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Human Factors in Air Displays:

Transfer of Behaviours and Error Path Study

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Human Factors in Air Displays:

Transfer of Behaviours and Error Path Study

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Acknowledgements

A number of display pilots and expert stakeholders contributed to this study by making themselves available for consultation through interview. Their open and committed involvement has made this study possible. These included:

Single-Engine Piston aeroplane and Jet-Powered aeroplane display pilots, Flying Display Directors (FDDs), Display Authorisation Evaluators (DAE), and representatives from the Civil Aviation Authority's General Aviation Unit (CAA GAU), the British Air Display Association (BADA) and the Historic Aircraft Association (HAA).

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EXECUTIVE SUMMARY

The Civil Aviation Authority (CAA) commissioned the Health and Safety Executive's Science Division, the Health and Safety Laboratory (HSL) to carry out a study to explore human factors in air displays.

The aim of this research was to enhance understanding of the error paths that lead to flying display accidents, including the potential for negative transfer of behaviours between aircraft. An error path is defined as the weaknesses in safety 'barriers' that, when aligned, can result in an unwanted outcome; safety barriers are conceptualised at the individual, job and organisational level. A research requirement was to use the research findings to develop human factors training for the display community.

Method

The scope was narrowed to focus on Single-Engine Piston (SEP) and Jet-Powered (JP) aeroplanes, and was divided into three phases: (i) desk-based collation and review of relevant theory, industry guidance and accident reports; (ii) consultation with the display community and analysis of findings and (iii) reporting of findings and provision of human factors training programme.

Main Findings

Display pilots are flying in a highly dynamic, time critical, evolving environment. They are generally operating at the automatic, skill-based level of human cognition, where the human error potential is generally related to slips and lapses, and where the transfer of behaviour between aircraft can increase error potential. Why transfer occurs, and what causes skills acquired in one setting to impact another has been extensively researched within the discipline of cognitive psychology and neuroscience, and is experienced by experts across all industrial sectors and in all skilled activities. The processes related to the assurance of the competence of air display pilots was a recurring contributory factor highlighted in accident reports. These included training, supervision, practical experience and assessment.

Consultation with pilots and the wider display community provided a rich source of potential error path data. The main findings were:

- there are important operating and handling differences between and within types and categories of SEP and JP aeroplanes that could impact safety;
- there is potential for negative transfer of behaviours between types and categories of aeroplanes;
- there are numerous error pathways that cannot be entirely eliminated, but problems arising from negative transfer of behaviours were perceived as a) often recoverable and b) as being normally mitigated by a number of measures;
- many pilots have developed strategies for minimising the likelihood of error (including those caused by negative transfer);
- currency on aeroplane, time pressures, distractions on display day (e.g. weather), stress and pressures to display were all considered factors that could influence pilot performance on the day of display.

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Wider issues were also highlighted and included:

- The role of the Display Authorisation Evaluator (DAE) and the Display Authorisation Evaluation process to ensure display pilots were suited to display flying in terms of their attitude, skills, behaviour and knowledge;
- Flying Display Directors (FDDs) activities, roles, and responsibilities including the variation in content and delivery of display briefs;
- Event organisation and how it can vary significantly in terms of how well pilots' needs are considered, which in turn can impact safety and performance;
- The role of the regulator, their relationship with the display community and how information is shared.

Conclusion

Design changes to aircraft are the most effective way of reducing the likelihood of slips and lapses caused by negative transfer, but this is not generally an option for aeroplanes in display flying. Pilots have, instead, developed their own strategies for minimising errors, which include minimising errors due to negative transfer. The research identified many excellent strategies used by pilots, who may not necessarily realise that they are managing human factors' related risk. The strategies that they have developed to safely manage and adapt to aeroplane type changes promote moving between System 1 fast thinking (automatic processing) and System 2 slow thinking (controlled processing). Whether or not a pilot can employ these strategies is not only dependent on the individual but also on wider display community processes and structures in place to support them.

There appeared to be variation in how extensively human factors expertise was utilised in accident investigations. Applying human factors resource to a wider range of incidents will likely help strengthen industry learning on error reduction/ performance enhancement. Such an investigation approach should be applied to high potential incidents, as well as those resulting in near misses, or less serious incidents. This would help to ensure that there is consideration of not only individual factors, but broader task and organisational/sector factors. It would also enable deeper and broader learning to help reduce the likelihood of high consequence events. There is a need at all levels of the display community to promote practices to ensure a positive health and safety culture, including a 'just' culture. It is important that pilots and other personnel can speak openly and honestly following an incident. Such openness and honesty enables learning and safety improvement.

The human factors principles and research data discussed in this report are applicable to all aircraft types where there are sufficient similarities in contextual information for negative transfer to occur. It is recommended that all pilots and operators consider how it might occur and be addressed in their aircraft. The research highlights that PIFs extend beyond those associated with negative transfer of behaviour and therefore, the proposed training programme is applicable to all.

Recommendations

A key requirement was to use the error path findings from this study to develop human factors training for display pilots, training that the CAA will require holders of Display Authorisations (DAs)

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to undertake. The authors of this study are aware that experts make errors irrespective of training and experience or how motivated they are to do things correctly and therefore, training forms part of a number of recommendations for consideration.

1. CAA should work with FDDs to improve the quality and quantity of reporting and feedback provided by FDDs following airshows. CAA should also consider ways in which this information can be shared across the display community. Sharing information from FDD reports on why incidents occurred and actions that have been, or can be, taken to prevent further similar incidents would be of benefit to the entire display community.

2. CAA and the Air Accident Investigation Branch (AAIB) should promote more consideration of human factors in accident investigations through application of human factors expertise. This would enable deeper and broader learning to help reduce the likelihood of high consequence events.

3. CAA should develop a human factors training programme based on knowledge sharing techniques to ensure there is an exchange of expertise across the display community. Engaging with the display community as a resource could bring about improvements in safety practices far beyond traditional training.

4. CAA should consider a blended learning solution comprising a combination of self-taught learning and reflection, online learning and face-to- face training, delivered in a modular format.

5. All display pilots, not just those flying multiple aircraft, should be required to participate in the proposed training programme. This includes pilots seeking initial display authorisation and display authorisation renewal. The inclusion of other critical support and management roles in training is also recommended in order to support a more holistic / systematic approach to enhancing safety for air displays.

6. To further facilitate the transfer of learning, the CAA should work to set up a community of practice to help ensure that the taught elements of the training are embedded into long term practice and delegates can share their own expertise. This could serve as a repository for human factors references and relevant information.

7. CAA should use face-to-face sessions in human factors training to activate the expertise within the display community. Face-to-face sessions should include further identification and discussion of PIFS and mitigation measures to optimise pilot performance. The outputs of such sessions could be defined as recommended safe practices which could be extracted and published in the community of practice.

8. CAA should work with FDDs to standardise the inclusion of human factors in FDD briefs and debriefs.

9. CAA should consider how to effectively engage with the display community, including DAEs, FDDs, event organisers, and other stakeholders (e.g. British Air Display Association, Historic Aircraft Association) to improve safety and regulatory compliance.

10. CAA should consider the pace of change of regulation and the timing of changes and how that may impact pilots in the display season.

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1 INTRODUCTION

1.1 STUDY CONTEXT

The Civil Aviation Authority (CAA) commissioned HSE's Science Division, the Health and Safety Laboratory (HSL) to carry out a study on human factors in air displays. Specifically, the study required exploration of the potential for negative transfer of pilot behaviour between aircraft types and identification of the potential for error and factors that have and could contribute to air display accidents.

The motivation for the current project was the investigation into the accident to Hawker Hunter T7, G-BXFI that crashed near Shoreham Airport on the 22nd August 2015. Following the extensive investigation carried out by the Air Accident Investigation Branch (AAIB), a number of recommendations were made. This work seeks to enable the CAA to address two of these recommendations:

i. AAIB Recommendation 2016-041**:**

It is recommended that the Civil Aviation Authority require a Display Authorisation to be renewed for each class or type of aircraft the holder intends to operate during the validity of that renewal.

In response to Recommendation 2016-041, the CAA agreed to:

Review the list of different categories of aircraft relevant to pilot Display Authorisation renewal and assess the impact of operating differences between each category. The CAA will expand this work to include a study of the potential for negative transfer of behaviours between aircraft types. The CAA will consider introducing any relevant findings into the ongoing training and assessment requirements for display pilots, including the requirements for Display Authorisation renewal.

ii. AAIB Recommendation 2017-006:

It is recommended that the Civil Aviation Authority undertake a study of error paths that lead to flying display accidents and integrate its findings into the human factors training it requires the holders of display authorisations to undertake.

In response to Recommendation 2017-006, the CAA agreed to:

Work with external experts to understand the influence of human factors on air displays. The CAA will expand this work to include a study of error paths that lead to flying display accidents and integrate the findings into the human factors training it requires the holders of display authorisations to undertake.

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1.2 AIMS AND OBJECTIVES

The aim of this study was to enhance understanding of the error paths that lead to flying display accidents including consideration of the potential for error resulting from the negative transfer of behaviours between aircraft types. A further requirement was to use the error path findings from this study to develop human factors training for display pilots, training that the CAA will require holders of display authorisations (DAs) to undertake.

To address the aims and requirements of this study, the following key objectives were formulated:

i. Identify the scope of the categories / groups of aircraft to focus on in order to maximise study outcomes;
ii. Review key industry guidance and 'negative transfer of learning' literature;
iii. Analyse a sample of accident / incident reports of UK flying display accidents / incidents;
iv. Collate examples on negative transfer from other industries;
v. Adopt a task analysis approach to enrich understanding of potential error paths that lead to flying display accidents;
vi. Develop research materials (e.g. semi-structured interview guides, images of aircraft cockpits) informed by the findings from (i) – (v);
vii. Collate error path data from the display community (to include display pilots, Flying Display Directors, Display Authorisation Evaluators and key stakeholders e.g. British Air Display Association, Civil Aviation Authority's General Aviation Unit and the Historic Aviation Association);
viii. Analyse the data to propose a draft training programme;
ix. Write up a draft summary report informed by results from i-viii;
x. Produce a final training programme following discussions with the Civil Aviation Authority's General Aviation Unit;
xi. Deliver findings in a final report; and,
xii. Deliver training materials and associated testing process and records informed by the final report.

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2 METHODS

This study involved three phases: (1) desk-based data collation (2) consultation and analysis and (3) reporting and provision of a training programme with associated materials. Figure 1 provides an overview of the three stages of the study with associated activities, project timeline (March 2018 to September 2018) and milestones.

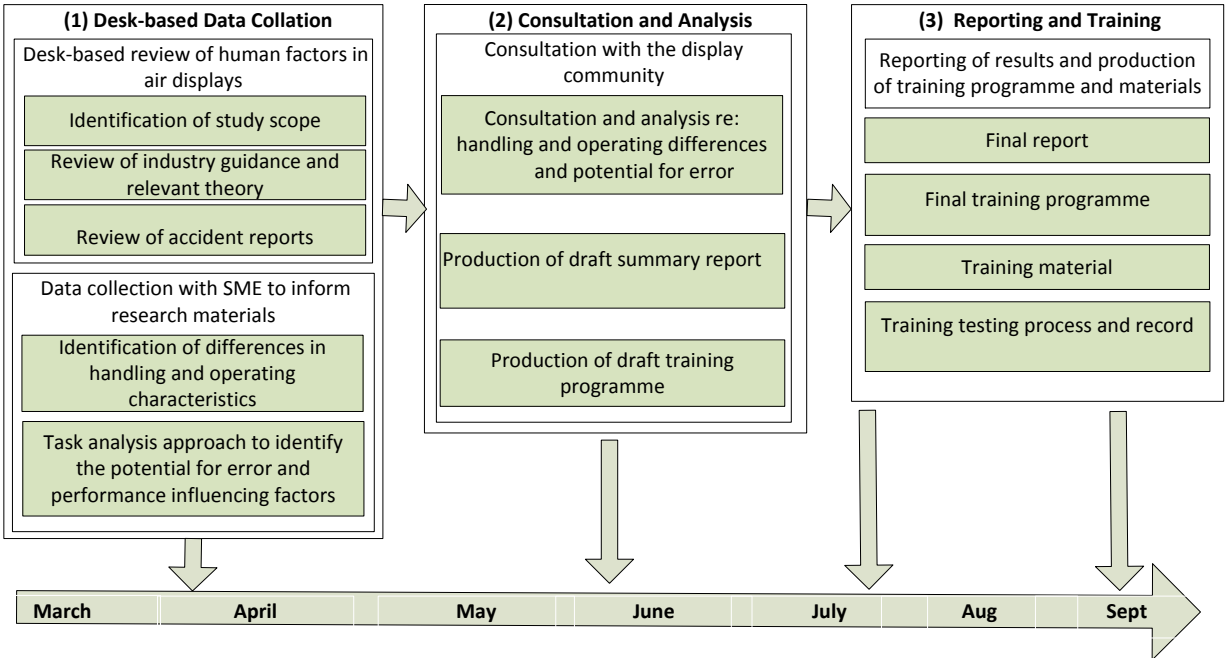

Figure 1 Project timeline and key activities

2.1 DESK-BASED DATA COLLATION

2.1.1 Study Scope

A pilot can seek authorisation to display an aircraft in 23 different categories of aircraft, as defined in the CAA's recently revised regulatory document referred to as CAP 403, Edition 15 (Civil Aviation Authority, 2018). These are divided into eight groups of aircraft:

- Single-Engine Piston aeroplanes;
- Multi-Engine Piston aeroplanes;
- Jet-Powered aeroplanes;
- Turbo-Prop Powered aeroplanes;
- Helicopters and Gyroplanes;
- Gliders, Hang Gliders and Paragliders;
- Microlight aeroplanes; and,
- Powered Parachutes, Powered Paragliders and Powered Hang Gliders.

In order to maximise the research outcomes, the scope of this study was narrowed to focus on five categories of aeroplanes: Single-Engine Piston (SEP) aeroplanes, categories A, B and C and Jet-Powered (JP) aeroplanes, categories G1 and G2 as defined in CAP 403, Edition 15 (Civil Aviation Authority, 2018).

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The type of aircraft, group and category of aeroplane was determined by an analysis of the DA database, Subject Matter Expert (SME) opinion, and research knowledge of how negative transfer can occur. Analysis of the 443 current DAs showed that the majority of DAs are for SEPs only (approximately 60%) and for SEPs and JPs (approximately 10%). Table 1 in Appendix A provides further information. The potential for negative transfer is greatest within the groups selected because of the similarities in aeroplane characteristics. As defined:

> *"When two situations have similar (or identical) stimulus elements but different response or strategic components, transfer will be negative…"* (Wickens et al., 2013, p.227)

In addition, the SME confirmed these groups of aircraft (SEPs and JPs) were most likely to be involved in high-energy manoeuvres during air displays and are, therefore, of most relevance to the project.

Conversely, the potential for negative transfer is reduced by increasing the differences between stimuli,

> *"…if the responses for two systems are different and incompatible… the amount of negative transfer may be reduced by actually increasing the differences… the operator confronting two control levers with incompatible motion directions will have few problems if the appearance of the handles (both visual and tactile stimulus elements) is quite distinct"* (Wickens *et al.*, 2013 p.227)

This means that the contextual and functional differences between, for example, SEPs and helicopters, or gliders and Multi-Engine Piston aeroplanes are sufficient to exclude them from the current work, as negative transfer is less likely to occur.

The principles identified in this research will be applicable to the operating differences between any of the aircraft categories. However, by limiting the scope, it was possible to 'deep dive' into issues, providing a much richer understanding of human factors issues linked to transfer of behaviours and error paths within the air display sector.

Section 3 provides more information about the background theory to human performance in air display, and is the basis of the rationale for narrowing the research scope.

2.1.2 Data Collation

Phase one (desk–based data collation) involved collation and review of key documents / information including:

- Data from the CAA e.g. Display Authorisation (DA) database; Flying Display Director (FDD) reports;
- Collation of examples of transfer from other industries;
- A sample of Flying Display Director (FDD) reports and AAIB reports;
- SME views on operating and handling characteristics of aircraft;
- Industry guidance (e.g. CAP 403, Edition 15) and 'transfer of learning' literature; and,
- Training material from a number of sources.

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2.1.3 Design of Research Materials

A walk-through talk-through task analysis approach was used with the Subject Matter Expert (SME) in this study to gain a greater understanding of display pilot actions and decisions when conducting a flying display. This involved the SME commentating through a hypothetical scenario highlighting key display pilot activities and decisions leading up to a display and during a display. To facilitate this discussion, large-scale images of cockpits and different types of aeroplane were used to prompt discussion and memory recall of key actions and decisions. The aim of this task analysis exercise was to inform the development of interview question guides that could be used with display pilots and other key stakeholders in this study.

Two sets of question guides were developed. These were informed by the output of the task analysis exercise, SME views on operating and handling characteristics of aircraft and a high level review of a sample of accident reports. The first question guide for display pilots was designed to enable exploration of the following topics:

- Display flying experience and aeroplane type;
- Operating and handling differences between different types of aeroplane;
- Views on the potential for all error, including the potential for error due to negative transfer of behaviours between aeroplanes; and,
- Factors considered likely to influence error.

A second question guide was developed for other expert stakeholders in this study (see Section 2.2.1 for a description of stakeholder consultation). This included a high level discussion on the topics above with additional questions relating to the organisational aspects of display flying. For example, questions relating to stakeholder views on currency requirements[1], the Display Authorisation Evaluation (DAE) process, the role of the FDD and any other views on the safety of airshow organisation.

2.2 CONSULTATION WITH THE DISPLAY COMMUNITY

Phase two involved recruitment of experts in the display community, consultation with the display community and analysis of findings.

2.2.1 Recruitment of Experts from the Display Community

A purposive sampling approach was used to recruit interview participants for the study. This approach focuses on particular characteristics of a population that are of interest and can best

[1] In CAP 403, Edition 15, the minimum currency requirement preceding a flying display (that includes a standard aerobatic skill level) is to complete three display routines within 90 days of the date of display and one display routine within 30 days of the date of display. The one display within 30 days must be in the specific category of aircraft being displayed. For intermediate, advanced and unlimited aerobatic skill levels, three displays within 90 days must be in the specific category of aircraft being displayed with one within 30 days in that category. CAP 403 also highlights that currency requirements should be viewed as a minimum and "*that pilots are encouraged, particularly during the winter months or pre-season work up, to undertake sufficient practice to ensure that a sufficiently high standard of safety is maintained*".

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address the research aims and objectives (Ritchie and Lewis, 2003). A key criterion for display pilot participation in this study was that display pilots held a current or recent DA. A DA is a national document detailing the types or groups of aircraft in which a pilot is authorised to display, together with any limitations and any specific endorsements.

A second criterion for display pilot participation in this study was that display pilots who held a current or recent DA were authorised to fly either SEP aeroplanes and / or JP aeroplanes. The rationale for this criterion was that the work focused on aeroplanes and, specifically, SEP aeroplane categories A, B and C, and JP aeroplanes, categories G1, and G2, as defined in CAP 403 (Civil Aviation Authority, 2018).

A third key criterion for participation in this study was to include expert stakeholders from a number of organisations who play key roles in informing the safety of air display. This included FDDs. FDDs are responsible to the CAA for the safe conduct of a flying display. A DAE was consulted, this is a CAA authorised person qualified to conduct examinations and tests for the award of DA. The CAA requested consultation with representatives from the Civil Aviation Authority's General Aviation Unit (CAA GAU), the British Air Display Association (BADA) and the Historic Aircraft Association (HAA).

Table 1 provides information on the number of interviews and who was consulted. It shows that consultation included seven pilots who display or have displayed SEP aeroplanes, three pilots who display or have displayed JP aeroplanes and six expert stakeholders. The majority of interviewees had extensive flying experience as a display pilot and as a commercial pilot or a military pilot. Furthermore, the majority of interviewees had received some form of formal human factors training and receive regular human factors refresher training as a commercial pilot or a military pilot. It was not evident that pilots had received any formal human factors training specifically in the context of air display. Some interviewees commented that they attended the pre-season and post-season symposiums arranged by the CAA and the Military Aviation Authority (MAA) and that human factors presentations can form part of these.

Table 1 Number of expert display pilots and expert stakeholders consulted

Roles / organisation relevant to study scope	Number of Interviews
Single-Engine Piston (SEP) aeroplane pilots	7
Jet-Powered (JP) aeroplane pilots	3
Flying Display Director (FDD)	1
Display Authorisation Evaluator (DAE)	1
British Air Display Association (BADA) and FDD	1
Historic Aircraft Association (HAA)	1
Civil Aviation Authority's General Aviation Unit (CAA's GAU)	2
Total Number of Interviews	**16**

2.2.2 Semi-Structured Interviews

Semi-structured interviews were particularly well suited for this study as they combine structure with flexibility, thus allowing researchers to be responsive to what the interviewee was expressing and to capture any relevant additional information.

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Two HSL researchers conducted the telephone and face-to-face interviews between May and June 2018. Each interview lasted approximately sixty minutes. At the start of each interview, details about the purpose of the research and assurances about anonymity and confidentiality were reiterated to participants. All interviews were audio recorded (with participants' consent), and transcribed for the purposes of data analysis.

2.3 DATA ANALYSIS OF INTERVIEWS

A thematic approach to analysis was adopted to identify the main themes from interviews. It involved the following steps:

- familiarisation with interview notes and audio recordings in order to obtain an initial understanding of the information and begin to formulate emerging themes;
- development of an analytical framework specifying a set of key themes drawing on the broad topics that were covered in the interviews;
- transfer of key themes onto a spreadsheet divided by discipline;
- population of the spreadsheet, which involved going through the interview notes and audio recordings; and,
- summarising the key issues that emerged for each theme in the relevant cells within the spreadsheet.

2.3.1 Considerations for interpretation of data

The findings that emerged from the qualitative data (the interview data) reflect the range and diversity of expert display pilots and expert stakeholders consulted in this study and therefore represent a good spectrum of views and experiences. Whilst views are wide and varied, this study used a small sample of display pilots and stakeholders (16 in total) relative to the display community population and therefore is not statistically representative of the display community. As the results are indicative only, it is not possible to comment on how far the results can be extrapolated across the display community. Given the main data collection method was via interviews, which tend to be more subjective, there may be additional performance influencing factors that impact on display pilots that have not been identified in this study. However, Subject Matter Experts who reviewed this work consider the findings to be representative of air display in practice. HSL researchers also noted that the expert interview participants were keen to participate, and actively engaged in interview discussions.

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3 BACKGROUND THEORY: HUMAN PERFORMANCE IN AIR DISPLAYS

This section provides a high level introduction to relevant theory for non-human factors professionals.

3.1 EXPERT BEHAVIOUR

Air display pilots are experts; in an air display they are operating in a highly dynamic time critical evolving environment. The airborne time during an air display is approximately seven to ten minutes. In this time, the display pilot is continuously monitoring parts of the system, shifting their attention from the inside to the outside of the aeroplane throughout the flight, managing risks, anticipating future conditions, reacting to threats, and responding to all sensory inputs.

When flying a display, pilots are generally operating at the skilled, automatic end of human behaviour. Daniel Kahneman's description of human behaviour usefully simplifies complex cognitive processes and therefore is a helpful model to use in this context. Kahneman describes skilled automatic behaviour as 'System 1: fast thinking', this end of human behaviour has a number of characteristics - it executes skilled responses and generates skilled intuitions after adequate training, it operates quickly (in milliseconds) with little or no effort, with no sense of voluntary control (Kahneman, 2011). When people operate at this automatic, skill-based level the human error potential is related to slips and lapses, and the transfer of behaviour between aircraft can increase this error potential.

At times, a pilot may move between automatic processing and controlled processing. Controlled processing, also referred to as 'System 2: slow thinking', is effortful and includes greater conscious processing. System 1 can be programmed by System 2 to mobilize attention when a particular pattern is detected (Kahneman, 2011).

If a pilot moves to controlled processing he / she may exhibit rule-based behaviours and even knowledge-based behaviours (e.g. when facing something unexpected). Figure 2 illustrates the stages of skill acquisition and how mental effort changes when pilots operate at skilled, rule and knowledge-based behaviour levels.

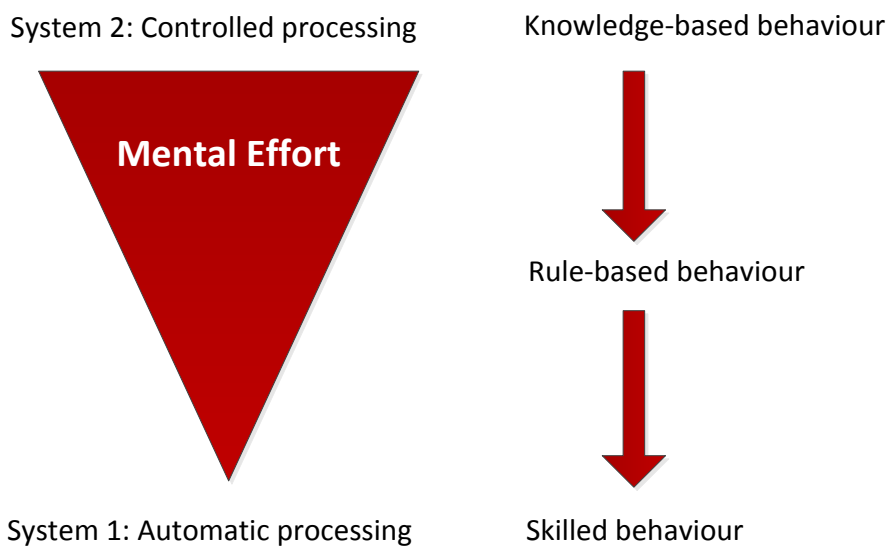

Figure 2 Rasmussen's stages of skill acquisition (adapted from Rasmussen, 1986)

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At these different levels of behaviour, different types of error occur. Table 2 provides a summary of the basic error types associated with skill-based, rule-based and knowledge-based behaviour.

Table 2 Generic Error Modelling System (Adapted from Reason, 1990)

Level of Performance	Basic Error Type	Description
Skill-based Behaviour	Slips and lapses	Automated unconscious failures of automatic processing (attention / memory) during routine actions which are detected fairly rapidly.
Rule-based Behaviour	Rule-based mistakes	Errors of ruled-based behaviour e.g. applying the wrong rule for a given situation.
Knowledge-based Behaviour	Knowledge-based mistakes	Errors of cognitive (knowledge-based) processing whereby a problem is not analysed correctly (or not at all) and results in an error.

3.1.1 Slips and Lapses

Slips are failures in carrying out the actions of a task. They are described as 'actions-not-as-planned'. Typical slips might include:

- doing the right thing but on the wrong object (e.g. switching the wrong switch);
- carrying out the wrong check but on the right item (e.g. checking a dial but for the wrong value);
- transposing digits when copying out numbers;
- performing an action too soon or leaving it too late;
- omitting a step or series of steps from a task; and,
- performing the action in the wrong direction (e.g. particularly with equipment that works differently to what the individual is familiar with).

Lapses cause us to forget to carry out an action, to lose our place in a task or even to forget what we had intended to do.

It should be noted that slips and lapses are errors which tend to occur in highly practised, well-trained behaviours, are by definition, not prevented by further training. They are best prevented by design but can be reduced by rigorous checking supported by mitigation measures such as use of checklists. In some cases, there may be an opportunity to enhance individual or team skills in order to more assertively reduce distractions/interruptions, but such approaches are likely less reliable then more preventative design measures. Preventative design measures include:

- ensure consistency in controls e.g. up always means off;
- layout controls so that those operated in sequence occur in that sequence and those which should not be operated in sequence are located separately;
- involve end users in designing the layout of controls and instrumentation;
- design in warnings and alarms which help people detect errors; and,
- design in features to prevent inadvertent operation.

The above list refers to cockpit design. Recognising that the aircraft being flown in air displays cannot generally be modified or redesigned, this study is focused on identifying mitigation measures used by display pilots to recognise the potential for error and mitigate against it (with a focus on

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