EVALUATION AND OPTIMIZATION OF THE HEAD-UP GUIDANCE SYSTEM MODEL 2100 WITH REGARD TO HUMAN-MACHINE INTERACTION

D. Bandow
dbs systems engineering GmbH
Thielallee 15, D-14195 Berlin

R. F. Neuhold
Lufthansa CityLine GmbH
Flughafen Hamburg-Fuhlsbüttel, D-22335 Hamburg

ABSTRACT

Based on ROHMERT'S integrated stress-strain concept it is analyzed how the semi-automatic flight guidance display system "*Head-Up Guidance System*" (HGS) Model 2100 affects the human-machine interaction and in particular the stress, strain, situational awareness and the pilot's attention compared to the autolandsystem of the Bombardier CRJ200 during the approach in different flight situations.

Based on a system model, a polygraphic measuring concept was used: within a cognitive task analysis seven measured quantities of stress, and the environment were determined. The behavioral data was gathered by a systematic observation in a simulator environment. The flight data was collected with the simulator's data system. Two physical measured quantities of strain were simultaneously recorded using physiological and subjective methods of measurements. By means of questionnaires and interviews physical and psychological influences of strain were collected. The situational awareness was determined through interviews and by SART, while the pilot's attention was measured by an eye movement analysis.

With deployment of the HGS, a tendency to stress reduction can be observed particularly during abnormal flight situations and the final approach. For HGS approaches, the differences and increases of the stress levels seem to be lower shortly before touchdown, during the occurrence of a system error and while initiating a go-around. The strain and the increasing pilots' qualification correlate during autoland approaches only. Only for pilots with an intermediate level of qualifications does the level of strain during autoland approaches adapt to the level of strain during HGS approaches. According to the pilots' rating, the use of the HGS improves the situational awareness.

Based on these results the design of the HGS was optimized by integrating system status information and improved energy state awareness.

1 INTRODUCTION

In its report, "Aviation Forecast Fiscal Years 2003-2014", the Federal Aviation Administration (FAA) assumes, as part of an optimistic scenario, an annual increase in the number of commercial airline passengers of, on average, 4.6% until 2014. An analysis of accidents according to flight phases in the period 1993 to 2002 reveals that 54% occur during the landing phase. The main cause of up to 75% of these incidents can be attributed to a breakdown in human behavior (Boeing. 2003 [1]). This finding should be seen in the context of an increasing degree, since the 1980s, of automation on the flight deck through the introduction of new technologies.

An ever-increasing system complexity demands an expansion of the mental model, which the pilot needs to create based on the system. In addition, the pilot is being increasingly distanced from a direct influence on the task of flight management (Billings. 1989 [2]). Numerous variations of this situation awareness are also influenced by automation in the cockpit. The effects of the new working environment on people such as fatigue, loss of vigilance or excessive trust are far-reaching.

The use of new, semi-automatic systems, such as the "Head-Up Guidance System Model 2100" (HGS), offers a solution to these problems. A manual flight management reintegrates the pilot into the loop, leading to a reduction in the demands placed on the mental model. Particular types of situational awareness should improve when the pilot can look out of the cockpit ("head-up") while flying.

Problems of Automation

Three examples of automation problems will be looked at in more detail.

The Flight Management System (FMS), an integration of various sub-systems and system modes, offers a significant increase in complexity, authority and autonomy compared to older systems managing flight. With FMS, the number of systems activated between the pilot and the control panels is increased and the pilot's direct influence on the plane is decreased. Consequently, the pilot's role becomes more of a system manager and observer. He/She is "peripherized" ("pilot-out-of-the-loop"; Wickens. 2000 [3]). If the user detects a difference between the expected and observed results of his/her input, then Sarter (1998) refers to this as "automation surprises" [4]. This is mainly caused by an incomplete mental model of the various modes and functions in automated systems, lack of knowledge by the operator and poor feedback from such systems.

According to the law of Yerkes and Dodson (1908), humans perform better when confronted with tasks of medium difficulty. When users of automatic systems feel underloaded and if they are suddenly confronted with more difficult tasks (e.g. occurrence of system errors) then they have to withstand a higher strain than persons within an optimum workload level (Roscoe. 1984 [5]). According to Last (1988) the pilot's situational awareness when flying an aircraft with a low degree of automation is heightened because he/she is actively participating and is more aware of changes in his/her surroundings [6]. This awareness has a positive impact on the problem solving process should an abnormal or emergency situation arise.

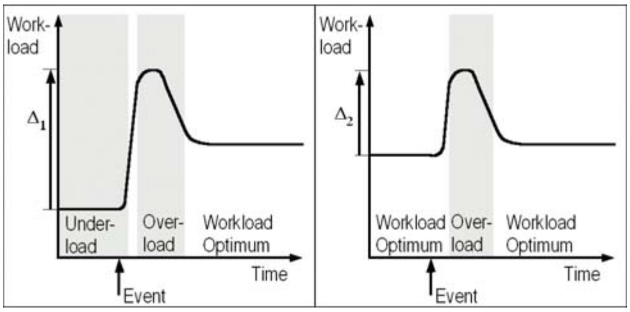

FIG. 1: Change of Workloadlevels

The difference between normal and heightened demands is small, giving the user more time to adapt to a more similar degree of difficulty (FIG. 1).

2 STATE-OF-THE-ART TECHNOLOGY

Principles of human-related, cognitive or cooperative automation have been applied over the last decades in an attempt to minimize the problems found in the area of automation. The development centres on the individual, who is integrated once again into the loop.

2.1 Head-Up Guidance-Technologies

The deployment of HGS since the 1980s has seen the extension of the "Head-Up Display (HUD)"-technology in use in commercial aviation to include a manual flight guidance system (deployment of a HUD as the primary flight guidance display system for semi-automatic guidance systems).

The majority of HUD systems can now be supplemented by FLIR-, UV- or MMW-imaging sensors, to provide a display of the forward view in the HUD. Since January 2004 the FAA has permitted the use of "Enhanced Flight Vision Systems" (EVS) in CAT I approaches within the decision height (DH) of non-precision approaches. "Synthetic Vision-Systems" (SVS) rely on a GPS-navigation system and a real-time in-flight database to generate a 3-D perspective view of the aircraft's surrounding environment and pathway the HUD combiner.

2.2 System solution "Head-Up Guidance System 2100"

The "*Head-Up Guidance System*" (HGS) Model 2100 is a possible system solution, which minimizes the problems of automation in the cockpit, thereby serving to improve safety during the accident-prone landing phase and low visibility procedures (to category CAT IIIa). It is an exemplary model for those flight guidance display systems, which try to enhance the system capability of automatic landing systems by means of a reduced level of automation ("intermediate level"), which support the manual flight guidance ("pilot-in-the-loop") and improve the situational awareness through a permanent view out of the cockpit ("head-up") during the approach. Deployment of this model throughout all flight phases has been permitted since 2004. Manual flight guidance proceeds by observing the symbols on the combiner, consequently focussing on the internal cockpit display is non-procedural (FIG. 2).

The electro-optical system contains the following components: the Head-Up Guidance Computer (HGC), the HGS Control Panel (HCP), the Overhead unit (OHU) and the Combiner. Data is fed from the sensors and other systems into the HGC, which converts it into symbols. System and flight performance are also calculated. The HCP, which is installed in the lower centre

FIG. 2: View of the Canadair Jet-Flightdeck incl. HGS 2100 (Source: CST)

pedestal, can be used by the pilot to, for example, input data such as the glide slope and runway elevation, and select and activate various HGS-modes. The flight guidance symbology projected by the OHU is partially (wavelength dependent) reflected in the holographic combiner, focused at optical infinity and conformal to the pilot's view of the real world. The OHU is installed above the captain's seat and projects the symbology forward onto the combiner, which is positioned over the portside windshield.

The HGS 2100, which was designed for regional jets like the "Bombardier Canadair Regional Jet", is currently in use in more than sixty of this model operated by Lufthansa CityLine GmbH.

3 HYPOTHESIS

It has already been proven in several studies that flight guidance accuracy is improved through the deployment of HGS due to a reduction in size of the touchdown zone area on the runway and the glide slope deviation. This study concentrates on evaluating whether and to what extent the use of such a system optimally impacts the stress and strain on the pilot and his/her situational awareness and ultimately the flight safety compared to an automated flight guidance system (autopilot system (AP)) in the Bombardier Canadair Regional Jet CRJ200. In addition, it will be attempted to determine whether these parameters can be positively influenced by the HGS, not only under normal system conditions but also during abnormal flight situations and go-around manoeuvres. The information-input, -processing and -output of the pilot when using an HGS has also been examined. Based on these findings the design of the HGS has to be optimized.

4 METHODOLOGY

Depending on the degree of automation employed the percentage of mental work is higher than the percentage of physical work during an approach. For this reason the integrated stress-strain concept according to Rohmert (1984) has been applied [7].

A theoretical system model, developed from a decomposing and functionally abstracting systems analysis, forms in turn the basis for the polygraphic measurement approach used in this study.

4.1 Determining the stress factors

Seven different stress factors were measured using a Cognitive Task Analysis (CTA; Shepherd. 1998), in which mental processes and skills can be recorded while carrying out complex cognitive tasks [8]. Image and sound data were recorded via camera- and videorecorder systems during the training sessions in the simulator and coded using behavioral observation software. The glide slope deviation was saved in the simulator's computer system. The stress factors (the type of task, change between levels of control of human actions, mental workload, illumination, spatial layout and level of informational design of the used cockpit's element) were assigned to the momentary pilot's interaction. The behavioral duration was automatically calculated and saved by the behavioral observation software.

To determine the stress factor "informational design" 80 systems elements of the CRJ-flightdeck were defined. The complexity of the flight deck displays was calculated by an analysis of interdependence. Therefore it was analyzed, whether and to what extent the human interaction with the momentaryly used systems element of the machine the systems status of all other systems elements influences. Environmental factors such as wind gusts influence the flight situation. For this reason the glide slope deviation was measured as an indicator of the flight situation.

4.2 Determining the influencing factors of strain

The factors for the physical capacity (body height and mass, gender, age, eyesight) and readiness (circadian rhythm) and the psychological capacity (consider qualifications according to numbers of hours flown (NHF), years of duty and rank) and readiness (motivation) were recorded by means of standardized questions and non-standardized answers. The data was encoded and saved.

4.3 Determining the measured quantities of strain

The strain was measured by the physiological measured quantities "heart rate" (via pulse oximeter) and "eye blink rate" (via video analysis). During the three experimental sessions, the subjective method "NASA-Task Load Index" helped to determine the pilot's strain.

4.4 Determining the situational awareness

Before the start of the flight training the subjects were interviewed and asked to give a subjective assessment of using the HGS. During the experimental sessions each participant noted a subjective estimate of his/her situational awareness on a SART questionnaire following every approach. All this data was also recorded and saved.

4.5 Determining the attention span

FIG. 3: Eye movement analysis system "SMI iView X HED"

Using two indicators of the attention span (saccades and fixation duration and frequency) it was possible to reach conclusions on the attention span for visual observation during the approach. This eye movement data was recorded using the eye movement analysis system "SMI iView X HED" (FIG. 3), which is attached to a subject's head. Recording head positions, which would have assisted in interpreting the data, was not possible due to space restrictions in the CRJ-cockpit. As a consequence, the eye movement data could not be automatically recorded, resulting in the eye movement having to be manually evaluated. In addition, the eye movement analysis sequences were gathered by a behavioral observation software using the "frame-by-frame" procedure (t_r = 0.001 s) involving areas of interest (80 cockpit- and 40 HGS-system elements). The saccades, the fixation duration and -frequency were subsequently used to assist in analyzing the attention span.

4.6 Experimental method and apparatus

The behavioral data was collected by a hidden, non-participatory systematic observational technique in a simulator. The flight data was recorded by the simulator's computer system.

In a full flight simulator environment of the Lufthansa CityLine Canadair Simulator und Training GmbH (CST), 141 approaches of 60 Lufthansa CityLine crews were recorded during their recurrent training for the stress-strain analysis. The data was analyzed and recorded with a resolution of 0.1 s. For the eye movement analysis, 18 approaches of three flight crews were recorded during experimental sessions. This forms a sufficient statistically representative sample.

In order to maximize authenticity, the measurements were carried out in a full flight simulator on line pilots participating in their recurrent training. CST has been using the CAE full flight simulators since 1992, which provide a 180° visual system, digital control loading system, flight dynamics system, smoke system, sound system and hydraulic motion system with six degrees of freedom, which are controlled by an IBM RISC computer system. The flight compartment consists of a cockpit for the crew, an instructor station and an observer seat and one jump seat.

Variability was introduced into the approaches by not prescribing any of the scenarios. The increased need to normalize and synchronize was solved by using a Visual Basic-oriented data integration and stress-strain analysis program.

5 RESULTS

120 airline pilots and, as a consequence, 60 HGS-users participated in the trial. The subjects' ages ranged from 27 to 60 years (average 42 a). The subjects heights were distributed normally between 165 and 193 cm (5 ft 41 in and 6 ft 33 in). Thirtyseven subjects (63.8%) had normal weight, 19 (32.8%) were overweight. Only 2 (3.5%) fell under the BMI Category Adipositas GI or GII. Twelve pilots (20.7%) had under 5,000 NHF while another 12 had between 5,000 and 7,500 NHF. Only 8 pilots (13.8%) had recorded between 7,500 and 10,000 NHF, however 24 individuals (44.8%) had exceeded the 10,000 NHF mark. The subjects' years of duty were distributed relatively normally along an axis of 10, 20 and 30 years. Nine (15.5%) of the 58 participating captains were training captains. While 9 (15.5%) and 10 (17.2%) of the subjects rated the use of HGS in civil aviation as low and neutral, 15 (25.9%) were motivated and 24 (41.4%) highly motivated to use this man-machine-system (MMS). One female pilot opted not to take part in the task analysis and this meant 6 females (10.4%) and 52 males formed the participating group of 58. Twentytwo (37.9%) of this total had corrected-to-normal sight.

5.1 Documentation of stress

The majority of subjects underwent a characteristic course of stress levels: a lower mean stress level with greater stress level differences and slopes for the entire approach phase in abnormal situations was observed when the AP-system, as opposed to the HGS, was deployed.

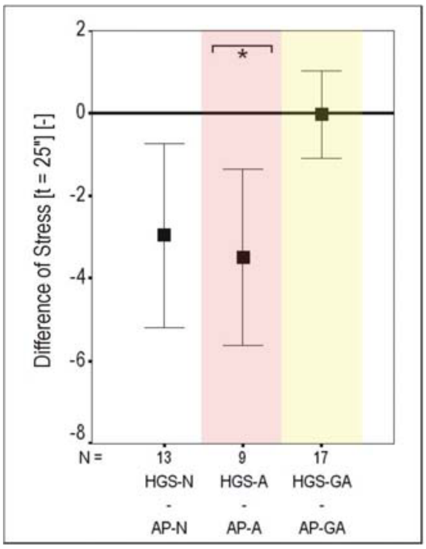

FIG. 4: Difference of stress [-] for the approach with a duration of t = 25 s before touchdown[1]

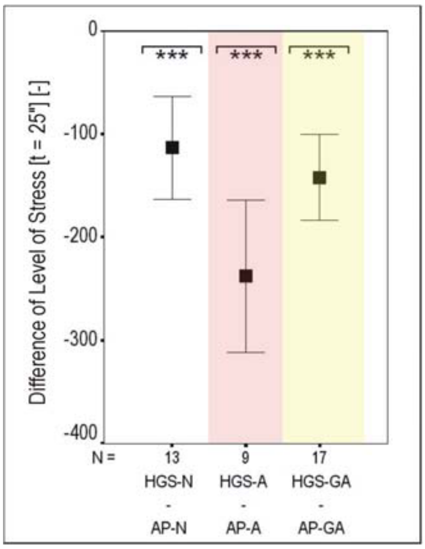

FIG. 5: Difference of level of stress [-] for the approach with a duration of t = 25 s before touchdown[1]

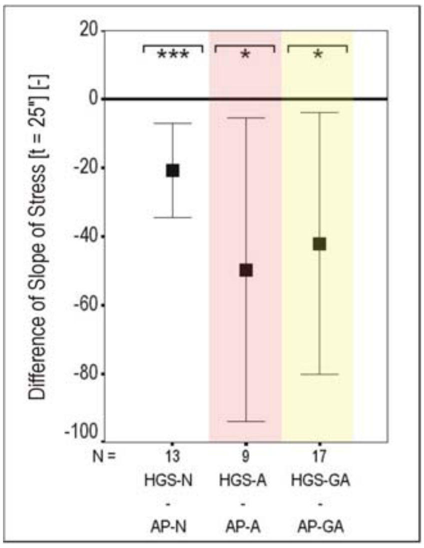

FIG. 6: Difference of slope of stress [-] for the approach with a duration of t = 25 s before touchdown[1]

If one examines the phase of the final approach (t = 25 s), one finds that the difference in stress levels during the HGS approach compared to those for the AP-system approach decreases for normal scenarios (Δ_N = -24.5%; α < 5%; t-test). The difference in stress levels is reduced for abnormal scenarios slightly significant by Δ_A = -28.3% (α < 5%; t-test). The difference in stress levels during go-arounds reduces slightly with the deployment of the HGS (Δ_{GA} = -0.5%; t-test) (FIG. 4).

The difference in stress levels for the final approach and touchdown during HGS approaches decreases by Δ_N = -55.1%, which is highly significant (α < 0.5%; t-test). The difference also reduces during abnormal flight situations by Δ_A = -65.7% with a high significance (α < 0.5%; t-test). Similarly difference in stress levels during go-around scenarios reduces significantly by Δ_{GA} = -46.6% (α < 0.5%; t-test) (FIG. 5).

The slope of stress reduces highly significantly during HGS approaches under normal flight conditions by Δ_N = -45% (α < 0.5%; t-test) and significantly under abnormal conditions by Δ_A = -64.4% (α < 5%; t-test). During Go-Around scenarios, the slope of stress reduces significantly by Δ_{GA} = -39.6% (α < 5%; t-test) (FIG. 6).

If one displays the stress readings separately for approaches in which a system error occurs within a time interval of $t_{AB\text{-}TD}$ < 30 s, then the difference in stress-increases during AP-system approaches is obvious. The median value of the stress levels for AP-system approaches, as compared to those for HGS approaches, in which an error occurs within a time interval until touchdown of $t_{AB\text{-}TD}$ < 30 s increases by $\Delta_{AP\text{-}HGS}$ = +66.3%.

Non-procedural behavior

Thirty pilots (54.6%) of the total number of subjects interact non-procedurally with the MMS “Head-Up Guidance System”. Twentyfive pilots (45.4%) do not look only at the HGS-Combiner but also interact with the PFD. Fifteen pilots (27.3%) behave in the final phase (t = 25 s) non-procedurally. An even greater number of pilots (n = 34; 61.8%) use the EICAS (Primary Page) N1-indicator (≙ low speed rotor rotations [% RPM]) to check the aircraft’s energy state. Seventeen pilots (31%) look during the approach phase at both, the PFD and the N1-indicator. This results in additional and (from a design point of view) unexpected fixations, head movements, accommodations and adaptations. Only 13 pilots (23.6%) behave procedurally during HGS approaches (FIG. 7).

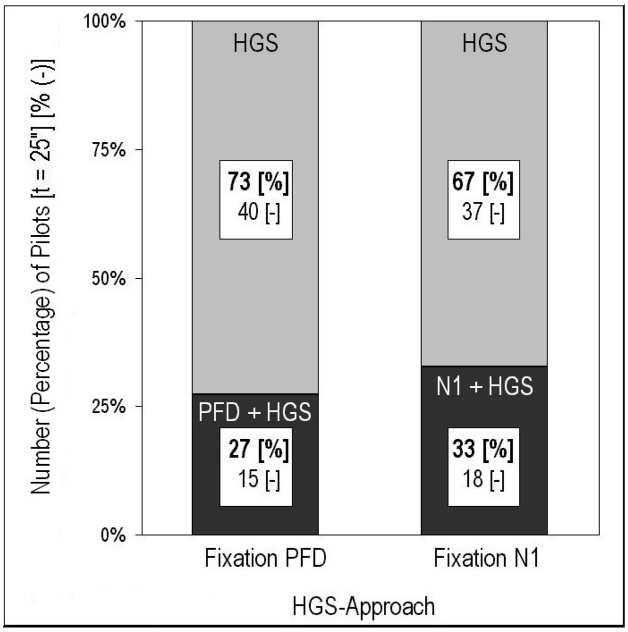

FIG. 7: Number (percentage) of pilots with non-procedural interaction with the HGS for the approach with a duration of t = 25 s before touchdown after fixations at the PFD and the N1-indicator of the EICAS-1 [% (-)]

5.2 Documentation of strain

The non-significant difference in the slope of the premaximal HR (≙ before touchdown) measures under normal conditions during HGS approaches Δ_N = -47.2% and under abnormal conditions Δ_A = -133.1% (t-test). During the go-around scenarios, the slopes of the normalized HR during HGS approaches increase non-significantly by Δ_{GA} = +2.2% (t-test) (FIG. 8).

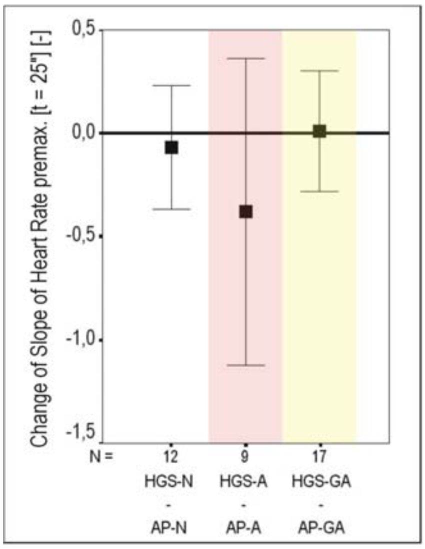

FIG. 8: Change of slope of the premaximal heart rate for the approach with a duration of t = 25 s before touchdown [1]

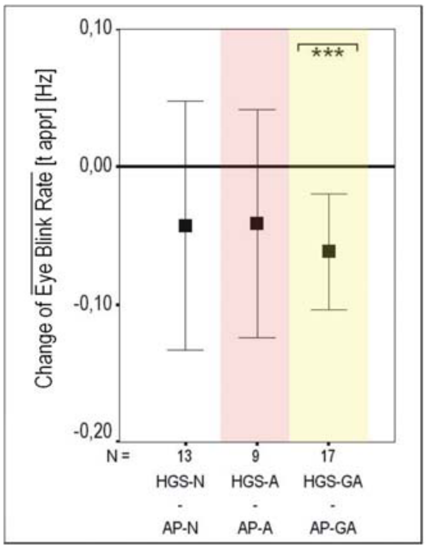

FIG. 9: Change of mean eye blink rate [Hz] for the approach before touchdown [t appr] [1]

The second measured quantities of strain, the mean EBR, reduces not significantly for HGS approaches in normal scenarios by Δ_N = -18.3% and under abnormal flight conditions by Δ_A = -12.8% (t-test). However, the mean EBR reduces highly significantly in HGS approaches in go-arounds by Δ_{GA} = -20.5% ($\alpha < 0.5\%$; t-test) (FIG. 9).

In contrast, the subjective strain, measured during experimental sessions (N_{VPN} = 3) by NASA-TLX, was clearly higher during AP-system approaches than that recorded during HGS approaches (Δ_N = +17%; Δ_A = +21%; Δ_{GA} = +12%).

5.3 Documentation of influencing factors of strain - individual parameters

The qualification-related parameters (age, numbers of hours flown and years of duty) and the factors of strain (HR, EBR) correlate solely during AP-system approaches (FIG. 10).

The values of the strain factors rise with increasing NHF, for AP-system approaches with observed approach durations of t = 3 min under go-around conditions (Pearson coefficient r = -0.455; $\alpha < 5\%$) and with a duration of t = 25 s under normal conditions (r = -0.510; $\alpha < 5\%$). Years of duty and the strain factors correlate negatively for AP-system approaches of duration t = 3 min under go-around conditions (r = -0.452; $\alpha < 5\%$), for durations t = 25 s under normal conditions (r = -0.553; $\alpha < 5\%$) and under go-around conditions (r = -0.450; $\alpha < 5\%$). A comparison of the two MMS "HGS" and "AP-system" revealed higher mean strain factor values overall among less qualified subjects for AP-system approaches than for HGS approaches. The mean values continue to reduce with increasing age for AP approaches such that the AP values for pilots aged approx. 45 a equal those of HGS approaches. The trend continues with levels recorded for pilots aged above 45 a lower for AP approaches than that those for HGS approaches.

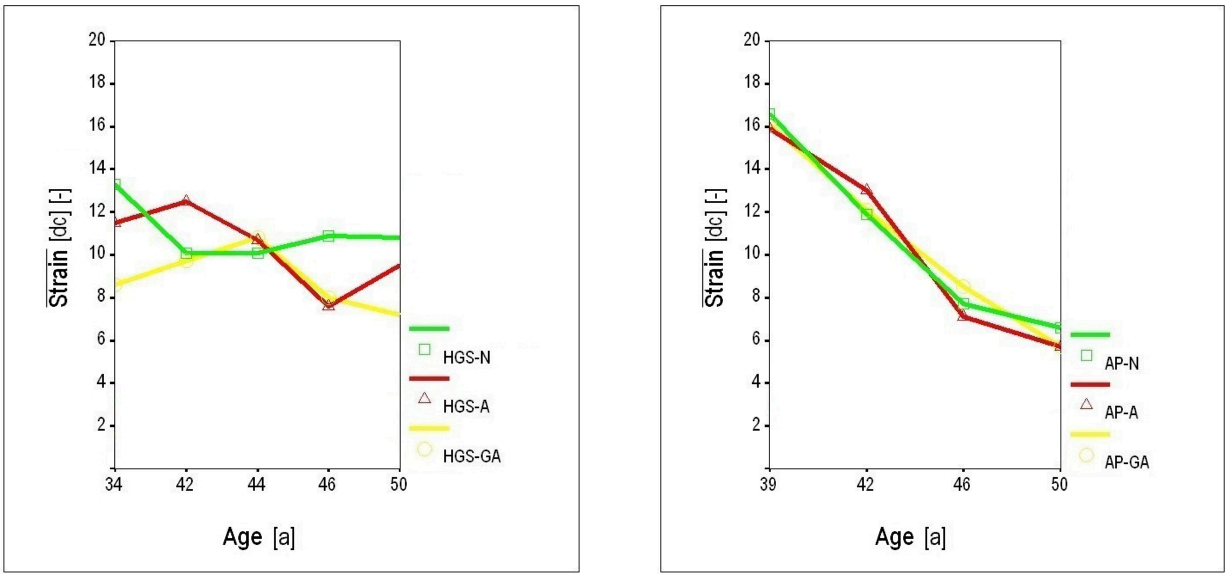

FIG. 10: Mean strain (HR and EBR) of the MMS (HGS; AP) as a function of qualification (indicator: age [a]) for the approach with a duration of t = 25 s before touchdown and the flight scenarios [N: normal; A: abnormal; GA: Go-Around]

The strain factor levels for pilots with a low numbers of hours flown and years of duty are higher under all flight conditions for AP approaches than HGS approaches. The strain levels increase for both of these factors for AP approaches up to a certain point (number of hours flown (NHF) ≈ 9,000 h; years of duty (YoD) ≈ 15 a) in contrast to the effect observed for age. With additional increases in qualifications (NHF, YoD) one observes that the strain parameter levels for AP approaches fall to those of HGS approaches. Highly experienced pilots (NHF > 10,000 h approx.; YoD > 20 a approx.) exhibit somewhat less strain for AP approaches than for HGS approaches. If one restricts the subject group to include only pilots aged 44 a or less, then the strain levels are lower for the final approach phase (t = 25 s) in HGS-approaches compared to those for AP approaches under normal flight conditions by Δ_N = -7.1% and for abnormal situations by Δ_A = -6%. Those for go-arounds reduce by Δ_{GA} = -7.6%.

5.4 Documentation of situational awareness

Pilots rated their situational awareness overall more highly when using the HGS. In the interviews carried out, 45 pilots (77.6%) logged an improvement in situational awareness for HGS approaches. N_{VPN} = 34 (58.6%) claimed it was improved, N_{VPN} = 11 (19%) said that it had improved significantly. Five pilots (8.6%) were of the opinion that their situational awareness deteriorated, while 8 subjects (13.8%) did not detect any difference. The situational awareness recorded during the experimental sessions in the SART analysis revealed that it was lower for the AP approaches compared to those of HGS approaches by Δ_N = -37% under normal conditions, by Δ_A = -27% under abnormal conditions and by Δ_{GA} = -38% under go-arounds.

5.5 Documentation of the attentional span

The data obtained as part of the behavioral analysis during the training sessions (N_{appr} = 141) revealed that the proportion of focussing on the combiner and cockpit instruments (head-up percentage; measured for the entire duration of the approach (t appr)) measured 96% for the HGS approaches compared to 5 to 16% for the AP approaches. The head-up percentage recorded in the eye movement analysis for HGS approaches (both HGS-modes) under normal conditions had a mean value of 86.3% compared to one of 54.2% for AP approaches. This difference of head-up percentage increases for abnormal flight conditions, 88.4% for HGS approaches as opposed to 30.4% for AP approaches.

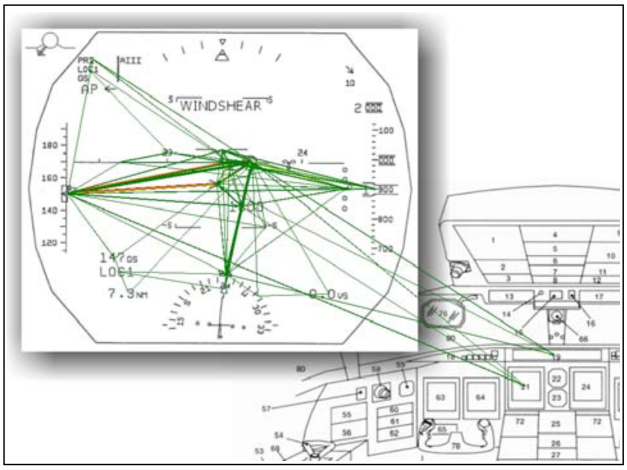

FIG. 11: Saccades of the subjects measured during the experimental sessions for the approaches with deployment of the HGS in PRI-Mode under normal flight conditions [2]

For go-arounds, the portion of focussing on the outside environment fell further to 22.2%, while that for HGS approaches remained at around 87.6%.

The pilot, particularly in the PRI-mode of HGS approaches, focused almost exclusively on the combiner (on average 91.3%). Fixations towards the cockpit only took place when entering the reference speed, releasing the approach mode on the flight control panel and checking the EICAS (Primary Page). Also observed with the deployment of the head-up guidance system is the application of the learned standard-instrument T-scan pattern as the scan path between the central flight guidance symbols. Fixations between the cockpit and within the HGS combiner (enlarged) can be clearly seen in the representation of the saccades (FIG. 11).

In AP-system approaches, eye movements take place mainly among the primary flight guidance instruments. This gain in information requires additional eye and head movements. None of these head movements are required when using HGS, as a result of the integrated data display. Under these kind of flight conditions, one also observes simultaneous vergence eye movements and conjugate eye movements (while looking from the far right back- to the left foreground) and (light-dark) adaptations during gathering information from various different located cockpit instruments with different lighting demands (FIG. 12).

6 DISCUSSION

6.1 Influence of HGS-deployment on stress

Increases in stress are halved for some highly significantly for HGS approaches under normal and abnormal conditions as well as for go-arounds. In addition, the differences in stress levels are reduced highly significantly by half for the final approach and touchdown phases under normal and abnormal conditions as well as for go-arounds. This was confirmed by Roscoe (1984) when he recorded (and according to NPAHF to be reduced) high stress levels which caused by a change from a comparatively easy to a more difficult task due to the occurrence of an abnormal system event among (up to then underloaded) subjects during automated approaches (Roscoe. 1984 [5]; Lofaro. 1991 [9]). Similarly Last (1988) recorded a great difference in stress levels while adjusting from normal to abnormal situations when automated systems are deployed [6]. Ewell and Chidester (1994) likewise observed high and frequent changes in stress levels within flight phases when using autoland-systems [10].

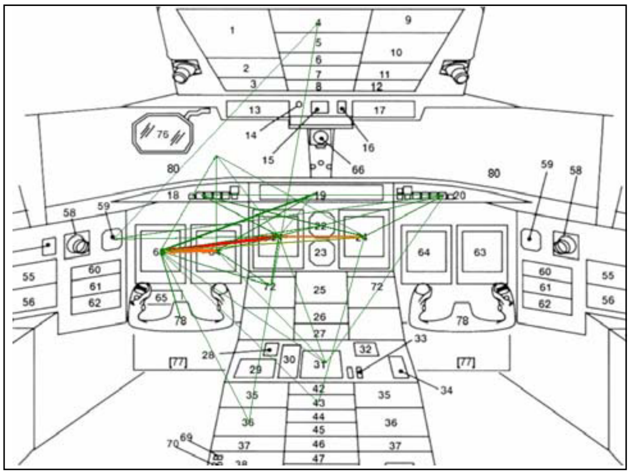

FIG. 12: Saccades of the subjects measured during the experimental sessions for the approaches with deployment of the AP-system under normal flight conditions [2]

The physical and mental stress on a pilot's muscular and visual system during approaches deploying an autoland-system can be attributed to the increased rate of the following behaviors: head movements, simultaneous vergence eye movements and conjugate eye movements and adaptations. This leads to higher overall muscular and mental stress on the visual sensory system (Converse. 1989 [11]).

6.2 Influence of HGS deployment on strain

Applying scaling methods has determined that subjectively experienced strain is reduced by up to a fifth when using the HGS system during the approach phase.

6.3 Influence of HGS deployment on the strain factor "heart rate"

The use of the HGS is characterized by lower strain levels before touchdown especially under abnormal conditions as a result of the lower increases of the mean values of the normalized HR. Lower increases of the normalized HR under normal flight conditions compared to those for AP-system approaches have also been recorded. A slightly lower strain level after the touchdown has also been observed while using the HGS because the HR returns quicker to the resting HR, as confirmed by low postmaximal HR delay values. To some extent this applies also to abnormal conditions and go-arounds.

6.4 Influence of HGS deployment of the strain factor "eye blink rate"

The strain parameter EBR reduces highly significantly for the entire duration of HGS approaches under normal and abnormal conditions and, especially, for go-arounds. One can conclude, at least for go-arounds, that HGS deployment leads to lower strain.

6.5 Influence of qualification on strain factors

The level of qualification, measured by age, NHF and YoD, would appear to have an effect on strain during AP approaches only. While strain increased among inexperienced pilots, strain levels during HGS approaches were reached only among pilots from age approx. 45 a.

If one analyzes the subject group such that only pilots younger than 45 a are included, it can be seen that the strain levels for HGS approaches are reduced by 7% under all flight conditions.

Restricting the under-45 a test group still further to include only those subjects with NHF < 5,500 h, one observes an increase in strain, especially under normal flight conditions and for go-arounds during AP approaches. This apparent dependency of strain on a subject's level of qualification solely when deploying a flight guidance system with a high degree of automation could be a result of conditioning effects from complex systems, as Rasmussen (1986) observed [12]. An individual's information processing, having undergone a phase of successful problem-solving, moves from a knowledge-based approach to a rule-based one. Using behavioral routines results in interactions shifting from a rule-based to a skill-based level.

Observations by Besnard (2003) also support this theory, linking fallibility with the precision of mental models in connection with automated systems [13].

Confidence in one's own mental model of an automated system can, particularly among inexperienced pilots, lead to rejection of inexplicable data or overlooking important information. Billings (1997) refers in this context to the growth in complexity of the mental model as the degree of automation in guidance systems increases [14]. The lower strain levels measured among inexperienced pilots during HGS approaches emphasize the demand from Roscoe (1980) for a simple and precise flight guidance system with sufficient manual control [15]. With such a system, one has an optimum display and flight guidance capacity, enabling the pilot to react flexibly to changing conditions.

6.6 Correlation of stress and strain

According to the stress-strain concept the recorded strain levels and the stress values correlate, indicating the validity of the system model.

6.7 Increase in situational awareness

According to Last (1988), the pilots' situational awareness, measured by subjective methods, is higher on flights where the level of automation is low due to active participation [6]. This agrees with observations made by Sarter and Woods (1993; 1994) and Ewell and Chidester (1994) and those made in an NPAHF study of situational awareness in automated cockpit systems, in which loss in both situational and system awareness was established [16, 17, 10].

7 SYSTEM OPTIMIZATION

The results gathered in this study were used to develop improvements in layout in which selected system and energy state displays are integrated. It is recommended that the information is displayed in analog form, because it has been established that the average fixation duration for analog displays is approx. 100 ms lower than that for digital read-outs or hybrid combinations.

In the course of future developments and new technology and particularly considering the increase in aviation volumes and its impact on accident rates during the approach phases, it is recommended that HGS be further developed and deployed in civil aviation in order to optimize stress and strain levels and situational awareness during flight guidance.

8 LITERATURE

[1] Boeing.
Statistical Summary of Commercial Jet Airplane Accidents: Worldwide. http://www.Boeing.com/news/techissues/pdf/2001_statsum.pdf Seattle, WA. 2003

[2] Billings, C. E.
Toward a Human-Centered Aircraft Automation Philosophy. pp. 1 – 8. In: *Proceedings of the Fifth International Symposium On Aviation Psychology*, The Ohio State University, Department of Aviation. Columbus, OH. 1989

[3] Wickens, C. D.; Hollands, J. G.
Engineering Psychology And Human Performance. Prentice Hall, 3rd Edition. Upper Saddle River, NJ. 2000

[4] Sarter, N. B. In: Woods, D. D.; Sarter, N. B.
Learning From Automation Surprises And 'Going Sour' Accidents: Progress On Human-Centered Automation. Final Report, NASA Ames Research Center, Contract-No.: NCC2-592, NCC1-209, Report-Nr.: NASA/CR-1998-207061. Moffett Field, CA. 1998

[5] Roscoe, S. N. In: Sandry-Garza, D. L.; Boucek, G. P., Jr.; Logan, A. L.; Biferno, M. A.; Corwin, W. H.
Transport Aircraft Crew Workload Assessment – Where have we been and where are we going? pp. 5 – 51. In: *Proceedings of the Sixth Aerospace Behavioral Technology Conference (SAE Aerospace Technology Conference & Exposition) # 871769.* Long Beach, CA. 1987

[6] Last, S. R.
Should Technology Assist or Replace the Pilot? pp. 151 – 155. In: *Proceedings of the Seventh Aerospace Behavioral Technology Conference (SAE Aerospace Technology Conference & Exposition) # 880774*. Anaheim, CA. 1988

[7] Rohmert, W.
Das Belastungs-Beanspruchungs-Konzept. pp. 193 – 200. In: *Zeitschrift für Arbeitswissenschaft,* 30. (10. NF) Jahrgang 1984/4, Verlag Dr. Otto Schmidt KG. Köln, D. 1984

[8] Shepherd In: Annett, J.; Stanton, N. A.
Task Analysis. Taylor & Francis. London, U.K. 1998

[9] Lofaro, R. J.
An Overview of Human Factors R & D in Flightdeck Automation: The National Plan for Aviation Human Factors. pp. 880 – 885. In: *Proceedings of the Sixth International Symposium On Aviation Psychology*, The Ohio State University, Department of Aviation. Columbus, OH. 1991

[10] Ewell; Chidester In: Chidester, T.
Introducing FMS Aircraft Into Airline Operations. pp. 153 – 194. In: Dekker, S.; Hollnagel, E. (edd.): *Coping with Computers in the Cockpit*. Linköping University. Linköping, S. 1999

[11] Converse, S. A.
Principles of Design for Complex Displays: A Comparative Evaluation. pp. 257 – 262. In: *Proceedings of the Fifth International Symposium On Aviation Psychology,* The Ohio State University, Department of Aviation. Columbus, OH. 1989

[12] Rasmussen, J.
Information Processing And Human Machine Interaction - An Approach To Cognitive Engineering. North Holland. New York, NY. 1986

[13] Besnard, D.; Greathead, D.; Baxter, G.
When mental models go wrong: co-occurrences in dynamic, critical systems. pp. 117 – 128. In: *International Journal of Human-Computer Studies, Vol. 60, Issue 1*, University of Newcastle upon Tyne, U.K. 2003

[14] Billings, C. E.
Aviation Automation: The Search For A Human-Centered Approach. The Ohio State University, Department of Aviation. Columbus, OH. Lawrence Erlbaum Associates, Publishers. Mahwah, NJ. 1997

[15] Roscoe, S. N.
Aviation Psychology. The Iowa State University Press. Ames, IA. 1980

Index [1]: depending on MMS [HGS; AP] and the flight scenarios [N: normal; A: abnormal; GA: Go-Around] (error bar with average, standard deviation and sample size in direct comparison; t-test) (***: highly significant on α = 0.5%-level; **: significant on α = 1%-level; *: slightly significant on α = 5%-level)

Index [2]: (width of lines = number of saccades)