



# Pilot gaze performance in critical flight phases and during taxiing

## Results from the DLR-Project MOSES

### Summary

Different approaches to measuring and improving situation awareness were the focus of the DLR internal project MOSES (More operational flight safety by enhancement of situation awareness).

This paper sheds light on information gathering (= *level 1* of situation awareness) depending on different tasks during approach and taxiing. Eye movements of forty pilot students and nine experienced pilots were analysed. Furthermore the influence of an additional taxi guidance system on eye movements will be described.

### 1. Introduction and main question

Situation awareness is considered an important factor for successful and safe acting in complex environments like the cockpit. Therefore adequate measuring techniques for situation awareness are required to evaluate impact and improvement of assistance systems.

It was the main goal of MOSES to investigate measurement methods for the construct situation awareness in order to evaluate advanced pilot assistance systems in a step-by-step approach.

Within the framework of MOSES Endsley's (1995) definition of situation awareness was used which is composed of three levels:

*level 1: perception*, the „serial“ perception of single elements of the environment,

*level 2: comprehension* of perceived elements (a “global picture”),

*level 3: projection*, resulting from *levels 1* and *2*, looking ahead into the near future.

Here, perception is of prime importance.

Inputs to be made by the operator are increasingly restricted in a highly automated environment like the cockpit. In contrast the monitoring task is becoming predominant. It is therefore necessary to study the way pilots gather their information, i.e. their eye movement behaviour (Anders, 2001; Duchowski, 2007).

Analysis of flight accidents shows that in more than 75% of the cases loss of situation awareness can be attributed to *level 1 errors*, meaning that relevant information is perceived erroneously (Jones & Endsley, 1996). Additional examination reveals that most accidents occur during approach, landing, and taxiing. These are the most safety critical phases (Boeing, 2004; Dismukes et al., 2007).

Therefore it was MOSES' goal to measure pilots' perceptive behaviour in these safety critical phases of flight in order to back-reference on *level 1 of situation awareness*. Beyond that, DLR pilot assistance systems like TARMAC-AS (Taxi And Ramp Management And Control – Airborne System [Härtl, 1997]) were evaluated. (In additional studies, the advanced flight management system AFMS and enhanced vision systems both developed by DLR were evaluated.) At present the taxi guidance system TARMAC-AS is provided to both pilots on the navigation display (ND) in shape of a Head Down Display (HDD) after landing. Different zoom stages and modes can be selected via mode and range selector of the flight control unit (FCU). A crucial sub-goal of MOSES was to verify that TARMAC-AS HMI does not provoke an *attentional capture*: pilot's main attention should not shift from the outside view to the displays. Two questions were derived:

**How does pilots' gaze in the cockpit change depending on a) the task / flight phase and b) pilots' experience?**

**How does pilots' gaze in the cockpit change if an additional taxi guidance system is used?**



Figure 1: MOSES experiment at DLR's generic cockpit simulator GECCO.

## 2. Methods

### 2.1 Experiment

The study took place in the Generic Experimental Cockpit (GECCO) of the DLR Institute of Flight Guidance in Braunschweig, Germany. This fixed based simulator (with collimated outside view) has the flight characteristics of a VFW 614 *fly by wire*. The simulator is equipped with sidesticks and additional input devices in the style of an Airbus aircraft.

A first study with Lufthansa Flight Training (LFT) pilot students was conducted between November 2003 and April 2004; an additional study with experienced pilots took place between October 2004 and March 2005. Each subject performed their tasks approximately ten hours altogether, starting with a theoretical briefing and practical instructions in the simulator. Each pilot flew a total of eight experimental scenarios. The subject flew the scenarios as pilot flying from the co-pilot's seat. The investigator acted as *pilot non flying* (tasks: r/t communication, items, reading checklists) but without actively intervening in the events.

### 2.2 Sample

Five female and 35 male pilot students of Lufthansa Flight Training (Bremen, Germany) aged 21 to 31 years (average=23.9; standard deviation=1.8) took part in the first study. Either they already held the commercial pilot licence or they were on the brink of the practical exam. Flight experience varied between 130 and 500 flight hours (average=225.1; standard deviation=66.2) (Lorenz et al., 2004). The second study was conducted with one female and seven male subjects aged between 33 and 62 years (average=42.6; standard deviation=8.6). Their flight experience was between 3000 and 10300 flight hours (average=5477.8; standard deviation=2897.7).

### 2.3 Methods

Eye movements were measured with the system iViewX by SMI (Berlin) (resolution: <0.1 degrees [pupil]; <0.5 degrees [compensated for movements]; frequency: 50 Hz). Raw data were condensed into cumulated *dwell times* for each flight and taxi segment (see chapter 2.4) on predefined *areas of interest* (AOI). These were:

- Displays
- Primary Flight Display (PFD)
- Navigation Display (NAV)
- Engine Display (ENG)
- Charts
- Approach chart
- Taxi chart
- Outside view
- Controls like
- Flight Control Unit (FCU)
- Gear
- Thrust lever

### 2.4 Scenarios

Each of the eight scenarios lasted about twenty minutes and was composed of different tasks and needs:

- *Initial Approach* (task: to fly straight ahead, hold altitude)
- *Intermediate Approach* (curved approach, sink 1000 feet),
- Final Approach (landing),
- Taxiing on Runway,
- Taxiing on Exit,
- Taxiing on Apron.

The subjects landed on runways 14, 16, and 28 of the airport Zürich-Kloten under different sight and wind conditions (Lorenz et al., 2004). In three scenarios the pilots had to taxi with the taxi chart, in four scenarios they were assisted by TARMAC-AS. In the remaining eighth scenario a failure of the taxi guidance system was provoked shortly before arriving on apron.

### 2.5 Analysis

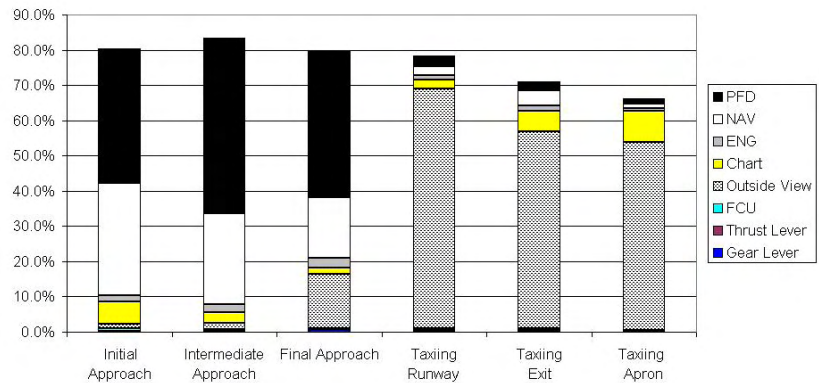
Corresponding to the first question, two-way analyses of variance with repeated measures were used to assess the effect of the flight segment on pilot's information gathering. Factor 1 represents the flight resp. taxi phase (six levels, cf. six phase in chapter 2.4), factor 2 pilots' experience (two levels, flight students vs. experienced pilots). Dependant variable in each analysis was the cumulated dwell time on an area of interest (see chapter 2.3) for each phase, averaged over four scenarios without taxi guidance support.

Corresponding to the second question, two-way analyses of variance with repeated measures were used to assess the effect of TARMAC-AS on pilot's information gathering. Factor 1 represents taxi guidance support (standard paper chart vs. TARMAC-AS display), factor 2 pilots' experience (two levels, flight students vs. experienced pilots). Dependant variable in each analysis was the cumulated dwell time on an area of interest (see chapter 2.3) for the taxi phase on apron, averaged over four scenarios with resp. without taxi guidance support.

### 3. Results

#### 3.1 Change of pilots' gaze depending on flight and taxi phases

Figure 2: Dwell times in percentages on areas of interest during three flight and three taxi phases (averaged over 49 pilots)



On a descriptive level, figure 2 shows pilots' areas of interest during three flight and three taxi phases (without additional taxi guidance system) in percentages. Data indicate that the importance of the PFD as main source of information declines after touch down from 49.8% of the dwell times in the segment *intermediate approach* to 1.6% during *taxiing on apron*. As expected the navigation display has more relevance during the flight phases compared to the segments after touch down. Data are within the range of 1.2% during *taxiing on apron* and 31.8% during the *initial approach*. During taxiing the outside view is the most important area of interest (range in these three segments between 53.4% and 68.0%). Time spent on the engine display is minor compared to the other displays: the highest ratio of 2.6% in the segment *final approach* reflects the monitoring of power thrust during landing. The approach chart is of use especially during the first segment (6.4%), for carefully preparing approach and landing. The main benefit of the paper taxi chart is seen during taxiing on the apron (8.7%), for identifying cleared taxiways and final stand at the terminal given by the apron ATCo. Controls like FCU, thrust and gear lever are sought out less frequently compared to other sources of information (in each segment below 1% for each area of interest).

Significant changes between the dwell times on the areas of interest PFD, NAV, ENG, chart, outside view, FCU and gear lever ( $p < 0.01$ ) are presented in table 1. Two differences between pilot students and experienced pilots can be observed: In each of the six phases, more experienced pilots make more use of the outside view (especially during taxiing on the exit 67.1% for experienced pilots vs. 53.2% for flight students.) Experienced pilots also pay more attention to the FCU during the flight phases.

**Tab.1: Significant differences in information gathering between six different flight tasks (calculated by two-way analyses of variance for areas of interest)**

Area of Interest	Source of Variance	Significance
Primary Flight Display (PFD)	Task (Flight / Taxi Phase)	.000**
	Experience	.548
	Task * Experience	.951
Navigation display (NAV)	Task (Flight / Taxi Phase)	.000**
	Experience	.214
	Task * Experience	.284
Engine Display (ENG)	Task (Flight / Taxi Phase)	.000**
	Experience	.345
	Task * Experience	.936
Paper Charts	Task (Flight / Taxi Phase)	.000**
	Experience	.349
	Task * Experience	.873
Outside view (front window)	Task (Flight / Taxi Phase)	.000**
	Experience	.004**
	Task * Experience	.000**
Outside view (window right hand sight)	Task (Flight / Taxi Phase)	.000**
	Experience	.339
	Task * Experience	.849
Flight Control Unit (FCU)	Task (Flight / Taxi Phase)	.004**
	Experience	.316
	Task * Experience	.001**
Thrust lever	Task (Flight / Taxi Phase)	.636
	Experience	.770
	Task * Experience	.395
Gear lever	Task (Flight / Taxi Phase)	.002**
	Experience	.502
	Task * Experience	.075

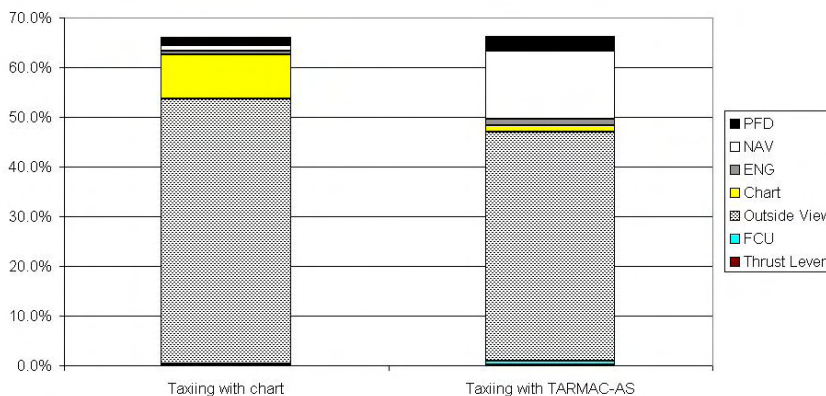
\* statistically significant (p<0.05)

\*\* highly statistically significant (p<0.01)

### 3.2 Change of pilots' gaze depending on use of taxi guidance system

In Figure 3 cumulative dwell times on the AOIs are depicted for trials with and without TARMAC-AS (averaged over 49 pilots) for the segment *taxiing on the apron*. Both in the condition with and without taxi guidance support the main source of information remains the outside view (53.4% in the baseline conditions with map vs. 46.0% while using TARMAC-AS). The second most important source of information is the taxi chart (8.7%) in the baseline condition resp. the navigation display (13.7%) in the condition "taxiing with TARMAC-AS". Whereas the PFD plays a subordinate role in both conditions, differences in information gathering are statistically significant for all other AOIs. The use of FCU becomes highly important (an increase of 0.3% to 0.8%,  $p = 0.000$ ) in TARMAC-AS trials. Significant differences arise for the thrust levers (0.1% in the baseline condition vs. 0.2% while using TARMAC-AS;  $p = 0,007$ ; highly significant) and display engine (0.8% compared to 1.2%,  $p = 0.029$ ; significant).

Figure 3: Dwell times in percentages on areas of interest during taxiing on apron (averaged over 49 pilots)



The difference in dwell times on the outside view due to the factor experience reported in chapter 3.1 can be found here as well: experience pilots use the outside view more than flight students do (cf. AOI front window;  $p=0.000$ ).

**Tab.2: Significant differences in information gathering between taxiing with standard map and taxi guidance support (calculated by two-way analyses of variance for areas of interest)**

Area of Interest	Source of Variance	Significance
Primary Flight Display (PFD)	Taxi guidance support	.288
	Experience	.249
	Taxi guidance support * Experience	.471
Navigation display (NAV)	Taxi guidance support	.000**
	Experience	.502
	Taxi guidance support * Experience	.419
Engine Display (ENG)	Taxi guidance support	.029*
	Experience	.344
	Taxi guidance support * Experience	.794
Paper Charts	Taxi guidance support	.000**
	Experience	.174
	Taxi guidance support * Experience	.776
Outside view (front window)	Taxi guidance support	.002**
	Experience	.000**
	Taxi guidance support * Experience	.382
Outside view (window right hand sight)	Taxi guidance support	.005**
	Experience	.985
	Taxi guidance support * Experience	.435
Flight Control Unit (FCU)	Taxi guidance support	.000**
	Experience	.906
	Taxi guidance support * Experience	.534
Thrust lever	Taxi guidance support	.007**
	Experience	.077
	Taxi guidance support * Experience	.091

\* statistically significant ( $p<0.05$ )

\*\* highly statistically significant ( $p<0.01$ )

## 4. Discussion

Depending on different flight and taxiing phases, different patterns of pilots' eye movement occur. Quantitative results can be gained by using a dedicated measurement device. Here the percentage of usable data collected in MOSES trials is encouragingly high (between 66.2% usable data for segment taxiing on the apron and 83.4% in the intermediate approach). Generally the proportion of usable data decreases in the course of a scenario, reflecting increased head movements during the taxiing phase and thus slight but crucial shifting of the measuring unit on the heads of the pilots.

Patterns of information gathering go mostly in the expected directions, in particular in relation to the AOIs displays and external perspective in question one. Assumptions on the information gathering go mostly in the expected direction, in particular in question one, related to the AOIs displays and external perspective. Effective strategies to gather information can be observed: Very brief glances at the map during the *final approach* are sufficient as the altitudes have already been read during the *initial approach*.

The secondary role of the factor experience related to the cumulative dwell times is an indication that the flight students already use the right sources of information at the right time. The higher proportion on the AOI outside view for experienced pilots during taxiing may reflect the fact that in previous training the taxi process for flight students was of secondary importance. Furthermore under instrument flight conditions experienced pilots tend to seek information in the outside view earlier than flight students. This perception pattern may result from longer experience as well.

The use of the taxi guidance system TARMAC-AS results in a different pattern of *dwell times for both sub-samples* (see fig. 2) without resulting in an *attentional capture* on the navigation display. It can be shown in single case studies that attention changes from the taxi charts to the navigation display (trade off). Main source of information by far remains the outside view. Further single case studies reveal that pilots use the TARMAC-AS display especially during holding times.

The increased need to monitor the FCU in the condition with taxi guidance support can be explained by pilots selecting different mode and zoom stages via the mode and range selector of the FCU. It can be explained that pilots monitor the status of the engine while using TARMAC-AS because thrust lever setting is checked more often because maybe taxi guidance systems tempt to roll faster. Compared with simulator data it can be shown that pilots do not taxi faster while using TARMAC-AS compared to scenarios with traditional taxi charts (Lorenz et al., 2004).

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