RESEARCH ON INTEGRATED COLLIMATED COCKPIT VISUAL AND FLIGHT INFORMATION SYSTEM

Christian Berth*, Gerhard Hüttig*, Oliver Lehmann*
***Technische Universität Berlin - Department of Aeronautics and Astronautics - Chair of Flight Guidance and Air Transportation - Secretary F3 - Marchstr. 12 - 10587 Berlin - Germany**
Keywords: *collimated visual, flight information system, windowless cockpit*

Abstract

The work presented introduces the development of an Enhanced Integrated Collimated Cockpit Visual and Flight Information System (ECVFIS) environment to further improve situation awareness and reduce workload through all phases of flight operation. The goal is to use this technology by several air system designs ranging from supersonic business jet to Unmanned Air System (UAS) ground control station.

This paper provides an overview of the theoretical background of previous research basically dealing with Human-Machine Interfaces (HMI) of aircraft cockpits before briefly introducing the ECVFIS environment concept.

After discussing potential concept advantages and visual sensor platforms to generate daytime and weather independent visual information, we will discuss the realization of the applied research to validate the proposed concept.

1 Abbreviations

UAV - Unmanned Air Vehicle
UAS - Unmanned Air System
CFIT - Controlled Flight into Terrain
LOC - Loss of Control
MAC - Mid Air Collision
RI - Runway Incursion
HMI - Human Machine Interface
HSR - High Speed Research
GPWS - Ground Proximity and Warning System
TCAS - Traffic Alert and Collision Avoidance System
EFIS - Electronic Flight Information System

2 Introduction

Despite the continuing growth of worldwide commercial air traffic, accident rate persist nearly the same over the past 20 years - therefore the number of fatal accidents will increase. Mainly human factors have been identified as the primary cause of air traffic accidents like *Controlled Flight into Terrain* (CFIT), *Loss of Control* (LOC), *Runway Incursion* (RI) or *Mid Air Collision* (MAC) [1]. Wrong decisions resting upon insufficient situation awareness are the main reason within that focus.

Today's passenger aircraft are very complex flying systems with a high level of automation. This in turn reduces pilot's workload and improves aircraft handling characteristics. In contrast, the number of subsystems increased disproportionately high to guarantee very low system failure probability of the automated systems. Associated, the focal point of pilot duties changed from aircraft handling to system monitoring during the most time of the flight. Current *Electronic Flight Instrument System* (EFIS) consisting of several displays form the core of modern system monitoring and flight information equipment.

Additional systems, developed to support the pilot in making adequate decisions, have been integrated into the EFIS. The *Ground Proximity Warning Systems* (GPWS) for instance helps to avoid unintended terrain approximation. Further systems like *Traffic Alert and Collision Avoidance System* (TCAS) are to prevent midair collisions. Besides the enhancement of today's flight operations, there are still some disadvantages that need to be solved.

The current flight information display area serves as an excellent indicator for increasing information diversity despite the growing automation. Altogether, the designed display area comparing e.g. Airbus A330 and Airbus A380 has been nearly quadrupled with constant pixel size per square inch.

Restrictions in human cognitive abilities question if a further increase of subsystems with own displays or additional information integrated into current display application, will improve situation awareness or just counteract. The main problem of human caused accidents is not restricted provision of information. It is mostly an overflow of inadequate pre-processed information in situation of reduced cognitive abilities caused by mental overload or even by mental underload.

On the other side, mental overload and underload is directly linked to the workload gradient. As aforementioned, workload has drastically been reduced through introduction of automated subsystems with parallel increase in demanded system knowledge to understand automatic processes and to handle abnormal situation. Thus workload gradient radically changed with automation. Long periods of mental underload (Cruise Flight) are followed by periods of excessive mental load (Approach, Landing).

To solve the collision between automation and pilot in the loop demands several strategies have emerged. One strategy e.g. follows full automation leading to an unmanned aircraft [2]. The strategy presented here still involves human interaction by drastically adjusting HMI's to comply with new standards of subsystems and automation.

3 Previous Research

The *Department of Aeronautic and Astronautic* (ILR) of the *Technische Universität Berlin* in particular the *Chair of Flight Guidance and Air Transportation* has been engaged in HMI research for a long time. Several projects in cooperation with different industrial and research institution partners have been carried out using a JAR STD-1A Level DG qualified *Airbus A330/340 Full Flight Simulator* (FFS) located at the ILR. Those projects among others addressed research on HMI specific themes like pilot performance, interface design, situation awareness etc.

Aircraft accidents and nearly accidents data have been collected and analyzed in preparation of the project. The results showed a great need in research for aircraft cockpit HMI taking a much further approach.

This being the situation, research has been started to further improve situation awareness by redesigning the today's passenger aircraft HMI with respect to growing automation and amount of subsystems. Within the ASSIST project research has been carried out to analyze effects of the enhanced Flight Management System (FMS) HMI [3]. The COSPACE project addressed spacing application for approaching aircraft and appropriate information presentation within current EFIS [4].

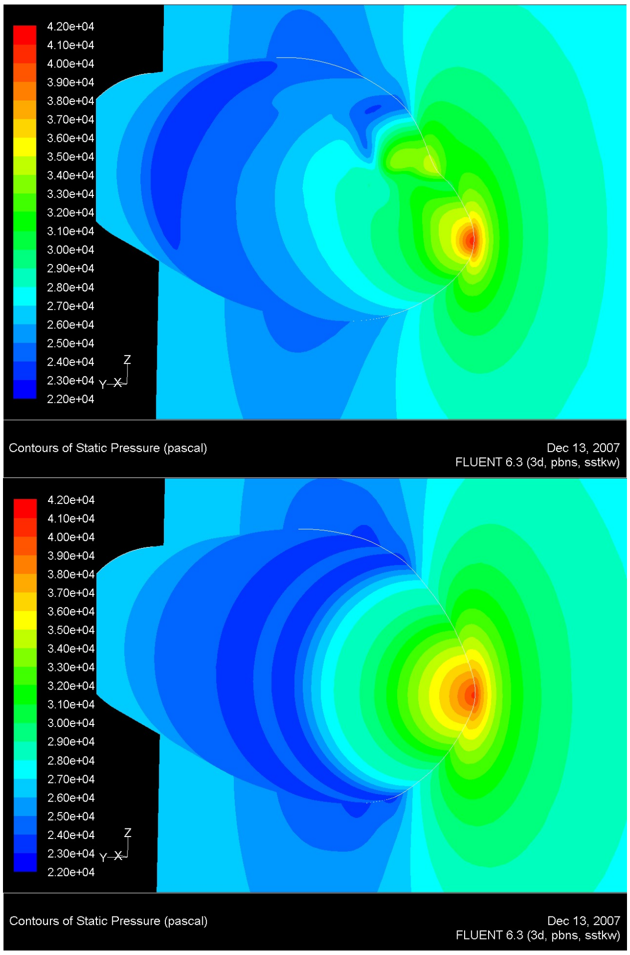

Fig. 1. Difference in pressure distribution between windowed and windowless nose section.

In preparation of this particular experiment several pre-experimental studies have been carried out. Extensive studies to outline visual relevance for air traffic accident have been arranged followed by research regarding structural and economic consequences of windowless aircraft cockpit (ref. Fig. 1.).
New EFIS display configuration and information presentation studies have been conducted as further preparatory work. At present the Airbus A330 FFS is prepared for the ECVFIS concept.

In addition, NASA has carried out flight tests during *High-Speed Research* (HSR) program. The feasibility of manually landing a Boeing 737 using a single TFT screen as visual for the pilot was successfully demonstrated (windowless manual landing) [5].

4 ECVFIS Concept

The fundamental concept consists of a collimated visual system using high resolution displays. There are several ways of implementations into a future cockpit layout. The furthermost concept will replace front cockpit windows and consist of a wide view screen placed in front of the pilots. Depending on aircraft type and design the visual may have up to 360° in azimuth. Visual information will be obtained by two or more hull integrated multi channel cameras comparable to current Enhanced Visual Systems (EVS). They will provide the main daytime and weather independent view for the visual system and additional zoom and tilt function to monitor objects of interest (aircraft structure, ground objects and runways) or to change point of view.

Aperture map radar sensor data can give additional ground information in situation of poor thermal camera view and backup the entire system.

High resolution generic ground map database including elevation will be used to highlight special structure, buildings and ground information.

All sensor and generic visual data are merged and projected on the pilot's visual system. Data fusion will be adjusted manually or automatically. Flight information is displayed within the field of view for each pilot and is adjusted depending on the flight phase. Priority information can be placed in the foreground while secondary information will be faded or placed in the background. TCAS information i.e. will be directly placed at the point of event (ref. Fig.2).

Within that concept displaced side or top windows may be kept as emergency, which may also prevent closed space anxiety (claustrophobia).

Fig. 2. Artiste impression of ECVFIS cockpit concept (night vision mode).

An interim solution within current aircraft cockpits will incorporate a removable head surrounding collimated screen including the same display features as the concept mentioned before. A fully head-mounted system like the one introduced with the F-35 JSF combat aircraft is possible but from ergonomic point of view out of question for passenger aircraft with much longer endurance.

4.1 Expected Concept Advantages

The ECVFIS itself is only part of an overlaying concept that is concerning the entire cockpit interface and adapting technologies like HOTAS principles, voice control, stereoscopic navigation and system information, etc.

Development of the presented concept was led by the intent to increase situation awareness of terrain and surrounding environment including air and ground traffic. Workload reduction by introducing an intuitive cockpit visual and information design without compromising flight safety will be the second goal. The replacement of windows with a redundant camera-visual system will reduce failure probability a several times and forms the core of the concept.

Therefore the ECVFIS concept is featuring known and new technological approaches to enhance flight safety at the level of human integration. Thus in turn will direct into several HMI and structure related advantages.

4.1.1 HMI

The use of this concept in future air traffic systems will improve situation awareness and handling processes by:

- *Daytime and weather independent visual system*
- *Nearly zero head down time through integrated visual and flight information*
- *Reduced risk of tunnel view and enhanced information scanning performance due to optimized large screen information presentation*
- *No restricted field of view (such as HUD)*
- *Optimized and flight situation adapted information presentation*
- *Coincident presentation of observable occurrences and related information*
- *Full CAT III landing and low visibility takeoff capability*

4.1.2 Structure

Beside advantages regarding the HMI, specific hardware advantages become effective:

- *Improved nose section aerodynamics considerably reducing noise and drag (ref. Fig.3.)*
- *No pivoting nose or complicated and expensive window layout needed for supersonic jet designs*
- *Lighter nose section structure*
- *Reduced nose structure and windows maintenance*
- *Enlarged and non obscured field of view (no glare shield and window struts)*
- *Merged generic and sensor data*

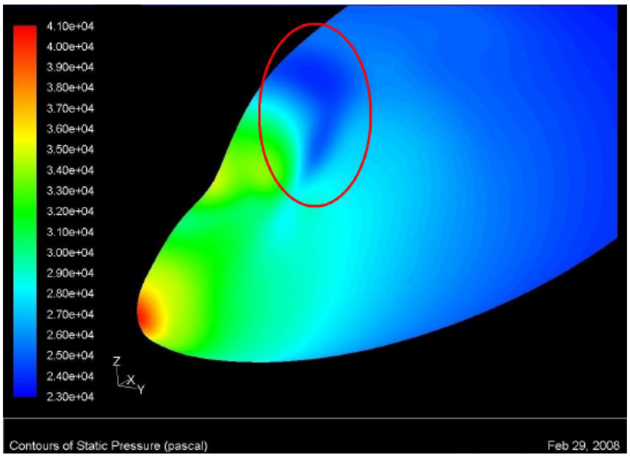

Fig. 3. Windowed Nose Section producing noise and drag

4.2 Sensors

Using visual sensor systems as a replacement for common window installation means no increase of failure probability in respect of flight safety. Considering the worst case scenario including loss of instrumentation under IMC, an independent and redundant integrated visual system will reduce failure probability.

To enhance situation awareness for terrain and air traffic situation a daytime and weather independent visual system based on visual sensor data should be preferred. A *Synthetic Vision System* (SVS), highly depending on positioning system integrity, is not as valuable as an independent system to decrease failure probability. Beyond this problematic SVS can be used as a backup.

The continuative development of visual sensor systems like *Enhanced Visual System* (EVS) forms the basis of the ECVFIS concept. The main EVS sensor system incorporates multi-channel camera modules with zoom and tilt function. Zoom function is used to locate and to reckon traffic or environmental hazards. The tilt function is used to adjust pilot eye point location depending on the flight or ground roll situation.

Radar data imaging generation functions can be used as additional visual data in cases of poor EVS performance (e.g. heavy snowstorm).

Synthetic vision functionalities are used to provide flight data and special information overlay and may serve as a backup system.

Fig. 4. shows sensor system components and potential installation positions.

Fig. 4. Possible sensor location in a wide-body aircraft

4.3 Visual and Flight Information Integration

There are two system configurations under research within the ECVFIS. A projector based configuration (ref. Fig. 5. - upper diagram) similar to visual systems known from Level D qualified simulators (ref. Fig. 6.) is applicable for wide-body and blended-wing-body aircraft providing up to 360° of visual view. The back-beam flight-visual and data concentrator will be served via an enhanced projector arrangement or a *Flexible Display Array* (FDA). The FDA solution is more optimized regarding the installation size but will be analyzed in a different project.

The second configuration uses standard TFT-Displays, a beam splitter panel as well as a collimation mirror (ref. Fig. 5. - lower diagram). This solution is more compact in size but only valuable as a single place solution with a reduced field of view. In dual pilot cockpits, separate systems must be installed for each pilot. On the other hand, this configuration is very applicable for supersonic designs requiring an extended nose section to decrease impact of sonic boom. Side windows should be installed within that configuration to keep peripheral vision and, as already said, to prevent closed space anxiety.

To improve overall situation awareness while using one of the presented hardware configurations, specific flight information should be presented in a careful method. Cluttered information presentation may cause delayed reception or loss of information. Information will be presented subject to flight phase and with a predefined minimum spacing to prevent information clutter within the given concept. This will help to support information scanning procedures that have to be performed by the pilot to obtain necessary information without ignoring important changes in situation affecting air traffic, ground traffic or terrain.

In addition, the adequate and intuitive integration of flight information within the visual system is the focal point of the given concept. To support useful flight psychological effects a wide-screen collimated visual as described, including a sophisticated flight information system should be preferred. Increased spatial perception and peripheral vision are only two underlying aspects. Moreover there is no need to focus between different (flight) information and visual reference points when using a merged information and visual system. Beyond, cognitive operations usually require more time, mental effort and attention [7]. Hence, the intuitive and coherent presentation of information within the visual will help to shift from cognitive operation to perceptual operation.

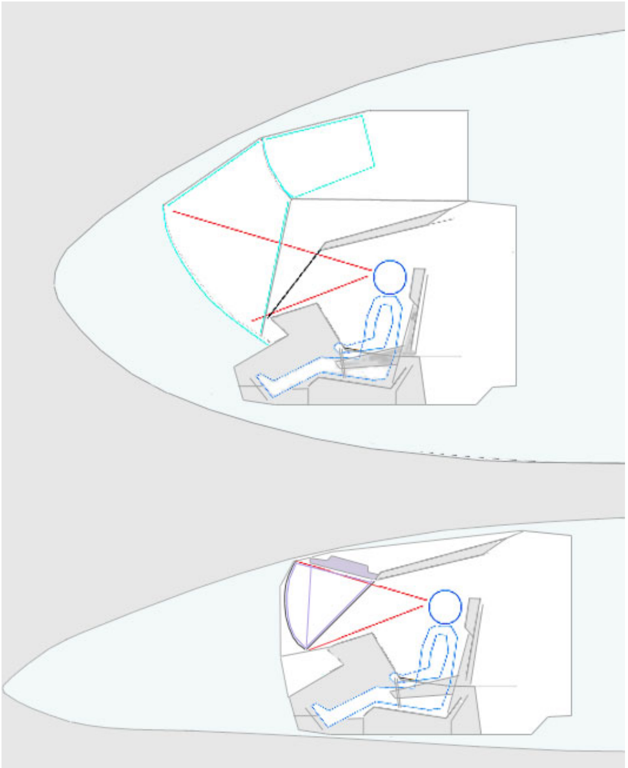

Fig. 5. Cockpit layout draft for ECVFIS concept.

5. Research Facilities

There are currently four flight simulators available at the ILR. Two of them, used to develop, verify and validate the given concept will be introduced in the following subsection.

5.1 Airbus A330 FFS

The Level DG qualified Airbus A330/340 convertible Full Flight Simulator (ref. Fig. 6.) located at the ILR is operated by the ZFB - *Zentrum für Flugsimulation Berlin GmbH*.

Fig. 6. Airbus A330/340 Full Flight Simulator Level DG.

This specific Simulator is equipped with a unique research environment. The environment is called Scientific Research Facility (SRF) and provides several interfaces to communicate with the complex A330/340 real-time simulation process as well as with different hardware components. The simulator incorporates a 6-DoF motion system and a 150° collimated visual system.

During the ECVFIS validation process the A330 simulator will be used for several experimental series carried out with qualified airline crews.

5.2 AACD Cockpit Demonstrator

The Advanced Aeronautical Cockpit Demonstrator (AACD) is a modular fixed based simulator to analyze new cockpit designs, HMI's, avionics systems and training procedures. The simulator is based on a Matlab-Simulink based, real-time simulation corresponding to an Airbus A330 regarding flight dynamics and subsystems. The visual apparatus is a single channel wide screen system based on Microsoft ESP. The AACD is mainly used to develop the ECVFIS concept.

Fig. 7. AACD fixed based Simulator.

6. Experimental Research

To validate the ECVFIS concept in terms of intuitive presentation of flight information, situation awareness and workload there will be several experimental trials using the Airbus A330 FFS. These trials will be performed initially by type rated airline crews followed by entry level private and commercial pilots to verify intuitiveness of this particular HMI concept. For the purpose of this research the A330 FFS has been equipped with different upgraded modules and special hardware options (ref. section 6.1).

The experimental procedures includes several objective and passive measurements as well as non-invasive use of sensory to detect physical and psychological reactions (ref. section 6.2).

6.1 Experimental Setup

6.1.1 A330 Visual System

The Airbus A330/340 FFS incorporates a three channel back-beam combined collimated visual system with a 150° field of view. To implement the combined visual and flight information system an additional wide view projector has been integrated. Equipped with an adjustable

platform the projector can be leveled on request via remote control.
The flight information display software has been realized by incorporating OpenGL 3D interface routines. The software is running on an external real time platform allowing simultaneous and lag free calculation of the graphical algorithm.

6.1.2 A330 Data Communication Subsystem
Communication between simulator and the external visual processing unit as well as between simulator and additional systems has been realized by implementing UDP/TCP based communication sockets running at 60Hz within the simulations real time core process. Up to 10MBytes/s of data can be transmitted.

6.1.3 Flight Control and Management System
The flight management interface (MCDU) has been upgraded to comply with the flight visual and information system specification allowing pilots to engage several settings. If the experimental series reveal shortcomings affecting handling characteristics the flight control laws can be adjusted via SRF as well.

6.1.4 Pilot View Acquisition System
To record data of pilot visual activities a dedicated head mounted eye point tracking system will be applied. The system allows to draw conclusions from visual behavior to situation awareness together with pulse and heart-beat monitoring systems (ref. Fig. 8.).

Fig. 8. Head mounted pilot eye tracking system.

6.1.5 Cockpit Surveillance System
The cockpit surveillance system comprises up to four high resolution cameras for pilot behavior monitoring and a sophisticated data recording system. The recording system can currently handle up to 50.000 labels real time and is adjustable via implemented GUI from an experimental instructor station.

6.2 Experimental Procedure

The given concept research will consist of two separate experimental series. The first one will be held with at least ten qualified airline cockpit crews and the second one with level entry private and commercial crews to validate the intuitiveness of the concept. Each crew has to complete two cockpit sessions. The first session will reflect the current standard cockpit design while the second one will represent the ECVFIS design. During the experimental processes several objective and subjective data will be obtained to validate the described concept.

6.2.1 Subjective Data
NASA TLX will be used to access significant data about mental workload. In combination with a post-test reproduction procedure, an expert rating as well as several objective data a significant picture about situation awareness will be achieved.

6.2.2 Objective Data
Non invasive methods like heart-beat, pulse and eye movement in addition with eye tracking system will be used to correlate with subjective data.

6.2.3 Experimental Flight Mission
The mission will start with a descent, 10 NM out from final approach fix, under IMC condition in a mountainous area. All flights have to be performed manually (Autopilot disengaged) considering MCC standards. 10kts starboard crosswind and runway incursion on short final will keep experimental work load at an appropriate level.

7. Conclusion

The introduced concept is a step forward to enhance modern airliner cockpit design to make it more intuitive in understanding flight situation in a more natural way. Hence it will increase situation awareness and decrease workload. But at least, this statement has to be validated during the foreseen experimental trials.

This is a very interesting, but moreso complex experimental concept and was therefore much harder to prepare for a significant experimental series. Additionally it is much more complicated to implement the necessary hard- and software in a qualified and full time deployed full flight simulator.

In the following weeks we will expect the first results and will continue work to further develop the concept into a ready to implement state.

The positive side effects on the aircraft structure as well as the reduction in drag, noise and fuel consumption let's the concept appear very promising for the next generation of wide-body and supersonic passenger aircrafts.

References

[1] Boeing. *Statistical Summery of Commercial Jet Airplane Accidents (Worldwide Operation 1959-2005)*, Boeing, US, 2005.

[2] Schmitt D.R. & Le Tallec C. *Remote Controlled from Frankfurt to New York – Vision or Fiction, IFATS Project*. DLR Nachrichten, GE, 2007.

[3] Hüttig G. & Lehmann O. & Schubert E. *Integration des Piloten Assistenz Systems ASSIST des DLR in den A330 FFS des ZFB – Abschlussbericht, Technische Universität Berlin, ILR* , GE, 2004.

[4] Hoffman E. & Lehmann O. & Pütz T. et al. *Assessing the Impact of Varied Speed Profiles on Airborne Spacing in a Full Flight Simulator.* AIAA 5th ATIO, US, 2005.

[5] Keith H. *Windowless Cockpit Concept Flight Tested*. NASA NEWS Rel.No. 96-012, http://www.nasa.gov/centers/langley/news/releases/1996/Feb96/96_12.html , US, 1996.

[6] Bandow D. *Head-Up-Guidance-Systeme und Mensch Maschine Schnittstelle*, Ergonomia Verlag, GE, 2006.

[7] Wickens C D, Hollands J G**.** *Engineering Psychology and Human Performance*. 3rd edition, Prentice Hall, US, 2000.

Copyright Statement