The role of maintenance and inspection in accident prevention

Robert L. Sumwalt
NTSB Board Member
NTSB is an independent federal agency, charged by Congress to investigate transportation accidents, determine probable cause, and issue safety recommendations.
Maintenance-Related Safety Alerts

- Proper use of self-locking nuts
- Risk management for maintenance techs
- Ensuring ELTs are properly mounted and installed
Loss of Control
Eurocopter AS350
Las Vegas, Nevada
December 7, 2011
Initial Information

• Sightseeing tour from Las Vegas to Hoover Dam
• Normal departure – visual flight rules
• Calm wind, good visibility
• Standardized tour route
Sequence of Events

Hoover Dam

Sudden climb and turn

Steep descent and crash site

Path approximate and not to scale, for visualization only

3,300 feet, 90° off course
Events prior to accident

- 100-hour maintenance inspection conducted the day prior
- Fore/aft servo replaced
- Check flight flown
- 2 tour flights flown
- Accident occurred on
  - Third tour flight
  - 3.5 flight hours after maintenance
View of Helicopter Components

Input rod and fore/aft servo

Main rotor assembly

Cockpit and cabin
Installed Connection

- Input Rod
- Fore Aft Servo with Ice Shield
Hardware

Input rod hardware

- Split Pin
- Washer
- Bolt
- Castellated Nut
- Servo Input Rod

Hardware installed

- Fore/Aft servo with Ice Shield
- Input Rod
Input Rod and Servo

- Input rod
- Servo body
- Lugs
Safety Issues Identified

• Reuse of degraded self-locking nuts
• Maintenance personnel fatigue
• Lack of human factors training for maintenance personnel
• Lack of work cards with delineated steps
Maintenance Issues
Maintenance Performed day prior to accident

• 100-hour inspection
• Replacement of the following:
  • Engine
  • Fore/aft and tail rotor servos
Fore/Aft Servo Installation

• Fore/aft servo installation procedures:
  - Assess hardware
  - Connect servo to input rod
  - Torque nut
  - Install split pin
• Inspect installation
Self-Locking Nut

Acceptable Nut

Degraded Nut
Hardware Reuse

• Post accident inspection of 13 Sundance helicopters - half of nuts did not meet below requirements

Manufacturer’s guidance: “If a nut can be easily tightened, it is to be discarded”

FAA guidance: “DO NOT reuse a fiber or nylon lock nut if the nut cannot meet the minimum prevailing torque values”
The fore/aft servo bolt most likely disengaged because:

- the split pin was installed improperly or it was not installed, and
- a self-locking nut that either was degraded or not torqued was used

This allowed the nut to unthread and separate from the bolt.
Post-maintenance Inspection and Check Flight

- Mechanic and inspector completed inspection
- Helicopter check flight conducted
  - Hydraulic belt tension
  - No flight discrepancies
“The mechanic, inspector, and check pilot each had at least one opportunity to observe the fore/aft servo self-locking nut and split pin; however, they did not note that the split pin was installed improperly or not present.”
FAA Actions

• GA Maintenance Alert Issued - November 2012
• Aviation Maintenance Alert to be issued - Early 2013
• Updated inspection authorization renewal training begins - Spring 2013
Human Performance Issues
Maintenance and Inspection Errors

• Improper securing of the fore/aft servo
• Improper tension of the hydraulic belt
• Incomplete maintenance inspection
Maintenance Personnel Fatigue

• The mechanic
  - Recent sleep and wake activity
  - Shift change
  - Inadequate sleep
Maintenance Personnel Fatigue

• The inspector
  - Recent sleep and wake activity
  - Shift change
  - Long duty day
<table>
<thead>
<tr>
<th>Personnel</th>
<th>Normal Shift</th>
<th>Shift Originally Scheduled for December 6</th>
<th>Actual Schedule on December 6</th>
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<tbody>
<tr>
<td>Mechanic</td>
<td>Noon to 11:00 pm</td>
<td>Off duty</td>
<td>5:50 am to 6:46 pm</td>
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<tr>
<td>Inspector</td>
<td>Noon to 11:00 pm</td>
<td>Off duty</td>
<td>5:31 am to 6:55 pm</td>
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Maintenance Personnel Fatigue

• Effects of fatigue
  - Difficulty sustaining attention
  - Memory errors
  - Lapses in performance
Fatigue Affects on Performance

- 2 hour sleep debt can produce performance decrements comparable to those produced by BAC of 0.045.
- 4 hour sleep debt can produce performance decrements comparable to BAC of 0.095.
Sleep loss decreases performance

- 2 hours sleep loss
  » Productivity decreases by 17 percent

- 4 hours sleep loss
  » Productivity decreases by 43 percent

- Source: Mark Rosekind, Ph.D.
According to experts...

“When you lose sleep or disrupt your sleep clock, every aspect of your capability as a human being is impaired.”

- Mark Rosekind, Ph.D.

Rosekind says that even moderate sleep loss can result in decreases in:

- **Memory** (up to 20%)
- **Vigilance** (75%)
- **Communication skills** (30%)
- **Reaction times** (25%)
- **Judgment-making skills** (50%)
• “Because both the mechanic and the inspector had insufficient time to adjust to working an earlier shift than normal, they were experiencing fatigue during the December 6 shift.”

• “In addition, the mechanic had an inadequate amount of sleep and the inspector had a long duty day, both of which also contributed to the development of their fatigue.”
“Both the mechanic’s performance and the inspector’s performance probably were degraded by fatigue, which contributed to the improper securing of the fore/aft servo connection hardware, the improper installation of the hydraulic belt, and the incomplete maintenance inspection of the accident helicopter, respectively.”
Human Factors Training

• Causes of fatigue, its effects, and countermeasures
• Fatigue education as part of a training curriculum
• No human factors training requirement in United States
Work Cards With Delineated Steps

• Paperwork for 100-hour inspection
• Inspector signoff for overall fore/aft servo installation
• No specific signoffs for critical steps within task
### 100-Hour Inspection Paperwork

#### DISCREPANCY

<table>
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<tr>
<th>MAKE</th>
<th>DISCREPANCY LIST</th>
<th>DATE</th>
<th>AF</th>
<th>ENG</th>
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<th>PG</th>
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<td>AS350B2</td>
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#### DISCREPANCY LIST

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<th>Description</th>
<th>Date</th>
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<th>Action</th>
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<td>RMVC F/A SERVO PN AC87246 SN RX 187 DUE OIH</td>
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<td>16</td>
<td>TR SERVO PN AC87032 SN FE 212 DUE OIH</td>
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<td>17</td>
<td>Remove Amx D1 Engine S/N 9999</td>
<td>12-6-11</td>
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<tr>
<td>18</td>
<td>Chk Thr Air Duct</td>
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#### CORRECTIVE ACTION

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### Sign off

- [X] Signature
- [ ] Cert. No.
- [ ] Action

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**Notes:**
- [X] Yes
- [ ] No
Work Cards With Delineated Steps

Sample work card

<table>
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<tr>
<th>DESCRIPTION</th>
<th>MECH</th>
<th>INSPECTION</th>
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<tr>
<td>3. INSTALL NOSE LANDING GEAR - REFERENCE AMM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. Check trunnion bearings and drag brace bearing for proper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>installation and freedom of movement.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B. Support gear and jack with axle jack to insert trunnion pins in</td>
<td></td>
<td></td>
</tr>
<tr>
<td>respective spherical bearings (13) on each side of the nose gear</td>
<td></td>
<td></td>
</tr>
<tr>
<td>wheel well.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. Jack gear to proper height and tap trunnion pin into place in each</td>
<td></td>
<td></td>
</tr>
<tr>
<td>trunnion and trunnion support spherical bearing (13) then remove axle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>jack.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOTE: NOSE GEAR MUST BE LIFTED INTO POSITION</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WITH GEAR TRUHNION AXIS PARALLEL TO TRUHNION BEARING AXIS.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ascertain that the trunnion pin lockpin holes are in alignment with</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mating holes in trunnion pin lockpins.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mech: X  Insp: Y
Probable Cause

Sundance Helicopters’ inadequate maintenance of the helicopter, including:

(1) the improper reuse of a degraded self-locking nut

(2) the improper or lack of installation of a split pin

(3) inadequate post-maintenance inspections, which resulted in the in-flight separation of the servo control input rod from the fore/aft servo and rendered the helicopter uncontrollable.
Probable cause (continued)

• Contributing to the improper or lack of installation of the split pin was the mechanic’s fatigue and the lack of clearly delineated maintenance task steps to follow.

• Contributing to the inadequate post-maintenance inspection was the inspector’s fatigue and the lack of clearly delineated inspection steps to follow.
“Establish duty-time regulations for maintenance personnel working under 14 Code of Federal Regulations Parts 121, 135, 145, and 91 Subpart K that take into consideration factors such as start time, workload, shift changes, circadian rhythms, adequate rest time, and other factors shown by recent research, scientific evidence, and current industry experience to affect maintenance crew alertness.”
Encourage operators and manufacturers to develop and implement best practices for conducting maintenance under 14 Code of Federal Regulations Parts 135 and 91 Subpart K, including, but not limited to, the use of work cards for maintenance tasks, especially those involving safety-critical functions, that promote the recording and verification of delineated steps in the task that, if improperly completed, could lead to a loss of control.
Recommendation

“Require that personnel performing maintenance or inspections under 14 Code of Federal Regulations Parts 121, 135, 145, and 91 Subpart K receive initial and recurrent training on human factors affecting maintenance that includes a review of the causes of human error, including fatigue, its effects on performance, and actions individuals can take to prevent the development of fatigue.”