Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

NLR-TP-2005-065

Three large LCD cockpit concept for retrofit applications

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This report has been based on a paper presented at the 23rd Digital Avionics System Conference, Salt Lake City, Utah, U.S.A., October 24-28, 2004.

Customer:	National Aerospace Laboratory NLR
Working Plan number:	AT.1.G.3
Owner:	National Aerospace Laboratory NLR
Division:	Air Transport
Distribution:	Unlimited
Classification title:	Unclassified
	February 2005

Approved by author:	Approved by project manager:	Approved by project managing department:
28/2/05	28/2/05	

Summary

Nowadays glass cockpits for commercial aircraft usually feature six display units. When one or two units are lost due to failures, continued safe flight is guaranteed using the remaining units. In this paper a cockpit concept is proposed with only three display units, and at least the same safety level. This Three Large LCD Cockpit can reduce costs for the airlines, while at the same time it provides built-in growth potential for emerging functions. Innovative display technology based upon the "fail safe concept" and a reconfigurable interface between pilots and the avionics system allow these seemingly incompatible goals.

The paper describes an example application of the new cockpit concept for retrofit applications in Airbus single aisle aircraft. The system architecture is explained, both on the cockpit level and on the level of the individual display units. Handling of detected and undetected display unit failures was the key issue in the human-machine interface development. The display reconfiguration principles are presented and the integration of back-up displays and new functions is explained. Both the reconfigurations and the new functions benefit from the availability of cursor-control devices.

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1 Introduction

1.1 Background

Commercial airlines operate in a rapidly changing and highly competitive environment. Especially in air transport, cost reduction is an important factor for success. Airlines are therefore keen to adopt features that make the operation more efficient.

On the flightdeck, screen real estate is highly valuable. Display units are often fully occupied by information related to flight, navigation, system monitoring and alerting functions. They leave little or no room for introducing new functions that satisfy near-term operational or safety needs. Using dedicated display and control devices for these functions is a costly matter and may lead to a less than optimal working environment for the pilots.

The Three Large LCD Cockpit (see Figure 1) primarily aims at two things at the same time: reducing costs for the airlines and providing them the necessary growth potential for implementing emerging functions. The new concept should also provide safety benefits and offer the pilots a user-friendly working environment.

Figure 1. Artist Impression of the Three Large LCD Cockpit

1.2 Objectives

The proposed cockpit design is intended for retrofit applications. The Airbus single aisle aircraft family was taken as an example application. In order to show that such a cockpit can be industrially, commercially and operationally attractive, the target has been set at a flightdeck with three identical large liquid crystal displays (LCD’s) in a non-redundant architecture. This objective ensures that the existing flightdeck philosophy can be respected while offering a larger usable display area and keeping an ambitious price target. Naturally the cockpit design is fully adapted to the type of operations performed with the target aircraft.

The fact that the cockpit design studied uses only three large LCD display units is an *a priori* choice aimed at ensuring the commercial attractiveness of the product. It allowed defining objective values such as 20% reduction of production costs, 20% reduction of power consumption and 20% improvement of the mean time between failures (MTBF) with respect to the contemporary cockpit with six display units.

1.3 Proposed Concept

In the proposed Three Large LCD Cockpit concept, a display unit should be able to continue displaying information after a single failure. This technology will guarantee continued safe flight and landing. Moreover, it should be possible to continue the operation without replacing the degraded display unit, for example at an outstation.

The new concept offers a substantial increase in usable display area compared to the current cockpit. This provides a mean to present more comprehensive and more consistent information in case of display unit failures. After a failure, the most important information can always be displayed and integrating back-up displays is straightforward.

The new cockpit also allows presenting more information at the same time than in the current cockpit. New functions like the display of vertical flight path information in relation to terrain can be integrated in a natural way, without sacrificing display area for existing functions.

The large displays also provide the display area needed for a truly interactive cockpit. Such a cockpit can reduce the need for dedicated hardware panels and control and display units. For example, an interactive datalink display can be used instead of a dedicated datalink command and display unit.

Finally, the larger display units open the way to present display formats that need a relatively large display area to be effective. Three-dimensional perspective displays, charts and cartographic maps are examples applications.

2 System Architecture

2.1 Three Instead Of Six Display Units

The choice of a cockpit concept with only three display units brings many consequences right from the systems layer to the display unit architecture. The aircraft system layer is taken from the latest Airbus single aisle family. In this aircraft the six square Display Units interface with three Display Management Computers (DMC’s). It then comes quite naturally to pair two small display units and to replace them by one large rectangular display unit (see Figure 2).

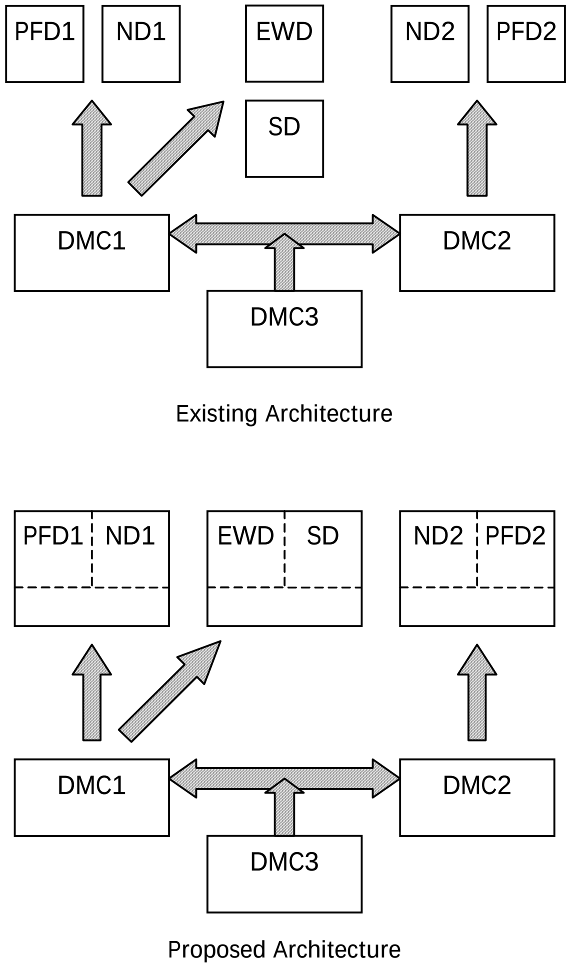


Figure 2. Cockpit System Architecture

Leaving only three display devices to show the primary flight information during a commercial flight implies that no complete loss of display unit is allowed as a single failure condition. This would cause the loss of information on one side, leading one pilot to bear the flight and navigation tasks for the rest of the flight. It would lead to undesirably high levels of workload. This possibility has been decided unacceptable. Thus, no complete loss of display can be possible in the Three Large LCD Cockpit.
In order to implement a display that would fit this requirement, all elements of the display unit were designed with three strict constraints:

- It can not be afforded to lose a function due to a single failure in the display unit.

- It is required to implement rigorous and absolute failure segregation in the display unit.

- Implementation of the resistance to a single fault must use the natural multiplexing of resources (no redundancy).

The respect of these rules in the implementation of the display unit is referred to as “fail-safe concept”.

2.2 Fail-Safe Concept

Figure 3 shows a high-level concept of an LCD based display unit. Input signals are received from the DMC’s and used to generate the picture, which is presented on the LCD glass. Naturally, the LCD matrix has a backlight module.

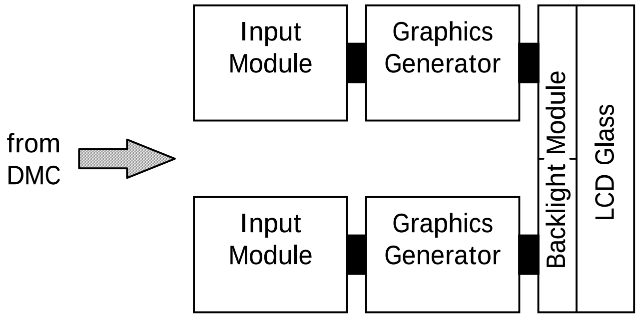


Figure 3. Main Functions in the Display Unit

Most of the time, the most critical failure mode for a display unit is directly related to the loss of the power supply. Such failure would directly lead to the loss of critical information. An additional constraint is related to emergency electrical power conditions. It can not be afforded to lose all three display units under these conditions; as in the current aircraft, Primary Flight Display (PFD) and Engine/Warning Display (EWD) must remain available. As a consequence, assuming that all display units are the same, two power supply modules are embedded per display unit.

Up to the graphic generation modules, multiplexing of the existing channels is quite obvious. Yet, entering in the details of allocating graphics computation resources implies to know what are the zones of the screen addressed by the different computation channels. This is what makes the LCD matrix the keystone of the architecture.

Structurally, an LCD is a matrix of dots addressed line by line through the columns drivers. Most commercial-off-the-shelf LCD’s are addressed through one or two column driving boards (see Figure 4). Addressing the whole LCD with one column board would not suit the fail-safe concept. Another option is to drive separately the odd and even columns with two driving boards. This solution was also rejected because it leads to failure modes that are not acceptable. Specially, the loss of sub-pixels of different colors (red, green and blue) leads to some color shift that is not affordable in an aircraft.

After investigation of the failure modes associated with the possible addressing schemes of LCD, the architecture of the matrix has been set to a left/right matrix. The addressing scheme is based on “bank writing”[1] addressing scheme for the columns and double-sided line addressing (see Figure 5).
The graphic processing resources are also split in order to have failure modes that correspond to the LCD ones: one channel is driving the left half, the other channel is driving the right half of the LCD. The backlight module is designed in a similar way.
As a consequence, any failure of the system can only lead at most to the loss of one side of the large LCD unit. In this case, we have acceptable and independent failure modes with an uninterrupted addressable area. It also allows presenting display formats covering more than half the display area, without visible interruption in the middle.

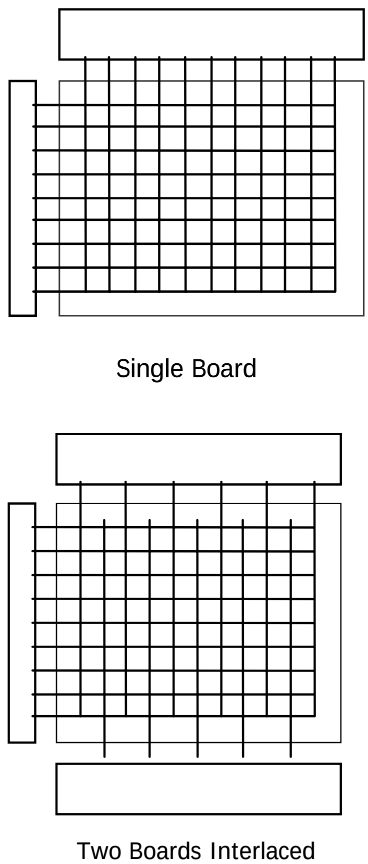
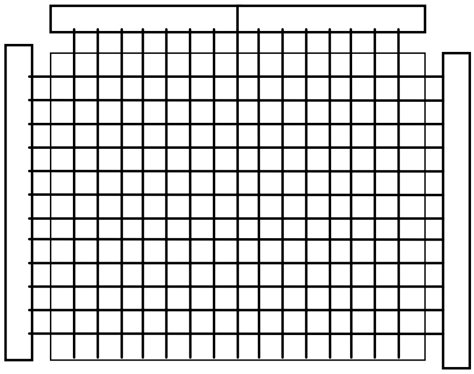


Figure 4. Common Commercial Driving Schemes

[1] Bank writing consist in addressing two groups of columns simultaneously during the same line selection.



Two Boards, Bank Writing

Figure 5. Selected Matrix Addressing Scheme

2.3 Cost Reduction

One of the principles of the fail-safe concept that we developed for the Three Large LCD Cockpit is the minimum redundancy. This principle is a guarantee that a cockpit built around this display unit should not cost more, in terms of acquisition costs, than a contemporary Airbus aircraft cockpit with six display units and the same functionality. Apart from this fact, other potential cost reductions were investigated like the reduction of the cost of the matrix and the reduction of the production cost of invested manpower. Another aspect that influences the cost reduction is the decision to keep only one video-processing module per display unit.
Hardware integration in the cockpit has also been explored as it has an important impact on the total cost of a cockpit. Two possible configurations are in competition: “smart” displays and “dumb” ones. The first case corresponds to the Airbus single aisle aircraft display units where the graphic processing is made inside the display unit together with all kinds of data processing. On the opposite, the “dumb” displays correspond to a set of two separate units: the processing unit that is usually remote from the cockpit and the display unit that receives and displays a video signal.
Both configurations have their pros and cons. For example, in the case of “smart” displays, the production cost is usually lower as the video transmission is simpler between the graphic processor and the display itself. Note that there are other factors that influence the production cost like the suppression of some recurrent costs and the sharing of different parts.
Last point about the cockpit architecture is the total cost of ownership of the cockpit. This does not only include the recurrent cost of the display units, but it also includes maintenance costs and operational benefits made out of the new capabilities of the cockpit, e.g. improved dispatchability.
As a first approximation, it seems that the maintenance aspects are negatively impacted by the use of smart displays that are likely to be more expensive to own. But to be precise, the aspects of maintenance strategy should be further studied.

Considering all aspects, using smart display units seems the most favorable. The architecture for the Three Large LCD Cockpit concept was thus based on this type of display units.

3 Human-Machine Interface

3.1 Methodology

The human-machine interface activities comprised of several design iterations. Each design iteration started with an analysis of the open issues. This was followed by proposals for improving the human-machine interface or the display unit itself. These proposals were also based on an analysis of the pilot tasks and the required information for these tasks. The most promising proposals for displays and controls were implemented in a simulation using a rapid cockpit prototyping tool, usually with a few variations. These were then evaluated in a cockpit mock-up (see Figure 6) with system experts and airline, certification and test pilots. The evaluations were mainly intended to obtain failure criticality ratings and to get feedback on usability aspects.

The cockpit mock-up had a realistic geometry and contained two commercial LCD's that could accurately represent important visual aspects of the proposed LCD's (e.g. pixel pitch). Furthermore, various light conditions could be simulated (day, dusk, night).

Input to the first design iteration was an analysis of potential human factor issues related to the new cockpit concept. The issues were identified by comparing the current Airbus cockpit with the new concept. This is in line with the JAA policy paper on human factor aspects of flightdeck design [1].

Figure 6. Cockpit Mock-Up (“Apero”)

In the later iterations, the results of the evaluations were used as the main input for optimizing the design. The results were not only used to optimize the human-machine interface, but also to improve the display unit hardware. The activities can be characterized by continuously collecting feedback and consequent and rigorous solving of open issues.
Handling of display unit failures was the focus of attention in the human-machine interface design and in the evaluations. Consequently the displays, failures and the recoveries were simulated in a realistic way. In order to allow efficient optimization of the control method, knobs and selectors were at first implemented in software; they could be operated with a trackball.

3.2 Three Phases

The human-machine interface design was split in three phases. The first phase was explorative of nature and was mainly used to find the strengths and weaknesses of the concept and to get a well-founded estimate of its safety potential.
In the second phase the additional screen area offered by the display units was used to counteract the effects of display unit failures by means of display reconfiguration. Main purpose was to design a safe cockpit with an improved level of dispatchability. Changes compared to the Airbus single-aisle aircraft cockpit were kept to a minimum.
In the third and last phase a completely new reconfiguration mechanism and the addition of new functions and interactive features were studied. Also in this phase compatibility with the existing cockpit remained an important issue, but the design team took more freedom to explore the full potential of the large display units.
The second and third phase each delivered a working human-machine interface concept. However, the remainder of this paper is primarily concentrating on the interactive cockpit from the third.

3.3 Cockpit Layout

The Airbus single aisle aircraft cockpit was taken as the example application for the cockpit concept and thus for the HMI. Both the captain’s and the first officer’s display units present the standard Airbus PFD and ND (see Figure 7). The center display presents the standard Engine/Warning Display (EWD) with an extended message area (compared to the baseline cockpit) and the standard System Display (SD) in a side-by-side configuration. A vertical line separates the displays.
The areas under the PFD, ND and SD are used for presenting new information and for presenting back-up displays in case of failures. These displays are new and specifically developed for the concept. A horizontal bar separates the standard displays from the displays in the lower areas. This bar also contains a menu for selecting and deselecting displays in the lower areas.

Each display unit has two knobs for brightness control and switching, corresponding to the left/right architecture. The concept also has a selector to transfer the SD to a ND position. The stand-by instruments in the concept are as in the latest generation of Airbus cockpit, including an LCD-based integrated stand-by instrument.

3.4 Interactivity

The displays in the lower area, except the back-up displays, have interactive controls like buttons and selectors. The interactive controls have a dedicated graphical design, but follow the Airbus color coding philosophy. The functionality of the interactive controls is based on Arinc 661 [2]. This makes it straightforward to incorporate a standard graphical design (e.g. that from the Airbus A380) in the concept. The captain and first officer each have a trackball in the center pedestal to operate the interactive features.

The interactive features were implemented as a demonstration of the possibilities and were not fully detailed. Some features, like sharing the center display unit with two cursors control devices, definitely need more attention, but no major obstacles are expected.

3.5 Failure Handling

Although the probabilities of failures are low, the new display unit can still fail in various ways. The display unit itself detects most of its failures and automatically takes the required action: the affected part of the display unit is switched off. The unaffected part – the other half of the screen – is still perfectly able to display information to the pilots. However, some failures can not be detected in a technically reliable or cost-effective manner. In those cases detection and taking action is up to the cockpit crew.

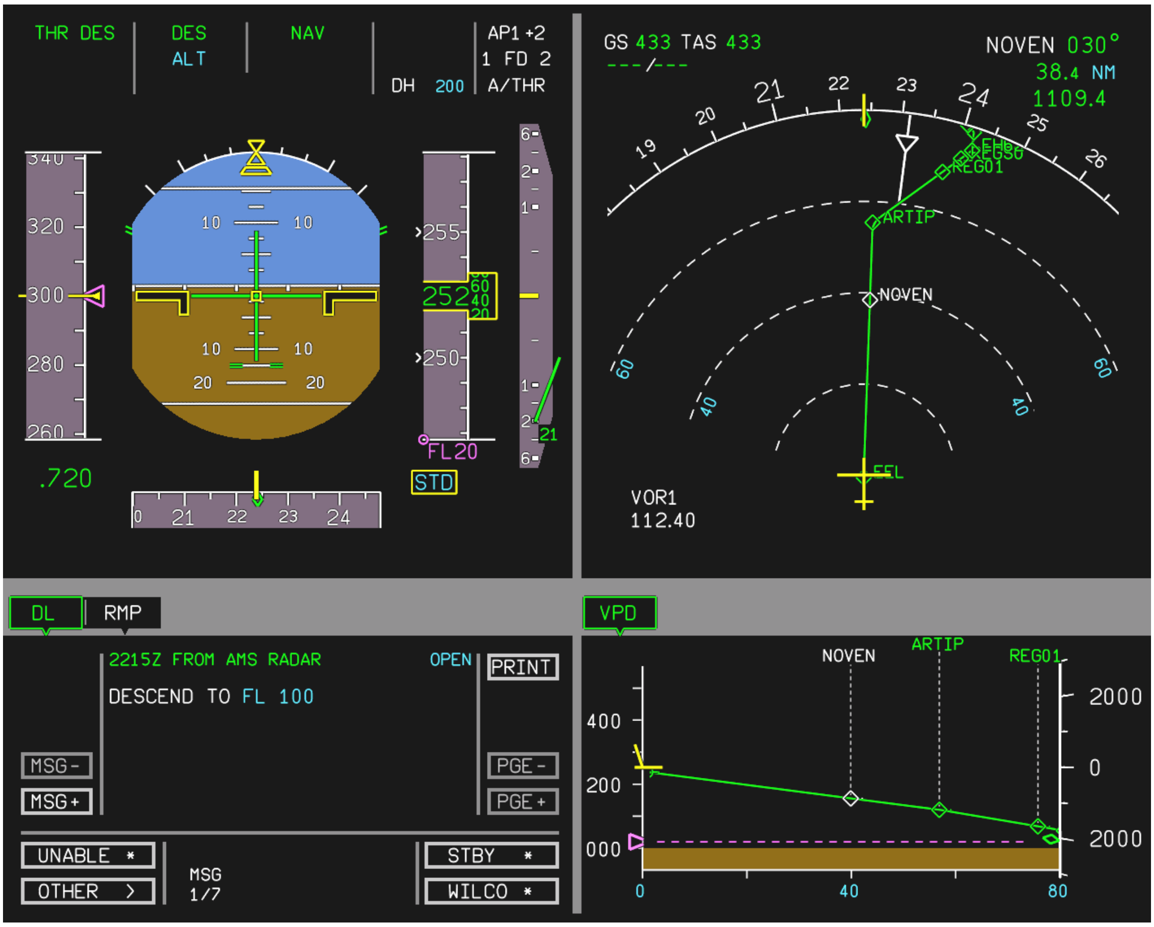


Figure 7. Nominal Layout of the Captain's Display Unit

When the automatic detection mechanism or the cockpit crew switches off half a display unit, the displayed information is automatically redistributed over the remaining display area. The redistribution is governed by a set of rules that assure that the most important information is displayed at all times, without requiring crew intervention.

The large usable display area also allows the presentation of back-up displays in the lower areas (see Figure 8). For example, when a full-size ND is lost, a compressed display with the same functionality is presented under the on side PFD. The Compressed ND (CND) was specifically designed for the concept; it is not an existing Airbus display. Note that it is an important element in the safety case.

This failure handling strategy minimizes intervention by the cockpit crew. This is an important aspect, in view of the fact that display unit failures occur rarely. Ease of use is therefore definitely a requirement in order to guarantee safety.

4 Results

4.1 Dispatchability

A reconfiguration scheme was developed that is tailored to the new display units and optimized for the dispatchability and safety oriented objectives of the concept. The original objectives aim for dispatch with a single failure in one display unit, but the design target was set more challenging to two display units with a single failure.

During the evaluations it became clear that the new cockpit concept could indeed offer an improved dispatchability level compared to contemporary aircraft. This is not only due to the reliability of the display units, but also due to the new capability to take-off with two display units with a single failure. The demanding design target can be met using the innovative technology of the display units, the larger display area they offer and by the automatic reconfiguration scheme.

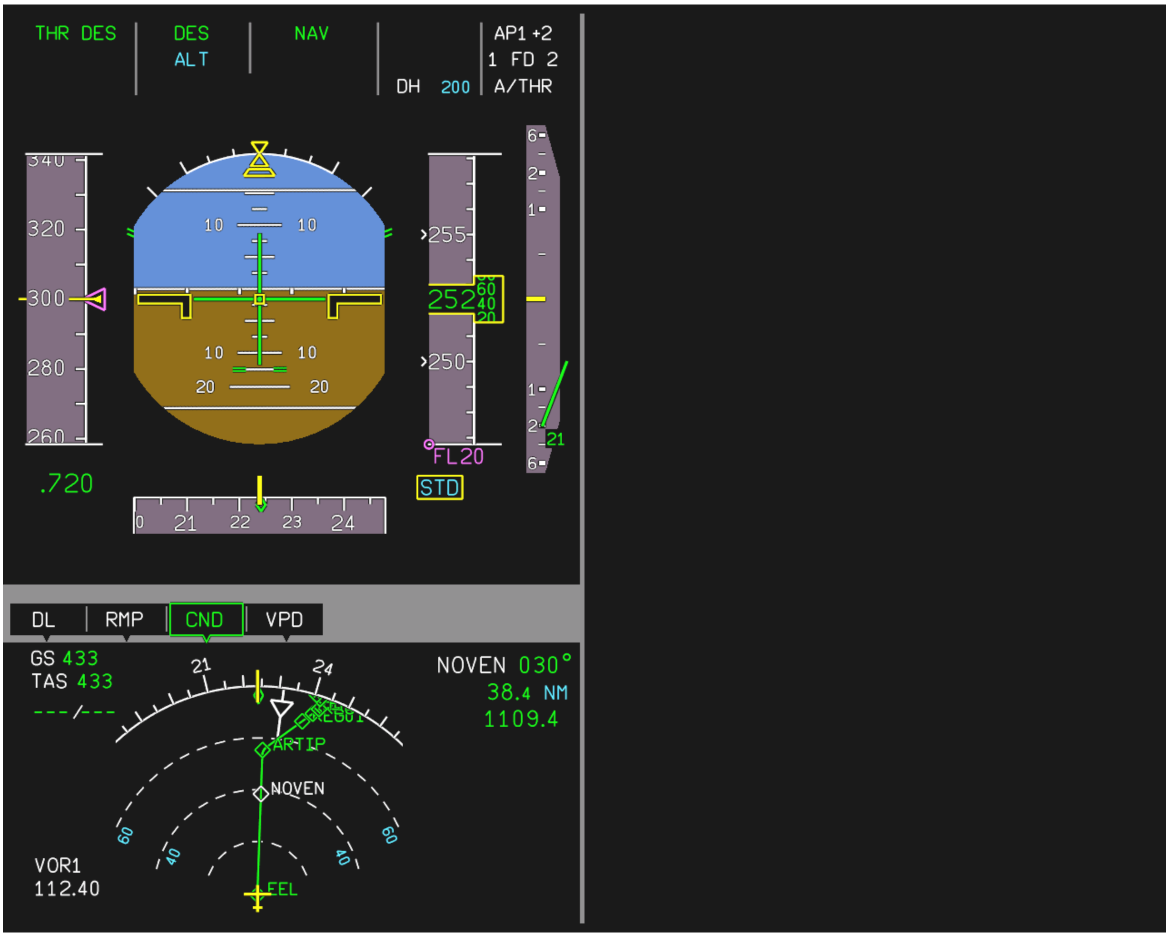


Figure 8. Non-Nominal Layout with Compressed ND

4.2 Safety

Criticality ratings of all possible display unit failures and some important electrical system failures were established, including an assessment of two consecutive independent failures. These were used in the numerical safety assessment of the new display units. In such an assessment the probability of failures is compared to their criticality as stated in the certification requirements [3]. This is to assure that safety is not compromised, even in critical flight phases. Compared to contemporary designs, the proposed display unit and its new reconfiguration scheme potentially have a positive impact on safety. It takes more failures before information is lost; the most important information is automatically displayed at all times, and the cockpit crew can easily call up the other information. This remains true, even after several display unit failures. Note that the chances that this will happen are not high, since the failure probabilities are already low in the proposed display unit.

4.3 Costs

The approach in terms of costs was driven by the objectives of reduction of the recurrent costs and increase of the MTBF. Among several "dumb" and "smart" architectures studied, the recurrent cost was always in favor of the "smart" ones. If we consider two "dumb" architectures amongst the best ones that are fail-safe, the first one (built around a common graphic processing architecture) is 8,6% more expensive and the second one (a copy of the "smart" architecture selected) is 22,4% more expensive. In consequence, the selection on recurrent cost criteria elected a "smart" architecture. A second round of recurrent costs analysis showed that such cockpit built around the "smart" architecture selected was less expensive than it would have been with six small display units. Yet the target of 20% cost reduction was not reached.
Last consideration is the total operational and ownership cost. This includes the maintenance strategy and the potential gain in operation. For the maintenance aspect, the MTBF of the cockpit is 16% better than its six display units equivalent. This promises a potential reduction of costs but yet the maintenance items are more expensive which can harm this gain. On the other hand, the maintenance strategy can be optimized according to the new dispatch case and bring a certain reduction of replaceable units. The influence of these factors is a complex tradeoff between price, stock and logistic, which is out of the scope of this study.

4.4 Reliability

The reliability of the cockpit is a combination of three parameters: the availability of hardware functions, the reconfigurations of the symbology (availability of flight monitoring functions), and the MTBF of the cockpit.
The MTBF mainly influences the maintenance strategy and is dealt with in the cost paragraph. This point was improved at cockpit level by the new architecture even though the per display

unit MTBF dropped. This improvement is caused by the factorization of functions like the weather radar input.
The availability of hardware functions has a direct impact on the level of safety as required in certification [3]. Regarding this point, the segregation model used to build the fail-safe display units guarantee that this availability is preserved with respect to a six displays architecture. The main change is the fact that the LCD matrix is a common failure mode for the display unit. Thus, if we consider that LCD glass breakage is improbable, the cockpit design offers at least the same level of availability per half display unit as a six display units cockpit.
The actual gain that this cockpit offers is its ability to reshuffle the functions using the reconfiguration logic. This mechanism described in the failure handling paragraph allows reaching a higher level of safety with comparable hardware reliability.

4.5 Usability

A key feature of the new concept is the newly designed Compressed Navigation Display. It takes up half the space of the normal ND and is presented when a full-size ND position is lost. It presents the same information as the ND in a highly compatible and compact format. This display would need to be certified when the concept is developed into a product. This should be feasible, although further optimization is definitely needed.
Some new features in the layout of the human-machine interface and the design of the displays assure that the existing Airbus displays can be integrated in the new framework. Examples are the separator lines and bars, and the position of the page name on the SD. The end result is a cockpit where the standard displays naturally fit in the new concept.
The new display unit technology allowed designing an optimized control method. The new design features fewer controls, but it still gives the pilots the required command in an intuitive way, also in case of display unit failures.

4.6 Growth Potential

In the third and last design phase four new functions were added to the human-machine interface (see Figure 9): a vertical profile display, a datalink display, a display for managing radios, and a security camera display. The latter three displays are interactive, and can be controlled by the pilots using trackball. In contrast to the back-up displays the new functions were meant as demonstrators and were not fully detailed.
The new functions could indeed be integrated easily, in a natural way for the pilot and not compromising presentation of existing functions. The new functions could also be included in the automatic display reconfiguration mechanism in a straightforward way. In fact, part of the strength of the final design is the possibility to select information with the cursor-control device. After failures, the most important displays are automatically presented, but the pilots can always select the other displays in an intuitive way.

Figure 9. Interactive Datalink and Radio Management

5 Conclusions

The objectives of the Three Large LCD Cockpit at first sight seem contradictory. Reducing the number of display units in the cockpit and at the same time increasing the levels of safety and dispatchability are seemingly incompatible. However, technological innovations make the Three Large LCD Cockpit an appealing prospect. The smart display units and the set-up of the human-machine interface allowed matching and even surpassing the original goals.

An aircraft fitted with the Three Large LCD Cockpit may lower costs for the airlines and result in less disruptions of the operation due to unscheduled maintenance. The new cockpit concept also provides the cockpit crew with a user-friendly working environment including built-in growth potential for emerging functions.

6 Concluding Remarks

The work presented was part of a research and technology development project. End products of the project were first prototypes of the display units and validated concepts for the human-machine interface.

The results were positive and there seem to be no major technical and certification obstacles for the Three Large LCD Cockpit concept. However, not all aspects were covered and for a real retrofit application more work is definitely needed. In such a case the developed concepts could be a valuable input.

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Acknowledgements

The work described in this paper was performed as part of the NEWSCREEN project, partly funded by the European Commission within the scope of the Fifth Framework Program.

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