Pilot Motion Perception and Control During a Simulated Decrab Maneuver

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Simulated Decrab Maneuver

Problem area

The tuning of a motion system for a flight simulator is still a highly subjective, and therefore costly, process. There simply is a lack of objective evaluation criteria specifying the motion requirements for the simulation of different aircraft (transport, fighter, or rotary wing) or manoeuvres. In practice, the determination of motion cues is based on a subjective process that relies mainly on the perception of the pilot or simulator instructor. Consequently, the simulation is sub-optimal for specific motion-critical manoeuvres (such as engine failure), which negatively affects the control behaviour of the simulator pilot, and may also give rise to simulator sickness. The efforts to optimise motion cueing should be in accordance with the relevance of a manoeuvre for training purposes.
Considerable progress has been achieved in the modeling of human control behaviour and motion perception to address the problem of objectively evaluating and optimising simulator motion cues. The effect and optimization of simulator lateral and yaw motion, occurring during flight critical maneuvers, is of particular interest.

Description of work

A simulator study was conducted in the NLR's Generic Research Aircraft Cockpit Environment (GRACE) simulator facility where pilots were asked to perform a decrab maneuver just before landing. The purpose of this study was to validate previous experiment results, to investigate the effect of simulator yaw and sway

motion on pilot performance and to analyze the effect of pilot workload on motion fidelity rating and motion perception.

Results and conclusions

The effect of simulator translational and rotational motion on perceived motion fidelity, motion perception, pilot workload and pilot compensation was determined for a manual decrab maneuver of a twin-engine regional civil aircraft. The study found that simulator translational motion had a larger impact on perceived motion fidelity and motion perception than yaw motion. Handling qualities ratings also showed that the addition of simulator sway motion is preferred by pilots. It was found that simulator sway reduced control activity and therefore pilot workload in both cases. The study also highlighted the importance of visual cues in motion perception. The study shows that simulator motion has a positive effect on both perceived motion fidelity and performance during the simulation of a demanding lateral-directional maneuver such as a decrab.

Applicability

The results of this study are applicable to current motion cueing systems as applied in the flight training and simulator manufacturing industry. Improvement in the tuning of the lateral-directional motion cues using the results of this study will improve training effectiveness in terms of pilot behavior during demanding asymmetric maneuvers. The results of this study will be further applied in conjunction with human perception modeling techniques to develop objective evaluation criteria for the optimisation of simulator motion cues.

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A set of experiments were conducted on the National Aerospace Laboratory (NLR) GRACE research flight simulation facility to determine the effects of sway, yaw and roll motion on perceived motion fidelity, motion perception, pilot workload and pilot compensation. Fourteen pilots were asked to perform a manual decrab maneuver when the aircraft was on final approach with a 30 knots crosswind. Platform yaw, sway and roll motions were varied independently to examine their relative contribution to the pilot's judgements on perceived motion cues and workload. To determine possible effects of workload on the pilot's opinion about motion fidelity and perception of motion, pilots were grouped in pairs. For each simulator run, one pilot was asked to fly the aircraft while the other pilot was asked to monitor the maneuver. Both pilots answered the same questionnaire after each run. The results show that perception of simulator motion was positively affected by platform sway for both pilots-flying and pilots-not-flying. Platform roll had only a main effect on the perceived motion of the pilots-not-flying. Platform yaw motion seemed to have a positive effect on motion perception only in the absence of platform sway. The pilot motion fidelity ratings show that platform sway improved the fidelity ratings for the pilots-not-flying only. Platform roll (in the absence of sway) also showed to have a positive effect on pilot fidelity ratings. On average, pilot fidelity ratings were higher when the pilot was controlling the aircraft. Handling qualities results show that pilots felt less compensation was required when platform sway was present. This was confirmed by the decrease in pilot pedal and column activity when platform sway was present. The results of the experiment as described in this paper will support our previous studies in the development of objective evaluation criteria for the optimisation of simulator motion cues.

Nomenclature

β = sideslip angle, deg
K = gain
ω = breakfrequency, rad/s
Ψ = heading angle, deg
ANOVA = Analysis of Variance
Vground = ground speed, knots
Vwind = crosswind, knots
Vtas = true airspeed, knots
VMC = Visual Meteorological Conditions

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I.   Introduction

PREVIOUS research has demonstrated that simulator motion improves pilot performance and subjective fidelity ratings (Reid and Nahon[1], Strachan[2]). There is still an ongoing research on the required fidelity of simulator motion and offline assessment of simulator motion requirements (Hosman[3], Groen et. al.[4,5,6], Ellerbroek et. al.[7,8]). Particularly, the effect of simulator lateral and yaw motion on pilot performance and fidelity ratings was the subject of some debate (Schroeder[9], Grant et. al.[10]). Schroeder (Schroeder[9]) studied the effect of sway and yaw motion on helicopter yaw control tasks. He performed a series of helicopter motion experiments using a representative helicopter model. For a yaw capture task, a pseudorandom disturbance rejection task and a 180 degree hover turn, simulator lateral motion significantly improved pilot control performance, subjective handling qualities rating, and pilot fidelity rating of the simulator motion. Simulator yaw motion had no effect on pilot performance or opinion, especially when translational motion was present.

Grant et. al. (Grant et. al.[10]) performed a similar experiment where the three helicopter yaw control tasks were a yaw capture, a disturbance rejection task, and a tracking task. They duplicated Schroeder's yaw capture task to compare results of experiments performed at different facilities. Grant et. al. found that translational motion improved performance and increased fidelity rating for all three tasks, which is in agreement with Schroeder's results. However, yaw motion increased pilot performance for the yaw capture and disturbance rejection tasks. Moreover, they found that translational motion provided little additional benefit when simulator yaw motion was present.

Groen et. al. (Groen et. al.[11,12]) investigated the effect of translational and yaw motion during a series of decrab maneuvers of a twin-engine passenger aircraft. The experiment was performed using the Generic Fighter Operations Research Cockpit Environment (GFORCE) at the National Aerospace Laboratory (NLR) in Amsterdam (Figure 1). Pilots were asked to judge various aspects of simulator motion by watching an auto-land decrab from the pilot seat. It was concluded that the most effective motion feedback for the simulation of the heading alignment during a decrab maneuver were platform sway and roll motions.

Since pilots were not actively controlling the aircraft in the previous study by Groen et. al.[11,12] and the cockpit environment was that of a fighter aircraft, a similar simulator study was conducted in the NLR's new Generic Research Aircraft Cockpit Environment (GRACE) simulator facility where pilots were asked to perform a decrab maneuver just before landing. The purpose of this study was to validate the previous experiment results, to investigate the effect of simulator yaw and sway motion on pilot performance and to analyze the effect of pilot workload on motion fidelity rating and motion perception.

Figure 1. NLR GFORCE facility as used during the simulator motion cueing study by Groen et. al[11,12].

II.   Flight Simulator Experiment

A. Simulator Facility

The simulator experiment was conducted at the National Aerospace Laboratory NLR in Amsterdam. For this experiment, the NLR Generic Research Aircraft Cockpit Environment (GRACE) flight simulator was utilised (Figure 2). The GRACE is a modular reconfigurable transport aircraft simulator for civil flight operations research. The simulator, operated on its 6 Degrees-of-Freedom (DOF) electrical motion platform, enables simulation of a wide range of transport aircraft in a complete operational traffic and weather environment. The basic layout of the simulator is based on Airbus (A330/340) cockpits, but interchanging instruments panels, glareshield panels, mid pedestal and sidesticks with column/wheel allows configurations in different types of aircraft. These range from small business jets up to large transport aircraft. For the experiment, and to compare the results with the study conducted by Groen et. al.[11,12], the simulator was configured to represent the Fokker 100 twin-engine regional aircraft.

Figure 2. NLR Generic Research Aircraft Cockpit Environment (GRACE).

To represent the Fokker 100 aircraft, as baseline model for the piloted motion cueing experiment, the GRACE cockpit was configured according to the Fokker 100 flight deck (Figure 3). This included all main electronic instruments including primary flight displays (PFD), navigation display (ND) and main engine instruments. The PFD contains information regarding aircraft attitude, airspeed and altitude. Information concerning the aircraft's heading is presented on the ND. Conventional control wheel and column, as used onboard the Fokker 100, were available to control the aircraft throughout the decrab maneuver.

Figure 3. NLR GRACE transport aircraft cockpit for the pilot motion perception and control experiment. Left: GRACE cockpit in Fokker 100 configuration. Right: Left pilot's view on primary instruments and outside scene during the decrab maneuver.

The GRACE visual system provided a view of the outside world during the decrab maneuver by means of four Wide-Angle Collimated (WAC) displays. These displays are mounted on top of the GRACE cockpit. The visual scene was presented to the pilots using an SXGA resolution of 1280 x 1024. Both left (Captain) and right (First Officer) seated pilots have a view of about $28°$ vertical and $75°$ horizontal. Side view at both left and right pilot positions provides peripheral view of the outside scene. The visual system configuration provides, however, no cross-cockpit viewing. The visual database used during the experiment represented Amsterdam Schiphol Airport

(Runway 18C) and surroundings (Figure 4). The airport scene contains detailed ground textures close to the ground for visual cues including runway and taxiway configurations, lighting and markings.

Figure 4. GRACE visual database illustrating the sequence of the outside visual scene during the piloted decrab maneuver for a left crosswind (from left to right).

B. Motion System Configuration

The GRACE cockpit and visual display system are mounted on top of an electrical motion system. The system (EMotion), manufactured by Bosch Rexroth, is an electrically driven synergistic motion system consisting of a triangular shaped moving platform (Figure 5). The platform is mounted on top of 3 pairs of servo-actuators positioned as inverted V's. The linear electric actuators are built-up using satellite roller screw spindles. The design is based on electric servo technology, which results in a system with high dynamic response.

The geometry has been tailored to deliver maximum excursion capability within the limits of the GRACE facility. Each actuator is equipped with software limit switches which stop movement of the system if an actuator runs outside predefined limits. A passive hydraulic cushioning device is provided at both ends to ensure safe operation of the system. In the event of platform runaway failures, the actuator is decelerated before the mechanical end stops are reached. Furthermore, the actuators contain an emergency braking system that smoothly decelerates the actuator in case of a failure. The performance specification of the GRACE motion platform, as applied for the piloted motion cueing experiment, can be found in Table 1. The data are based on a net payload up to the maximum of 8000 kg.

Figure 5. GRACE electrical motion platform configuration.

Table 1. GRACE EMotion platform specifications.

Direction	Operational excursion		Velocity	Acceleration
Surge	- 0.557 m	0.660 m	0.88 m/s	6.0 m/s^2
Sway	- 0.553 m	0.553 m	0.88 m/s	6.0 m/s^2
Heave	- 0.414 m	0.446 m	0.63 m/s	7.3 m/s^2
Roll	- 17.75 °	17.75 °	30 °/s	160 °/s^2
Pitch	- 17.25 °	16.60 °	30 °/s	160 °/s^2
Yaw	- 22.05 °	22.05 °	40 °/s	200 °/s^2

C. Pilots

A total of fourteen pilots were selected for the experiment based on their previous operational experience in twin-engine regional aircraft like the Fokker 100. Most of them had additional type ratings for twin-engine medium range aircraft up to large transport aircraft types. The mean age of the pilots was about 43 years and they had a mean experience of about 8000 flight hours. The pilots were all briefed before and during the experiment. All pilots had the opportunity to manually fly the decrab maneuver in the GRACE simulator according to the procedures defined for the experiment.

D. Aircraft Model

The Fokker 100 aircraft model was used for the piloted motion cueing study. The Fokker 100 (Figure 6) is a twin-engine regional aircraft that can carry about 100 passengers. The aircraft model, as operational in the GRACE simulator, is based on windtunnel data and validated against flight test data from Fokker Aircraft B.V. for the aerodynamics and mechanical flight control system. For the motion cueing study, the Fokker 100 was selected based on its decrab maneuvering capabilities and to compare the results of this experiment with the study by Groen et. al.[11,12].

Figure 6. Fokker 100 aircraft model as used for the piloted motion cueing study.

E. Experimental Design

The aim of the experiment in this piloted motion cueing study was to determine the effect of motion platform sway, yaw and roll on the pilot's subjective perceived motion and control behaviour. The results of this experiment were also used to compare these effects with the results of the *passive* flight task as performed in the study by Groen et. al.[11,12]. For both studies, a decrab maneuver has been defined that enables motion cueing and pilot control behaviour analysis during lateral-directional maneuvering. In contrast to the study done by Groen et. al.[11,12], in this experiment pilots conducted the maneuver as an *active* flight task in which they had manual control of the aircraft. The decrab maneuver was executed in the simulator at the maximum aircraft certified crosswind limit of 30 knots.

The decrab maneuver is an asymmetric maneuver that is usually performed to compensate for crosswind conditions during final approach. The maneuver is performed in a coordinated way using aileron and rudder. Figure 7 (left) illustrates the conditions before decrab for a right crosswind (V_{wind}). The aircraft flies with a wind correction angle (ψ) to compensate for the right crosswind by turning the true airspeed vector (V_{tas}) in the wind direction. Ground speed (V_{ground}) is towards the runway. In this condition, the stick and rudder pedal are in neutral position. Figure 7 (right) illustrates the condition after decrab. The aircraft is lined-up with the runway (heading alignment) and flies with a slideslip angle (β). The decrab for this right crosswind condition is performed by applying left rudder for runway heading alignment and right control wheel deflection to induce a roll angle (right wing down) in order to compensate for left drift due to the crosswind. For a left crosswind, the situation and control technique is reversed.
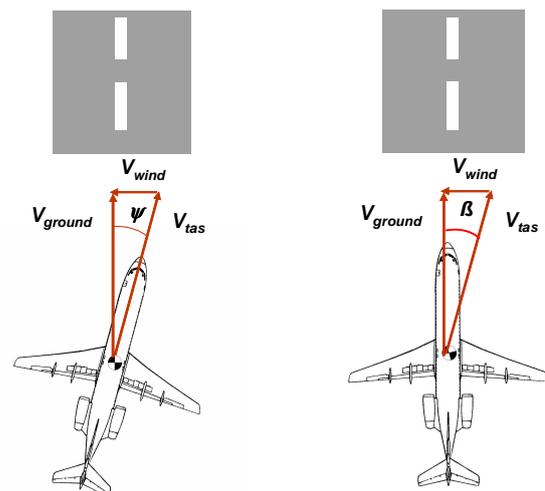
Figure 7. Geometry of the Fokker 100 decrab maneuver for a right crosswind.

The washout filters of the GRACE motion system were configured to provide motion cues in all six degrees-of-freedom during the decrab maneuver. The lateral-directional motion cue channels, including sway, yaw and roll, could be switched on and off independently. This resulted into eight combinations (2x2x2) of lateral-directional motion cue configurations ranging from lateral-directional motion off up to full motion (all channels on). For all six motion cue channels, classical washout was applied with second-order high-pass filters for the onset cues (Table 2). Tilt co-ordination for sustained sway motion (including surge) was achieved with second-order low-pass filters (Table 3). Damping coefficients of all filters were set to one. The breakfrequency gains of the filters were adjusted to assure that during the maneuvers the motion system stayed within its physical limits. This prevented false cues from hitting the GRACE motion system limits during the decrab maneuver.

Table 2. Experiment motion system high-pass filter configurations.

Channel	Breakfrequency ω (rad/s)	Gain K
Surge	2.00	0.50
Sway	0.25	0.50
Heave	2.00	0.45
Roll	0.25	0.60
Pitch	0.25	0.45
Yaw	0.13	1.00

Table 3. Experiment motion system low-pass filter configurations.

Channel	Breakfrequency ω (rad/s)	Gain K
Surge	0.7	0.45
Sway	5.0	1.0

All fourteen pilots were grouped into a crew of two pilots. Each pilot would assess the decrab maneuver during 32 runs both as pilot-flying (PF) and pilot-not-flying (PNF). The pilot-flying (left seated) would manually fly the maneuver during 16 runs in which the eight combinations of sway, yaw and roll motion cues were provided in a random order and repeated ones. The task of the pilot-not-flying was to only monitor the maneuver from the right seat. After 16 runs, the pilots changed their seat positions depending on the position they were most used to as pilot-flying in real operational flight. All maneuvers were flown in visual meteorological conditions (VMC). The test matrix of conditions for the experiment (as compared to the study by Groen et. al.[11,12]) is shown in Figure 8.
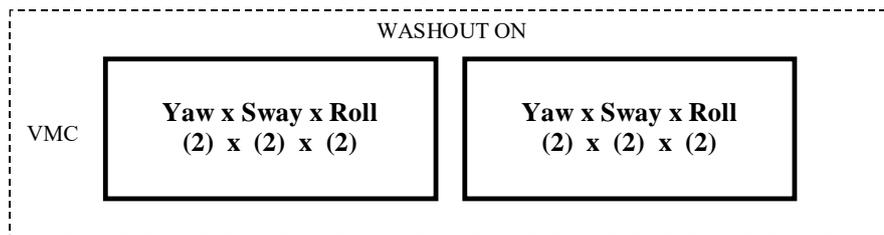
Figure 8. Experiment matrix of conditions used during the piloted motion cueing study.

The flight task of the experiment consisted of manually flying the aircraft, during final approach at Amsterdam Schiphol airport, from an initial altitude of 500 feet, at an airspeed of 123 knots and in a 30 knots crosswind from the left. At the start of each run, which took about 3 minutes to complete, the aircraft flew with the nose into the wind (wind correction angle). At an altitude of 200 feet, the pilot initiated the decrab maneuver by aligning the nose of the aircraft with the runway heading (heading alignment). At an altitude of 50 feet, the run ends just before flare and touchdown to prevent cues that are not purely related to the decrab maneuver. The pilots were briefed to complete the heading alignment and compensating roll angle before reaching 50 feet.

F. Procedure

Pilot motion perception and control behaviour during the simulated decrab maneuver was evaluated using a subjective rating scheme and objective measurement data from the simulator. Following each run, both pilot-flying and pilot-not-flying provided ratings concerning handling qualities (only pilot-flying), perceived motion fidelity and motion perception. Handling qualities ratings were provided using a subjective rating scale and gave an indication on the amount of compensation required to achieve good performance. Performance was in this case defined as the amount of workload and ease required to complete the decrab maneuver without large deviations from the glideslope and runway centerline. *Motion fidelity* was judged as the *quality* or *realism* of the maneuver as perceived in the simulator. The *strength* of the perceived motion sensation was evaluated using a *motion perception* rating. The motion perception rating was related to the strength of the heading alignment motion. When motion was perceived by the pilots they were asked to indicate whether the perceived motion consisted of rotational motion, linear motion or a combination of both. The objective measurements from the simulator consisted of pilot control activity (wheel, column and pedal rates and deflections) and aircraft state parameters.

III.   Results

A. Data Analysis

Data from this study were analysed using within-subjects Analysis of Variance (ANOVA). Due to the structure of the experiment, it was not possible to perform a direct comparison between each pilot's active (flying) and passive (not flying) task results. Therefore, the analysis was divided into three parts. First, the subjective ratings of the pilots-not-flying were analysed and compared with the experiment results of the study by Groen et. al.[11,12]. Then, the subjective ratings of the pilots-flying were analysed and compared with the pilots-not-flying results. Finally, handling qualities of simulator motion were analysed using both subjective ratings and pilot control activity (representative of pilot workload). In all the above analyses, simulator sway, yaw and roll were the factors being tested and effects with $p < 0.05$ were considered significant.

B. Motion Fidelity (MF) Rating

The pilots were asked to rate the fidelity of simulator motion for each run as 'low', 'medium' or 'high fidelity' (score of 0, 1 or 2 respectively). A repeated measure ANOVA showed that for pilots-not-flying, simulator sway has a significant effect on motion fidelity rating. An interaction between simulator sway and roll also turned out to be a significant effect. From Figure 9 it can be seen that, on average, simulator sway motion increases motion fidelity ratings. In the absence of simulator sway motion (the blue lines), fidelity ratings seem to increase as simulator roll motion is introduced (going from the left plot to the right). In the previous study by Groen et. al.[11,12] simulator roll and yaw motions were significant effects. The results for the pilots-flying showed no significant effect other than a three way interaction between simulator sway, yaw and roll motions. Figure 10 demonstrates the effect of sway, yaw and roll motion cues on fidelity ratings given by the pilots-flying. The results suggest that pilot fidelity ratings, for cases when they were actively controlling the aircraft during the decrab maneuver, can be considered as random.
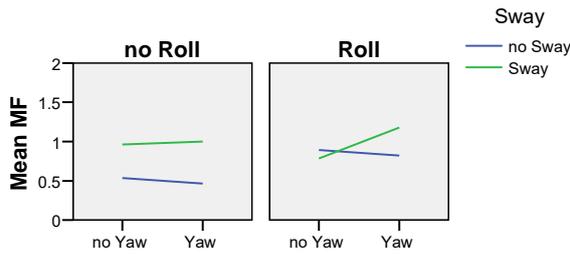
Figure 9. Effect of simulator sway, yaw and roll motion on pilot-not-flying motion fidelity ratings.
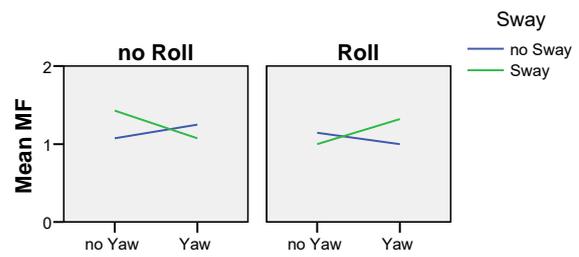
Figure 10. Effect of simulator sway, yaw and roll motion on pilot-flying motion fidelity ratings.

C. Motion Perception (MP) Rating

The *strength* of the simulator motion as perceived by the pilots was rated as 'no motion', 'too weak', 'natural' or 'too strong', which corresponded to scores of 0 to 3 respectively. According to ANOVA results, simulator sway motion positively effected motion perception ratings for pilots-flying and pilots-not-flying. This is in agreement with results of the study by Groen et. al.[11,12]. For pilots-not-flying, simulator roll had also a significant effect on perceived motion, which further agrees with the experiment results as described by Groen et. al.[11,12]. The positive effect of sway and roll motion on the motion perception ratings can be seen in Figure 11. The ANOVA results also showed a two-way interaction effect between sway and yaw motion for pilots-flying, which can be explained by the positive slopes of the blue lines in Figure 12. In the absence of sway motion, the experiment results show that simulator yaw increases motion perception ratings. This interaction was also seen in the experiment results of the study by Groen et. al.[11,12].
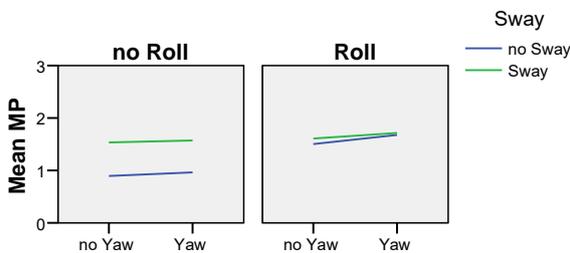
Figure 11. Effect of simulator sway, yaw and roll motion on pilot-not-flying motion perception ratings.
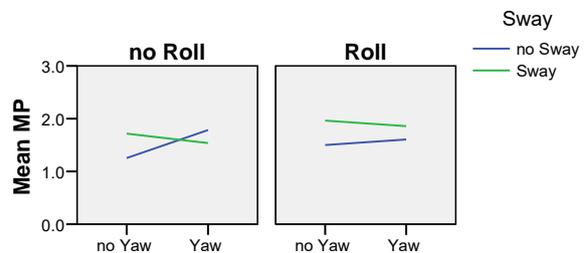
Figure 12. Effect of simulator sway, yaw and roll motion on pilot-not-flying motion perception ratings.

D. Handling Qualities (HQ) Rating

After each run, the pilot-flying was asked to rate the amount of compensation required to achieve the desired performance. The handling qualities rating was based on a five point scale ranging from minimal (score of 1) to maximum tolerable (score of 5). The ANOVA results indicated that none of the motion factors had a significant effect on the handling qualities ratings. However, considering p-values between 0.05 and 0.1 as marginally significant, it was shown that platform sway reduced the handling qualities rating. This can be seen in the top-left plots of Figure 13 where the addition of platform sway (green lines) decreases the average handling qualities rating scores.

Time histories of pedal, column and wheel activities for each run were also investigated. For each run, the root-mean-square (RMS) values of control inputs were averaged in order to have three scores representing the pedal rate, wheel rate and column rate for each motion condition. It can be seen in Figure 13 that the addition of platform sway decreases pilot workload for almost all cases. The ANOVA results also indicate that platform sway had a marginally significant effect on pedal and column activities. This is also in agreement with the subjective ratings of the pilots as mentioned above.
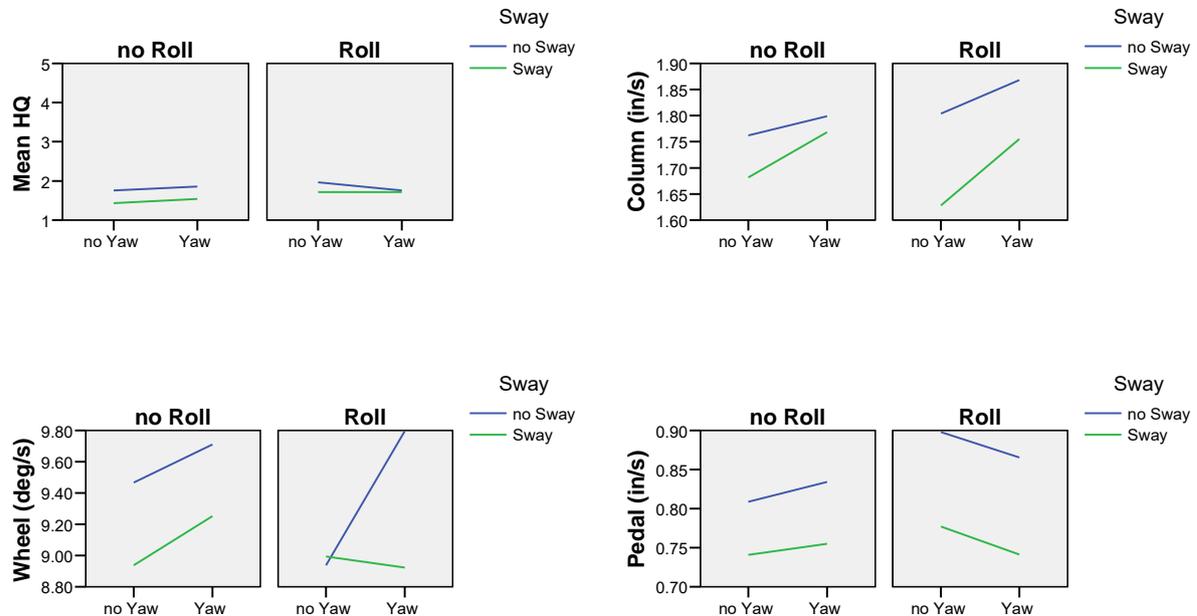
Figure 13. Effect of simulator sway, yaw and roll motion on pilot-flying handling qualities ratings and measured control activities.

E. Motion Interpretation

During the experiment, the pilots were asked to indicate whether the simulator motion felt like a rotational motion, lateral motion or a combination of both. As expected, the pilots had a hard time detecting the applied type of motion, and there were no correlations between the perceived type of motion and fidelity ratings or motion perception ratings. An interesting observation was that only one of the subjects was able to correctly identify a no-motion condition every time. For all the runs where there was no lateral-directional motion, pilots who were not flying felt some kind of motion (rotation, translation or both) 64% of the times. For the same condition (no-motion), the pilots who were flying reported a perception of motion in 86% of the trials.

IV. Discussion

The results of the analysis of variance for the motion perception (MP) and motion fidelity (MF) ratings are summarized in Table 4. It can be seen that platform sway motion had a significant effect in almost all cases. Platform yaw motion did not have any significant effect in the current study, but had a significant effect on motion fidelity rating in the experiment conducted in the NLR GFORCE facility in the study of Groen et. al.[11,12]. Roll motion had a significant effect on motion perception and a significant effect on motion fidelity when sway was absent. It can also be seen that the only factor that had a significant effect for pilots-flying was the simulator sway motion.

Table 4. Significance of platform sway (S), yaw (Y) and roll (R) on pilot-flying and pilot-not-flying motion perception ratings and motion fidelity ratings.

Effect	MP			MF		
	GFORCE	PNF	PF	GFORCE	PNF	PF
Sway	Sig.	Sig.	Sig.	-	Sig.	-
Roll	Sig.	Sig.	-	Sig.	-	-
Yaw	-	-	-	Sig.	-	-
S x Y	Sig.	-	Sig.	-	-	-
S x R	-	Sig.	-	-	Sig.	-
Y x R	-	-	-	-	-	-

The results of the analysis of variance for the subjective handling qualities (HQ) rating and pilot control activities are summarized in Table 5. Since there was no significant effect of platform motion on handling qualities ratings, factors that were marginally significant are shown abbreviated as 'M.S.'. The results in the table show that mainly platform sway is seen to have an effect on handling qualities ratings and pilot workload.

Table 5. Significance of platform sway (S), yaw (Y) and roll (R) on pilot-flying handling qualities ratings and control activity.

Effect	HQ	Pedal rate	Column rate	Wheel rate
Sway	M.S.	M.S.	M.S.	-
Roll	-	-	-	-
Yaw	-	-	-	-
S x Y	-	-	-	-
S x R	-	-	-	-
Y x R	M.S.	-	-	-

Although the results of pilots-not-flying are in most cases in agreement with the study performed by Groen et. al.[11,12], one major difference in the experimental design is worth noting. In the study done by Groen et. al.[11,12], all subjects were experiencing the exact same motion cues for the same motion condition. Since the subjects were actively flying the maneuvers in the present study, each subject was experiencing a different motion cue for the same motion condition. This is shown in Figure 14. The figure demonstrates pedal deflection time histories of the same motion condition for two different subjects. It can be seen that one subject performs the decrab maneuver in about 2 seconds, while the other one takes about 10 seconds to complete the maneuver. The difference in pilot aggressiveness shown in this figure will result in different accelerations and angular rates at the pilot's head. It is, however, assumed that since each subject was experiencing different motion conditions performed by only one other subject, pilot skills and aggressiveness did not have any significant impact on the subjective ratings.
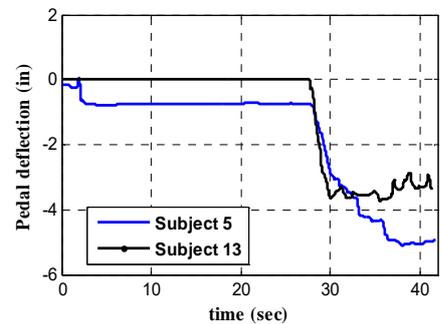
Figure 14. Measured pedal deflections of two different subjects in the same motion cueing configuration.

V. Conclusions

The effect of simulator translational and rotational motion on perceived motion fidelity, motion perception, pilot workload and pilot compensation was determined for a manual decrab maneuver of a twin-engine regional civil aircraft. The study found that simulator translational motion had a larger impact on perceived motion fidelity and motion perception than yaw motion. Handling qualities ratings also showed that the addition of simulator sway motion is preferred by pilots. This result was confirmed by investigating pilot pedal and column activities during the performed decrab maneuvers in the simulator. It was found that simulator sway reduced control activity and therefore pilot workload in both cases. The study also highlighted the importance of visual cues in motion perception. For cases where no lateral-directional motion cues were provided by the simulator and only visual cues were available, 86% of pilots-flying and 64% of pilots-not-flying perceived some kind of simulator motion.

The experiment, as presented in this paper, generally confirms the results of the experiment as conducted in the study by Groen et. al.[11,12]. The study shows that simulator motion has a positive effect on both perceived motion fidelity and performance during the simulation of a demanding lateral-directional maneuver such as a decrab. The results of the study will be further applied in conjunction with human perception modeling techniques to develop objective evaluation criteria for the optimisation of simulator motion cues.

Acknowledgments

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