AIR COMBAT TRAINING – THE EFFECTIVENESS OF MULTI-PLAYER SIMULATION

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ABSTRACT

This paper describes a transfer of training trial conducted on a multi-player desktop simulator used for air combat training and provides an analysis of the interim results. The availability of networked desktop simulation technology means that team training in air combat tactics is now achievable at low cost. The critical test of the effectiveness of such a simulation system is the transfer of training to the aircraft. Whilst previous studies have demonstrated performance improvement in simulator exercises in air combat, up until now, transfer of training to the aircraft has not been demonstrated. A trial has been conducted to establish if such transfer occurs from training in pairs tactics conducted on the JOUST multi-player, desk-top simulation system to the airborne environment. The interim results indicate that transfer of training has been demonstrated. Students trained on the new system exhibited superior performance on a range of behavioural indicators, including communications and tactical leadership.

BIOGRAPHIES

Flight Lieutenant John Huddlestone is a training specialist in the Royal Air Force. He is currently employed as the Chief Ground Instructor on the Operational Conversion Flight of No 33 Squadron, which operates the Puma helicopter. In previous tours he has designed training for TriStar aircrew, developed multimedia CBT and lectured in software engineering. He holds a Masters degree in computing science from Imperial College, London, and is a PhD student in the Human Factors Group of the College of Aeronautics at Cranfield University.

Don Harris is the Senior Research Fellow in Human Factors Engineering in the Human Factors Group at the College of Aeronautics, Cranfield University. His principle teaching and research interests lie in the design and evaluation of flight deck control and display systems, accident investigation and analysis, and flight simulation and training. Until very recently he was also an aircraft accident investigator (specialising in human factors) on call to the British Army Division of Army Aviation. He sits on the editorial boards of the International Journal of Cognitive Ergonomics and the International Journal of Cognition, Technology and Work.

Flight Lieutenant Martin Tinworth is an instructor on No 56 Squadron, the Tornado F3 Operational Conversion Unit. His current tour follows operational tours on the F4 Phantom in Germany and the F3 Tornado in the UK, where he was involved in the introduction of JTIDS into service. In his current post he teaches on all flying phases of OCU training, as well as having responsibility for all simulator and ground training. As JOUST project officer, he has responsibility for the introduction of the JOUST multi-player desktop simulation system into the OCU course.

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INTRODUCTION

The final phase of training for RAF Tornado F3 crews on the Operational Conversion Unit (OCU) focuses on pairs tactics. This is a highly demanding phase, during which effective and timely communication between crews is paramount. In the past, the technology had not been available for these skills to be practised effectively on the ground. Now, with the introduction of a multi-player, desktop simulation system, the teamwork and communications skills required for pairs work can be fully rehearsed before the flying sorties. A transfer of training trial was conducted to determine the effectiveness of this new system, with positive results.

Background

Students attending the Tornado F3 Operational Conversion Unit undertake 18 weeks of demanding training. During the final phase of the course (the Pairs Phase) students learn how to operate as crews of a pair of aircraft fighting multiple targets. This is particularly challenging, as a high degree of teamwork is required between the crews in order for them to operate effectively. Clear, precise and timely communication is fundamental to success. The OCU staff have long recognised that effective training in the necessary communication and teamwork skills has been difficult to achieve on the ground due to the limitations of the training devices previously available. The principle device used, the Tornado Air Intercept Trainer (TAIT), only took one crew, had no visual system and the flight model was limited. It was also missing a key sensor, the Radar Homing and Warning Receiver (RHWR), which is the principle sensor used for threat evaluation. Consequently, fundamental aspects of pairs training could only be conducted in the air. The JOUST multi-player, networked, desktop simulation system, which was already in squadron use, was identified as potential replacement for the TAIT system. It had a visual system, an RHWR, and was designed for use by multiple crews.

JOUST

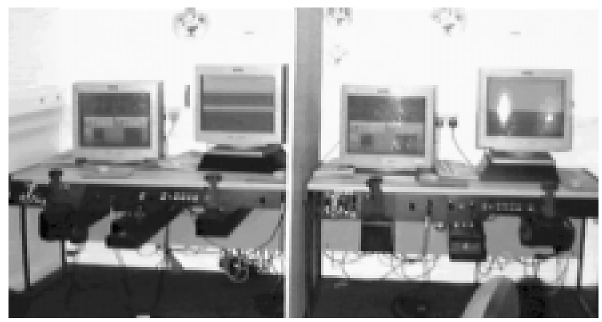

Figure 1. JOUST player stations

The JOUST simulation system was developed by the Defence Evaluation and Research Agency (DERA) at Farnborough, England. The name JOUST is not an acronym, it is derived from the name of the mediaeval form of combat training, jousting. The system consists of a number of player-stations with high functional fidelity, which are networked together. In the system used by the OCU at RAF Coningsby, two of the player stations are configured to represent the Tornado F3 (see Figure 1). There are two screens and two sets of controls. The right-hand screen provides the visual picture with a HUD superimposed on it. The field of view is limited to 72° in elevation and 90° in azimuth. The pilot's controls, including throttle and stick are in front of this screen. The left-hand screen provides the navigator's radar displays and the RHWR. In front of it are the navigators radar hand controller and switches. Chaff and flare switches are available to both pilot and navigator. In the actual aircraft the pilot has his own RHWR display and a repeat display of the navigator's radar. In the JOUST he has to look at the navigator's screen, but this is within view.

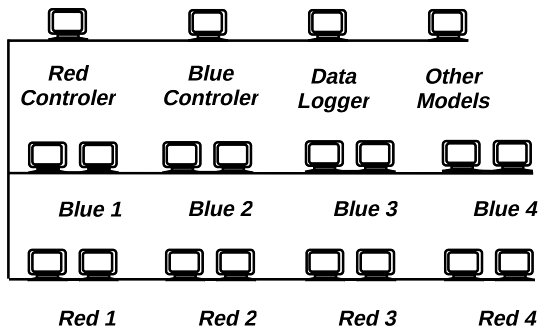

Figure 2. JOUST network

The overall system consists of eight aircraft stations, two ground controller stations, a station running additional models such as missiles, and a data logger (see Figure 2). The ground controller stations provide a replay facility using data stored by the data logger. An engagement can be replayed and viewed in three dimensions for debriefing purposes. Missile models allow missile fly-outs to be viewed with missile success being determined statistically based on kill probabilities.

Methodological Considerations

The fundamental principle underlying the use of simulators in training is that of transfer of training. That is to say that skills learnt in the simulator can be transferred to the target environment. This is clearly demonstrated in the use of zero flight time training for crews of commercial aircraft, whereby they are taught to operate the aircraft entirely in the simulator before flying the aircraft for the first time operationally. This would be described as positive transfer of training. If training in the simulator results in degraded performance in the target system, then negative transfer would be said to have occurred.

Caro (1977) identified a range of study design models for determining the effectiveness of simulators. Bell and Waag (1998) categorised these into utility evaluations, in-simulator learning models and transfer of training models. Utility evaluations are based on subjective opinions of the value of the simulator. Salas, Bowers and Rhodenizer (1998) point out that positive user opinion about a simulator, frequently based on the level of fidelity, does not necessarily translate to effective learning having taken place. However they recognise that user acceptance of a simulator is an important condition for its successful use. In-simulator learning models rely on comparing student performance in the simulator before and after a period of simulator training. An improvement in performance after training would suggest that use of the simulator has produced a positive training effect. Whilst such improvement in performance is a necessary condition for simulator effectiveness, it does not prove that transfer will occur. The acid test of any simulator is a transfer of training in which student performance in the target system is compared for two groups of students, one of which has trained in the simulator and the other of which has not. Superior performance in the target system from the group which has undergone simulator training would suggest that transfer has occurred.

The USAF has conducted the majority of the research into the effectiveness of simulation for air combat. Waag (1991) conducted a comprehensive survey of research completed in the field. In five studies of transfer of training, positive transfer of training results have been observed for students who had previously undertaken training in a simulator for air-to-surface weapon delivery. Positive transfer of training results were also reported in two trials conducted with A10 pilots who participated in Red Flag and Green Flag exercises after simulator training. Significantly, negative transfer was observed for pilots who flew aircraft configured differently from the simulator.

Two studies conducted on the McDonnell Douglas multi-ship training facility have yielded positive simulator performance improvement results. Similar results were also obtained on a later study reported by Waag and Bell (1994) conducted on the USAF Armstrong Laboratories multi-ship facility which, like the McDonnell Douglas facility, combines full mission simulators with other simulation components. Transfer of training studies have yet to be conducted. In a recent survey of research, Bell and Waag (1998) report that no transfer of training results have been obtained for two verses many air-to-air combat. The resource requirements in terms of aircraft and crews required for a transfer of training trial on a significant scale in this area is, no doubt, a contributory factor.

The introduction of JOUST into the F3 OCU training system provided an ideal opportunity for a transfer of training trial to be undertaken, as resources for the necessary flying sorties were already allocated. The system was to be used in place of the TAIT during the pairs phase of the course where the student are taught 2v1 and 2v2 tactics. JOUST would replace the TAIT for the ground training sessions undertaken before each flying sortie. The OCU staff had undertaken a utility evaluation of JOUST and considered that it would be suitable for use subject to modification. In their original form, the JOUST player stations were configured for single seat use with generic displays. A modification programme was instigated to configure the stations such that they were representative of the Tornado F3 with pilot and navigator stations and appropriate displays and controls as described earlier. Once the system was introduced it would have been impractical to split small courses into two groups to have one group trained on JOUST with a control group trained on the TAIT. Therefore, control data werecollected from students trained on the TAIT whilst the JOUST was being modified. Experimental data would then be collected on students trained on JOUST once it was introduced. This trial structure conforms to the Pre-Existing Control Transfer Model outlined by Caro (1977).

METHOD

Two groups of students were assessed on their performance in the air during the Radar to Visual Pairs Phase of their Tornado F3 OCU course. This phase consisted of 6 flying sorties. A one-hour ground training session preceded each of the first 4 sorties. The first group, the control sample, received ground training in the TAIT. The second group, the experimental sample, received ground training in the JOUST. The performance of the groups was then compared.

Sample Description

The control sample consisted of 16 pilots and 8 navigators. Of these, 3 of the pilots and 3 of the navigators had previous experience of air defence. At the time of writing, the experimental data has been collected for 8 pilots and 7 navigators. Three of the pilots, but none of the navigators had previous air defence experience. Experimental data gathering is continuing.

Sortie Descriptions

Each sortie consisted of a series of practise intercepts (PIs) following a radar to visual profile. The sorties could be characterised by the number of opposing aircraft, or ‘bandits’, the height level at which the sortie was conducted and the weapon range of the bandits (see Table 1).

Sortie	Bandits	Level	Weapon Range
PR3	1	Medium	Medium
PR4	1	Low	Short
PR5	2	Low	Short
PR6	2	Medium	Short
PR7	2	Medium	Medium
PR8	2	All	Medium

Table 1. Sortie descriptions

The first 2 sorties were flown against a single bandit, allowing the students to focus on pairs procedures rather than the issues of fighting acomplex target. The transition to 2 bandits was a significant step up in complexity.

The level at which the sorties were flown was also significant. At low level, the students were confronted with the physical danger of carrying out aggressive manoeuvres in close proximity to the ground. This difficulty was counterbalanced by the relative ease of the fight being 2-dimensional, the aircraft fighting in a narrow height band. At medium level, the danger of ground proximity was removed but the fight itself was inherently much more complex, as it was executed in 3-dimensions with height differences being exploited. The 2v2 sorties at medium level were considered to be more complex and were therefore sequenced after the 2v2 low level sortie.

The range of the bandits’ weapons was the final factor. The students’ aircraft were equipped with short-range, infra-red guided missiles and medium-range, semi-active, radar-guided missiles. The bandits in sorties PR4 – PR6 were only equipped with short-range, infra-red guided missiles. Therefore, in these sorties, the students had the tactical advantage at the start of the sortie. For sorties PR3, PR7 and PR8 the bandits had a similar but slightly inferior weapons fit to the students. This meant that the students could be pushed into a defensive posture much earlier in the sortie, as they would only have a tactical advantage in weapon range if they maximised weapon performance by use of aircraft height and speed.

Conduct of the Sorties

During this phase of the course the students worked in groups of two, a pilot being teamed with a navigator. During ground training the students worked together as a crew. In the flying sorties, one student flew in each aircraft of a pair, the student pilot being crewed with a staff navigator and the student navigator being crewed with a staff pilot.

Sortie Assessment

Students' performance in the air had to be assessed in order to establish if transfer of training to the airborne environment had taken place.

Types of Measure. Previous studies have used instrumented range data and instructor ratings to measure student performance. On the F3 OCU, student performance was measured by a combination of instructor assessment in the air and post sortie evaluation of cockpit videos. The videos provided recordings of cockpit displays, HUD camera pictures and audio from the intercom and radios. The instructors were all trained to evaluate the validity of the weapons shots from the videos. Since this mechanism already existed for evaluating key process elements, such as communications, and product in terms of shot validity, instructor rating of student performance was selected as the measurement technique.

Selection of Behavioural Indicators. To develop a suitable measurement tool it was necessary to identify critical behavioural indicators of a student's ability to successfully undertake pairs operations. A task analysis of BVR intercepts with the F-15C had already been completed by Houk, Whitaker and Kendall (1993). This analysis identified the types of decisions that were made, the information required to make these decisions, the actions required for gathering it, and the actions taken in response to these decisions. In a subsequent study by Waag and Houk (1994), these results were further analysed to produce 24 behavioural indicators observable in day-to-day squadron training activities. Waag and Bell (1994) used these indicators successfully as assessment criteria for instructor ratings of student performance during their investigation of interactive air combat simulation. Therefore, this list was used as the start point for the development of measurement tools for the study. The OCU JOUST Project Officers were the nominated subject matter experts (SMEs) for this development. They identified communications as the most significant area with threat assessment, decision-making and visual weapon employment and also being of importance. The following nine behavioural indicators were selected:

BVR Communications
Visual Communications/Co-ordination
RHWR Awareness
Chaff and Flare Employment
BVR Weapons Employment
Visual Weapons Employment
Tactical Awareness
Defensive Considerations
Tactical Leadership

These indicators were then reviewed and agreed by a cross section of instructors on the OCU.

Development of a Ratings Scale. Once the behavioural indicators had been defined a ratings scale had to be devised. As OCU instructors have a particularly high workload, running up to 3 training events per day, the major constraint on any ratings scale was that it had to be quick to administer. Each item could be rated on a binary scale, with a tick for acceptable performance, or a graduated scale could be used. A graduated scale was favoured, as it would provide greater sensitivity. The OCU already employed a seven point rating scale on its sortie assessment forms for the behavioural indicators already in use. A score below the mid-point of the scale represented unsatisfactory performance. Since this scale was clearly defined and well understood, it was adopted for the study. The new behavioural indicators were included on the standard sortie assessment forms.

Conduct of Sortie Assessment

At the end of each PI during a sortie, each staff member debriefed the student with whom he was crewed on the key learning points. At the end of each sortie all of the F3 crews participating met for a full debrief. Each participant had the opportunity to contribute to the discussion on an equal footing. During the debrief, the staff ran and evaluated the cockpit videos from each aircraft. After the debrief was completed, each member of staff completed a sortie assessment form on his student. Narrative comments on significant aspects of the sortie were also made. An overall sortie score was also awarded using the same numerical scale. The cockpit videos were archived for later review by an independent panel of instructors.

RESULTS

Data Description

A total of 116 sortie reports were collected for the TAIT group of 24 students. Whilst data collection for the JOUST group was ongoing, 84 reports had been collected for the group of 15 students at the time of writing. This was deemed sufficient for an initial evaluation to be conducted. The distribution of reports across sorties was checked (see Table 2).

Sortie	Number of reports received	
	TAIT Group (max 24)	**JOUST Group (max 15)**
PR3	14	14
PR4	21	14
PR5	22	15
PR6	18	14
PR7	23	13
PR8	18	12
Total	**116**	**84**

Table 2. Reports received per sortie

Ideally, 24 reports would have been received for each sortie undertaken by the TAIT group of 24 students. In practice, copies of reports were not always available, but an average of 20 reports were received for each of the 6 sorties. Fewer logistical problems were experienced with the JOUST group of 15 students, with an average of 14 reports being received per sortie.

Data Evaluation

At the end of each sortie, the students had been scored on the behavioural indicators described previously. Scores below the midpoint of the rating scale reflected unsatisfactory performance and were regarded as failure scores. In any high quality training system the instructors strive to enable the students to achieve their maximum potential. However, the bottom line is that students should achieve a satisfactory standard in all areas of performance. The data analysis is based on comparing the number of failure scores for each of the groups in each performance area. As there were different numbers of students in each group, the numbers of failure scores are expressed as percentages. If 5 out of 20 scored 4 or less on an item, this is expressed as a percentage failure score, or failure rate of 25%.

Failure Scores Per Sortie

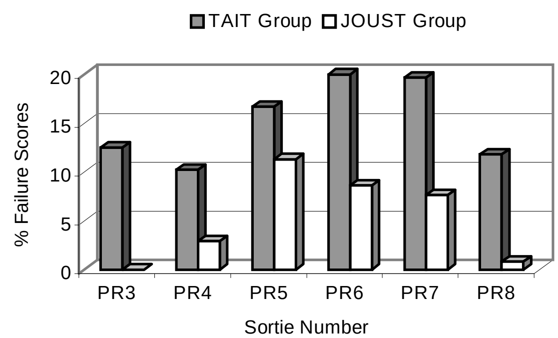

Figure 3. Total % failure scores per sortie

The percentages of failure scores per sortie were calculated (see Figure 3) to get an overall impression of how students performed in each sortie. Considering the TAIT group first of all, it can be seen that failure rates for sorties PR3 and PR4 are close to 10%. These are the 2v1 sorties. The failure rate then increases sharply at sortie PR5 and reaches a maximum for sorties PR6 and PR7. Improvement is seen at PR8 with the level reducing to 12%. Sortie PR5 was the first 2v2 sortie and represented a step change in difficulty. The difficulty level increased further at PR6 as it was conducted at medium level, making the fight 3-dimensional. At PR7, the added complication of a semi-active missile threat was introduced. This was considered by the staff to be the most demanding sortie. At PR8 the only additional complication was that the height band of the threat was not known, it could have been at low or medium level. Overall, the pattern of failure scores is consistent with the difficulty of the sorties. The pattern of failure scores for the JOUST group is similar but much reduced in level. Few failure scores occurred at PR3 or PR4. The step change at PR5 is marked, but the level of failure scores is only 11% compared with 16% for the TAIT group. At PR8 only 1% of scores were 4 or below.

These figures suggest that the students trained on JOUST have performed significantly better than the students trained on the TAIT. However, student performance in each of the individual areas assessed was evaluated to determine the nature of the improvement.

Failure Rate by Performance Indicator

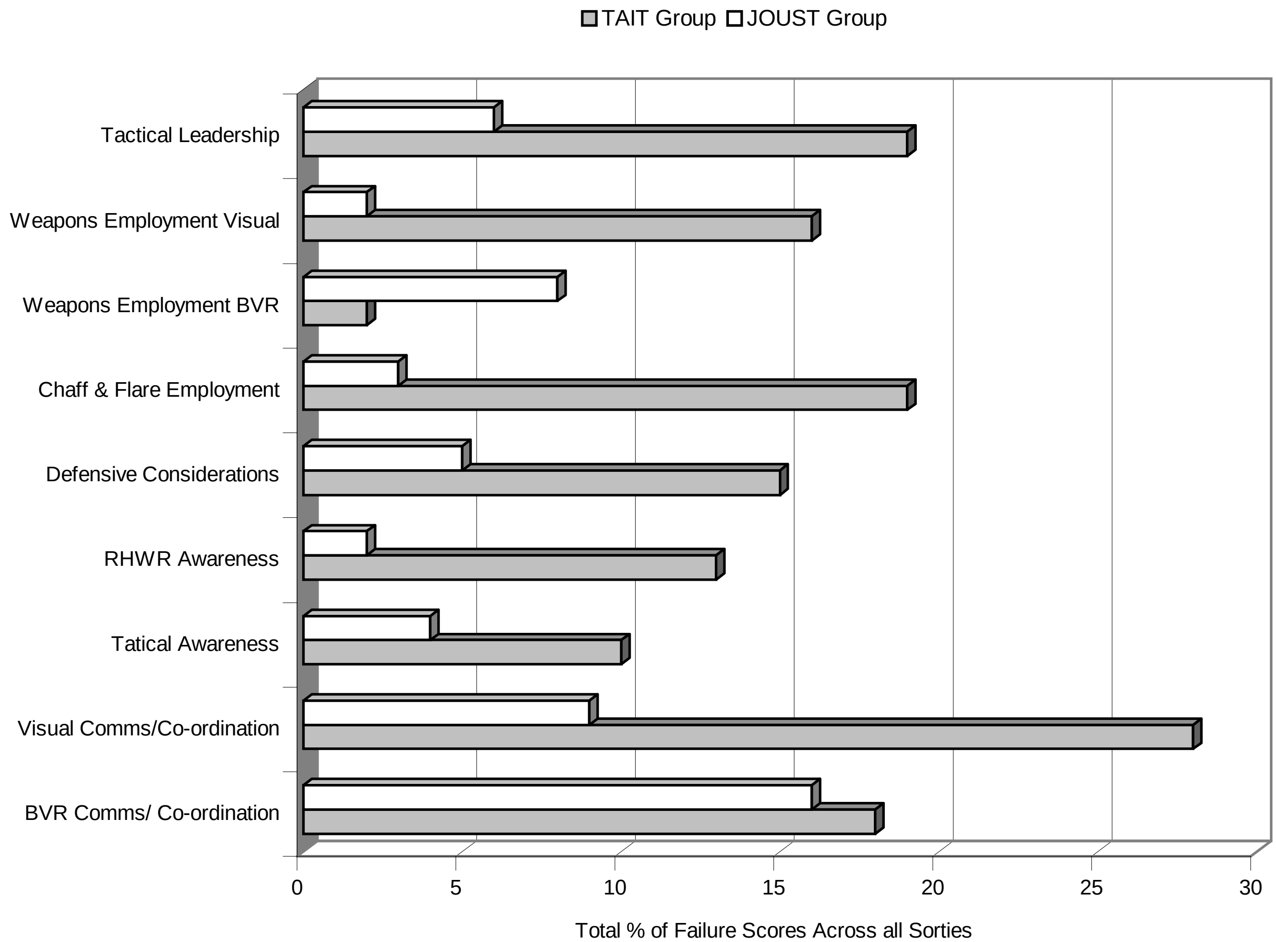

Figure 4. Total % failure scores across all sorties for each behavioural indicator

An overview of the areas in which the improvements in performance occurred was provided by calculating the total percentage of failure scores for each behavioural indicator across all of the sorties (see Figure 4). It can be seen that there has been a significant reduction in failure scores for the JOUST group for most of the indicators, with the exception of BVR communications and co-ordination and BVR weapons employment. Each behavioural indicator is considered in detail.

BVR Communications. For this indicator, it was found that there was little difference in performance between the TAIT group and the JOUST group in each of the sorties. Although the TAIT had severe limitations for pairs work, it was relatively simple for the instructors to provide realistic communications input from a second aircraft. Consequently, little improvement in training value was expected from introducing JOUST. The results would appear to support this hypothesis.

Visual Communications and Co-ordination. Visual communication and co-ordination was scored for the pilots alone as it was a pilot task. This was the by far the worst performance area for the TAIT group, with failure rates in the region of 35%- 40% for sorties PR5 to PR7. The failure rates for the JOUST group were markedly lower, with no failures at PR7 at all. The JOUST group had the advantage in ground training as the visual phase of each intercept could be practised as the JOUST had a visual system. This was not possible in the TAIT. It would seem reasonable to infer that a positive ground training effect was being transferred to the air for the JOUST group.

RHWR Awareness. The TAIT group had failure rates in the region of 10 – 20 % across all of the sorties. By comparison, the JOUST group had failure rates of 7% for sorties PR5 and PR6 and zero elsewhere. As there was an RHWR in the JOUST but not the TAIT, it would seem likely that for the JOUST group, practice on the ground has transferred to the air.

Chaff and Flare Employment. One of the most marked improvements in performance was noted for chaff and flare employment. This improvement was focussed on sortie PR7 (see Figure 5).

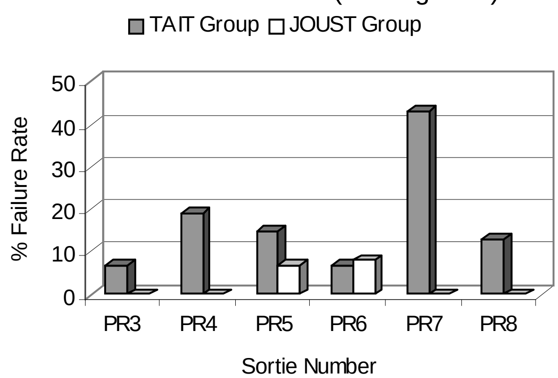

Figure 5. % failure rate per sortie for chaff and flare employment.

The failure rate for the TAIT group on PR7 was over 40%, whereas the entire JOUST group achieved an acceptable score. The significant point about PR7 was that it was the first occasion when students were likely to have been forced defensive BVR as a pair. In that situation, the appropriate defensive tactics would require the use of chaff to counter a radar guided missile threat. The TAIT group had no opportunity to practise on the ground as the TAIT did not have a chaff facility. Students were able to practise this in the JOUST. The marked difference in scores would suggest that the training on the ground transferred to the air.

BVR Weapons Employment. BVR weapons employment was the only area in which the JOUST group performed less well than the TAIT group. As there was nothing inherently lacking in the JOUST system which would have prevented this skill being practised, it is thought that simply less attention was being focussed on this item as time was devoted to other areas of performance. The TAIT group had greater opportunity to focus on BVR weapons employment since there were fewer skills, which they could practise, in the more restricted environment of the TAIT. This needs further investigation.

Visual Weapons Employment. A significant improvement in student performance was observed for visual weapons employment (see Figure 6).

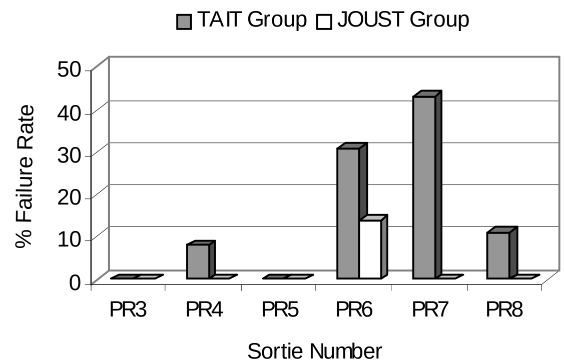

Figure 6. % failure rate per sortie for visual weapons employment.

The TAIT group had a failure rate of 30% and 40% for sorties PR6 and PR7 respectively. They had no opportunity for practice on the ground, due to the lack of a visual system on the TAIT. The very low failure rates for the JOUST group would suggest that the opportunity to rehearse this skill on the ground was beneficial and the training effect was transferred to the air.

Defensive Considerations. In the area of defensive considerations, the students were being scored on their ability to make appropriate defensive decisions based on their evaluation of threat information. This involved assessing the status of their own weapons and the targets' weapons, and target manoeuvre. As the RHWR was the principle sensor for providing threat information, students using the TAIT (which had no RHWR) were at a disadvantage, since they did not have all the appropriate information available to practise this skill on the ground. In the relatively complex threat environment of the 2v2 sorties the TAIT group had failure rates in the region of 20% compared with failure rates of only 5% for the JOUST group. The SME's view of this improvement was that the students had greater mental capacity available during the sorties, as they had previously had the opportunity to practise the component tasks on the ground.

Tactical Awareness. In the area of tactical awareness, students were being assessed on their ability to make sound, timely and aggressive decisions in prosecuting the fight. Effective decisions would only be made if the students had good situational awareness built from correct sensor interpretation and effective communication within the pair. The TAIT group was found to have particular difficulty in sorties PR3 and PR6 with failure rates of 21% and 17% respectively. The JOUST group had a zero failure rate in these sorties. The SME's view was that the argument concerning capacity put forward for defensive considerations also applied to this item.

Tactical Leadership.

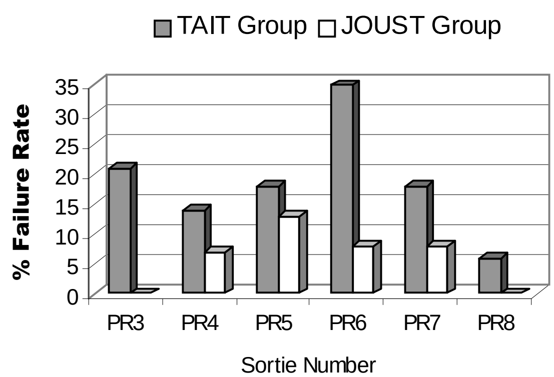

Figure 7 % failure rate per sortie for tactical leadership.

Tactical leadership is concerned with making tactical decisions for the formation and communicating them in an effective and timely manner. It is a high-order activity dependent on good situational awareness of both aircraft in the formation and relies upon all of the performance areas previously discussed. Once again, cognitive capacity is a key issue. The TAIT group experienced difficulty across all of the sorties, notably in PR6 where they were confronted by two bandits in a 3-dimensional fight (see Figure 7). The JOUST group experienced much less difficulty. It would appear that the overall improvement in performance across the range of performance areas considered has given the students more capacity to make effective decisions in a complex environment.

Instructor Observations

A number of observations made by the instructors support the analysis presented. Firstly, they noted that much more time was needed to fully debrief a JOUST session compared with a TAIT session because many more learning points were brought out. They also commented on the apparent increase in capacity demonstrated by the JOUST group. One example given was that pilot students were giving considerably better visual commentary and were also able to manoeuvre the aircraft at the same time as talking. One average student was credited as giving visual commentary at PR3 of the same standard as a staff demonstration by an SME independently reviewing a sortie video. This sort of observation is very indicative of students having more mental capacity available. They could carry out two tasks simultaneously. Before, when the communication task was so overwhelming, they had no spare capacity available to manoeuvre the aircraft. Staff response to the use of JOUST has been very positive.

DISCUSSION

The interim trial results demonstrate robustly that transfer of training to the air has taken place from a multiplayer desktop simulator used for 2v2 air combat training.

Previous studies have shown positive simulator performance improvement results for multi-player air combat training and are complimented by positive aircrew opinion about the value of simulator training in this area. Positive transfer of training has been demonstrated for air to surface combat training. We would strongly support the view that multi-player simulation has a significant part to play in the training of crews for many verses many air combat.

Bell and Waag (1998) recommend that flying sorties for transfer of training trials for air combat should be flown on an instrumented range so that objective performance data can be collected. We would agree that this is the most effective way of collecting performance data. However, range data gives no information about the key processes employed by the crews in achieving the observed performance. We would also contend that instructor ratings of performance are an essential tool in evaluating overall performance. After all, if the desired product is not produced, it is likely that it is the processes that are at fault which need to be improved. We have shown that instructor ratings can be used effectively for such process assessment, provided appropriate behavioural indicators are used and that a sufficiently sensitive rating scale is employed.

The place for learning is on the ground. The opportunity for practice is in the air. This study has shown that effective learning for multi-ship air combat can be achieved on the ground with simulation.

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