in terminal areas, and crossing and passing applications in en-route airspace. For the sequencing part, two sub-applications are considered and three levels of delegation are proposed (Table 1).

<table>
<thead>
<tr>
<th>Delegation level</th>
<th>In-trail</th>
<th>Merging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Report separation</td>
<td>Report in-trail distance</td>
<td>Report merging distance</td>
</tr>
<tr>
<td>Maintain separation</td>
<td>Remain behind</td>
<td>Merge behind</td>
</tr>
<tr>
<td>Resume then maintain separation</td>
<td>Heading then remain behind</td>
<td>Heading then merge behind</td>
</tr>
</tbody>
</table>

Table 1. Sequencing applications.

Before and during delegation, the controller has to make sure that all applicability conditions are respected (e.g. compatible performances and compatible speeds).

The delegation is composed of three phases:

- Identification, in which the controller designates the target aircraft to the flight crew.
- Instruction of delegation, in which the controller specifies the task delegated.
- End of delegation, which marks the completion of the task delegated.

The task repartition between controllers and flight crews is defined for each application. The highest level of delegation is detailed now, since it requires more actions from the flight crew. For the “heading then merge”, the task repartition is defined as follows:

**The controller:**
- Gives a heading instruction to create the desired separation to the target aircraft;
- Indicates the desired separation to be applied.

**The pilot:**
- Estimates and reports when the predicted separation at the merging point would reach the desired separation (and to ensure that minimum separation is never infringed), then
- Resumes navigation to merging point, and then
- Adjusts speed to maintain the desired separation at the merging point.

The associated procedure is given below (Figure 2).

In terms of technology, no controller-pilot data-link communication, no intent information from aircraft, no automation on-board, no coupling to the autopilot nor to the flight management system are expected at this point – although they could be of interest. Only the knowledge of a subset of the air traffic situation is needed on board aircraft along with appropriate display cues.

![Figure 2. "Heading then merge behind" scenario.](image-url)
The proposed phraseology is:

Controller: “DLH456, select target 1234”
Pilot: “Selecting target 1234, DLH456”

After pilot selection and identification on the cockpit displays:

Pilot: “DLH456, target 1234 identified”
Controller: “DLH456, turn left heading 270 then behind target, merge to WPT to be 15NM behind”
Pilot: “Turning left heading 270 then will merge to WPT to be 15NM behind target, DLH456”

Once merging distance is 15NM:

Pilot: “DLH456, merging behind target”

This delegation can be transferred to the next sector. When required, the controller in charge of the delegated situation ends the delegation:

Controller: “DLH456, end delegation, reduce speed to 220 kts”

4 Eliciting user needs

The elicitation of the users’ needs aims at understanding how the future system could comply with the needs, but also foreseeing potential limits, bottlenecks and necessary trade-offs [4]. This initial step provides, on the one hand, specifications based on elicited flight crews tasks, and on the other hand, arisen issues to be closely assessed during evaluation.

4.1 Identifying flight crews tasks

As described earlier in section 2, involving flight crews in the design cycle aimed at understanding if and how delegation could be integrated in their current practices. On the basis of the principles initially defined, four successive tasks were then identified for the flight crew.

4.1.1 Identifying target aircraft

The initial step of the delegation consists in selecting and identifying the target aircraft upon controllers request (e.g. “DLH456, select target 1234”). This step has the objective to ensure that the target aircraft is “visible” (electronically), and potentially contribute to error detection. Indeed, the absence of a target reveals problems, technical (e.g. unavailability of target data) or operational (e.g. misunderstanding with controllers, interactions with the system).

4.1.2 Assessing feasibility

As described in section 3.1, the flight crew can reject a delegation instruction in case of inability to comply with it. In addition to technical reasons (e.g. equipment failure), rejection could result from delegation-related reasons, in particular applicability conditions not respected. For example, the ability to acquire the proper separation within the given time-constraint. Although inability to comply should be exceptional, flight crews always have to assess feasibility prior to start delegation. For that purpose, flight crews require a specific support from the system.

4.1.3 Implementing solution

Even though controllers identify the objective (e.g. “DLH456, turn left heading 270 then behind target, merge to WPT to be 15NM behind”) it is up to the flight crews to identify and implement the appropriate manoeuvre. As expressed by pilots, support from the system in terms of suggesting this manoeuvre (e.g. speed, resuming point) would be of great benefit. Indeed, depending on the flight phase (cruise, approach) and the conditions of flight (duration, turbulence) pilots’ cognitive resources can be diminished or already completely monopolised.

Once identified, the manoeuvre is implemented, in selecting on the flight control unit (FCU) either speed or heading, depending on controller’s instruction. An additional demand is related to automating the manoeuvre implementation, typically in coupling the delegation-related functions (e.g. suggestion of the optimal speed) with the flight management system (engagement of a dedicated managed guidance mode).

4.1.4 Monitoring situations

The dynamic nature of the situation and the numerous evolving parameters (speed of target aircraft, altitudes) require flight crews to continuously assess the separation. Indeed, even when acquired, the separation needs to be actively maintained through a continuous monitoring leading to potential adjustments. Yet, it is not possible to expect flight crews to remain continuously focused on the information displays, spending time assessing the situation. In this context, flight crews require support from the system, alerting on drifting situations (current separation becoming either above or below desired one).

For the “resume then maintain” applications, flight crews require support to identify the appropriate moment to resume own navigation.

4.2 Arising issues

4.2.1 Removing versus adding tasks

Early studies of station keeping feasibility in part-task simulations pointed out an increase of workload in the cockpit, especially in final approach [11][22][25]. Although delegation requires the flight crew to perform new tasks, such as identifying and monitoring a target (and possibly surrounding traffic), it should remove successive speed instructions and information requests (e.g. “report your indicated air speed”). Potential benefits in dense terminal areas have been shown in [29].

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In terms of design, interactions with the system (both data input and output processing) should be reduced to a minimum. In terms of evaluation, both the usefulness and the usability of the system need to be assessed.

4.2.2 Maintaining separation versus flying aircraft

As stressed in Wickens et al [24][26][27], automation, and especially display features provided in the cockpit could potentially induce attentional and cognitive tunnelling impacting perception and information processing. This might impair the flying capabilities of flight crew, in particular by disrupting the detection of significant events and the execution of associated tasks. In the context of delegation, and specifically for monitoring tasks, the use of information display could have similar impact, in restricting flight crew “field of view”. Therefore, the design should limit the head down time, and not encourage the human tendency to immerse oneself in displays.

Flying capabilities might also be impaired by high workload in the cockpit. Design must simultaneously consider the relative weights and context of occurrence of these tasks, and ensure that maintaining separation does not prevail over flying the aircraft. Typically, the acceptance and implementation of delegation is always conditioned by the flying context: problems encountered in the cockpit could lead flight crews to abort delegation.

4.2.3 Anticipating versus reacting

In terminal areas, flight crews have to react to successive time-critical instructions resulting from vectoring. Pilots do not feel comfortable with this reactive mode, and sometimes with their lack of knowledge of the controller tactical objectives. The goal-oriented instructions (e.g. “remain 8NM behind target”) should contribute to expand the flight crews’ temporal horizon, enabling anticipation of required actions and a smoothing of overall activity.

Delegation along with cockpit display of traffic information (CDTI) is expected to give flight crews more contextual knowledge (controllers’ strategy, possibly surrounding traffic). Whereas up to date situation awareness can enable flight crew to anticipate future actions and goals, as stated in [6], “a key to maintaining situation awareness is to anticipate; stay ahead of the airplane”. Even though the role of such situation awareness in the efficient and safe flight crews performance is indisputable, its emergence and updating are still opaque.

4.2.4 Getting aware versus interpreting situation

As underlined by SAE ([19], §6.2.2), a trade-off is necessary between providing sufficient information in terms of awareness, and cluttering display (and consequently pilots’ cognitive resources) with excessive and superfluous information.

The provision of traffic information on the CDTI raises issues of advantages and costs of situation awareness. Whereas the benefits of situation awareness in terms of anticipation and safety are admitted, the risks associated to build and update it are seldom pointed out. Delegation might occur in cognitively demanding periods (terminal areas), when flight crews might not be in a position to filter and interpret a large amount of information. In such a context, the relevance of displaying surrounding traffic (in addition to the target) is questioned.

4.2.5 Monitoring target versus controlling surrounding traffic

The issue of situation awareness and possible information display cluttering could also be described in terms of confused task allocation. Indeed, providing information about surrounding traffic might spread a dangerous feeling among flight crews: it may lead them to think they are in a position to play a direct role in the traffic control. While they could without a doubt contribute to incident detection and prevention, they might also from time to time spend time either questioning controllers’ strategies or assuming controllers intentions. This is highly related with the issue of cognitive tunnelling, where traffic information displayed on cockpit displays might possibly mask navigation and surveillance information and distract flight crews from their core task of maintaining separation relative to a single given target.

4.2.6 Detecting versus generating errors

The addition of new “human” tasks might lead to the introduction of new human errors. As discussed in [15], new errors could occur at each step of the process (target selection, solution identification, implementation). Yet, the involvement of the flight crews in the monitoring and in the separation tasks might enable them to contribute to the overall system safety, typically in detecting controllers’ errors (related to target selection or applicability conditions) or suspicious target behaviour.

In addition, compared to conventional situation (without delegation), having the flight crew in the separation loop (with delegation) provides a redundant monitoring.

5 Designing cockpit interfaces

5.1 Specifying interfaces

The first step described in the previous section aimed at eliciting generic needs in terms of information. The second step consists of translating these needs in terms of high level constraints. Even before the issue of displaying information, the interactions between flight crew and systems is tackled. The specifications were based on the combination of pilots requirements
and existing requirements ([19], §6.3) and standards [2][3][16][17][18][23].

5.1.1 Data input

In the cockpit, interactions with systems need to be reduced both in terms of time and cognitive effort. Whereas touch input devices, or even more advanced choices such as voice recognition could have been considered, we restricted ourselves to devices currently in use, namely the control display unit (CDU).

In terms of data input, delegation requires the flight crew first to select a target, second to enter given parameter (separation, merging waypoint) and third to validate the selection. These interactions are only made through the CDU. However, they lead to information displayed on the CDU and on the navigation display (ND).

An incompatibility was identified between the proposed design scheme and the airlines standard operating procedure that currently prevent flight crew from entering data in the CDU below FL100.

5.1.2 Information displays

Once the interactions are defined, it is necessary to identify first why information needs to be displayed (e.g. assess feasibility, monitor, detect incidents), second what information is required and third where and when to display it.

Following pilots feedback, the primary flight display (PFD), restricted to own aircraft flight parameters is not used to display delegation-related information. At this stage, no need to use it was expressed (even more, some pilots rejected the idea of adding non-essential information on the current PFD).

In relation to existing flight crews practices, as well as constraints (e.g. limited head down time), it was decided to display on the CDU information related to the delegation set up and use the ND as the monitoring support. However, once delegation is initiated, redundant information related to the ongoing delegation are also presented on the CDU.

5.1.3 Information content

The content and format of information refers to what to display (e.g. ground speed, along track distance, separation value) and how to display it (e.g. auditory, graphical or textual cues).

It was initially decided to restrict the evaluation to a given type of aircraft (Airbus A320), therefore in line with (SAE [19] §6.3.3 and §6.3.5) the choice of symbols, abbreviations and the colour coding were based on existing Airbus rationale.

To take into account issues raised previously (in particular in sections 4.2.4 and 4.2.5), it has been decided to show only the target aircraft, and not all the surrounding traffic.

The following symbols were chosen:

- Own aircraft is represented with a yellow symbol, always at the centre bottom of the ND (arc mode).
- Target aircraft is represented with a white triangle associated to level and vertical trend; it might become amber or red in case separation is lost.
- Additional information about the target is initially displayed at the bottom centre of the ND (below own aircraft), and is then displayed on the bottom left of the display, once the delegation is implemented. Information provided in this box consists of delegation constraints (separation and waypoint), current along track distance, target aircraft ground speed.
- In addition to textual information displayed in information box, separation is indicated by an arc of circle positioned in front of own aircraft, always on aircraft trajectory. An “arc and arrow” indicates where separation is established. This symbol is similar to the “broken arrow” used for indicating top of descent / climb.
- Links are displayed to indicate relation and relative positions of target and own aircraft. A double dashed line is used to allow for easy visualisation especially in situations when the links overlay the trajectory (e.g. merging).

In terms of colour coding, the following was implemented:

- Green refers to information provided to the system, but which flight crews can not modify (e.g. target information).
- Blue indicates temporary information (e.g. ongoing process of establishing the separation).
- White is used to indicate nominal situations, in particular to indicate when the separation is established.
- Magenta indicates a constraint.
- Amber is used to highlight that the constraint is not acceptable; it is also used to capture flight crews attention in case the separation is lost.
- Red is used as a final indicator that the separation is far below or above the given constraint.

In addition, attention was paid to ensuring consistency between the CDU pages, in terms of format and position of information displayed.

5.2 Resulting interfaces

5.2.1 Identifying target aircraft

In order to reduce the time induced by the target selection, a direct input of the target identifier (the SSR code here) was decided, rather than a selection in
a list of surrounding traffic. The resulting page (Figure 3) displays details about the target, that are the SSR code, ground speed, current distance to own aircraft, relative altitude and vertical trend. Indeed, in terminal areas, surrounding traffic might be quite numerous. The risks of errors related to inputting the code on the CDU are tackled with an explicit positioning of the target, which should contribute to detecting if the target appearing on the ND is the expected one (Figure 4). Moreover, in case the code entered does not correspond to an existing target, an explicit message “Invalid SSR code” is displayed on the scratchpad (CDU).

Once pilots select a specific type of applications, they input the separation value (e.g. 8NM), and the merging point if applicable (e.g. TUNOR). The system calculates if delegation is achievable in such a context, taking into account the time constraint (two minutes here) and the target current speed, position and direction.

If delegation is not feasible, the value of the requested separation is displayed in amber, and the message “UNABLE DELEGATION” is displayed on the scratchpad (Figure 5).

If the delegation is feasible, in addition to CDU display (Figure 7), visual information relative to the separation is displayed in cyan on the ND. Three cues support the flight crews in understanding the current situation: (i) a link between own and target aircraft, anchored at the merging point if applicable; (ii) an arc of circle displaying the position of the requested separation (i.e. where the aircraft should be now if the separation was established); (iii) an “arc and arrow” indicating where the aircraft will be when separation is established. The position of these symbols is continuously updated (Figure 6).

It is worth noticing, that unlike design choices presented in [1], here the relevant information to monitor is distance between the own aircraft and the arc, rather than the distance between the target aircraft and the arc. Merging situations where aircraft are not following the same path and where the target aircraft may potentially be off scale, motivated this choice.

Redundancy between information displayed takes the form of graphical and textual data. Typically, the current separation is represented by the links between own aircraft and target, and by textual information in the target information box. The requested separation is represented by the arc of circle and by a value also displayed in the target label. Colour consistency reinforces the association between this redundant information.

5.2.2 Assessing feasibility

Prior to assessing the feasibility of delegation, pilots have to select the type of application (e.g. remain, merge). In order to reduce the number of interactions with the interfaces, it was decided to limit the number of CDU pages. Therefore, the page displaying the features of the target is used as a “portal” leading to sub-pages (Figure 3).

The displays presented in the figures are not direct screen dumps but rather drawings used in the specification process.
5.2.3 Identifying required flight parameter

Simultaneously with the feasibility assessment, the system calculates the “optimal” speed (given aircraft performances) enabling separation to be established within the given time constraint. The required speed is displayed on the CDU (Figure 7). Pilots involved in the design rejected the provision of such an information on the PFD.

Once the pilot has validated (i.e. pressed the INSERT option) and reported its acceptance to the controllers, a new page provides an update on the situation. The current speed (i.e. selected on the FCU) is used to provide an estimate of the time required on the CDU (Figure 8) and to position symbols described previously. On the ND, the arc of circle now validated as a constraint is magenta (Figure 9). It is important to clarify that even though the solution suggested by the system is the “optimal” one, the flight crew might decide to choose a more appropriate one taking into account parameters not available to the system (e.g. weather conditions).

5.2.4 Monitoring situations

Colour coding was used in order to inform about the status of the situation and potentially capture flight crews’ attention in case of drifting situation. White colour reflects the nominal situation, when separation is established and maintained within pre-defined limits (Figure 10).

In case separation is lost, information is then displayed first in amber (between 1 and 2NM above or below the requested separation), and later on if necessary in red (once at least 2NM above or below the requested separation). The alerting colour scheme is applied to the links, the target symbol and the target information box, excluding the separation value (Figure 11).
The next step will now consist in going from qualitative to quantitative evaluation of the usability of the interface in a full mission human in the loop simulation, and in particular the separation maintenance performance. Beyond these specific aspects, the issues listed in this paper and which served as design constraints, will be used as guidelines to assess the applicability of the proposed delegation of tasks.

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**Acronyms**

ASAS  Airborne Separation Assurance System  
CDTI  Cockpit Display of Traffic Information  
CDU  Control Display Unit  
FCU  Flight Control Unit  
FMS  Flight Management System  
ND  Navigation Display  
PFD  Primary Flight Display

**References**


