Abstract. Competing aircraft and simulator manufacturers are currently incorporating dissimilar flight control systems into commercial aircraft and training equipment. In response to such industry developments, a recently emerging field of aviation training transfer research is examining the distinctiveness of conventional and alternate flight control systems and their underlying transfer relationships. This paper recounts a series of experiments where human skill acquisition in simulated flight was examined to identify differences between transfer effects facilitated by yoke and stick flight control systems. Flight naïve adult participants twice completed a sequence of visual approach to landing trials in a low fidelity fixed based synthetic flight trainer using either a yoke or a stick. Participants either utilised the same control mechanism throughout the study or participants converted between the alternate systems across experimental phases. Assessment phases were conducted one week apart with vertical deviations from a constant 3-degree glideslope being analysed. The collective research provides evidence of positive transfer of training in low fidelity flight training equipment and that a performance difference exists between the stick and the yoke. Results consistently revealed a lower rate of performance error resulted from use of the yoke compared to the stick.

1. INTRODUCTION
A series of research projects conducted by The University of Newcastle Human Factors Group have investigated various issues of training transfer including a performance-based analysis of the transfer characteristics of primary flight controls. Such research is in response to developments within the aviation industry where differing flight control systems are being integrated into commercial aircraft and training equipment - viz., a yoke and a stick. Examination of the distinctiveness of alternate flight control systems has been identified as a critical area of research and training [1],[2],[3] and is an area lacking in empirical guidance.

The current research follows traditional transfer assessment through an analysis of the degree to which prior learning is retained and conveyed to a second experimental situation. Transfer may be either positive or negative: Positive transfer occurs when prior knowledge aids task performance while negative transfer occurs when prior knowledge obstructs task performance. Experimental transfer analysis involves a two-phased process. The initial acquisition phase – where a baseline measure of performance is established – is followed by a transfer phase – where training effectiveness is assessed.

The vast majority of aviation training transfer studies are quasi-transfer by design, that is, they are conducted entirely in a synthetic environment and may involve participants alternating between different simulators or performing a modified task in the same simulated environment [4]. In contrast, flight-transfer studies assess the acquisition of skills in the synthetic environment and their degree of transfer to the operational environment. The quasi medium has been shown to produce a heightened form of transfer analysis [2] largely resulting from high levels of control over task elements, environmental conditions, and other potentially confounding variables. The vast majority of aviation training transfer studies have not specifically investigated performance differences between alternate flight control systems or have predominantly utilised a yoke flight control.

The theoretical basis of human learning provides insight into the acquisition of skills in humans and the issues surrounding transfer effects facilitated by alternate flight controls. Thorndike [5] proposed the law of identical elements, a theory of skill transfer based on the notion of similarity. According to the theory transfer will occur relative to the aggregate of common elements between two tasks. Positive transfer can be anticipated in experimental situations where there are higher numbers of shared components due to greater levels of similarity. This notion has been empirically upheld in the simulated flight-training domain [6]. The similarity premise continues through a theory of motor skill acquisition proposed by Schmidt [7]. According to the theory, generalised motor programs under which motor schemas are formed for certain movements guide motor behaviour. The application of motor schemas in highly similar circumstances results in an increase of speed and accuracy of movements and substantially contributes to positive transfer effects [7],[8].

Empirical investigations have provided extension and further clarification of the similarity principle. Research conducted by Lincoln [1] investigated the issue of similarity between primary and secondary (emergency) flight control systems on a transfer task. The study investigated the effect of transferring to
manual control systems that responsively differed to those systems on which training was received. The research identified the role of certain technical control characteristics over the transfer relationship and found the greater the similarity between the systems, the greater the ability to predict positive transfer effects. In addition, a study conducted by Holding [9] indicated that while positive transfer is expected in situations of maximal similarity between stimuli and responses, stimulus variation between tasks will not necessarily result in negative transfer. This finding has since been replicated [10] in an experiment assessing the requirements for transfer effectiveness of a synthetic training device, noting that stimulus variation may produce positive transfer effects.

The extensive use of low fidelity fixed based synthetic flight trainers in transfer research has provided numerous demonstrations of the ability of such devices to disclose transfer relationships and produce positive transfer effects [11],[12]. Furthermore, research indicates that higher fidelity training equipment is not independently sufficient to produce positive transfer effects [11],[12],[13],[14]. As such ‘ability to produce effective transfer’ has been identified as a critical factor in assessing simulator value [15].

This research assessed transfer of training across two experiments in which conditions varied according to either the flight control mechanism utilised throughout the study or their sequence of use across experimental phases. Transfer was examined in each study on an identical simulated approach to landing (ATL) task. The performance of participants was assessed on the ability to maintain a constant and steady glideslope angle (GSA) – the fixed vertical angle with respect to the runway which is customarily approximately 3-degrees for smaller aircraft – a critical factor in determining the success and safety of the landing [16].

The task was identical across the acquisition and transfer phases in Experiment 1. In accordance with the similarity principle [5],[7] positive transfer was expected for both groups. The lack of past research in this field generated the null hypothesis that no performance difference would exist between the yoke and stick on this particular task. Similarly, in Experiment 2 conditions remained invariant across the experimental phases for participants in the control groups. As such positive transfer was anticipated for these conditions again in accordance with the similarity principle [5],[7]. Alternatively, participants in the experimental groups for Experiment 2 alternated between the yoke and stick across the acquisition and transfer phases. Due to the similarity of the perceptual elements and the similarity of the motor task and given the experimental findings of [9],[10], positive transfer was also predicted in further accordance with the theoretical notions of similarity [5],[7]. The lack of empirical guidance in this domain generated the null hypothesis that on this particular task there would be no performance-based difference between the groups.

2. EXPERIMENT 1
The ability of flight naïve participants to successfully acquire and transfer the skills required to perform a simulated approach to landing task was examined to identify performance-based differences between yoke and stick flight control systems.

2.1 Method

2.1.1 Participants
Thirty-two flight naïve participants ranging in age from 18 to 54 years ($M = 22.91$ years; $SD = 8.21$ years) took part. Participants were recruited from staff and students at The University of Newcastle, Australia. No payment was received for participation.

2.1.2 Apparatus
A fixed based synthetic flight trainer, an Enhanced Novasim Flight Simulator (Novasim), was used for the experiment. The Novasim has the capacity to simulate several aircraft models. In this experiment a twin engine Piper PA-30 was selected. The Novasim interior resembles a fully instrumented cockpit and uses coloured real to life interactive graphics projected onto a 1.2m x 1.8m screen approximately 2.75m from the eye. The Novasim has the ability to record data across trials, and the capacity to be manoeuvred by two differing flight control mechanisms, a yoke and a stick. Inside the Novasim the yoke is conventionally located directly in front of the participant similar to the Boeing design; the stick is located on a left hand side extendible and retractable console, in a location similar to that of an Airbus design.

The University of Newcastle Human Factors Group produced a six-minute instructional video that supplied standardised instructions for all participants. The video provided basic information on flying and flight control operation, use of the Novasim, and task execution.

2.1.3 Procedure
Participants were randomly allocated to one of two experimental conditions according to flight control mechanism, each with an equal number of participants and an equal number of females and males per group. The task was identical for both groups with the exception of the control mechanism they were assigned for use throughout the experiment: either the yoke or the stick. Participants viewed the brief instructional video prior to performing the simulated ATL task during the initial stage of the transfer assessment. The acquisition phase consisted of performing 15 consecutive ATL trials in the Novasim. Each trial required the participant to maintain an optimum GSA.

Participants were not required to land the aircraft and all trials were terminated at 0.5 nautical miles (nm) from the runway. Participants returned one week later to complete the final stage of transfer assessment. The transfer phase consisted of a further 15 consecutive ATL trials in the Novasim. The control mechanism
used during the transfer phase was the same as the control mechanism used during the acquisition phase for all participants.

All trials were conducted with the same visual display and initial positioning for the ATL task. For each trial the aircraft was set at a distance of 2 nm from the runway at an approximate altitude of 650 feet, intercepting a 3-degree glideslope. Simulator parameters were set as follows: throttles were set to 2,100 revolutions per minute for both engines; attitude indicator was covered from participant's view; no cross wind; no turbulence; cloud base 30,000 feet; and optimal visibility conditions.

### 2.2 Results

Figure 1 shows the mean VGSE for all participants, on average, for both acquisition and transfer phases across trials. As shown there is a reduction in performance error from the acquisition phase to the transfer phase for both groups. There was a significant effect of phase $F(1, 28) = 12.116, p < 0.01$, indicating overall positive transfer across the phases. Preliminary analysis revealed the main effect of gender was not significant $F(1, 28) = 0.173, p > 0.05$. As such gender was not considered to be a source of variance. The interaction between phase and trial was not significant $F(14, 392) = 0.747, p > 0.05$. The interaction between phase and control was also not significant $F(1, 28) = 0.091, p > 0.05$. The effect of trial was not significant $F(14, 392) = 1.427, p > 0.05$. The interaction between trial and control was not significant $F(14, 392) = 0.626, p > 0.05$. The interaction between phase, trial, and control was also not significant $F(14, 392) = 0.662, p > 0.05$. However, the main effect of control was significant $F(1, 28) = 16.223, p < 0.01$, likely due to the consistently lower rate of error evident with the yoke compared to the stick as shown in Figure 1. Additional analysis was performed on the individual groups to further investigate the performance difference between the yoke and the stick.

### 2.2.1 Yoke Data Analysis

Performance was analysed according to mean VGSE per trial with a 2 x 2 x 15 (Gender x Phase x Trial) one between, two within, factorial analysis of variance (ANOVA). Analysis was conducted in SPSS Version 10 for Windows with a rejection rate of $p = 0.05$. A reduction in mean VGSE from the acquisition to the transfer phase is evident in Figure 1 for participants in the yoke condition. The effect of phase was significant $F(1, 14) = 11.634, p < 0.05$, signifying positive transfer effects with the yoke. The main effect of gender was not significant $F(1, 14) = 2.575, p > 0.05$, indicating gender was not a source of variance. The effect of trial was not significant $F(14, 196) = 1.631, p > 0.05$. The interaction between phase and trial was also not significant $F(14, 196) = 0.588, p > 0.05$. The effect of trial was not significant $F(1, 14) = 4.568, p < 0.05$, indicating positive transfer effects for the stick condition. The main effect of gender was not significant $F(1, 14) = 0.000, p > 0.05$, suggesting gender was not a source of variance. The effect of trial was not significant $F(14, 196) = 0.899, p > 0.05$. The interaction between phase and trial was also not significant $F(14, 196) = 0.730, p > 0.05$.

### 2.2.2 Stick Data Analysis

Performance was analysed according to mean VGSE per trial with a 2 x 2 x 15 (Gender x Phase x Trial) one between, two within, factorial analysis of variance (ANOVA). Analysis was conducted in SPSS Version 10 for Windows, with a rejection rate of $p = 0.05$. A reduction in mean VGSE from the acquisition to the transfer phase is evident in Figure 1 for participants in the yoke condition. The effect of phase was significant $F(1, 14) = 11.634, p < 0.05$, signifying positive transfer effects with the yoke. The main effect of gender was not significant $F(1, 14) = 2.575, p > 0.05$, indicating gender was not a source of variance. The effect of trial was not significant $F(14, 196) = 1.631, p > 0.05$. The interaction between phase and trial was also not significant $F(14, 196) = 0.588, p > 0.05$.

### 2.3 Discussion

The hypothesis that positive transfer would result in both conditions was supported. Preliminary analysis revealed overall positive transfer effects with participants on average executing the ATL task with greater accuracy during the transfer phase compared to the acquisition phase. Analysis of the individual groups also found positive transfer effects resulted independently in the yoke and stick conditions. According to the theoretical principles of similarity proposed by Thorndike [5], positive transfer is the result of high levels of similarity between training and transfer conditions. The task and conditions remained...
invariant across the experimental phases producing maximum similarity. The null hypothesis that no performance difference would exist between the yoke and stick conditions was rejected. A comparison of the mean error rates as shown in Figure 1 reveals a consistently lower rate of glideslope deviation where participants performed the task with the yoke compared to the stick. This indicates the yoke was the more effective mechanism for flight control on this particular task. Such a finding may have been influenced by the high levels of variance produced by the stick.

3. EXPERIMENT 2
Skill acquisition in simulated flight was examined to further identify performance-based differences between yoke and stick flight control systems. The performance of flight naïve participants was assessed according to their ability to successfully acquire and transfer the skills required to perform a simulated approach to landing task.

3.1 Method

3.1.1 Participants
Thirty-two participants were recruited from within The University of Newcastle, Australia, being either students or members of staff. Participants ranged in age from 18 to 46 years (M = 23.5 years; SD = 7.651 years). No financial incentives were offered for participation.

3.1.2 Apparatus and Procedure
The apparatus was the same as that described in Experiment 1. Participants were randomly allocated to one of four groups that predetermined the control mechanism they would be assigned for use during the acquisition and transfer phases. Participants either maintained the same control mechanism for use throughout the experiment (control groups) or they alternated between the yoke and the stick across the phases (experimental groups). The groups were Yoke-Yoke (Y-Y); Yoke-Stick (Y-S); Stick-Stick (S-S); and Stick-Yoke (S-Y). The task was identical to that described in Experiment 1 with the exception of the control mechanism for the experimental groups (Y-S and S-Y) where participants alternated between the yoke and the stick across the phases.

3.1.3 Performance Measurement and Data Analysis
Performance measurement followed the same process as that outlined in Experiment 1. Performance was analysed with a 4 x 2 x 15 (Group x Phase x Trial) one between, two within, factorial analysis of variance (ANOVA). Analysis was conducted in SPSS Version 10 for Windows with a rejection rate of $p = 0.05$.

3.2 Results
Figure 2 shows the mean VGSE for all groups, on average, for both the acquisition and transfer phases across trials. As shown there has been an improvement in performance across the experimental phases. The effect of phase was significant $F(1, 24) = 8.507, p < .05$, indicating overall positive transfer. The effect of trial was not significant $F(14, 11) = 1.522, p > .05$. However, the interaction between phase and trial was significant $F(14, 11) = 6.246, p < .05$ as a consequence of improved performance across trials during the acquisition phase as shown in Figure 2.
improvement across trials during the acquisition phase. The effect of trial for both the Y-Y and S-S conditions were not significant. The only significant trial by phase interaction effect was found in the S-Y condition $F(14, 98) = 2.879, p < .05$, due to the improvement across trials during the acquisition phase and the reduction in error across the phases evident in Figure 4.

![Figure 3](image)

**Figure 3:** Mean vertical glideslope error for acquisition and transfer phases by group

![Figure 4](image)

**Figure 4:** Mean vertical glideslope error across trials for acquisition and transfer phases for each group

### 3.3 Discussion

The hypothesis that positive transfer would occur in each of the four conditions was not supported. Positive transfer was anticipated in accordance with the similarity principle [5],[7], due to the high levels of similarity between training and transfer conditions. Overall results reveal positive transfer effects with participants, on average, executing the ATL task with greater proficiency in maintaining a constant 3-degree GSA during the transfer phase compared to the acquisition phase. However, independent groups analysis revealed positive transfer effects in only the Y-Y condition where the yoke flight control was used for both phases of the experiment. Positive transfer effects did not occur for any other condition. In fact, no other group attained a transfer effect of significant magnitude in either direction. However, there was a reduction in performance error across the phases for participants in the S-S and S-Y conditions and an increase in performance error across the phases for participants in the Y-S group as shown in Figure 3.

The null hypothesis that no performance-based difference would exist between the groups was rejected. Analysis revealed a significant difference between the S-S and the Y-S conditions. The overall highest rate of glideslope deviation occurred in the S-S group where the stick flight control was used for both phases of the experiment. Interestingly, the overall lowest rate of performance error occurred in the Y-S condition irrespective of the increase in error across the experimental phases. A comparison of the mean error rates as shown in Figure 3 reveals this effect was contributed to by the low rate of performance error during the acquisition phase where trials were completed with the yoke and the comparatively low rate of error during the transfer phase where trials were completed with the stick. Participants in the Y-S condition were the only group to be introduced to the stick for the first time during the transfer phase. Notably, this group appears to have a lower mean VGSE on initial use of the stick during early trials in the transfer phase, as compared to the early trials completed by the two groups who were introduced to the stick during the acquisition phase (S-S and S-Y), as shown in Figure 4. This suggests the attainment of some level of transferable skill during the acquisition phase for participants in the Y-S condition. It appears that the ATL task performed with the stick was initially a more difficult skill to acquire in this particular context. Furthermore, on average trials performed with the yoke produced a consistently lower rate of glideslope deviation compared to the stick as shown in Figures 3 and 4.

### 4. General Discussion

The research reported here provides evidence of positive transfer of training and reveals a performance-based difference between yoke and stick flight control systems on a simulated approach to landing task. The findings provide some additional insight into the training effectiveness and underlying transfer relationships of alternate flight control systems. Collective results reveal positive transfer effects with participants on average performing the simulated ATL task with a lesser rate of vertical glideslope deviation in the transfer phase compared to the acquisition phase for both yoke and stick flight control systems. Independent groups analysis further revealed positive transfer effects for both yoke and stick conditions in Experiment 1 and for the yoke-yoke condition in Experiment 2. Such a finding extends the evidence of positive transfer effects being disclosed in low fidelity synthetic flight training devices [11],[12],[13],[14].

According to the law of identical elements [5], positive transfer is the result of high levels of similarity between tasks and across experimental conditions. Motor skills theory [7] further states that positive transfer is the result of constancy in sequence and timing of movement, while stimulus variation between tasks has been shown to produce positive transfer effects [9],[10]. Conditions for individual groups during Experiment 1 were identical across acquisition and transfer phases. Throughout Experiment 2 the visual stimuli remained largely invariant across the experimental phases for all groups while the tactile
stimuli and the kinaesthetic experience varied to some extent between the phases in the conversion conditions. While similar, the control mechanisms were not identical in their sensitivity. It is probable this disparity has contributed to the outcomes of Experiment 2 – significant transfer effects found in only the Y-Y condition – and the performance-based difference evident between the yoke and stick in both Experiment 1 and Experiment 2. Collective results disclose a consistently lower rate of performance error resulted from the use of the yoke compared to the stick suggesting the yoke to be the more effective mechanism for flight control in this instance. Furthermore, conditions where participants used the stick consistently across the experimental phases resulted in the highest rate of performance error in both studies. Such findings may be the result of differing levels of sensitivity between the two systems. The stick was a more sensitive system than the yoke: the yoke required larger arm movements while the stick required smaller wrist movements to produce the same desired response. The results from Experiment 2 would indicate it was easier to transfer to the less sensitive yoke than it was to transfer to the more sensitive stick, demonstrating the need for further research into this area. The higher levels of performance error evident in conditions where the stick was utilised were also potentially influenced by the required use of the participant’s left hand for system operation. Experimental evidence suggests use of the non-preferred hand to hold a significant effect over transfer magnitude and direction [17]. Further investigation is required to identify the extent of the effect of handedness on performing similar flight tasks.

While there is evidence to suggest that learning has occurred across the phases, there is no available information to identify which specific skill was developed during the acquisition phase. Given that all participants in all groups were presented with the same visual information which remained relatively invariant from the acquisition phase to the transfer phase, it is possible that it was perceptual information which was learned leading to transfer effects rather than any motor schema [7]. It is also possible that participants have acquired knowledge about the particular performance characteristics of the simulated aircraft. These notions would be consistent with Thorndike's [5] law of identical elements.

There is an initial need for the study to be replicated due to the limited empirical guidance in the domain of comparative flight control effectiveness and control conversion [1],[2],[3]. Continued research is also required in search of support of the current findings since the quasi-transfer experimental design holds limitations in its application to actual flight [4],[18],[19]. Consequently, it would be beneficial to be able to investigate quasi-transfer and flight-transfer relationships of this nature in Boeing and Airbus type specific simulators and to compare the performance of flight naïve participants, student pilots, and experienced pilots to further advance integrative training strategies.

REFERENCES

transfer effects of scene detail and visual augmentation in landing training. *International Journal of Aviation Psychology*, 7, 149-169.