MINIATURE FLIGHT DATA RECORDERS

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ABSTRACT

This research project aims to deliver a reference design for a light aircraft (Helicopter or Aeroplane) solid-state flight data recorder utilising new technologies and to produce new flight data analysis software tools.

It is envisaged that such a device and software tools would contribute to flight safety through improvements in flight training and providing pro-active aircraft maintenance data, while lowering operating costs. It could also provide valuable extra information to accident investigators. The culmination of this research will be results indicating whether or not this is true.

The flight data recorder device will be similar in capabilities to current commercial flight data, engine monitoring and voice recorders but of a size, weight and (very low) cost appropriate to ‘General Aviation’ light aircraft. The design itself will be modular to allow for use in different aircraft and different circumstances, as becomes appropriate. Three primary uses for this device have been identified; 1) a blackbox for accident investigators, 2) a flight profile recorder for use in training organizations and 3) an engine and airframe condition recorder for use by operators and maintenance organizations.

At this time, two innovative prototype devices have been designed and are currently undergoing initial trials in Robinson helicopters with full trials to follow later this year. Ongoing discussions with other manufacturers and operators are expected to lead to evolved designs.

The associated database / software would be capable of displaying flight data using a variety of graphical techniques and would make use of statistical analysis to automatically determine various stages of flight and engine / airframe limit exceedances.

INTRODUCTION

The National Transportation Safety Board (NTSB) (Ref. 1) describes “black boxes” thus:

“Currently large commercial aircraft and some smaller commercial, corporate, and private aircraft are required by the Federal Aviation Authority (FAA) to be equipped with two “black boxes” that record information about a flight. Both recorders are installed to help reconstruct the events leading to an aircraft accident. One of these, the Cockpit Voice Recorder (CVR), records radio transmissions and sounds in the cockpit, such as the pilot’s voices and engine noises. The other, the Flight Data Recorder (FDR), monitors parameters such as altitude, airspeed and heading. Older analog units used one-quarter inch magnetic tape as a storage medium and the newer ones use digital technology and memory chips. Both recorders are installed in the most crash survivable part of the aircraft, usually the tail section.

Each recorder is equipped with an Underwater Locator Beacon to assist in locating in the event of an overwater accident.

Following an accident, both recorders are immediately removed from the accident site and transported to NTSB headquarters in Washington D.C. for processing. Using sophisticated computer and audio equipment, the information stored on the recorders is extracted and translated into an understandable format. The Investigator-in-Charge uses this information as one of many tools to help the Safety Board determine the Probable Cause of the accident.

Both the FDR and the CVR have proven to be valuable tools in the accident investigation process. They can provide information that may be difficult or impossible to obtain by other means. When used in conjunction with other information gained in the investigation, the recorders are playing an ever increasing role in determining the Probable Cause of an aircraft accident.”

Whilst there are many initiatives to improve General Aviation helicopter flight safety there is very little emphasis on the recording and analysis of flight data for small helicopters, and any existing “black box”
solutions are too cumbersome and expensive for this segment of the industry. It may be possible to create cost-effective new solutions specifically appropriate to smaller helicopters which would significantly contribute towards improving flight safety.

Small helicopters are typically used for flight training, personal transport and certain Air Operator Certification (AOC) work rather than for Emergency Medical Services (EMS), Construction / Fire fighting / Logging type work or mass passenger transport.

This research concentrates on the most common small helicopters, weighing less than 800kg and which typically have no or very limited forms of digital flight data recorder.

Taken all together (Table 1), the Enstroms, Robinsons, Schweizers and smallest Bells account for slightly more than 50% of the U.S. Civil Registered Helicopter Fleet (Ref. 2) and just under 50% of all helicopter accidents as recorded in the (NTSB) on-line database for 2004 (Ref. 3).

Also, the FAA states in Flight Plan 2005-2009 (Ref. 4) that its goal is to “achieve the lowest possible accident rate and constantly improve safety” and a specific objective is “reduce the number of fatal accidents in general aviation”.

Therefore this subject area is extremely worthy of additional flight safety research.

The FAA Revisions to Cockpit Voice Recorder (CVR) and Digital Flight Data Recorder (DFDR) Regulations; Proposed Rule (Ref. 5) states that they are applicable only to aeroplanes and helicopters certificated for 10 or more seats and so are not immediately relevant to any DFDRs for small helicopters. Despite not being mandatory, the rules do suggest sensible criteria for any DFDR.

Table 1: Small Helicopters in U.S. Fleet

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<tbody>
<tr>
<td>Bell TH-13/47</td>
<td>749kg / 3</td>
<td>1,192</td>
<td>9</td>
</tr>
<tr>
<td>Bell 206 (Ref. 13)</td>
<td>777kg / 5</td>
<td>2,444</td>
<td>34</td>
</tr>
<tr>
<td>Enstrom F-28/280</td>
<td>744kg / 3</td>
<td>440</td>
<td>6</td>
</tr>
<tr>
<td>Robinson R22 (Ref. 14)</td>
<td>388kg / 2</td>
<td>1065</td>
<td>30</td>
</tr>
<tr>
<td>Robinson R44 (Ref. 15)</td>
<td>684kg / 4</td>
<td>576</td>
<td>11</td>
</tr>
<tr>
<td>Schweizer 269/300</td>
<td>499kg / 3</td>
<td>926</td>
<td>12</td>
</tr>
<tr>
<td>Total (small helicopters)</td>
<td>(53.7%) 6,643</td>
<td>(48.8%) 102</td>
<td></td>
</tr>
<tr>
<td>Total of all types</td>
<td></td>
<td>12,365</td>
<td>209</td>
</tr>
</tbody>
</table>

Key points for CVRs are:
- Minimum 2 hours recording time.
- Solid state only - no magnetic tape.
- Minimum 10 minute operation after a loss of aircraft power.

Key points for DFDRs are:
- Time, Airspeed, Altitude, Heading, Acceleration, Attitude and Outside Air Temperature.
- Engine and Rotor speed.
- Cockpit controls at 4x per second.

A brief summary of proposed rules can be found in FAA Press Releases (Ref. 6) and Fact Sheets (Ref. 7).

A VARIETY OF LOW-COST DEVICES

Although potentially very useful for the U.K. Air Accidents Investigation Branch (AAIB) or U.S. NTSB, it may be difficult to sell a non-mandatory black box device to a helicopter owner / operator with the marketing phrase “it might tell us what went wrong just before you got killed”.

Any black box or digital flight data recorder device would also need to offer some additional “value-for-money” in everyday operations.
For example:

- **Flight Training Organizations;**
  In conjunction with “flight path re-creation and statistical analysis” computer software it would become a tool for examining pilot technique, whether during dual flight exercises or solo cross-country flights, such that further training could become more focused on any area identified as causing specific problems to that student pilot. Such automatic statistical analysis computer software could automatically determine various stages of flight (for example; take-off, level flight, banked turns, descents) and compare against published flight test acceptance criteria. This analysis could measure the progress of a trainee pilot and help their flight instructor identify manoeuvres which were repeatedly carried out unsuccessfully or in an unsafe manner.

- **Maintenance Organizations and Aircraft Re-Sale;**
  It could produce a ‘tech. log’ record of all airframe / engine activity such that any limitation exceedances could be immediately indicated. Also, analysis of airframe and engine related data might predict and highlight maintenance future issues.
  A permanent life-time record could be achieved either by downloading data from the device during each regular maintenance cycle into a database or by ensuring that the device contains sufficient storage capacity to hold all data that would be ever be generated (between rebuilds).
  Such a life-time audit trail of airframe / engine activity could be useful during the re-sale of an aircraft as evidence of prior ‘one careful owner’ handling.

- **Operators - Tracking / Limitations;**
  It could phone home with regular position update information or only if / when a certain airframe limitation has been exceeded.

Some of these concepts are neither particularly new or innovative but typically have not been made available for small helicopters at a size / weight / cost which was attractive enough to be of interest to a large segment of the industry.

During the course of this research designs / solutions or actual working prototype devices (nicknamed EMMA and Jemma have been created) covering these three example application areas and the majority of the FAA key points for CVRs and DFDRs.

It is important to note that these prototype devices have been designed to be as small and light and low-cost as possible. They have not been specifically designed to be fully crash-proof (or fire-proof). This is partly because they are just prototypes and partly because it is considered that the only component which needs to survive an impact is the postage stamp sized removable solid-state memory device and if sensibly installed in the target aircraft then survival of this is very likely.

Since such DFDRs would be useless without comprehensive associated software tools, some work in this area also been carried out. It is extremely important that any such software would be readily usable by engineers and flight instructors with only average computer experience as opposed to requiring extensive training.

**EMMA PROTOTYPE**

The EMMA device is a full featured and extensible Cockpit Voice Recorder and Digital Flight Data Recorder about the size of a small shoe box. It is capable of recording dozens of input channels, including GPS (time, speed, altitude, heading), attitude, magnetic heading, outside air temperature, engine and rotor system parameters, airframe vibration, audio and video.

It contains a relatively powerful embedded computer (sufficient to also drive an external graphical information display for the pilot and support a real-time communications link) as well as extensive solid state data memory and an internal backup power source.

The 'manufacturing cost' of this device would be <$1,000 and currently weights around 750g.

Figure 1 shows prototype computer software for displaying GPS flight paths and other parameters using 2-d and 3-d techniques. The data set is from a flight test in November 2003 carried out in a Cessna 172.

**JEMMA PROTOTYPES**

In contrast to the 'large and expensive’ EMMA (CVR and DFDR) device, the Jemma (DFDR only) device is about the size of a cigarette packet (not carton) and would typically have a 'manufacturing cost' of well below $500.

The reason for the reduction in size and weight and cost is a considerable reduction in the computing power and input / output capabilities of the device. Instead of being full featured and extensible, Jemma can perform only a limited number of specific tasks.

Data storage capacity however would not be sacrificed with capacities of 1000’s of hours being easily available.

In order to support the different example application areas a series of different devices would be required. For example, a GPS and Attitude recorder, an Engine and
Rotor parameter recorder or a Control Positions recorder would be separate although very similar devices.

**LYCOMING ENGINE OVERSPEEDS R22/R44**

The Lycoming Service Bulletin (SB) on Engine Inspection after Overspeed (Ref. 8) says:

*“Every Lycoming piston engine is rated at a specified RPM value above which it may not be operated safely. Operating above the rated engine speed can accelerate wear of stressed parts possible resulting in their damage or failure.*

*For rotary wing aircraft, overspeed is defined as operating at any speed above rated engine RPM for any period of time. No momentary overspeed is allowed for rotary wing aircraft.”*

The SB goes on to list mandatory maintenance actions to be carried out in the event of an overspeed. These actions include:

- Drain lubrication system and inspect oil screens and filters for metal contamination.
- Perform a differential pressure check on all cylinders to determine the sealing quality of the rings and valves.
- Examine the walls of each cylinder for scoring, which could be caused by stuck or broken piston rings.
- Disassemble magnetos and inspect all components for damage.

Engine Overspeed can happen in a number of circumstances including improper setting of throttle during starting and incorrect use of the Robinson governor. Such events have a real cost as shown (Table 2).
The Robinson Maintenance Manual section on Rotor / Engine Overspeed (Ref. 9) says:
- Check main rotor and tail rotor dynamic balance.
- Remove main rotor blades. Drain pitch bearing housings and rotate spindles to verify no binelling.
- Visually inspect main and tail rotor blades and tail rotor drive shaft.
- Perform NDT inspection of spindles and hub and bolts, washers, etc.

Rotor system overspeeds can happen in a number of circumstances including during practice auto-rotations. Such events have also a real cost as shown (Table 3).

### Table 2: Engine Overspeed Actions

<table>
<thead>
<tr>
<th>Overspeed%</th>
<th>Action</th>
<th>Average Cost</th>
</tr>
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<tbody>
<tr>
<td>upto 5</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>5 - 10</td>
<td>Inspect engine and overhaul magnetos</td>
<td>£2,000</td>
</tr>
<tr>
<td>over 10</td>
<td>Remove and disassemble engine</td>
<td>R22 £6,000</td>
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<td></td>
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<td>R44 £14,000</td>
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### ROTOR OVERSPEEDS R22 / R44

The Robinson Maintenance Manual section on Rotor / Engine Overspeed (Ref. 9) says:
- Check main rotor and tail rotor dynamic balance.
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### Table 3: Rotor Overspeed Actions

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<td></td>
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<tr>
<td>6 - 12</td>
<td>Remove and inspect blades and spindles</td>
<td>£1,200</td>
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<tr>
<td>over 12</td>
<td>Also NDT check spindles and hub</td>
<td>£2,000</td>
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<tr>
<td></td>
<td>To replace spindles</td>
<td>R22 £2,000</td>
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Typically an overspeed event must be reported by the Pilot In Command (PIC) to the aircrafts owner / maintenance organization but this might not always occur - especially if the person responsible was concerned that they would receive a potentially large bill for the repair.

Sometimes the PIC cannot even accurately recall what happened. This was the case in NTSB Accident Id MIA03LA166 (Ref. 10). The occupants of the Robinson R22 were the Designated Pilot Examiner (DPE) and the Certified Flight Instructor (CFI) on a check-ride flight. During a 180-degree auto-rotation the DPE decided that the manoeuvre was not being performed well and took over the controls. The DPE stated "as I attempted to recover, it seemed as though the engine did not respond. The helicopter was substantially damaged in the resulting hard-landing and some minor injuries were sustained. Immediately afterwards the DPE said to the CFI "... we should say that when the [throttle] was rolled [off] the engine stopped running and to stick to that story.". It is very disturbing that the DPE and CFI, both experienced pilots, would not know or be able to agree between them about what happened with engine and rotor speeds during the manoeuvre and resulting accident.

Thus a device for automatically recording engine and rotor speeds would be useful.

Following discussions at HeliExpo 2004 with engineers from Robinson Helicopter Company (RHC) and HeliAir Ltd., U.K. (the largest reseller of Robinson Helicopters) a specification was drawn up for an engine and rotor overspeed recorder.

### A ROBINSON ENGINE AND ROTOR OVERSPEED RECORDER

Engine and Rotor overspeeds are relatively common occurring in perhaps around 10% of an operator’s Robinson fleet, each year, being used for Flight Training and Rental purposes. Careful inspection after an overspeed event and repair as necessary is essential to keeping the aircraft airworthy.

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The potential advantages offered by this device:

- Data and time of every engine start / stop are recorded.
- Exceeding a set engine or rotor speed limit will result in the overspeed indicator lamp becoming lit - which can only be turned off by maintenance.
- Data traces show whether certain safety critical pre-flight checks are being carried out - such as the Sprag Clutch disengage check and the Low Rotor RPM Horn/Light check.
- Data traces showing whether correct engine warm-up and shutdown procedures are being followed.
- Data traces showing actual engine and rotor RPMs being maintained during practice auto-rotations (in Flight Training).
- In the event of an accident the data traces would show any engine or rotor RPM decay / overspeed as well as the order in which these actually occurred. This “black box” information might greatly assist accident investigators to understand the cause.

Figure 3 shows a normal R44 start-up (Ref. 12) with rising CHT throughout and warm-up at around 60% for almost 3 minutes. Then there is a sharp drop indicating that the Sprag Clutch disengage check was done, followed by an increase to normal 102% RPM at which there is another small drop indicating that the Low Rotor RPM check was done.

**SUMMARY**

Black box flight data recorders have proved invaluable to the aircraft industry over many decades and similar improvements in flight safety across the large fleet of small helicopters would likely be achieved if there existed suitable black box DFDRs even with modest data acquisition capabilities.

However because the size / weight / cost is not zero and such devices are not mandatory then there needs to be another considerable incentive for an owner / operator to make the decision to purchase and install one.

Within Flight Training Organizations and for Maintenance and Operating Organizations there exists good reasons why the cost of such a device could be inconsiderable compared to the benefits.

Specifically a low-cost DFDR device for recording and indicating Engine and Rotor over speeds and related information for Robinson R22 and R44 helicopters, has been tested, is currently being certified in Europe and should be available from HeliAir Ltd. (Ref. 16) during 2nd half of 2005.

The use of this device may contribute to increasing flight safety while still being considered to be of a low size / weight / cost.
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REFERENCES