HUMAN FACTORS INVESTIGATION METHODOLOGY

Sarah Harris
Royal Air Force (RAF) Centre of Aviation Medicine
RAF Henlow, United Kingdom

There are many tools for assessing the Human Factors (HF) of accidents. Although these tools can aid the classification of factors in military accidents, they do not completely support the military *investigation* process. The RAF has therefore adapted the Human Factors Analysis and Classification System (HFACS) to develop a new Human Factors Investigation Methodology. This methodology combines some of the HFACS categories with the military operational process, providing a timeline to plot when accident factors may have emerged and a source framework to plot whether the factor emerged at the organisation, supervisory, task, equipment, environment or operator level. The benefit of the methodology is that it helps identify at which point the factor influenced one of the four key accident events; hazard entry, recovery, escape and survival, thus facilitating more effective recommendations. As it is generic, the methodology can be used for any investigation type, including preventative investigations.

This paper describes initial difficulties experienced with current investigation and classification tools and how a new methodology was developed to address these difficulties. Each part of the methodology is discussed in turn, along with recommendations for further development.

Requirement

The RAF initially used HFACS (Wiegmann and Shappell (2003)) to understand and classify accidents. Although this approach was effective at classifying accident factors and Reason's Swiss Cheese Model of Latent and Active Failures (Reason (1990)) was effective at understanding errors, neither approach was conducive for mapping to the standard military aviation process. Specifically, it did not reflect the timeline element of the military accident, which made it difficult to plot at which point each factor became a contributor, e.g. a pre-condition for an unsafe act can occur as a result of a previous unsafe act, making the standard template of supervision>preconditions>unsafe act difficult to use. Most importantly, the framework was not conducive for explaining to and integrating with the remaining Investigation Panel, who may have limited understanding of human factors and how HFACS may integrate with their part of the investigation.

Although other investigation tools are available, these are typically designed to provide inter-rater reliability and validity when offered across investigators to be applied to their accident scenario. Although these variables are important when non HF experts are attempting to understand their identified unsafe acts, these tools were found to be either too prescriptive and/or they focused mainly on the accident event itself. Again, they were not conducive for visual presentation to the remaining Investigating Panel as the models were visually different from their perception of the aviation process. Investigator buy-in and HF integration are key aspects to any investigation if the HF Investigation is to be effective.

To this end, as accidents and incidents occurred, a new methodology was developed. This included a timeline that visually represented the aviation process and allowed a more detailed understanding of the *route* and *timing* of risks and hazards.

Development

The Human Factors Investigation Methodology was developed to meet the investigation requirements. This methodology was developed throughout more than 30 military aircraft accidents, of which involved fixed-wing, rotary, multi-engine and unmanned aircraft and accident types from mid-air collisions to enemy action. This wide variety of accidents enabled the methodology to be refined as and when development issues arose.

As the methodology developed it was clear it would be based around some kind of timeline. It was also clear the factors from HFACS would also have to be represented as not only were these factors technically valid, they would also still be used in the post-accident phase of classification. This resulted in the identification of two axis: a timeline of events and a source for the type of factor. For this reason a *matrix* was developed to plot these two axis.

On the Y axis high level HFACS categories were plotted with some amendments:

1. A 'task' level was introduced to explicitly examine what it was the operator was trying to do at the time of the incident or accident. Specifically, this enabled explicit examination of the estimated margin for error for that task to assess its performance reliability.
2. The categories 'environment' and 'equipment' were separated out from technological environment and physical environment. This was easier to visually present to the remaining Investigation Panel.
3. Unsafe Acts or Acts were made into 'behaviours and actions' to include actions that were positive or benign, such as eating habits and secondary taskings.
4. The sub-categories within each level were broken out to include the most common areas within the military process. Not every sub-division within HFACS was represented at each relevant level as the methodology was designed to be an aid to detect routes, timings and relationships and not to be entirely prescriptive.

On the X axis the timeline was initially divided into 'Entry Conditions' to reflect those factors that occurred prior to the day of the event and the 'Accident Point', to reflect those factors that occurred on the day of the event. However, it was soon clear a distinction had to be made within the Accident Point to include a 'Readiness' stage, i.e. the stage the operator prepared themselves for what it was they were doing at the time of the accident. It then became apparent that the X axis timeline represented two 'Key Transition Points' (KTP): Entry Conditions > Accident Point and Readiness > In-Flight. These points were clear stages in the accident route when existing hazards and risks could have been mitigated. For this reason, estimation of the KTPs was included as a specific stage in the methodology.

Accounting for the X and Y axis, the matrix was termed 'Accident Route Matrix' (ARM).

During the refinement of the methodology additional factors were also realised. It became apparent there were certain questions that an HF investigator needed to answer to understand the sequence of events. By answering these questions it not only ensured the HF Investigator understood the accident but it also acted as a checklist for ensuring they had sufficient evidence. For this reason, the 10 important questions were termed 'Key Accident Characteristics' and also included as a specific stage in the methodology. Further, it became clear there were always four factors that occurred in the accident sequence: Hazard Entry, Recovery Response, Escape Response and Survival Response. For this reason, these factors were included in the ARM and 'Hazard Management' became another stage in the methodology. Finally, it was also realised that it was equally important to look at, from a HF perspective, how *detectable* the hazards were. For this reason, Detection became one of the final stages.

Results

The methodology consists of seven elements; Evidence Collection, ARM, Key Accident Characteristics, Hazard Management, KTPs, Detection and Advice (see Figure 1).
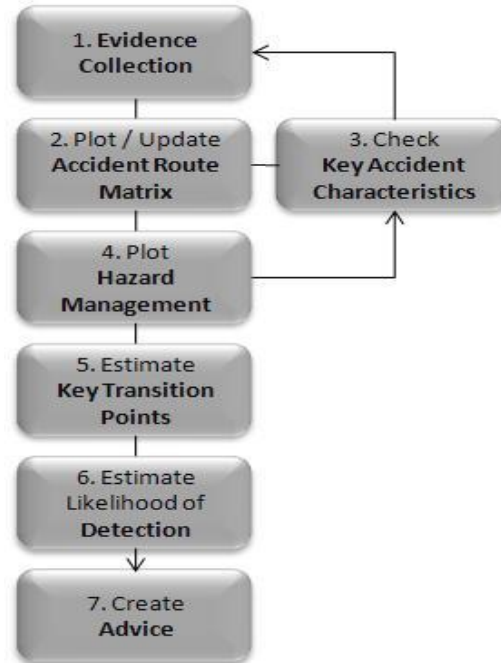

Figure 1.

All seven elements of the Human Factors Investigation Methodology

Evidence Collection

Subjective evidence. The initial stage of the methodology is to collect time-critical subjective evidence as soon as feasible post-crash. This usually involves one to one detailed interviews with the relevant operators using a semi-structured format. The types of questions usually follow the framework of the ARM (see Figure 2) but they can vary if required. Subjective data is collated for pilots within the aircraft (crew) and between aircraft (formation) to compare mission perspectives. Subjective data is also collated for other relevant parties such as Engineers, Supervisors and Air Traffic Controllers. Although not prescriptive, the subjective data can include performance data, which can be achieved by asking the operator to rate factors such as perceived arousal, demands, difficulty, frustration, pressure, awareness, understanding, communications and predicted success for each key phase of flight. For this methodology, individuals estimate these factors by pointing at a simple *Very Low > Very High* 5-point scale. The operator is also questioned on their point of focus, decisions and actions. Operators are then asked to estimate their views on Entry Condition and Readiness factors by pointing at a simple colour coded *Ideal > OK > Poor > Very Poor* 4-point scale. Although perceived estimates are not considered scientifically valid accounting for error in judgement, memory decay and distortion, the *change* in ratings, or the report of very negative ratings, has proved very useful for identifying areas for further assessment.

Objective Evidence. To validate subjective data, objective data from the crash site and Aircraft Data Recorder can be used to ascertain *actual* control inputs, crew communications, aircraft performance and hazard management.

Accident Route Matrix

The ARM forms the basis of the new HF methodology (see Figure 2). The ARM assists the HF investigation process by providing a framework to plot the subjective and objective data. Factors can be plotted by type (those at the Organisation, Supervision, Equipment, Environment or Operator level) and by time of effect (Entry Conditions or Accident Point). Data can be actually plotted using a blank ARM or the investigator can plot evidence in a report using the ARM as a framework. Once completed, the ARM can be read from top to bottom to understand how factors eventually influence Operator behaviours and operator Conditions, or it can be read left to right on each row to assess the route-cause of in-flight events, e.g. an unusual tasking in-flight may be explained by looking at typical tasking in the Entry Conditions and what tasks the operator is used to.
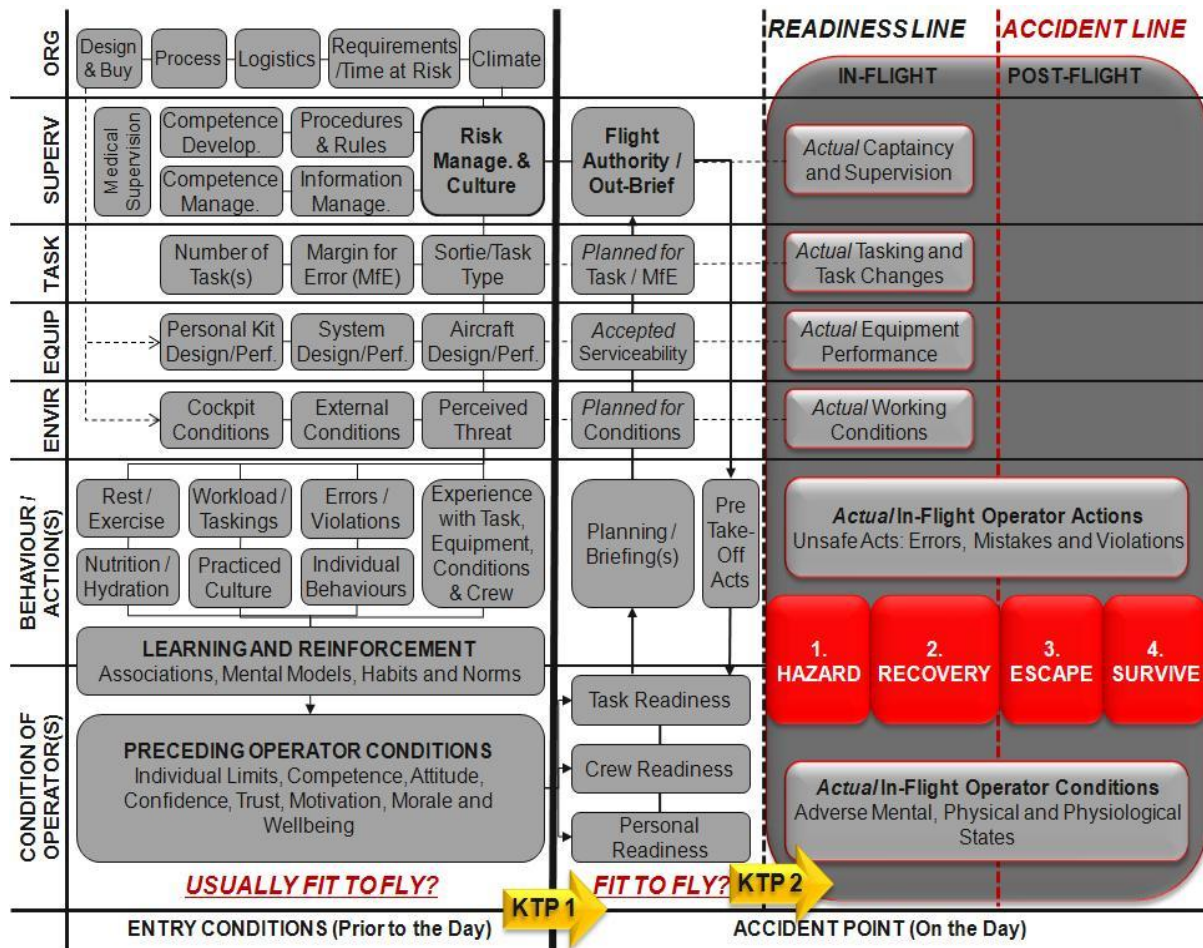

Figure 2.

Element 2 of the Human Factors Investigation Methodology: Accident Route Matrix

The ARM framework is based around a typical military aviation process. Within the Entry Conditions on the left-hand side, Organisation factors will influence the working environment in which the pilot will be working, Supervision and culture will influence the life the pilot will have on their Squadron and Equipment and Environment factors will influence their experience of flying.

In terms of the end state or effect of this, the Operator Behaviours section reflects what they have been doing, accounting for the conditions, tools and tasking, and how this has influenced their learning, associations and ultimately reinforcement of their behaviour. All factors eventually lead to Operator Conditions, i.e. the preceding condition the operator was in leading up to the accident day. Within the central Readiness column, the operator's Readiness will be influenced by the Entry Conditions + any over-night or on-the-day factors. At this point the operator may enter the planning and briefing stage and eventually, prior to take-off, their mission Readiness will be influenced by all Entry Conditions and Readiness factors. Post take-off the operator will enter the In-Flight stage and at some point, will pass through to the Post-Flight stage. This sequence can be applied to other operators, as it can be used to reflect generic on-shift Readiness and on-task performance.

Realistically in an accident sequence, subjective data is used to initially plot the centre and right-hand side of the ARM. As the investigation progresses, further subjective data may be collected and the ARM can be built up progressing to the left-hand side as appropriate. If available, further data from the aircraft, such as the Aircraft Data Recorder, Cockpit Voice Recorder and Head Up Display may be available to validate the ARM, turning any *suspect* or *reported* data into *actual* data.

Key Accident Characteristics

The investigator can now use the Key Accident Characteristics to ensure most significant data has been collected. Although this checklist is not exhaustive, it does act as a good prompt during the investigation. The Key Accident Characteristics include:

1. Was the operator suitably qualified?
2. Was the operator suitably current?
3. Had they recently practiced the task?
4. Had they been in the same situation before?
5. Was the task suitably planned?
6. Was the task achievable / reliably achievable?
7. Was the task justified (accounting for operational benefit v risk)?
8. Was the task correct (accounting for current procedures and rules)?
9. Was the task suitably authorised?
10. Was the behaviour intended and/or recognised?

Hazard Management

A Hazard Management assessment will help the HF Investigator identify how the crew managed the accident and how they progressed into the escape and survival stages. With both subjective and objective data, the investigator should be able to plot the points in Figure 3.
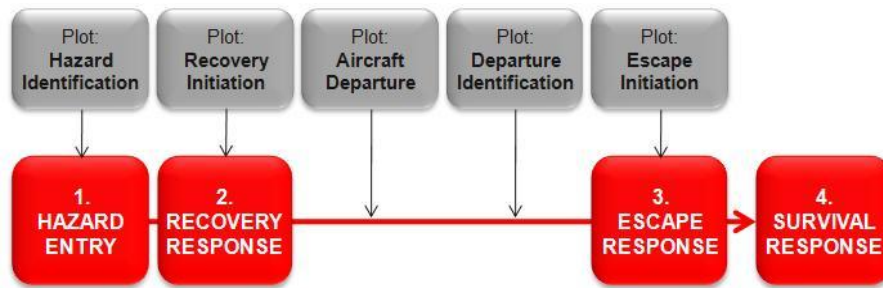
Figure 3.

Element 4 of the Human Factors Investigation Methodology: Hazard Management
Key Transition Points

Once the ARM has been completed and the HF Investigator is confident all available data has been assessed, the two KTPs can be qualitatively estimated (see Figure 2 for location of KTPs).

1. KTP 1 is based on the identified Entry Conditions and addresses the question - what was the level of risk carried for the entire Squadron, i.e. were all pilots at risk of this accident?
2. KTP 2 is based on the identified Readiness stage and addresses the question - what was the level of risk carried for the specific crew, i.e. were the crew at risk of this accident before they even took off?

These questions will help identify at which point the hazard/risk developed to a point it increased the probability of the accident being investigated.

Detection

Once the ARM and KTPs have been completed, the HF Investigator should use knowledge of information processing and perception to qualitatively estimate whether the hazards and risks could have been realistically detected by either the crew and/or the supervisory chain. Such information facilitates a better understanding of why the hazards and increased risks existed in the first place.

Advice

The final stage of the methodology is to provide advice based on the outputs of the investigation. Advice can be at any of the ARM levels and can state its probable improvement of one or more of the four key accident factors - Hazard Entry, Recovery Response, Escape Response and Survival Response.

Conclusion and Application of the Human Factors Investigation Methodology

The Human Factors Investigation Methodology has been developed to the stage it is usable for all accident sequences and aircraft types. It is also usable for all levels of operators, e.g. for a supervised individual and their supervisor. It can be used preceding use of HFACS and it can be used as a *preventative* methodology. The RAF currently use the methodology to conduct Operational Events Analysis, which includes application of the Human Factors Investigation Methodology but *before* an accident has happened.

However, for the methodology to be distributed as a tool, scientific validation would need to be conducted to assess factors such as inter-rater reliability. Further, should the methodology be required to produce quantitative results, the KTPs and Detection elements would need further work to ascertain if risk and error probabilities could be reliably used.

References

Reason, J. (1990). Human Error. New York Cambridge University press.

Wiegman, D. A., & Shappell, S. A. (2003). A human error approach to aviation accident anlaysis: The Human Factors Analysis and Classification System. Ashgate Publishing.