

## Air Combat Student Performance Modelling Using Grounded Theory Techniques

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### ABSTRACT

This paper describes the use of grounded theory techniques to develop a performance model for fighter crews undergoing initial training in pairs combat techniques on the Tornado F3 Operational Conversion Unit (OCU). The work was undertaken as part of a study to evaluate the training effectiveness of the JOUST low-fidelity, multi-player simulator system used for pairs air combat training. The OCU instructors considered that students performed poorly in communications related aspects of pairs combat, and attributed this to the fact that the available synthetic training aids only took a single crew. They had identified the JOUST system as being a more appropriate training device.

The empirical evidence, in the form of archived narrative reports of past student performance in the pairs phase, was investigated in order to develop a student performance model, identifying the essential aspects of performance upon which the instructors were focused. A total of 46 reports completed by an equal mix of pilot and navigator instructors (80% of the instructor population) were analysed to provide 200 performance statements. The performance model was developed through successive application of open, axial and selective coding of these statements. Grounded theory technique was selected for evaluating this qualitative data as it provided a rigorous analytical procedure, and it facilitated the development of a model of student performance by analysis independent of input from the subject matter experts, namely the instructors whose opinions were to be validated. The model that was developed was found to support the anecdotal evidence from the instructors on students' communications problems, and was consistent with published models of situational awareness in air combat.

### ABOUT THE AUTHORS

**Squadron Leader John Huddleston** is a training specialist in the Royal Air Force. He is currently employed as an IT project manager for Training Management Information Systems. His main professional interests are in the development of flying training and the use of simulation in training. Previously he has held the post of Chief Ground Instructor on the Operational Conversion Flight of No 33 Squadron, which operates the Puma helicopter and has designed training for TriStar aircrew. He has also developed multimedia CBT and lectured in software engineering. He is a professional member of the British Computer Society and holds a Masters degree in computing science from Imperial College, London, and a PhD in Applied Psychology from Cranfield University. His pastimes include fixed and rotary wing flying.

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## INTRODUCTION

Grounded theory, as described by Glasser and Strauss (1967), provides a rigorous, structured method for analysing unstructured qualitative data. Predominantly utilised in social science research programmes, grounded theory techniques have also been applied in management research (Partington, 2002). This paper provides a demonstration of the power and effectiveness of the grounded theory approach when applied to the analysis of training data in a simulation context. This study was conducted as part of a larger research programme to evaluate the effectiveness of a multi-player, low-fidelity simulation system for pairs air combat training on the Tornado F3 Operational Conversion Unit (OCU). Grounded theory techniques were used to develop a model of student performance during pairs training, based on an analysis of archived student sortie reports.

The use of a pair of visually supporting aircraft has formed the basis of virtually all tactics since aircraft have been used in combat (Tornado F3 Training Course Pairs brief, 1998). Leadership of a pair of aircraft is heavily dependent on effective communication between the aircraft crews, as they have to build and maintain situational awareness whilst engaged in a fast moving, three-dimensional fight and make appropriate tactical decisions. The results of a task analysis of Beyond Visual Range (BVR) intercepts conducted by Houk, Whitaker and Kendall (1993) were used by Waag and Houk (1994) to derive a set of behavioural indicators suitable for evaluating proficiency in air combat in day to day squadron training. They identified communication, information interpretation and decision-making as key activities. Bell and Lyon (2000) reported that communication was one of the most highly rated elements contributory to good situational awareness, based on a survey of mission ready F-15C fighter pilots. The results of these studies were also consistent with the model of situational awareness and its position in the decision-making, action-taking loop proposed by Endsley (1995).

The instructors on the Tornado OCU considered that students were weak at communication during the pairs phase and that this was impacting on their situational awareness and decision-making. They attributed this to the unsuitability of the ground training device in use, which only took a single crew. A multi-player simulator was to be evaluated to determine if it produced positive transfer of training to the airborne environment for pairs training. A student performance model for the pairs phase of training was required in order to validate the anecdotal evidence from the instructors of students' performance, and to inform the development of suitable behavioural indicators for the evaluation of the multi-player simulation. The archive of student sortie reports from the pairs phase of training on the OCU provided a source of empirical data in the form of narrative accounts of student performance in that phase of training. Selected narratives were analysed in order to develop the required model.

## METHOD

### Overview

The approach taken to applying grounded theory to this study was based on the procedures and techniques suggested by Strauss and Corbin (1990). Data were gathered and then the processes of open, axial and selective coding were applied. The following sections describe the nature of each of these steps and the methods that were employed in implementing them.

### Data Gathering

The data were collected from pairs-phase sortie reports. Reports were selected from the archive of reports from courses completing the pairs phase over the three-month period preceding the study. Each report was broken down into individual sentences or small groups of sentences that referred to a single observation about an aspect of performance. Four sampling criteria were employed at this stage. The first element was concerned with the selection of observations directly relevant to the study. Each

sortie report covered the whole of the sortie from starting up the aircraft and taxiing out, through the transit to the exercise area, then on to the practice intercepts (the performance area of interest), and finally the recovery back to base. . As the aim of this study was to investigate the evaluation criteria for pairs intercept training, comments on the other elements of the sorties were excluded from the analysis. The second element of sampling was aimed at achieving a balanced view of both pilot and navigator assessment issues. Two tables of comments were constructed, one for navigators and one for pilots. The third element of sampling was the selection of reports from across all six sortie types flown in the pairs phase. The final sampling criteria was to select from as wide a range of instructors who had written the assessments as possible.

### Data Sample

A total of 203 performance comments were collected from 46 sortie reports . There was an even split of navigator and pilot student reports. A total of 28 instructors had completed reports that were used in the sample. With the sample obtained it was thought reasonable to assume that the comments would represent a suitable cross-section of both instructor priorities in assessment and student performance in the pairs phase.

### Data Analysis

#### Open Coding

Open coding is defined by Strauss and Corbin (1990) as:

*“The process of breaking down, examining, comparing, conceptualising and categorising data.”*

The tabulated comments produced by the line-by-line analysis during data gathering were analysed to identify categories into which they could be grouped. This analysis was conducted using the constant comparison technique, as described by Partington (2002), whereby each data item was compared with preceding items to see if it described the same phenomenon as one of the items and therefore could be allocated to an existing category, or if a new category needed to be developed. The application of this method to the set of instructor comments by the first rater yielded an initial set of coding categories. The comments were then independently re-categorised using these categories by a second rater, to check for inter-rater reliability. Differences in

coding were discussed and resolved to produce an agreed list of categories.

#### Axial Coding

Strauss and Corbin (1990) define axial coding as:

*“A set of procedures whereby data are put back together in new ways after open coding, by making connections between categories. “ (p96)*

The output from this stage was a set of higher order categories along with a description of the nature of the connection between the lower order categories that they contained. This required a detailed re-evaluation of the comments within each category.

#### Selective Coding

Selective coding is defined by Strauss and Corbin (1990) as:

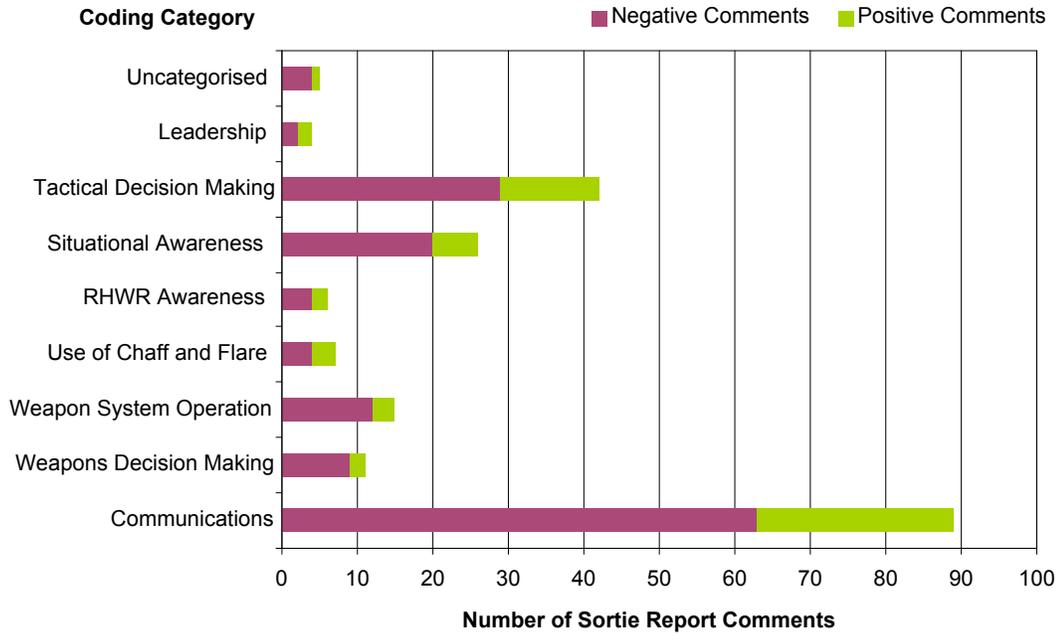
*“The process of selecting the core category [and] systematically relating it to other categories.” (p116)*

The core category is the over-arching phenomenon or concept that links each of the categories or phenomena that are developed during axial coding. After the core category had been identified, the links between the categories were revealed through further analysis of the comments in each category. Once all the categories had been linked together to form a complete model, a narrative description was developed.

## RESULTS

#### Open Coding

The open coding process yielded eight coding categories. These were: communications; weapons employment; use of chaff and flares; Radar Homing and Warning Receiver awareness; situational awareness; decision-making, tactics and leadership and “unknown”. The meanings of five of the 205 comments were unclear and no obvious category could be allocated. These were recorded as uncategorized. Each comment was annotated as to whether it was a positive or negative description of performance.



**Figure 1.** Number of Sortie Report Comments for each Coding Category.

A second rater then re-coded the comments, using the groups identified by the first rater. This process yielded agreement on 143/203 (71%) of cases. The 60 cases (29%) where there was disagreement were then analysed and discussed to resolve conflicts between the raters and finally assign comments on which there was a disagreement to a category.

***Evaluation of Overall Comment Frequencies***

Figure 1 shows the frequencies of positive and negative comments for each of the finally agreed coding categories. There were substantially more negative comments than positive comments. The likely cause for this was that instructors were focussed on ensuring that students had a clear understanding of what elements of performance to work on in the preparation for the next sortie, notwithstanding the value of positive reinforcement of good performance.

It was also notable that the frequencies for some coding categories were far higher than for others. The bar chart shows a number of striking features about the data. The communications, weapons employment, situational awareness and tactical decision making coding categories had a much higher frequency of comments associated with them than the remaining categories. Furthermore, communications had more than double the frequency of comments than any other category. The disparity in the numbers of positive and negative comments was

reflected equally amongst all of the categories, rather than being associated with just one or two. The existence of both positive and negative comments for each category was interpreted as underlining the significance of each category to the instructors. They were making a deliberate point of commenting on that aspect of performance, whether good or bad. The high incidence of comments for some of the categories indicated that these were areas of performance where students were typically weak. The proportionately higher numbers of both positive and negative comments for these categories also indicate a greater focus on these performance areas on the part of the instructors. Finally it was noted that whilst in the most part there was an even distribution of comments in each of the categories for the pilots and navigators, virtually all of the comments concerning weapons systems operation and weapons decision making were attributable to pilot students.

***Subdivision of Categories.***

Strauss and Corbin (1990) point out that theoretical sensitivity can lead to a “blinkered” view of the data. Sensitised to this issue by the decomposition of the weapons employment category, each of the categories was re-examined to see if they could be further decomposed. Sub-categories were found for communications and situational awareness.

Communications

The broad scope of the communication required was captured in the following report comment:

*“You must talk to the other aircraft – let him know where you are, what you can see and what you are going to do.”*

The comments in the communications category were re-examined to see if there were any sub-categories. It was found that, not only were comments made about the overall quality of the students communication, in addition the different contexts in which communication were required were identified. It is notable that decision-making was an activity that was identified in relationship to communication. For example, one comment made was:

*“If things are worth saying to your pilot, they could be worth transmitting.”*

This suggests that, on some occasions at least, the student should have decided to communicate with the other aircraft and didn't. Another feature of communication that emerged from the analysis is that it appeared to be related to many of the other areas of activity commented on such as tactical decision-making and weapons employment.

Situational Awareness.

As with communications, situational awareness had been expected as a category and comments about it were often placed under a heading of situational awareness in the narrative reports. The fundamental importance of developing and maintaining situational awareness within the formation was brought sharply into focus by this instructor comment:

*“lost situational awareness momentarily and shot at his wingman”*

Analysis of the set of comments made about situational awareness revealed that the instructors viewed it as a set of processes. The need for students to monitor displays and communications as sources of information for situational awareness is highlighted in comments such as:

*“At times his situational awareness was not as high as it should have been, he must build it through listening and monitoring the tactical display.”*

Other comments implied that situational awareness also involves processing this information in some

way in order to make judgements. For example, the following comment indicates that evaluation of the bandits' actions and anticipation of their possible intentions were considered essential activities:

*“...situational awareness– don't just say what the bandits are doing – try to draw some conclusions about their behaviour and our RHWR indications”*

The need for anticipation of future events is also illustrated in the comment:

*“ The profiles happen very quickly, anticipate and then if necessary action then description”.*

Re-analysis of all the situational awareness comments resulted in four sub-categories being identified, as shown in Table 1

**Table 1.** Situational Awareness Comment Distribution.

Category	Number of Comments
Monitor	6
Evaluate	10
Anticipate	5
Overall SA	9

Comments in the overall situational awareness category were summary comments in which students' performances in situational awareness were quantified as either poor or good. From Table 1, it can be seen that the comments were essentially evenly distributed amongst the categories, with slightly more comments made about evaluation.

**Axial Coding**

Consideration of the categories concerned with weapons utilisation provided a natural start point for the axial coding process, since they had been derived from the decomposition of the weapons employment category in the first instance. This decomposition and re-composition highlighted the possibility that other categories may also decompose in a similar fashion to yield sub-categories and inter-linking relationships. The decomposition of the communications category produced a set of sub-categories that were related to a number of the other categories from the open coding stage. Consideration of these relationships led to the development of the over-arching categories of decision-making and actions. Finally a situational awareness model was

developed based on a decomposition and re-composition of the situational awareness category.

**Decision-Making and Actions**

During the open coding stage, decision-making had been identified as a central component of tactics, weapons employment and communications. The instructor comments in the remaining categories were reviewed to identify if it occurred elsewhere. The one category where it occurred was in the use of chaff and flares. The importance of decision-making in this category is highlighted by the following comment:

*“[Use] flares at the correct range otherwise, as you saw, you will get a Fox 2 [infra-red guided missile] in the face”*

All the instructor comments were focussed on the appropriateness of the decisions made about when to use chaff and flares. From this analysis, decision-making was identified as a new high-level category.

The identification of this category raised the question of what the consequences were of such decision-making. Many of the remaining categories could be viewed as actions that were taken in response to such decisions. The various sub-categories of communication could be related to a number of aspects of decision-making. The requirement to pass the aircraft’s position and the details of what can be seen in terms of targets is suggestive of a requirement to communicate information, based on situational awareness, for the purpose of building the other crew’s situational awareness. The giving of tactical orders suggests a relationship between communication and tactical decision-making, communication being required to inform the other aircraft of the tactical decision made along with directions on how to implement it. The following comment illustrates the requirement for communication related to missile shots:

*“If the lead engages and you see an obvious shot opportunity, call it and await response.”*

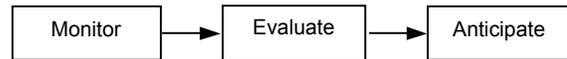
Such communication would be required subsequent to a decision about weapons use being made. Similarly, weapons system operation could be viewed as an action taken in response to a decision on weapons use.

It can be seen that many of the actions are communication, highlighting the importance of communication across the range of areas activity.

The actions associated with chaff and flare use are simply the pressing of a button. It is not surprising that such a simple action was not cause for comment. Similarly, only a communications action is shown subsequent to tactical decision-making. Whilst in practice the pilot will often have to manoeuvre the aircraft in response to the order related to the decision, this again does not constitute a complex task and comment would not have been expected.

**Situational Awareness**

During open coding, situational awareness was decomposed into the activities of monitoring the environment, evaluating this information and anticipating future events. These activities could be viewed as sequential, resulting in the model of situational awareness shown in Figure 2.



**Figure 2.** Situational Awareness Model.

The following comment suggested that the RHWR awareness category was another aspect of such monitoring:

*“He is not monitoring his RHWR, he made no mention of threat indications – he must bring it into his scan”*

Therefore, this category was subsumed within the overall situational awareness category.

**Selective Coding**

Following the procedure recommended by Strauss and Corbin (1990), the core category is first identified. The relationships between the main categories identified during axial coding are then determined. Finally, the overall model is built and a narrative description of the model is provided.

**Identification of the Core Category**

The key to the selective coding stage and the subsequent development of an overall model is the identification of the core category. This was required in order to facilitate the integration of the decision-making, action and situational awareness categories identified in the axial coding stage. As a result of re-examining the full set of comments, the following comment was identified which pointed to a potential core category:

*“when flying as wingman he must be more missile launch success zone aware, he was generally trying to do all things rather than the main priority – killing the bandit.”*

The significance of this comment is that it identified the primary goal of all the activities engaged in during the practice intercepts, that was killing the enemy. An essential sub-goal that can be inferred from the comment about the use of chaff and flares, quoted in the decision-making section, is not being killed in the process.

**Identification of the Relationships between Categories.**

The next stage was to identify the relationships between high-level categories. The connection between decision-making and actions was simple; actions were taken in response to decisions made. This had already been identified during axial coding. The connection between situational awareness and these categories had to be established. A clear insight into the purpose of situational awareness, namely that it informs decision-making, was given by the previously quoted comment:

*“He lost situational awareness momentarily and shot at his wingman.”*

In this instance poor situational awareness resulted in an erroneous weapon employment decision. The connection between situational awareness and tactical decision making was brought out by the comment

*“50% of merges were entered without obvious tactical advantage and he correctly took the formation out.”*

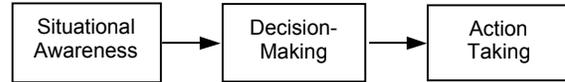
In this instance, awareness of the lack of tactical advantage was a prerequisite to making the tactical decision to leave the fight. Building the situational awareness of the other element in the formation to facilitate that elements’ decision-making was also found to be a constant theme in comments such as:

*If you can see your wingman in the fight call it, that way your wingman can manoeuvre freely to engage the bandits without the worry of collision avoidance.”*

The point here is that the wingman could only make the decision to focus on his fight, and therefore disregard the position of his leader as a factor to be considered, if he was made aware that the leader can see and avoid him. However, the leader would only

make the necessary call to that effect if he was aware that his wingman was engaging a target and that his own position was a factor in his wingman’s decision making. This highlights the complex nature of the teamwork involved in pairs combat and underlines the significance of team situational awareness built upon effective communication.

Based on this analysis, a model showing the connection between the three high-level categories was developed, shown in Figure 3.



**Figure 3.** Relationship between High-Level Categories

The question then arose as to what happened once an action had been taken? A number of comments pointed to the iterative nature of the process. Take for example the following comments:

*“If carrying out defensive actions, he must think chaff and flare.”*

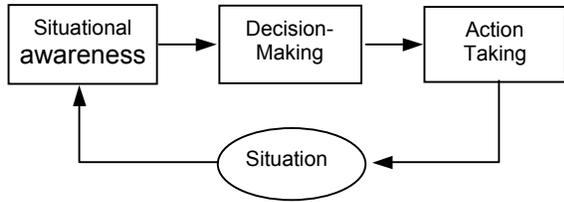
And

*“If missile shot does not come off, shoot again or reposition.”*

Both highlighted that the consequence of an action had to be considered and further decisions made and then acted upon. Furthermore, multiple decisions could have been required as suggested by the following comment:

*“If situational awareness breaks down in the visual – leave, use height and cloud and use chaff and flares as required.”*

In this instance, chaff and flare employment needed to be considered at the same time as the tactical decision to leave a fight because of changing situational awareness. The change in the situation as a consequence of a decision that was actioned was the key point, as it suggested that there was a feedback loop. The model at Figure 3 was revised to incorporate this, as shown in Figure 4.



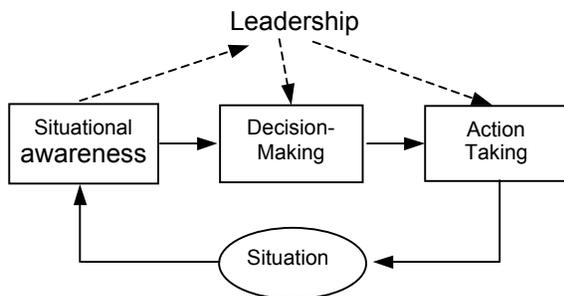
**Figure 4.** Relationship between High-Level Categories with Feedback Loop.

The “situation” component was introduced to reflect the fact that the actions did not directly feed into situational awareness but changed the situation itself. The change in situation would have to be perceived before it could be evaluated.

One further extension to the model is required to take account of the leadership category. Whilst there were only a few comments made in the sortie reports about leadership, the negative comments also made reference to communication. For example:

*“If tactical leader, he must show more control over the formation i.e. calling defensive manoeuvres, etc”*

This comment serves to illustrate the point that communication forms the medium of leadership. It is the leader of the pair that issues the tactical orders and as such has the primary responsibility for tactical decision making for the formation. Effective leadership therefore requires good situational awareness and is manifested in appropriate decision-making and communication. The leadership category could be seen as sitting on top of the model. This is represented in Figure 5.



**Figure 5.** Relationship between Leadership and the other High-Level Categories.

This extension to the model is intended to show leadership as being influenced by situational

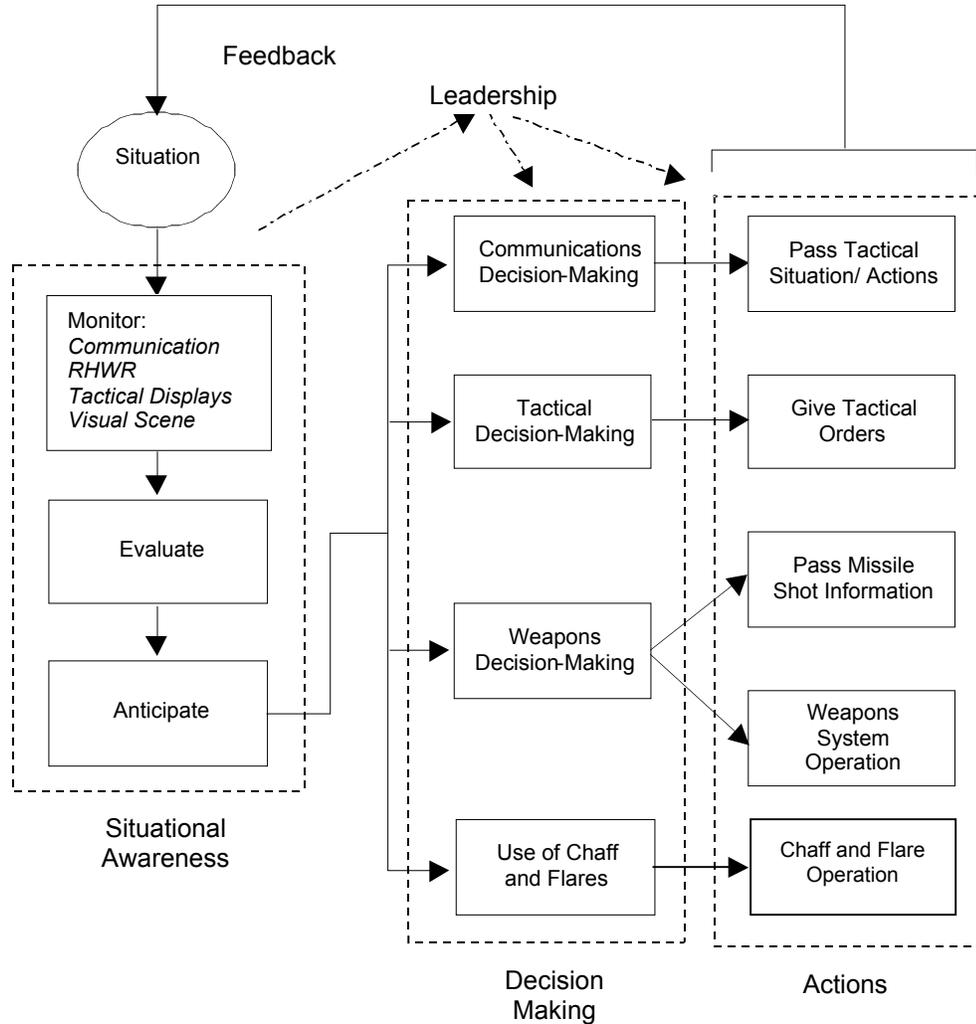
awareness but influencing the intercept through decision-making and the medium of communication.

**Detailed Student Performance Model**

Figure 6 shows the complete performance model, with situational awareness, decision-making and action categories broken down into their sub-components. The model describes the sequence of actions that the instructors expect students to take in response to the constantly changing situation in a pairs intercept in order to achieve the aim of killing the enemy.

Beyond visual range, the first indication of the presence of enemy aircraft would be either a radar contact or an indication on the Radar Homing and Warning Receiver (RHWR) that the radar of an enemy fighter or missile was illuminating the aircraft. Monitoring the tactical displays and the RHWR for such events would then lead to evaluation of situation in which the pair was placed. By analysing the indications on the displays, the students can determine whether they are in an offensive or defensive position relative to the enemy aircraft and anticipate how the situation may evolve. They are then in a position to make decisions about what to do in response to the detected change in situation. In the first instance a communications decision is required about what information to pass to the other aircraft in the pair in order to build formation situational awareness. The appropriate information is then passed. A decision about what tactical action, if any, is required to either take tactical advantage of the situation for an attack or to take defensive actions. Tactical orders can then be given to the other aircraft.

If there is an appropriate shot opportunity, a weapons decision can be made and the weapons system then operated to take the shot with actions taken being communicated to the other aircraft in the pair. The taking of missile shots is central to the primary goal of killing the enemy. In a defensive situation and decision to use chaff or flares to protect against enemy missiles may be required and chaff or flares then deployed. This, along with suitable evasive action, is central to the achievement of the sub-goal of not being killed. The cycle is then repeated as the situation progresses. The enemy aircraft may make a counter manoeuvre or attack, which would become apparent from changes in the indications on the displays, which would require further decisions and actions to be taken. As the fighters move into visual range, scanning of the visual scene begins to take prominence.



**Figure 6.** Detailed student Performance Model

The central feature of the model is the constant repetition of development of situational awareness leading to decision-making and subsequent actions. Communication features prominently as a required action following decision-making. Effective leadership of the pair during the intercept requires good situational awareness and sound decision-making and is implemented through effective communication.

**Discussion**

From a methodological perspective, the grounded theory techniques applied during this study provided a powerful toolset for the analysis of the sortie report data, enabling a detailed model of student performance during the pairs

phase to be built. Taking a broader view, the high degree of convergence between the results from this grounded theory analysis and the results from the divergent methods used by Endsley (1995), Waag and Houk (1994) and Bell and Lyon (2000) give a high degree of confidence in the validity of the underlying constructs common to each study.

The model that was developed was found to be highly consistent with the published models of air combat and situational awareness. The sequential model of situational awareness in Figure 4, derived purely from analysis of the instructors' comments, is directly equivalent to the perception-comprehension-projection model of situational awareness proposed by Endsley

(1995). Furthermore, the model in Figure 5 is equivalent to Endsley's (1995) situational awareness – decision –performance of actions model of situational awareness in dynamic decision-making. Instead of situation, Endsley (1995) uses the term “state of the environment”. The consistency between this model and that proposed by Endsley (1995b) lent weight to the argument that the model was valid.

The first reason for developing the model was to validate the instructors' view, expressed anecdotally, that communications was a major area of weakness in student performance in the pairs phase. The analysis of the number of comments in each of the categories identified in the model showed that nearly 50% of the comments were made about communications and that the majority of those were negative. This validated the instructors' perception of the students' performance, namely that they were weak at communications during pairs combat.

The second purpose of the model was to inform the selection of behavioural indicators for the evaluation of the multi-player simulator. The analysis showed that there were other areas apart from communication where students showed weaknesses in performance. The most notable were situational awareness, tactical decision-making, and for pilots, weapons employment. These results were highly consistent with those of Waag and Houk (1994), derived by task analysis, and Bell and Lyons (2000) from survey questionnaire results. From the training perspective, the question arises as to why students should be making errors in these areas of performance. The requirement for communications was new to the students in the pairs phase as for the first time they had to communicate and co-ordinate their actions with another aircraft. Situational awareness and tactical decision-making were not new areas of performance but they did have an added dimension with another aircraft involved. Situational awareness had to be built between aircraft and tactics that are more complex were required for operating as a pair. It was surprising that weapons employment appeared as a category, since there was no pairs phase specific change in this area. The fact that it was pilot specific, and that pilots are responsible for weapons employment in the visual arena, suggested it was perhaps an issue related to training in the visual phase of combat rather than to pairs combat per se. In summary, the model

that was produced clearly identified the areas of performance where students were typically weak in the pairs phase. Therefore, the model provided a sound basis upon which to determine candidate measures for a subsequent training effectiveness trial.

Perhaps one of the most notable features of this study, yet the most easily overlooked, is that the analysis was conducted on existing data that were easily accessed. The significance of this is that unstructured narrative reports are produced on many courses across a wide range of training endeavour. These can provide a rich source of information provided the data are analysed in a rigorous way and the right questions are asked. Grounded theory has proved to be an ideal tool for such analysis, complementing other evaluation techniques. It is under active consideration for evaluation of other RAF flying training courses.

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