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Assessment of Manual Flying Skills by Combining Aircraft Parameters with Pilot Control Inputs

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ASSESSMENT OF MANUAL FLYING SKILLS BY COMBINING AIRCRAFT PARAMETERS WITH PILOT CONTROL INPUTS

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In a recent full flight simulator experiment, 57 commercial airline pilots (long-haul captains and short-haul first officers) had to accomplish a realistic scenario ending in a manual flown "raw data approach" (localizer and glideslope capturing with absence of autopilot and flight director aid). The manual flight performance was evaluated by an instructor. Various flight path parameters and pilot control input data were collected from the simulator for an objective evaluation and comparison with the instructor assessment. At first the outer control loop was analyzed by using flight path tracking errors. This showed significant difference between the two groups of pilots. Additionally the pilot steering (roll and pitch) strategy and the aircraft reaction were analyzed in the frequency domain to analyze the inner control loop. The steering strategy for pitch consist significant lower frequency than for bank in both groups. The results showed that pilots used steering inputs with higher frequency than the aircraft reaction frequency. Pilots with lower instructor evaluation show significant higher portions in this ineffective frequency band. The results show that a combination of outer and inner loop parameters is a good indicator to evaluate pilot manual flying skills.

Introduction

Issues with manual aircraft control are a contributing factor in 42% of all accidents. 67% of these accidents would have been avoidable by training (IATA 2012). Many studies and accident reports indicate an increasing lack in manual skills, due to the increasingly automated environment; pilots are reluctant to revert to manual flying when automated systems fail. So pilots should be well trained in manual flying skills to control the aircraft especially in critical situations. During pilot training in full flight simulators pilots train difficult malfunctions (e.g. hydraulic or engine failures) and they have to demonstrate an adequate performance to meet authority requirements. The training of manual flying skills is usually done on the job, without special simulator lessons. The pilot performance is checked subjectively by an observer. To implement a training program for manual flying skills as a countermeasure into the safety management process, it is necessary to use objective and consistent performance metrics.

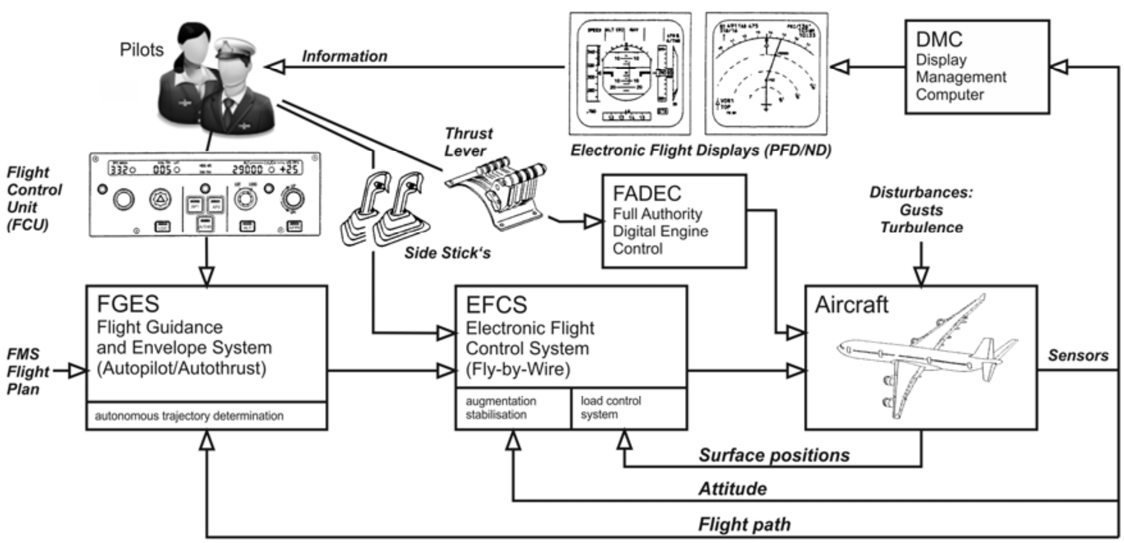

Figure 1. Illustration of Airbus A340 flight control loops (adapted from Airbus Industries 2000)

When evaluating performance of pilots on manual aircraft control, it is common to measure the outer loop control of the flight path in a time based analysis. Statistical metrics only have strong validity if applied to parameters that are associated to a well descripted flight path such as an instrument landing system (ILS). There is a certain disassociation between the control inputs of the pilot and the flight path response of modern and large transport aircraft, because of factors like inertia, transport delays of signals, possible control power and the relatively high stability of the machine. Especially in airplanes from Airbus Industries with fly-by-wire control laws, pilots have no longer direct influence on the aircraft control surfaces (see Figure 1).

From subject matter expert's opinion, the skilled pilot operation is done in a more pre-cognitive mode: To archive a smooth flight path this could be archived with less side stick inputs in a gentle manner and mostly to only one axis. Pilots with less skill level trend to give more diagonal inputs on both stick axes in a relative aggressive manner. The aim of this study is to evaluate these effects with three tiers of statistical methods.

Methods

Method 1: Time based analysis

Research studies like Mixon (1981) or Johnson (2005) describe pilot performance by analyzing various flight parameters (altitude, speed, deviation) and calculating statistic parameter out of them. In this study, the outer control loop was analyzed by using various flight parameter and flight path tracking errors. The Standard Deviation (SD) and Root Mean Square Error (RMSE) Deviation Index are good indicators to describe the preciseness. The sum of the RMSE and SD of the lateral and vertical profile is combined to the Deviation Index for both directions. The target flight path is given by the ILS.

Method 2: Frequency based analysis

The pilot steering (roll and pitch) has the main influence on the aircraft movement and trajectory. The steering strategy or inner-loop can be analyzed in the frequency. The analysis of the control input strategy is less intuitive and requires more technical resources to achieve significant results. This method has the advantage to estimate the pilot performance in all phases of flight. Rantanen (2001) and Ebbatson (2009) have already tested this method successfully in previous studies. Rantanen used flight data parameter from a small aircraft and Ebbatson used a Boeing 737 Full Flight Simulator. The main results show significant differences in the used frequency bands. More skilled pilots were able to adapt their steering inputs and show smaller variance in the used steering frequency. In this study the Power Spectral Density (PSD) is calculated by the Fast Fourier Transformation (FFT) of the steering signal. The PSD is calculated in five frequency bands from 0.01 until 0.3 Hertz (Hz).

Method 3: Steering pattern based analysis

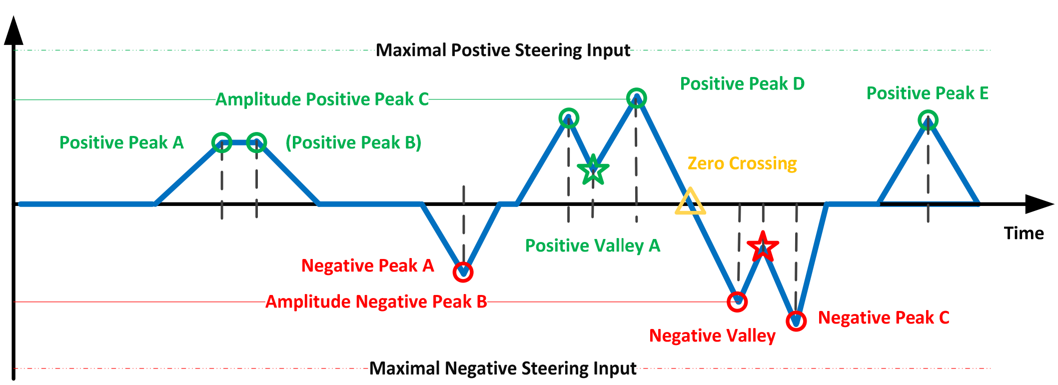

Figure 2. Steering Input Nomenclature

Under normal conditions all flight control surfaces of modern Airbus aircraft are controlled by various flight control computer and were moved by hydraulic actuators (see also Figure 1). The pilot is using a sidestick to control the aircraft in roll and pitch. The pilot commands roll rates in roll axis and g-loads in pitch axis. The control surfaces and the sidestick deflection are not proportional. Corrections in steering commands are characterized by multiple peaks and valleys in the steering signal (see Figure 2), which can be detected precisely with a signal peak detection algorithms (Appel 2012). For this study the Valley Peak Ratio (VPR) is used to describe the number of steering correction and a high VPR is an indicator of a high amount of steering corrections. The pilot can command pitch and roll simultaneously and these inputs can be measured as a Single or Dual Steering Input (SSI or DSI). The Dual-Single-Ratio (DSR) describes the proportion of number of SSI and DSI.

Experiments

This study was conducted in cooperation with a major European airline. Pilots with different levels of practice and training were selected randomly. Twenty-seven long-haul captains with Airbus A330/340 type-rating and thirty first officers with Airbus A319/320/321type-rating had participated. Two certified (JAR-STD 1A Level D) full flight simulators, with Airbus A340-600 and A320 configuration, were used for this study.

To provide a realistic scenario for manual flying tasks, a real approach was developed (for details see Haslbeck *et al.* 2012). During base leg turn, the auto flight approach mode (automatic interception of localizer and glide slope provided by the ILS) could not be armed. Shortly after this mode confusion event, the whole auto flight system was disabled and immediately the Pilot flying (PF) had to perform a raw data ILS approach. The aircraft performance, trajectory and control steering inputs were recorded with a sample rate of 15 Hz from the flight simulation process. The overall flight performance of the PF also was evaluated by an experienced instructor.

Hypothesis

Pilots with higher deviation in track and altitude use more steering inputs (H1a) and inputs with higher amplitude (H1b). Pilots with higher deviation concentrate their steering inputs on few frequency bands (H2a) and tend to higher frequencies bands (H2b). Pilots with higher deviation use simultaneously more steering inputs with on two axes (H3). Pilots with higher deviation correct their steering inputs more often (H4; Valley-Peak-Ratio). Pilots with a height deviation use steering inputs with higher frequency as the aircraft reaction frequency (H5).

Results

Method 1: Time based analysis

The deviation index showed significant difference between the two groups of pilots (A320 and A340).

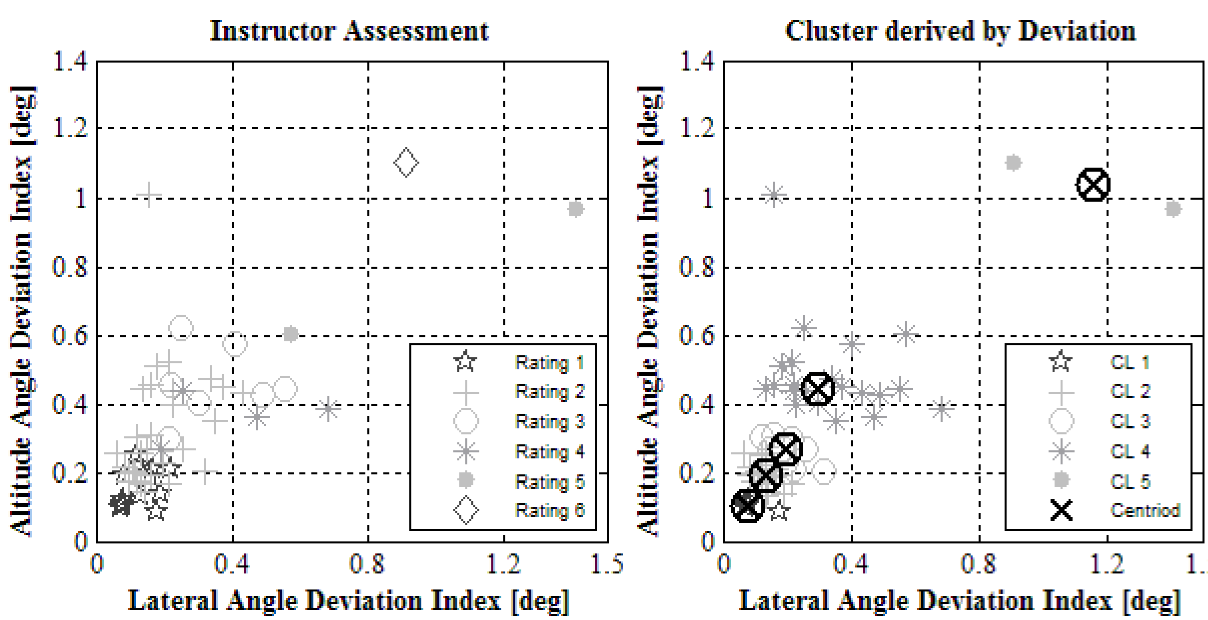

Figure 3. Instructor Assessment and Cluster derived by Deviation Index

The deviation index and the instructor ratings correlate in most cases (Figure 3, left) and a cluster algorithm is use to group similar results by using the deviation index for lateral and vertical deviation. The result of five clusters (CL) is shown (Figure 3, right). The members of CL1 represent pilots with the 5% lowest and 5% highest deviations (CL5). The clusters CL2 - CL3 represent the main group with 25-75% of the deviation index probability. The member of CL1 and CL2 are summarized to one single Cluster “good performers” and the member of cluster CL3, CL4 and CL5 are summarized to one single cluster “improvable performers” to achieve groups with approximately equal members.

Method 2: Frequency based analysis

The statistical results (see Table 1 on next page) indicates that’s the number of steering inputs (H1a) are not significantly different in both groups and only a trend to a higher number of steering inputs can be determined. The statistical results confirm the hypothesis H1b, that good performers are using steering inputs with lower amplitudes in roll. The steering strategy is analyzed by using the five deviation index cluster for pitch and roll commands. The steering command for pitch consist significant lower frequencies than in roll for all groups. The PSD results (Figure 4) indicate that pilots with lower deviation are using steering inputs in the effective frequency bands (VLF - MF). But Pilots with higher deviation concentrate their steering inputs on 1-2 frequency bands only and tend also to use steering inputs with higher frequency. The frequency based results indicates and confirm the hypothesis H2a and H2b in most frequency bands. Especially the power spectral densities for roll commands differ significantly from each other. Pilot with lower deviations use steering input in all frequency bands and the pilots with higher deviation concentrate their steering on few and higher frequency bands. The aircraft pitch and bank angle react only in the frequency bands VHF-MF (0.01-0.18 Hz) and the pilot with higher deviation show a significant higher PSD in pitch and roll in this ineffective steering area above 0.18 Hz (H5).

Method 3: Steering pattern based analysis

The results of the steering pattern analysis (Figure 4) show only tendencies and no significantly results. The results for dual input differ in roll and pitch. The pilots with lower deviation use more dual inputs in pitch to control the aircraft and neglect the hypothesis H3. But in roll pilots with lower deviation use less dual inputs and tends to confirm the hypothesis H3. The hypothesis H4 can be confirmed significantly for roll and pilots with higher deviation correct their inputs more often and show a higher valley peak ratio. In pitch the valley peak ratio is tended to be higher for pilots with higher deviations.

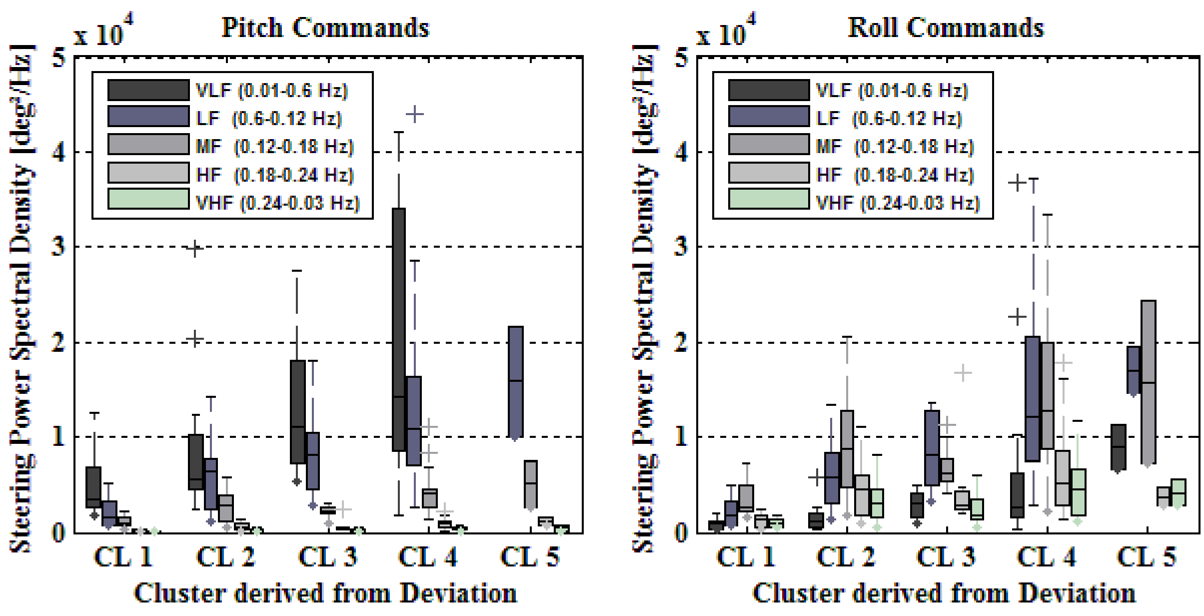

Figure 4. Steering Power Spectral Density (PSD)

Table 1.
Statistical Results.

Variable Unit	Axis	Group	No	Mean	SD	VAR	T - Test p Value	U - Test p Value	F-Test p-Value
Number of Inputs [-]	Pitch	CL good CL improvable	33 23	139,9 161,8	54,5 59,8	2971,4 3581,3	0,1622	0,1967	0,6179
Number of Inputs [-]	Roll	CL good CL improvable	33 23	184,0 197,6	54,8 53,1	3003,9 2817,6	0,3586	0,4192	0,8908
Mean Amplitude of Inputs [deg]	Pitch	CL good CL improvable	33 23	2,18 2,30	0,47 0,42	0,2 0,2	0,3316	0,4050	0,6163
Mean Amplitude of Inputs [deg]	Roll	CL good CL improvable	33 23	3,34 4,29	0,72 0,98	0,5 1,0	**0,0001**	**0,0004**	0,1069
SD Amplitude of Inputs [deg]	Pitch	CL good CL improvable	33 23	1,63 1,87	0,33 0,35	0,1 0,1	**0,0120**	**0,0137**	0,8363
SD Amplitude of Inputs [deg]	Roll	CL good CL improvable	33 23	2,27 3,03	0,61 0,67	0,4 0,5	**0,0001**	**0,0001**	0,6279
PSD VLF (0.01-0.06 Hz) [deg²/Hz]	Pitch	CL good CL improvable	33 23	2112 3492	1951 2035	3,8E+06 4,1E+06	**0,0133**	**0,0001**	0,8116
PSD LF (0.06-0.12 Hz) [deg²/Hz]	Pitch	CL good CL improvable	33 23	1253 1274	980 574	9,6E+05 3,3E+05	0,9272	0,2790	**0,0110**
PSD MF (0.12-0.18 Hz) [deg²/Hz]	Pitch	CL good CL improvable	33 23	949 1359	622 849	3,9E+05 7,2E+05	**0,0420**	0,0555	0,1057
PSD HF (0.18-0.24 Hz) [deg²/Hz] No ACFT Reaction	Pitch	CL good CL improvable	33 23	723 1056	802 582	6,4E+05 3,4E+05	0,0947	**0,0038**	0,1196
PSD VHF (0.24-0.3 Hz) [deg²/Hz] No ACFT Reaction	Pitch	CL good CL improvable	33 23	674 1391	631 1125	4,0E+05 1,3E+06	**0,0036**	**0,0002**	0,0029
PSD VLF (0.01-0.06 Hz) [deg²/Hz]	Roll	CL good CL improvable	33 23	1775 6414	1416 8287	2,0E+06 6,9E+07	**0,0026**	**0,0007**	**0,0000**
PSD LF (0.06-0.12 Hz) [deg²/Hz]	Roll	CL good CL improvable	33 23	6252 17642	4093 15815	1,7E+07 2,5E+08	**0,0002**	**0,0001**	**0,0000**
PSD MF (0.12-0.18 Hz) [deg²/Hz]	Roll	CL good CL improvable	33 23	7438 14145	4568 7844	2,1E+07 6,2E+07	**0,0002**	**0,0015**	**0,0053**
PSD HF (0.18-0.24 Hz) [deg²/Hz] No ACFT Reaction	Roll	CL good CL improvable	33 23	3859 6119	3325 4393	1,1E+07 1,9E+07	**0,0327**	**0,0215**	0,1477
PSD VHF (0.24-0.3 Hz) [deg²/Hz] No ACFT Reaction	Roll	CL good CL improvable	33 23	2678 4608	1978 2808	3,9E+06 7,9E+06	**0,0038**	**0,0063**	0,0691
Dual/Single Steering Input Ratio [-]	Pitch	CL good CL improvable	33 23	1,3604 1,1372	2,1896 1,4244	4,7945 2,0290	0,6695	0,6891	**0,0388**
Dual/Single Steering Input Ratio [-]	Roll	CL good CL improvable	33 23	1,0697 1,1682	1,2494 1,4146	1,5610 2,0011	0,7844	0,6526	0,5115
Valley/Peak Steering Input Ratio [-]	Pitch	CL good CL improvable	33 23	0,2920 0,3267	0,0862 0,0940	0,0074 0,0088	0,1590	0,0909	0,6433
Valley/Peak Steering Input Ratio [-]	Roll	CL good CL improvable	33 23	0,2870 0,3529	0,0813 0,1052	0,0066 0,0111	**0,0107**	**0,0439**	0,1809

Discussion

The results of this study show, that frequency and steering pattern methods can be used to evaluate pilot performance independently from aircraft parameters and they are suitable on fly-by-wire controlled aircrafts. The PSD analysis present similar results as in other studies and the metric can be further developed to achieve an objective pilot measurement metrics. The steering pattern method shows heterogeneous results by evaluating steering performance and can be improved to give pilots a better feedback on their manual flying performance. This metric is easier to understand and is more helpful to implement corrective action during pilot training sessions.

Acknowledgements

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