Proactive Tools For Identifying and Managing Human Factors Risks in Aviation Maintenance

Dr David Embrey
Managing Director
Human Reliability Associates
Aims of the workshop

• To introduce a tried and tested HF analysis process SHERPA (Systematic Human Error Reduction and Prediction Analysis)
• To illustrate how the analysis method can systematically identify risks of errors in aviation maintenance
• To illustrate application of SHERPA to procedures / checklist design
• Application of SHERPA to incident investigation and Root Causes Analysis
• To provide practical experience in the application of these techniques.
What is SHERPA?

• Systematic Human Error Reduction & Prediction Approach
• A set of tools to document and risk assess safety critical tasks
• Combines FMEA, HAZOP, root cause analysis and procedures development in a single methodology
SHERPA Capabilities

• Provides a structured and transparent process for prospective analysis of human error potential
• A method for evaluating how tasks are actually carried out (including undocumented knowledge) from subject matter experts, e.g. aircraft maintainers
• Identifies potential failures with severe consequences
• Assesses factors influencing maintenance error (Performance Influencing Factors) in specific situations
• Generates ‘Risk Aware’ procedures and training recommendations from the task and risk analyses
Application areas for SHERPA

- Design of maintenance tasks to minimise error
- Analysis of root causes of near misses and failures
- Development of ‘Risk Aware’ training and competency management
- HF risk assessment of existing maintenance procedures
- Development of ‘Risk Aware’ procedures and job cards
- Analysis of root causes of near misses and failures
Stages of SHERPA

- Task Identification
- Task Analysis
- Failure Identification
- PIF (Performance Influencing Factors) analysis
Task analysis
Why do we use Hierarchical Task Analysis (HTA)?

- It allows us to document and understand how maintainers interact with the hardware, the maintenance system and each other.
- Graphical representation of the task and its structure - easy to understand.
- HTA documents the *why* as well as *what* is done.
- HTA paves the way for systematic human failure analysis.
HTA – Some basic pointers

• Use direct language – for example:
  – Insert, Open, Push, Check, Calculate, Monitor
  – This clarifies the actions which are involved using the device

• Assign only one action per box
  – This is important for the failure analysis steps which will follow
  – We can break this rule if actions are very tightly coupled, e.g. push the cable through the pulley and into the nose cone
HTA – Some basic pointers

• Separate actions from descriptive text
  – Use Plans to define how the actions are to be carried out to achieve the objective of the task or subtask
  – Do in order/sequence, do in parallel, if condition X do Y

• Assigning attributes to boxes
  – Agent/person who performs the activity
  – Activity type (see later discussion)
  – Where activity is performed
Top level of HTA:
Replace tail rotor control cable
Breakdown of subtask 1: Prepare for replacement

1. Prepare for replacement

Plan 1
- Do 1-4.
- If necessary (?) do 5.
- If helicopter has a self-centering quadrant, and the tail rotor cables are spring loaded do 6.
- do 7-8.

1.1 Remove electrical and hydraulic power from the aircraft and ensure that systems are depressurised
1.2 De-panel the aircraft as required to gain access to the full run of the control cables
1.3 Remove the fairleads for the forward portion of the right and left cables
1.4 To aid reassembly, mark the side of the frame from which each fairlead was removed
1.5 Remove the sleeves at stations 188 and 300
1.6 Have an assistant hold the quadrant levers in the retracted position against the quadrant stops before disconnecting the cables at the turnbuckle barrels
1.7 Disconnect the cable at the turnbuckle barrels
1.8 Allow the quadrant levers to extend to relieve the spring tension
<table>
<thead>
<tr>
<th>ID</th>
<th>Description</th>
</tr>
</thead>
</table>
| Plan 0 | Do 1-3  
Do 4-5 in parallel  
Do 6-9 in sequence |
| 1 | Prepare for replacement |
| Plan 1 | Do 1-4.  
If necessary (?) do 5.  
If helicopter has a self-centring quadrant, and the tail rotor cables are spring loaded  
do 6.  
do 7-8. |
| 1.1 | Remove electrical and hydraulic power from the aircraft and ensure that systems are depressurised |
| 1.2 | De-panel the aircraft as required to gain access to the full run of the control cables |
| 1.3 | Remove the fairleads for the forward portion of the right and left cables |
| 1.4 | TO AID REASSEMBLY, MARK THE SIDE OF THE FRAME FROM WHICH EACH FAIRLEAD WAS REMOVED |
| 1.5 | Remove the sleeves at stations 188 and 300 |
| 1.6 | HAVE AN ASSISTANT HOLD THE QUADRANT LEVERS IN THE RETRACTED POSITION AGAINST THE QUADRANT STOPS BEFORE DISCONNECTING THE CABLES AT THE TURNBUCKLE BARRELS |
• Workshop Exercise 1

Using the Human factors Risk Manager software or Post-it notes and Flip charts, map the steps in the maintenance procedure provided onto the subtasks shown in the earlier slide (or create your own subtasks)
Failure analysis

Applying a systematic approach to the identification of foreseeable use errors
From Activity types to Error modes

• We can classify the different types of activities in a maintenance task
• In aviation maintenance the main activities that are documented in the procedures are actions and checks
• However, other types of activity are present (undocumented) that can have a bearing on error
  – Information communication-person to person
  – Information retrieval / entry (referring to a checklist or manual)
  – Selection (between similar items)
• Each activity type has an associated set of possible error modes
<table>
<thead>
<tr>
<th>Actions</th>
<th>Checking</th>
<th>Information retrieval</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACT1 Action too long/short</td>
<td>ACT7 Right action on wrong object</td>
<td>CH1 Check omitted</td>
</tr>
<tr>
<td>ACT2 Action mistimed</td>
<td>ACT8 Wrong action on right object</td>
<td>CH2 Check incomplete</td>
</tr>
<tr>
<td>ACT3 Action in wrong direction</td>
<td>ACT9 Action omitted</td>
<td>CH3 Wrong object or action checked</td>
</tr>
<tr>
<td>ACT4 Action too little/much</td>
<td>ACT10 Action incomplete</td>
<td>CH4 Wrong check</td>
</tr>
<tr>
<td>ACT5 Action too fast/slow</td>
<td>ACT11 Action too early/late</td>
<td>CH5 Check too late/early</td>
</tr>
<tr>
<td>ACT6 Misalign</td>
<td>ACT12 Action in wrong order</td>
<td></td>
</tr>
<tr>
<td>Selection</td>
<td>Information entry</td>
<td>Communication</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>-------------------------------------------------------</td>
<td>---------------------------------------------------</td>
</tr>
<tr>
<td>SEL1 Selection omitted</td>
<td>INFE1 Information entered into wrong place/field</td>
<td>COM 1 Information not communicated</td>
</tr>
<tr>
<td>SEL2 Wrong selection</td>
<td>INFE2 Wrong information entered</td>
<td>COM 2 Wrong information communicated</td>
</tr>
<tr>
<td></td>
<td>INFE3 Information entry incomplete</td>
<td>COM3 Incomplete information communicated</td>
</tr>
<tr>
<td></td>
<td>INFE4 Information entry not checked/verified</td>
<td>COM4 Ambiguous/unclear information communicated</td>
</tr>
</tbody>
</table>
Failure analysis

• Classify the steps in the HTA into activity types
• Assume that one or more of the failure modes could occur for the steps under consideration
• Are they credible (may need further information on this—see later)?
• Evaluate their consequences - low, medium high?
• Could they be recovered, by the individual or barriers built into the system (Risk Control Measures)?
  – Are these recoveries (barriers) robust and resilient over time?
  – Are they ever tested?
Analysis of a critical step

4.1
Thread both aft cables through the vertical stabiliser
Maintenance technician 1

4.2
Thread both aft cables through the pulleys at the intermediate gearbox and on through the tail cone
Maintenance technician 2

4.3
Thread the RIGHT aft cable through the tail gear box INNER pulley
Maintenance technician 2

4.4
Thread the LEFT aft cable through the tail gear box OUTER pulley
Connect the RIGHT aft cables to the aft quadrant
Maintenance technician 1

4.5
Connect the LEFT aft cables to the aft quadrant

4.6
Maintenance technician 1

4.7
ENSURE THAT THE CABLES ARE.Thread through the grooves in the pulleys but do not insert the pulley guard pins yet

AND

Fm 4.4.1
ACT7 Right action on wrong object

Fm 4.4.2
CH1 Check omitted
<table>
<thead>
<tr>
<th>ID</th>
<th>Description</th>
<th>Agent/Person</th>
<th>Activity Type</th>
<th>Failure Mode</th>
<th>Error Description</th>
<th>Consequences</th>
<th>Consequence Type</th>
<th>Existing Risk Control Measures / Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.4</td>
<td>Thread the LEFT aft cable through the tail gear box OUTER pulley</td>
<td>Maintenance technician 2</td>
<td>Actions</td>
<td>ACT7 Right action on wrong object</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fm 4.4.1</td>
<td></td>
<td>Actions</td>
<td>ACT7 Right action on wrong object</td>
<td>LH cable through inner pulley</td>
<td>Control sense would be reversed</td>
<td>Major Accident Hazard</td>
<td>Self Verification by maintenance technician</td>
<td></td>
</tr>
<tr>
<td>Fm 4.4.2</td>
<td></td>
<td>Checking</td>
<td>CH1 Check omitted</td>
<td>No verification of preceding step</td>
<td>Previous error would be unrecovered</td>
<td>Recovery failure</td>
<td>None</td>
<td></td>
</tr>
</tbody>
</table>
Workshop exercise 2

• Classify the activity types in some of the subtasks in the helicopter maintenance procedure example

• Using the list of failure types provided, document
  – The possible error types
  – Their consequences
  – Possible barriers or recovery that could mitigate or prevent these consequences
Performance Influencing Factor (PIF) Analysis

Assessing the factors that determine likelihood of error
Purpose of PIF analysis

• Evaluate factors that drive error probabilities
• Evaluate factors that degrade barriers and recovery likelihood
• Identify deficiencies
• Evaluate cost effectiveness of alternative error reduction interventions
• Implement improvements
Example Classification of Performance Influencing Factors (PIF)

• Task related
  – Complexity
  – Cognitive demands

• Hardware related
  – Control layout
  – Display design-information input
  – Display design-information retrieval
  – Physical barriers to incorrect operation
  – Constraints / interlocks to prevent incorrect operation (forcing functions)
  – Feedback to allow error correction
  – Labelling

• Context of use
  – Distractions
  – Physical environment
  – Time pressure
  – Multitasking

• Individual/team
  – Level of experience / training
  – Fatigue
  – Quality of external support from procedures / checklists
  – Quality of communications
Summary of Human Factors Failure Analysis Process

1. Decide on activity types involved in task or task step, e.g. Actions, Checking Communication
2. For each activity type specify failure modes, e.g. action omitted, right action, wrong object
3. For each failure mode evaluate Performance Influencing Factors (PIFs) which affect likelihood of error
<table>
<thead>
<tr>
<th>ID</th>
<th>Description</th>
<th>Agent/Person</th>
<th>Activity Type</th>
<th>Failure Mode</th>
<th>Error Description</th>
<th>Consequences</th>
<th>Consequence Type</th>
<th>Existing Risk Control Measures / Recovery</th>
<th>Performance Influencing Factors</th>
<th>Risk Reduction Measures</th>
<th>Warnings</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.4</td>
<td>Thread the LEFT aft cable through the tail gear box OUTER pulley</td>
<td>Maintenance technician 2</td>
<td>Actions</td>
<td>ACT7 Right action on wrong object</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Take care! Severe operational consequences as rotor may not be controllable</td>
</tr>
<tr>
<td>Fm 4.4.1</td>
<td></td>
<td></td>
<td>Actions</td>
<td>ACT7 Right action on wrong object</td>
<td>LH cable through inner pulley</td>
<td>Control sense would be reversed</td>
<td>Major Accident Hazard</td>
<td>Self Verification by maintenance technician</td>
<td>Distractions</td>
<td>Additional checklist for safety critical steps</td>
<td></td>
</tr>
<tr>
<td>Fm 4.4.2</td>
<td></td>
<td>Checking</td>
<td>CH1 Check omitted</td>
<td>No verification of preceding step</td>
<td>Previous error would be unrecovered</td>
<td>Recovery failure</td>
<td>None</td>
<td></td>
<td>Likelihood of failure perceived to be low by maintainer</td>
<td>Additional checklist for safety critical steps</td>
<td></td>
</tr>
</tbody>
</table>
Workshop exercise 3

• Using the potential failures identified earlier,
  – Identify the PIFs that could typically affect the likelihood of failures (based on your experience)
  – Suggest countermeasures, barriers or improvements in the PIFs to reduce the likelihood of failure to an acceptable level
    • Redesign the task?
    • Introduce checklists?
    • Reduce the distractions?
Applications for SHERPA Analyses

• Design of new maintenance tasks to minimise error
• Human Factors risk analyses for safety critical maintenance operations
• Development of ‘Risk Aware’ procedures, checklists and training programmes
• Using the PIF tools to identify Root Causes of incidents or near misses
From concept to detailed design: Using HTA as an iterative process in maintenance task design

• Concept stage
  – Identify the key (proposed) maintenance operations. This would initially form the top level of the analysis.
  – Further detail will follow once device understanding and the engineering specification develops.
  – *IMPORTANT Using Task and Error analysis to identify potential vulnerabilities as the design develops allows early interventions to optimise PIFs and minimise design induced error.*

• Detailed design
  – Progressively build up the HTA as understanding of the maintenance task develops.
  – At each stage of increased detail HTA can be used to outline additional design requirements.
Using SHERPA for designing procedures and checklists

• Use the HTA as the basis for the structure of the procedures
  – Breakdown into subtasks facilitates understanding of objectives of individual steps
  – Risk analysis information collected during the SHERPA analysis can be transmitted to the procedure/checklist in the form of warnings or comments
  – Alerts the maintainer regarding error vulnerability / negative consequences of errors

• The Human Factors Risk Manager software can automatically convert the HTA and Risk analysis into a MS Word procedure which highlights critical steps and warnings
Branch from HTA

Plan 4
Do in Sequence

4
Connect aft cables to aft quadrant
Maintenance technician 1

4.1
Thread both aft cables through the vertical stabiliser
Maintenance technician 1

4.2
Thread both aft cables through the intermediate gearbox and on through the tail cone
Maintenance technician 1

4.3
Thread the RIGHT aft cable through the tail gear box INNER pulley
Maintenance technician 2

4.4
Thread the LEFT aft cable through the tail gear box OUTER pulley
Maintenance technician 2

4.5
Connect the RIGHT aft cables to the aft quadrant
Maintenance technician 1

4.6
Connect the LEFT aft cables to the aft quadrant
Maintenance technician 1

4.7
ENSURE THAT THE CABLES ARE THREADED THROUGH THE GROOVES IN THE PULLEYS BUT DO NOT INSERT THE PULLEY GUARD PINS YET
Checker

4.8
Loosely install the aft cable fairleads (14)
Maintenance technician 1
## Procedure generated from HTA including warnings

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
<th>Role</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Connect aft cables to aft quadrant</td>
<td>Maintenance technician 1</td>
<td></td>
</tr>
<tr>
<td>Plan 4</td>
<td>Do in Sequence</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.1</td>
<td><strong>WARNING:</strong> Take care! Error at this stage could have <strong>Severe operational consequences as rotor may not be controllable</strong></td>
<td>Maintenance technician 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thread both aft cables through the vertical stabiliser</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.2</td>
<td>Thread both aft cables through the pulleys at the intermediate gearbox and on through the tail cone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.3</td>
<td><strong>WARNING:</strong> Take care! Error at this stage could have <strong>Severe operational consequences as rotor may not be controllable</strong></td>
<td>Maintenance technician 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thread the RIGHT aft cable through the tail gear box INNER pulley</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Using SHERPA for Incident investigation and Root Causes Analysis

• The HTA produced by SHERPA represents the agreed way to carry out a maintenance task
• RCA focuses on which activities failed to give rise to the unwanted consequences
  – Map the incident on a timeline (STEP / Swimlane diagram)
  – Identify the type of activity that failed
  – Evaluate the immediate and organisational PIFs that contributed to the failure
  – Identify improvement strategies
HTA converted to Swimlane diagram for Root Causes analysis

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>Maintenance technician 1</td>
<td>Thread both aft cables through the vertical stabiliser</td>
<td>Maintenance technician 1</td>
<td>4.2</td>
<td>Thread both aft cables through the pulleys at the intermediate gearbox and on through the tail cone</td>
<td>Maintenance technician 1</td>
<td>4.3</td>
</tr>
</tbody>
</table>

4.7 Ensure that the cables are threaded through the grooves in the pulleys but do not insert the pulley in the socket.
4.7: ENSURE THAT THE CABLES ARE THREADED THROUGH THE GROOVES IN THE PULLEYS BUT DO NOT INSERT THE PULLEY GUARD PINS YET

Failure Probability = 0.0244

Success Likelihood Index (SLI) = 0.49

1. -100
   5.1 The need to carry out the check is not obvious
   25

2. -100
   5.2 The value of carrying out the check is perceived to be low compared with other competing priorities
   75

3. -100
   5.3 The value of the checks seems to be low because there are other checks/barriers that are perceived as able to recover/prevent errors
   50

4. -100
   5.4 There is insufficient time to carry out the check
   50

5. -100
   5.5 Distractions are excessive
   50

6. -100
   5.6 Training and/or experience in carrying out the check is limited
   50

5.1 Access to/ maintenance of the area is poorly controlled
0

5.2 Several jobs are being carried out at once
75

5.3 An excessive amount of paperwork is required
100

5 Point Scale
100 Point Scale
Statement Assessment
Acceptable / Unacceptable

Comments
Formula
ADEPT / ART Options
Deficiency
Action

- Strongly Agree
- Agree
- Neither Agree nor Disagree
- Disagree
- Strongly Disagree
Profile of PIFs when the incident occurred based on ratings

SLI (Quality Index) = 0.49  Probability = 0.0244