Aircraft Accident Investigation Commission

Ministry of Economic Affairs and Communications

Estonia

FINAL REPORT
AIRCRAFT ACCIDENT INVESTIGATION

COPTERLINE OY
SIKORSKY S-76C+

In Tallinn Bay, Estonia
on 10 August 2005

6 August 2008

Intentionally blank

TABLE OF CONTENTS

ABBREVIATIONS

AAIB (United Kingdom)	Air Accidents Investigation Branch in the United Kingdom
AIB (Finland)	Accident Investigation Board in Finland
AD	Airworthiness Directive
AOC	Air Operator Certificate
AOL	All Operators Letter
ASB	Alert Service Bulletin
ATC	Air Traffic Control
ATP	Acceptance test procedure
ATPL	Airline Transport Pilot Licence
ATPL (A)	Airline Transport Pilot Licence - Aeroplanes
ATPL (H)	Airline Transport Pilot Licence - Helicopters
BEA (France)	Bureau d'Enquetes et d'Analyses in France
BS	Blade station
C (degrees)	Degrees Celsius
CAA	Civil Aviation Authority
CG	Centre of Gravity
CPL	Commercial Pilot Licence
CPL (A)	Commercial Pilot Licence - Aeroplanes
CPL (H)	Commercial Pilot Licence - Helicopters
CRM	Crew Resource Management
CRS	Certificate of Release to Service
CVR	Cockpit voice recorder
DAFCS	Digital Automatic Flight Control System
DDAFCS	Dual Digital Automatic Flight Control System
E	East
EASA	European Aviation Safety Agency
EDS	Energy dispersive x-ray spectrometer
EFIS	Electronic Flight Information Systems
ELT	Emergency Locator Transmitter
EUROCAE	European Organization for Civil Aviation Equipment
FAA (USA)	Federal Aviation Administration in USA
FADEC	Full Authority Digital Engine Control
FDAU	Flight Data Acquisition Unit
FDR	Flight data recorder
ft	Foot or feet

ft/sec	Feet per second
GMH	Ground Handling Manual
HEMS	Helicopter Emergency Medical Service
Hg	Mercury
hPa	Hectopascal
Hz	Herz
ICAO	International Civil Aviation Organization
IFR	Instrument flight rules
in/sec	Inches per second
JAR	Joint Aviation Requirements (Europe)
JRCC Tallinn	Joint Rescue Coordination Centre in Tallinn
kg	Kilogram
kg/cm^2	Kilogram per square centimetre (pressure)
km	Kilometre(s)
km/h	Kilometre per hour
kt	Knot(s)
KTAS	Knots true airspeed
lb	Pound (mass)
m	Metre(s)
mm	Millimetres
MEL	Minimum Equipment List
MCV	Main control valve
mg/l	Milligram per litre
MHz	Megaherz
Ml/min	Millilitre per minute
MLG	Main landing gear
MME	Maintenance Management Exposition
MMEL	Master Minimum Equipment List
MOE	Maintenance Organization Exposition
MP	Maintenance program
MP	Multi-pilot
MRSC Helsinki	Maritime Rescue Sub-Centre in Helsinki
msl	Mean sea level
MSSR	Monopulse Secondary Surveillance Radar
N	North
NTSB (USA)	National Transportation Safety Board in USA
OATL	Operator Aircraft Technical Log Book
OFP	Operational Flight Plan
OM	Operations Manual

PF	Pilot flying
PFC	Pre-flight check
PFI	Pre-flight inspection
PNF	Pilot not flying
psi	Pounds per square inch (pressure)
QFE	Height above aerodrome elevation (or runway threshold elevation) based on local station pressure
QNH	Altitude above mean sea level based on local station pressure
ROV	Remotely operated vehicle
rpm	Revolutions per minute
SAIB	Special Airworthiness Information Bulletin
SAR	Search and Rescue
SAS	Stability augmentation system
SB	Service Bulletin
SEM	Scanning electron microscope
SSR	Secondary Surveillance Radar
STA	Fuselage station
TBO	Time between overhaul
USA	United States of America
UTC	Co-ordinated Universal Time
VFR	Visual flight rules
Vne	Never exceed speed

FOREWORD

Following the accident on 10 August 2005 to the Copterline Oy helicopter Sikorsky S-76C+, nationality and registration marks OH-HCI, in Tallinn Bay in Estonia, an Aircraft Accident Investigation Commission (the Commission) was appointed under the decree No. 313 of the Minister of Economic Affairs and Communications. The Commission was to investigate the circumstances of the accident, determine the causes of the accident and formulate safety recommendations, as appropriate, in order to prevent aircraft accidents or incidents. It was not the function of the Commission to assign fault or to determine civil or criminal liability. The composition of the Commission was:

Chairman

Taivo Kivistik	Deputy Secretary General, Ministry of Economic Affairs and Communications

Deputy Chairman

Tõnu Ader	Executive Officer, Emergency Management Department, Ministry of Economic Affairs and Communications; Investigator-in-charge

Members of the Commission

Oleg Harlamov	Counselor to the Minister, Ministry of Economic Affairs and Communications
Mati Iila	Counselor, Emergency Management Department, Ministry of Economic Affairs and Communications
Tiit Kaurla	Executive Officer, European Union and International Cooperation Department, Ministry of Economic Affairs and Communications
Toomas Kasemaa	Head of the Bureau of Border Guard Policy, Internal Security Policy Department, Ministry of the Interior
Aleksander Dintšenko	Senior Inspector, Department of Air Traffic Services and Aerodromes, Civil Aviation Administration
Jaanus Ojamets	Senior Inspector, Flight Operations Department, Civil Aviation Administration

The accident was investigated in accordance with the Estonian Aviation Law, in accordance with the Standards and Recommended Practices of the International Civil Aviation Organization (ICAO) as contained in Annex 13 (Aircraft Accident and Incident Investigation) to the Convention on International Civil Aviation, and in accordance with the European Council Directive EU/56/94.

As the State of Registry of the helicopter, Finland (the Accident Investigation Board (AIB)) appointed an accredited representative (Mr. Hannu Melaranta) and technical advisers to him to participate in the investigation. As the State of Design and the State of Manufacture of the helicopter, the United States of America (USA) (the National Transportation Safety Board (NTSB)) appointed an accredited representative (Ms. E. Lorenda Ward). In addition, experts from

Sikorsky Aircraft Corporation, HR Textron, Honeywell, Helicopter Support Incorporated (a subsidiary of Sikorsky), and the Federal Aviation Administration (FAA) of the USA participated in the investigation as technical advisers to the USA accredited representative. Also, France (Bureau d'Enquetes et d'Analyses (BEA)) as the State of Manufacture of the engines appointed an accredited representative to the investigation.

On 13 August 2005, three days after the accident, the wreckage of the helicopter was recovered from the sea. It was transported to a hangar at Tallinn Airport for a detailed examination. It was later moved to the Estonian Air Force base at Ämari.

In late August 2005, arrangements to read out the flight recorder (a combined flight data recorder (FDR) and cockpit voice recorder (CVR)) were made with the Air Accidents Investigation Branch (AAIB) in the United Kingdom. The United Kingdom (AAIB) appointed an accredited representative to coordinate and assist in the flight recorder read-out arrangements. Subsequently, the flight recorder was read out at the flight recorder manufacturer's (Penny & Giles) read-out facility in the United Kingdom.

On 12 September 2005, the Commission issued a preliminary report on the helicopter accident. An interim report was issued on 6 August 2007. In accordance with ICAO Annex 13, a draft final report was sent for comments on 18 June 2008 to the States that participated in the investigation (Finland, France, United Kingdom and USA). The comments received were reviewed and taken into account, as appropriate. The final report was issued on 6 August 2008.

The final report was issued in English and Estonian language versions. If any differences between two mentioned versions could be revealed, the version in the English language should be assessed the main version.

Note 1. - *Unless otherwise indicated, all times are Estonian local time (Coordinated Universal Time + three hours (Estonian daylight saving time)), based on a 24-hour clock. Estonia and Finland were in the same time zone.*

Note 2.- *Unless otherwise indicated, the altitudes are referenced from mean sea level.*

SYNOPSIS

On 10 August 2005, a Sikorsky S-76C+ helicopter, registration OH–HCI, was operating a scheduled passenger service by Copterline between Helsinki, Finland and Tallinn, Estonia. The helicopter departed Tallinn at 12:39 hours (local time) with 12 passengers and two pilots on board. Approximately three minutes after take-off while climbing at 1380 ft above sea level, the flight data recorder showed that the flight was interrupted by a sudden helicopter pitch-up and left roll maneuver, then remained in varying attitudes of right yaw (rotation), roll and pitch for 37 seconds until impacting the water at 12:42:28 hours. There were no survivors.

The Aircraft Accident Investigation Commission determined that the cause of the accident was an uncommanded extension of the main rotor forward actuator and subsequent loss of control of the helicopter. Contributing to the uncommanded extension of the actuator was the separation of the plasma coating on one of two actuator pistons and the operator's failure to detect the internal leakage of the main rotor forward actuator.

In the months following the accident, the Commission initiated interim safety recommendations, which resulted in NTSB Safety Recommendations A-05-33 through -35, Sikorsky All Operators Letter CCS-76-AOL-05-2001, FAA Special Airworthiness Information Bulletin SW-06-15, and an FAA Notice of Proposed Role Making (2006-SW-05 AD).

In this report, the Commission issued four additional safety recommendations addressed to Sikorsky, FAA, NTSB, Copterline and CAA-Finland.

1. FACTUAL INFORMATION

1.1 History of the flight

On 10 August 2005 at 12:39 hours (local time), the Sikorsky S-76C+ helicopter, nationality and registration marks OH–HCI, departed Tallinn City Hall heliport in Estonia for Copterline heliport Hernesaari in Helsinki, Finland on a scheduled passenger service flight. There were 12 passengers and two pilots on board the helicopter. The scheduled departure time from Tallinn was 12:30 hours.

The route was 80 km and the usual flight time was 18 to 20 minutes. The operator's (Copterline) home base was Helsinki/Malmi Airport in Helsinki, Finland. There were 14 scheduled flights per day from Helsinki during weekdays. Departure from Helsinki was on the hour, and departure from Tallinn was 30 minutes past the hour. The flight crew was on their tenth leg, i.e. the return flight of their fifth round trip to Tallinn that day.

The pilot-in-command (pilot) was seated in the front right seat and he was the pilot flying. The co-pilot handled the radio communications. The engines were running during the short stop in Tallinn (Linna Hall), and there were no abnormal indications during ground time. No problems were reported as a result of the pre-flight checklist. The take-off at 12:39 hours in the direction of Helsinki was normal and no problems were reported stemming from the after-take-off checklist. After take-off on heading 110°, the helicopter turned left to heading 355° while increasing airspe ed and climbing. Usually, the flights were conducted at an altitude of about 1 500 ft and with an indicated airspeed of about 150 kt. The co-pilot reported by radio to the Tallinn Air Traffic Control (ATC) Tower that the helicopter was airborne.

When the helicopter approached the border of Tallinn Airport Control Zone, it was reaching an altitude of 1 200 ft above mean sea level (msl) and an airspeed of 130 kt. According to the CVR record, the flight crew assessed the cloud conditions ahead and discussed avoiding cumulus clouds by climbing to an altitude of 2 000 ft or higher. About two minutes after take-off, the pilot told the co-pilot that he was going to increase power. According to the FDR data, the collective control moved up, indicating an increase in power. This occurred at an altitude of 1380 ft msl.

At 12:41:50 hours, according to the FDR data, five seconds after the power increase, the cyclic control moved rapidly aft over half of the maximum travel and the collective control started to move up. The attitude of the helicopter changed rapidly. It pitched up abruptly and rolled to the left. Following the initial upset flight condition, according to the FDR data, the helicopter began a rotation to the right with significant oscillations in pitch and roll attitudes.

An air traffic controller at Tallinn Airport observed the helicopter disappear from the radar coverage and witnesses saw the helicopter impact the water. As a result, a search and rescue operation was initiated immediately.

1.1.1 Observations by eyewitnesses

The last seconds of the helicopter flight were witnessed by a local inhabitant on the western coast of Viimsi peninsula, about four km southeast of the accident site. Usually, the helicopters on this route passed the location of the eyewitness at a distance of approximately 2.5 km. The eyewitness described that he heard an unusual intermittent sound of a flying helicopter which was quite different from the usual sound. At first, he did not see the helicopter when he looked in the direction of the sound. Soon, however, he saw the helicopter appearing from clouds. The helicopter with the front part slightly down spiraled downwards and impacted the sea (at 12:43 hours according to the eyewitness's watch) producing two high columns of water. The eyewitness made immediately a telephone call to the police and then to the emergency services.

The last seconds of the helicopter flight were also observed by the captain of a port authority vessel (AHTO 23) at the quay of Rohuneeme port (approximately three km from the accident site). The helicopter attracted the captain's attention because of some loud consecutive banging sounds. He called the emergency services immediately. He also contacted another port authority vessel (AHTO 07) which was closer to the accident site and he directed it to the accident site.

1.2 Injuries to persons

All 14 occupants of the helicopter were fatally injured. The nationalities of the 12 passengers were: four citizens of Estonia, six citizens of Finland, and two citizens of USA. Both pilots were citizens of Finland.

Injures	Crew	Passengers	Others
Fatal	2	12	-
Serious	-	-	-
Minor/None	-	-	

1.3 Damage to aircraft

The helicopter was destroyed.

1.4 Other damage

There was no other damage. Environmental water pollution was minimal, as the amount of kerosene in the helicopter was small (approximately 400 kg).

1.5 Personnel information

1.5.1 Pilot-in-command

1.5.1.1 Pilot – Licences and ratings

The pilot was male, 41 years old. He held a JAR Airline Transport Pilot Licence (Helicopter) (ATPL (H)) renewed on 29 June 2005 by the Civil Aviation Authority (CAA) in Finland. He had had a Commercial Pilot Licence (Helicopter) (CPL (H)) since 1988, and the ATPL (H) since 1993. His ATPL (H) was valid until 21 November 2007. His Sikorsky S-76 A/A+/B/C/C+ ratings (including instrument rating) were valid until 31 May

2006. The pilot held the required licence and ratings to operate Sikorsky S-76C+ helicopters in scheduled passenger service by Copterline between Helsinki and Tallinn.

The pilot's last medical check was on 23 March 2005. His JAR Class 1 Medical Certificate was valid until 4 October 2005, and his JAR Class 2 Medical Certificate was valid until 4 April 2007. His ATPL (H) and Medical Certificate contained no limitations.

The pilot held a valid Radiotelephony Certificate (English, IFR).

The pilot also held the following licences and ratings:

- JAR - Flight Instructor, Helicopters (valid until 28 February 2007);
- JAR - Flight Instructor for Instrument Rating, Helicopters (valid 28 February 2007);
- JAR - Flight Instructor for Type Ratings, Helicopters with Multi-Pilot Flight Crew (valid until 28 February 2007);
- JAR - Night Rating, Helicopters;
- JAR - Flight Instructor for Flight Instructor Courses;
- JAR - Check Pilot for Type Ratings, Helicopters (valid until 9 June 2007); and
- Valid type ratings for Sikorsky 76A/A+/B/C/C+, Bell 206/206L, 212, and 412 models.

1.5.1.2 Pilot – Training records with Copterline

According to the training records maintained by Copterline, the pilot joined Copterline on 1 May 2005. He received Sikorsky S-76 flight simulator training in the last week of May 2005 at the Flight Safety International training and flight simulator facilities in USA, a total of 23 hours simulator flight time. On 31 May 2005, the pilot passed a two hour check flight (simulator).

In Finland, the pilot flew the Sikorsky S-76 on 21 June (0:30 hours), 2 July in the morning (1:10 hours), and 2 July in the afternoon (2:20 hours) as company training, company supervised flights, and a line check. On 3 July, the pilot flew 4:35 hours as company pilot-in-command training. His line flying for Copterline started on 11 July 2005.

The training items for the pilot contained in the Copterline training records were valid and included the following: S-76 Recurrent Flight Training/ MP, IFR Procedure Training, S-76 Recurrent Theory Training, S-76 Operators Proficiency Check/ MP, S-76 Proficiency to Operate on either Seat, S-76 Line Check, CRM Recurrent Training, and Emergency and Safety Equipment I and II.

1.5.1.3 Pilot – Flight and duty time

On the day of the accident (10 August 2005), the pilot had completed nine legs between Helsinki and Tallinn for a flight time of 2:46 hours. On the preceding days, the pilot had flown as follows:

- 9 August – 5:50 hours;
- 8 August – 5:50 hours;
- 7 August – no flights;
- 6 August – 6:00 hours;

- 5 August – 10:20 hours;
- 4 August – 5:50 hours;
- 3 August – 5:45 hours;
- 2 August – 5:00 hours; and
- 1 August – no flights.

The pilot's flight time in the month of August was 47:20 hours. The pilot's flight time in the month of July was 102:15 hours. The flight time for July included the 94:10 hours which the pilot flew from 11 to 31 July 2005, when he started flying the line flying (passenger service) with Copterline on 11 July 2005.

The pilot's flight time in the last 30 days was 141:30 hours. His flight time in the last 90 days was 173:05 hours. His total flight experience on Sikorsky S-76 helicopters was 173:05 hours, which included 23:30 hours of S-76 simulator time. His total flight time experience was 7 068 hours.

According to the Copterline Operations Manual (OM) – Part A – General / Basics, Chapter 7.3. – Flight and Duty Time Limitations, 7.3.1 – General Limitations: "Maximum flight time in any calendar month is 100 hours". The Copterline flight time limitation was identical to the CAA Finland requirements in Aviation Regulation OPS M3-2 – Flight and Duty Time Limitations.

The pilot had flown the Sikorsky S-76 together with the co-pilot for a total of 21 h 20 min, all within the last 30 days.

The AIB – Finland informed the Commission that the pilot's working hours in the last 24 hours were 14 hours, in the last 48 hours 22 hours, in the last seven days 47.5 hours and in the last 14 days 87 hours. The duty times were within the duty time limitations in the Copterline Operations Manual (OM) – Part A – General / Basics (section 7.3.1 – General Limitations).

1.5.2 Co-pilot

1.5.2.1 Co-pilot – Licences and ratings

The co-pilot was male, 56 years old. He held an Airline Transport Pilot Licence (Helicopter) (ATPL (H)) renewed on 27 June 2005 by the CAA in Finland. He had had a Commercial Pilot Licence (Helicopter) since 1989 and the ATPL (H) since 1997. His ATPL (H) was valid until 22 March 2010. His Sikorsky S-76 A/A+/B/C/C+ ratings (including instrument rating) were valid until 30 November 2005. The co-pilot held the required licence and ratings to operate Sikorsky S-76C+ helicopters as co-pilot in scheduled passenger service by Copterline between Helsinki and Tallinn.

The co-pilot's last medical check was on 22 June 2005. His JAR Class 1 Medical Certificate was valid until 3 February 2006, and his JAR Class 2 Medical Certificate was valid until 3 August 2006. His Medical Certificate contained a limitation: Corrective glasses (to improve close-up vision), as well as a set of spare glasses, were to be accessible.

The co-pilot held a valid Radiotelephony Certificate (English, IFR).

The co-pilot also held the following licences and ratings:

- Commercial Pilot Licence (Airplanes) (CPL (A)) (valid until 20 September 2009);
- Night Rating, Aeroplanes;
- Night Rating, Helicopters;
- Flight Instructor, Helicopters (valid until 25 September 2006);
- Flight Instructor for Type Rating, Helicopter (Eurocopter BO-105);
- JAR - Check Pilot, Aeroplanes (valid until 5 September 2006);
- JAR - Check Pilot, Helicopters (valid until 15 September 2006);
- Flight Instructor, Aeroplanes - Single Engine Land VFR (valid until 30 September 2007);
- Single Engine – Piston, Class Ratings, Land and Sea, Single Pilot;
- Tow Pilot Rating;
- Valid type ratings for DHC-6, Robinson R22, Bell 206/206L, Hughes 369 / McDonnell-Douglas MD500N / 600 and Eurocopter BO-105/105LS/105CBS; and
- Valid type ratings for Sikorsky 76A/A+/B/C/C+.

1.5.2.2 Co-pilot – Training records with Copterline

The co-pilot joined Copterline on 1 January 1992. The training items for the co-pilot contained in the Copterline training records were valid and included the following: S-76 Line Check, S-76 Operators Proficiency Check/ MP, S-76 Recurrent Flight Training, S-76 Recurrent Theory Training, IFR Procedure Training, CRM Recurrent Training, Instrument Recency Flight Training for Helicopter Emergency Medical Service (HEMS) Pilots, and Emergency and Safety Equipment I and II.

1.5.2.3 Co-pilot – Flight and duty time

On the day of the accident (10 August 2005), the co-pilot had completed nine legs between Helsinki and Tallinn for a flight time of 2:46 hours. On the preceding day, the co-pilot had flown 1:00 hour with the Sikorsky S-76 and 1:10 hours with other helicopter types. In the last 30 days, the co-pilot had flown 51:50 hours with the Sikorsky S-76, 8:20 hours with other helicopter types, and 1:45 hours with aeroplanes. In the last 90 days, he had flown 258:15 hours with the Sikorsky S-76, 31:45 hours with other helicopter types, and 9:30 hours with aeroplanes.

The co-pilot’s total flight experience was 7 618 hours on helicopters and 2 601 hours on aeroplanes.

The Commission was informed that the co-pilot’s working hours in the last 24 hours were six hours, in the last 48 hours 11:30 hours, in the last seven days 37:12 hours, and in the last 14 days 39:24 hours. The duty times were within the duty time limitations in the Copterline Operations Manual (OM) – Part A – General / Basics (section 7.3.1 – General Limitations).

The co-pilot had flown the Sikorsky S-76 together with the pilot for a total of 21 h 20 min, all within the last 30 days.

1.6 Aircraft information

1.6.1 General information

Manufacturer	Sikorsky Aircraft Corporation, USA
Type and model	Sikorsky S-76C+
Aircraft serial number	760508
Date of construction	February 2000 in West Palm Beach, Florida, USA
Powerplants	Two Turbomeca Arriel 2S1 turbo-shaft engines, manufactured by Turbomeca in France. Engine no. 1 (left) was installed on OH-HCI on 30 June 2003; time at installation 3356 hours; time since installation 2493 hours. Engine no. 2 (right) was installed 30 July 2003; time at installation 1600 hours; time since installation 2360 hours.
Total airframe hours	6 256 hours
Total airframe cycles	23 459 cycles
Certificate of Registration	Registered in Finland on 21 March 2000 with nationality and registration marks OH–HCI. Registered owner was Copterline Oy.
Certificate of Airworthiness	Certificate of Airworthiness was issued by CAA Finland on 21 March 2000. The last renewal was valid until 31 March 2006.

The normal flight crew complement in regular passenger flights was two pilots. The passenger section of OH-HCI was configured for a maximum of 12 passengers, three rows of benches with four passengers per row.

1.6.2 S-76 helicopter description

The Sikorsky S-76 was a general-purpose all-weather helicopter. It was used extensively for passenger transport, corporate executive transport, offshore oil support and general utility operations.

Photo 1. Sikorsky S-76C+

There were a number of S-76 versions. The original S-76 was the designation of all models delivered before 1 March 1982; these were powered by Allison 250-C30 turbo-shaft engines. The designation S-76A+ defined a helicopter retrofitted with Turbomeca Arriel 1S engines. Models delivered after March 1982 were designated S-76 Mark II. In 1987, the S-76B was produced with many enhancements and Pratt & Whitney PT6B-36A engines. In 1990, the S-76C model was produced with Turbomeca Arriel 1S1 engines. The S-76C+ was equipped with Turbomeca Arriel 2S1 engine. The engines were located side by side in the upper part of the fuselage behind the main gearbox.

The helicopter S-76 has a four blade main rotor which turning counter-clockwise. The main rotor diameter is 13.41 m. Its rotation speed at 107 % is 313 rpm. It has a four-blade tail rotor on the left side of the tail pylon which turning clockwise when observing from the left of the helicopter. The tail rotor rpm is 1 721 rpm. The S-76 using a conventional transmission system with both engines driving a main gearbox. The main rotor blades are mounted on elastomeric rotor hub bearings and has hydraulic dampers. The S-76 could be equipped with either one or two main rotor vibration absorbers (5P and 3P bifilar); OH-HCI had one vibration absorber (the 3P bifilar). The flight controls and the retractable landing gear wheels are hydraulically powered. The fuselage is a composite-structure glass-fiber nose, light alloy-honeycomb cabin, semi-monocoque light alloy tail cone, and Kevlar fairings.

The maximum airspeed (Vne)) of the helicopter is 155 kt (287 km/h).

The helicopter OH-HCI was equipped with four inflatable emergency floats for an emergency landing on water.

OH-HCI was equipped with a Honeywell SPZ-7600 Dual Digital Automatic Flight Control System (DDAFCS) which assisted the pilots in maintaining the attitude of the helicopter (stability augmentation). System provides fully coupled autopilot and flight director functions in the pitch, roll, yaw and collective axis.

1.6.3 Minimum Equipment List (MEL)

The Copterline MEL (Revision 9 dated 30 December 2004) was based on the FAA approved Sikorsky S-76 Series Master Minimum Equipment List (MMEL). The MEL complied with JAR OPS 3 and was approved by CAA Finland for Copterline. There were no deferrals listed on the last technical log sheets dated 10 August 2005.

1.6.4 Mass and balance

According to the mass and balance calculation prepared by the Copterline team leader of Tallinn City Hall Heliport and signed by the pilot-in-command, the actual take-off mass of the helicopter was 10 867 lb (4 924 kg). The Centre of Gravity (CG) was longitudinal arm 198.79 inches, lateral arm –0.13 inches, which was within the allowed limits. Actual fuel on take-off was 890 lb (400 kg) of jet fuel. The capacity of the two fuel tanks in the helicopter was 281 US gallons (1 084 litres).

According to the Copterline Ground Handling Manual (page 8), the maximum take-off mass for OH-HCI was 11700 lb (5307 kg). The Category A (scheduled passenger flight) restricted maximum take-off mass in the prevailing conditions (air temperature, pressure altitude, engine power marginal) was 10900 lb.

In accordance with the Copterline Flight Operations Manual, Part A, paragraph 8.1.8.2, a standard mass of 86 kg for each male passenger and 68 kg for each female passenger was used in the mass and balance calculation. The standard mass of hand baggage was 6 kg (where applicable). The standard flight crew mass was 85 kg including hand baggage. Checked baggage was always to be weighed as true mass. The mass and balance load sheet indicated that 55 kg (presumably checked baggage) was in the cargo compartment.

1.6.5 Maintenance of the helicopter

1.6.5.1 General

Copterline was the owner, the operator and the maintenance organization for the helicopter. The Copterline Maintenance Management (JAR OPS 3, Subpart M) and the Copterline Maintenance Organization (Part 145) had been approved by CAA Finland. According to Copterline, the helicopter line maintenance and scheduled maintenance had been performed in accordance with the approved maintenance program.

1.6.5.2 S-76 maintenance program

The Copterline S-76 maintenance program (CA-HO-S76) was based on the Sikorsky S-76 Maintenance Manual. Also engine manufacturer’s maintenance manual requirements were included into maintenance program. The maintenance intervals, the inspections and the limits for certain life time limited components were specified in chapters 4 and 5. Copterline used the recommended flight time, cycles, and calendar time based intervals. Sikorsky updated the maintenance requirements by publishing Service Bulletins (SBs). Also, the FAA in United States (the authority that had issued the helicopter Type

Certificate) published maintenance requirements in the form of Airworthiness Directives (ADs). Normally, the ADs, SBs, and other changes in the required maintenance actions also required changes in the Copterline maintenance program. Copterline used a temporary revision procedure, i.e. manual updates in between Sikorsky's revisions to HELOTRAC.

The Copterline maintenance program was entirely performed through HELOTRAC, a computerized aircraft maintenance monitoring program developed and provided by Sikorsky. According to Sikorsky, HELOTRAC contained all the maintenance requirements from the Sikorsky Maintenance Manual SA_4047-76C-2-1 AWL & INSP REQUIREMENTS, i.e. Chapter 4 Table 1, Chapter 5-10-00 Overhaul Schedule, Chapter 5-20-00 Scheduled Maintenance and Chapter 5-50-00 Conditional Maintenance. Before a scheduled maintenance, the maintenance due-listings were printed from HELOTRAC. HELOTRAC was designed to provide all the tasks required for any specific maintenance provided that the user/maintenance organization has ensured that the appropriate updates have been done, including any component changes with part codes and part numbers.

It was the operator's responsibility to assure that the HELOTRAC software accurately conveys the information of the original maintenance publications which were the basis for airworthiness determinations and the approved maintenance program.

1.6.5.3 Checks and maintenance performed

The helicopter checks and maintenance performed according HELOTRAC database:

	Date	Total time	Total cycles
Pilot's Pre-flight Check (PFC)	Daily		
25 hours Inspection	6 Aug 2005	6244 hours	23 438
50 hours Inspection	28 July 2005	6219 hours	23 323
50 hour Eng 1 Inspection	28 July 2005	6219 hours	23 323
50 hour Eng 2 Inspection	28 July 2005	6219 hours	23 323
100 hour Inspection	30 June 2005	6167 hours	23 128
300 hour Inspection	30 June 2005	6167 hours	23 128
340 hour Inspection	*Note. - 1*		
450 hour Inspection	*Note. - 2*		
500 hour Inspection	30 June 2005	6167 hours	23 128
500 hour Eng 1 Inspection	5 Feb 2005	5783 hours	20 307
500 hour Eng 2 Inspection	30 June 2005	6167 hours	23 128
600 hour Inspection	*Note. - 3*		

750 hour Inspection	7 Dec 2004	5683 hours	19 975
900 hour Inspection	30 June 2005	6167 hours	23 128
1250 hour Inspection	30 June 2005	6167 hours	23 128
1000 hour Eng 1 Inspection	5 Feb 2005	5783 hours	20 307
1000 hour Eng 2 Inspection	30 June 2005	6167 hours	23 128
1500 hour Zn 1 Inspection	5 Feb 2005	5783 hours	20 307
1500 hour Zn 2 Inspection	5 Feb 2005	5783 hours	20 307
1500 hour Zn 3 Inspection	5 Feb 2005	5783 hours	20 307
1500 hour Zn 4 Inspection	5 Feb 2005	5783 hours	20 307
1500 hour Zn 5 Inspection	5 Feb 2005	5783 hours	20 307
3000 hour Inspection	7 June 2005	6103 hours	21 397
Major Eng 1 Inspection (3000 h)	7 June 2005	6150 hours	23 064
Major Eng 2 Inspection (3000 h)	15 Aug 2004	2980 hours	4376
12 month Calendar Inspection	30 June 2005	6167 hours	23 128
24 month Calendar Inspection	28 Jan 2004	4476 hours	15 581
36 month Calendar Inspection	28 May 2003	3619 hours	12 625
48 month Calendar Inspection	28 Jan 2004	4476 hours	15 581
60 month Calendar Inspection	5 Feb 2005	5783 hours	20 307

Note. – 1 Inspection for main rotor blade was not applicable by part number on OH – HCI.

Note. – 2 The 450-hour engine inspection was not applicable to OH-HCI due to previous compliance with Turbomeca SB TU-37A.

Note. – 3 Inspection for main landing gear (MLG) Aft jury brace (not applicable by helicopter serial number) and inspection of air conditioning system (not installed on OH-HCI).

1.6.5.4 Helicopter log books

The helicopter technical log books for airframe and engines were reviewed. They contained the times and dates of the required inspections on the helicopter from April 2000 to June 2005. It also contained annotations of the removal and replacement of components.

The Operator Aircraft Technical Log Book (OATL) was reviewed for daily annotations (i.e. discrepancies, servicing, deferrals, MEL issues, etc.). Specifically, the flight logs from 5 July through 10 August 2005 were reviewed. The flight logs showed that actual flight times were recorded. The helicopter was operated as a shuttle between Helsinki and Tallinn (except for approximately a week in late July 2005), and the helicopter was usually “hot-loaded” with the engines running and the rotors still turning. Time on the ground with engines and rotors still turning was not included into log books even it was considerable (approximately 1/3 of total flight time).

1.6.5.5 Airworthiness Directives and Alert Service Bulletins

The Copterline records of ADs on OH – HCI were reviewed. The list was compared to the FAA compliance list, which included airframe, engines and accessories. All applicable ADs were complied with. Of note is the AD:

AD 2005-22-01 (Inspection of main rotor lower bifilar arm assembly in the attachment area around the lower bifilar lugs for cracks) was not effective until after the OH – HCI accident. Sikorsky issued Alert Service Bulletin (ASB) No. 76-65-62 dated 14 December 2004, after receiving two reports of cracks in the lug areas of helicopters. Sikorsky stated that the cracked lugs were found despite the lower support lug joining being torqued and stabilized. For a bifilar with more than 1500 hours, perform a one-time inspection of the lower bifilar support lugs for cracks in the lug attachment areas within 100 flight hours from the issue date of the ASB. These were considered interim actions until terminating action could be taken. Sikorsky has designed and was currently testing a new main rotor hub pilot fitting.

According to Copterline, the ASB was complied with during the main gear box replacement in April 2005.

1.6.5.6 Reliability and trend monitoring

Copterline held reliability meetings infrequently (17 September 2003 and 20 September 2005), however, Copterline stated that reliability and trends were discussed through e-mails on a regular basis.

According to the Copterline reliability and trend information for 2004 – 2005, ATA 67 showed one main rotor aft actuator (2004) and one main rotor lateral actuator (2004), both having lower ball bearings loose. ATA 29 showed one incident in which the landing gear extension and retraction rates were reported as slow with a corresponding drop in system no. 2 hydraulic pressure. The system no. 2 hydraulic pump was replaced to correct the discrepancy.

1.6.5.7 Major repairs and alterations

One major repair was accomplished on the helicopter at helicopter total time 4476 hours. On 1 January 2004, during a scheduled intermediated gear box replacement, maintenance found extensive cracking on the aft spar web. The mid-spar cracking extended to both the aft spar cap angles although not confirmed as cracked. C & C Aviation, United Kingdom, accomplished the repairs to the aft spar web.

1.6.5.8 S-76 hydraulic system maintenance

Regarding Hydraulic Power – Inspection / Check, the Sikorsky Maintenance Manual SA 4047-76C-2 stated: *“To determine the general health of the helicopter hydraulic systems* *a periodic / check procedure (…) is provided and done as required by the Scheduled Maintenance Checks, 5-20-00, SA 4047-76C-2-1. This procedure checks the level of contamination in the hydraulic system by using a patch test kit or by independent laboratory analysis. An acceptable level of contamination has been established for the hydraulic system and when this level is exceeded an inspection / check (…) of the hydraulic system must be done. Hydraulic system contamination is generally caused by component malfunction, improper servicing, or poor maintenance practices. System contamination is usually indicated by extended (popped-out) differential pressure indicator on either pressure or return filter on hydraulic module, or loss of system performance. When contamination is indicated, an inspection / check of the hydraulic system must be made."*

In accordance with the Sikorsky Maintenance Manual, the hydraulic system was monitored, as follows:

- When a degradation or loss of hydraulic system performance was noted;
- After a hydraulic filter blocked indication (popped-out);
- Following a hydraulic component failure; and
- As a task in the annual periodic check.

If the hydraulic fluid was found contaminated through the patch test or by using an independent laboratory, the hydraulic fluid in the hydraulic ground power unit was also to be tested. The contaminated hydraulic system in the helicopter and the hydraulic ground power unit were to be flushed until ascertained clean.

The Copterline maintenance documentation showed several maintenance actions related to the hydraulic system in the last few months, including an annual period check in June 2005 and some hydraulic fluid filter changes. However, the documentation did not indicate the reasons for filter changes. From the annual periodic check, there was no patch or fluid sample saved, and there were no annotations of the hydraulic fluid test result (Part 145 requirement). The hydraulic system maintenance and the deficiencies in the maintenance documentation are analyzed in detail in the analysis part of this report.

1.6.6 Description of the main rotor flight control system

1.6.6.1 General

The helicopter has conventional flight controls consisted of a collective control stick, a cyclic control stick, and tail rotor pedals (refer to Figure 1). Moving the cyclic control stick forward or aft caused the helicopter to change pitch in commanded direction, moving the control stick left or right caused helicopter to roll in the commanded direction. Raising or lowering the collective control resulted in an increase or decrease, respectively, in the lift produced by the main rotor blades. Moving the tail rotor pedals (which where equivalent to airplane rudder pedals) positioned the tail rotor blades to cause the helicopter to yaw. Either pilot could control the cyclic, collective and rudder pedals (dual controls). Cyclic and collective trim and a force gradient system permitted trimming of the controls in the cockpit to the desired position. The control stick trim system provided stick trim and feel for the pilot and co-pilot controls.

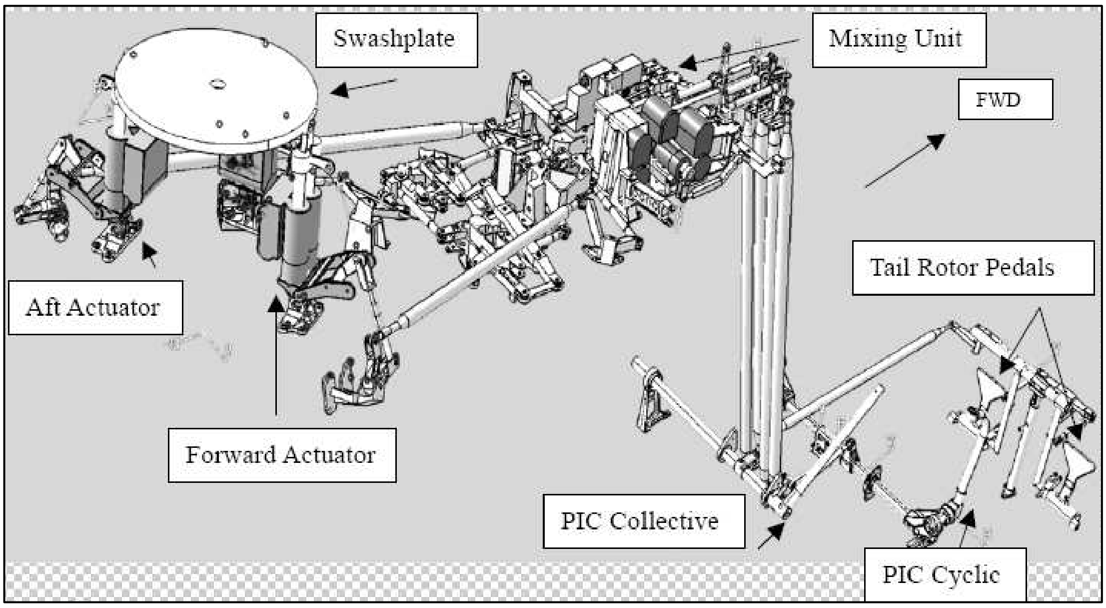

Figure 1. S-76 flight control system.

(The tail rotor actuator and control cables connecting mixing unit with the tail rotor actuator are not shown.)

The pilot's command inputs to the helicopter flight controls mechanically moved the hydraulic actuator (so-called "servo", forward, lateral and aft) inputs. The inputs were then augmented by each hydraulic actuator to the actuator outputs, which through a swashplate transmitted the pilot's commands from the non-rotating fuselage to the rotating rotor hub and main rotor blades. Cyclic control was used to change a helicopter's roll and pitch. The actuators tilted the swashplate in response to the pilot's commands.

The S-76 used sophisticated cyclic / collective pitch mixing design for automatic compensation of the tail rotor torque. The system also has a spring centering unit for tail rotor control in case of cable brake.

The three actuators moved the swashplate into a position determined by the cyclic and collective controls; and the swashplate then changed the pitch angles of the main rotor blades. Thus, the control inputs by the pilot, including the control inputs made by the Digital Automatic Flight Control System (DAFCS) were routed through a mechanical mixing unit with an input link to each actuator, opening the control valves of each actuator to correspond to the selected control inputs. Feedback of the actuator piston positions was accomplished through a trapezium feedback link that connected the heads of the actuator piston rods with the actuator cases. The feedback link was a mechanical link that ensured that the actuator pistons remained in a position determined by the cyclic and collective control inputs made by the pilot.

1.6.6.2 Description of the main rotor hydraulic actuators

On the S-76C helicopter, three hydraulic actuators (forward, aft, and lateral) controls the main rotor blades. Each actuator is featured a side-by-side dual design in which the helicopter's two independent hydraulic systems (systems no. 1 and no. 2) powering each side of an actuator. The actuator systems are independent of each other with regards to the hydraulics, but the housings of the two actuator systems are rigidly bolted into one piece. In addition, both systems are attached to each other through a joint head of piston rods and a feedback link (trapezium). Therefore, the pistons can move only in unison and the piston motion is reflected in the position of the flight controls in the cockpit.

Externally, a hydraulically centered *"floating sloppy link"* provides input to both of the main control valves from the single input control rod. Internally, each system has a spool-type main control valve (MCV) to serve as the hydraulic control for supplying hydraulic fluid pressure to the extension and retraction chambers of the actuator. The fluid return paths from each piston chamber through a pair of small orifices in the MCV secondary spool. The total orifice area in secondary spool for an extension or retraction chamber is controlled by position of primary spool, which controls the rates of extension and retraction of the actuator. Depending on which actuator and the movement of the helicopter, flight loads could provide additional extension or retraction forces.

Additionally to the own MCV both hydraulic actuator systems has own bypass/sequence valve, which in case of hydraulic pressure drop below 1600 psi disconnects actuator side from pressure line and connecting both extension and retraction chambers with return line.

Additionally to the bypass/sequence valve also MCV has its own safety function, what disconnects hydraulic actuator side from pressure line is case of jam the control spool in the secondary spool.

Two hydraulic systems provided hydraulic pressure for the operation of the actuators. In addition, the hydraulic system no. 2 was used for the extension and retraction of the landing gear, for the pedal damper / yaw trim actuator and vibration absorber in the front part of the helicopter. The hydraulic fluid specification was MIL-H-5606; and the hydraulic pressure was 3000 - 3100 psi (204 - 211 kg/cm^2).

A loss of hydraulic pressure in one of the two actuator systems or a malfunction of one system should not prevent the control of the helicopter. In case of a malfunction, a warning signal would be activated and the failed hydraulic system would be switched off. The warning signal would alert the pilot that only one of the two actuator systems was operational, and he was to discontinue or complete the flight as soon as possible.

Each actuator must function. A hydraulic jamming or complete failure of one of the actuators would upset the control of the main rotor to the extent that a complete loss of control of the helicopter could be expected, or should be considered catastrophic.

Sikorsky used two main rotor actuator manufacturers for the S-76: HR Textron and Helicopter Support Incorporated (HSI). The actuators can be used interchangeably on all S-76 series helicopters.

1.6.6.3 Operation and maintenance of the main rotor actuators

The actuators were of an unbalanced type-design, i.e. the surface area of the piston that received pressure for extension was bigger than the surface area of the piston that was used for the retraction of the piston. Since the piston rods were only one third thinner than the actuator pistons, a balance tube within the piston rod was utilized to, *inter alia*, reduce the difference between retraction and extension forces. The balance tube linked the inside of the piston rod with the return port, reducing the surface area of the piston bottom to which hydraulic pressure for extension was applied.

In order to minimize friction and to provide a sacrificial wear surface, an aluminum-bronze coating was applied to tangential grooves in the piston heads. The coatings were applied using plasma spray technology and the surface was afterwards mechanically treated. In an overhaul, the material on used pistons was chemically removed. Then, a new aluminum-bronze layer was applied. The maximum permitted thickness of the aluminum-bronze layer was 0.0125 inches (0.318 mm).

On OH-HCI, the forward actuator had been manufactured by HR Textron (Sikorsky part number 76650-09805); and the aft and the lateral actuators had been manufactured by HSI. .In accordance with the Sikorsky Maintenance Manual, section 5-10-00, the HR Textron actuators had a 3000hrs, flight time period between overhaul (TBO).

Section 5-10-00, (HELOTRAC Task reference *671530F/L/A) also contained a term to the usage of this period:

Note 1. (a) :"Do leakage test at 2250 hours (Refer to Adjustment/Test, 67-15-00)"

The HSI actuators were maintained "on condition", i.e. they did not have a specified flight time limit when overhaul was required.

The helicopter's maintenance and component log book contained an annotation that a HR Textron main rotor servo actuator had installed in place of a HSI actuator.

The due-list generated by the HELOTRAC called out the 100 hour inspection for internal leakage test to HR Textron servo in accordance per ASB-76-67-23C (HELOTRAC Task reference 671506A), which was "Not Applicable" because of the main rotor servo actuator part number (76650-09805-110).

Another task called out was: Main rotor servo actuator replacement (HELOTRAC task reference 671542F) which referred to Airworthiness Limitations section 4-00-00. Task had still remaining of 724 hours flight period.

However, Copterline had not updated the HELOTRAC records accurately. Therefore HELOTRAC did not generate task, with the origin to section 5-10-00, for 2250 hour internal leak test, which on the forward main rotor actuator had its due-time before the accident. The actuator had accumulated 2276 hours at the time of the accident.

According maintenance records, the internal leakage test for HR Textron servo part number 76650-09805-110 serial number 0846 was not found to be performed.

Any documented decision, made by the operator or approved by CAA Finland, for to deferring this internal leakage test task before the due-time or the accident, has not been established. The internal leakage test task, based on section 5-10-00, has not been found as "active" when the accident helicopters Maintenance Status was examined from HELOTRAC data base at situation: Date 19.08.2005.

During investigations final draft's comment period, copy of the printout from due-list dated at 01.08.2005 was provided by Copterline. This copy included a differing task description versus the one existing in the printed Helicopter Maintenance Status at date 19.8.2005. In this copy the task: "Main rotor servo actuator replacement, HELOTRAC task reference 671542F, based on Airworthiness Limitations section 4-00-00", had an extra "Part information" at 2250 hours, which was, at that time, 1. August 2005, found overdue by 7 flight hours.

The Commission shortly reviewed the records and manuals (also rechecked the HELOTRAC database by the date 19. August 2005) and did not find any document or record what could explicate this part information. This task had exactly same manual references than the existing task for servo replacement.

Copterline presented this information as the task for internal leakage test. No reference to section 05-10-00 was found. Any decision or approval for deferring this newly presented task, which was already overdue, was not found as documented. Either the internal leakage test for forward servo actuator was not found performed under this task.

The HR Textron actuator pistons had a maximum service life of 37 000 hours, and the number of overhauls of the pistons (within the maximum service life) was not limited.

The three main rotor actuators were to be inspected every 100 hours for condition and external leakage. The actuators and supports were to be inspected in detail every 300 hours and 12 months. This inspection included full stroke movement while externally powered on the ground. Also patch test to be performed to the hydraulic fluid. Copterline stated that they had complied with both these inspections on 30 June 2005 in connection with the scheduled maintenance of the helicopter. No specific work was required to be performed on the actuators.

Copterline also stated to the Commission that during inspection on the last 50 hours inspection on 28 July 2005 on the main rotor forward actuator lower spherical bearing was discovered play almost reaching the allowable limits due to the normal wear. This play indicated that it will be soon necessary to replace the forward actuator. Nevertheless, no remarks about discovered play and required additional attention to the play limits were discovered by the Commission in the helicopter's maintenance log, nor in the Copterline maintenance documentation.

1.6.6.4 Examination of the main rotor actuators

1.6.6.4.1 Forward actuator

The main rotor forward actuator, part number 76650-09805-110, serial number 0846, had been in service for a total of 11 180 hours. On 21 July 2003, the last overhaul of the actuator had been performed by HSI after 8 904.6 hours in service. On 19 August 2003, the actuator had been installed on OH-HCI. At the time of the accident, the forward actuator had been in service for 2 276 hours.

Photo 2. Main rotor forward actuator. (The spherical bearing at the lower left attaches to the helicopter structure above the cabin. The spherical bearing at theupper right connects to the swash-plate.)

Photo3. Forward main rotor actuator installation on the helicopter

According to the maintenance records, the pistons installed in the main rotor forward actuator in the last overhaul had been in service for 24 100 hours. As the stripping of the aluminum-bronze coating on the pistons was a requirement in an overhaul, it might be assumed that there had been seven reworks of the pistons. However, according to Sikorsky, the pistons were not reworked more than three times.

During post-accident testing, the forward actuator failed the manufacturer's acceptance test (a test used for new or newly-overhauled actuators). A detailed description of the discrepancies is presented in section 1.16.

1.6.6.4.2 Aft actuator

The main rotor aft actuator, part number 76650-09807-101, serial number B345-00137, had been overhauled by HSI on 27 September 2001 and installed in OH-HCI on 1

December 2001. After the last overhaul, the actuator had been in service for 3 290 hours. Its total time in service was 6 783 hours.

In post-accident testing, no major discrepancies in the operation of the actuator were found.

1.6.6.4.3 Lateral actuator

The main rotor lateral actuator, part number 76650-09807-101, serial number B345-00322, had been overhauled by HSI on 11 January 2004, and installed in OH-HCI on 4 February 2004. Its time in service since last overhaul was 1 620 hours.

In post-accident testing, no major discrepancies in the operation of the actuator were found.

1.6.7 Examination of the tail rotor actuator

Additionally to the main rotor hydraulic actuators helicopter also has one hydraulic actuator for controlling of the tail rotor pitch angle. The tail rotor actuator functioning similarly to the main rotor actuator but it has different design. The tail rotor actuator assembly, part number 76650-05803-102, serial number B346-00033, had been manufactured by HSI. No post-accident testing with the tail rotor actuator could be carried out due to cracks in the housing walls at the pilot valves for both hydraulic systems. The cracks in the housing walls were consistent with a hydraulic fluid pressure shock in the retract line, which typically occurred as a result of the impact forces.

At the request of the Estonian Commission, the NTSB Materials Laboratory examined the tail rotor actuator assembly. According to the NTSB laboratory report, both actuator housings were consistent with the specified corrosion resistant steel. The measured average hardness was within the hardness range specified. The cracks were examined using a scanning electron microscope (SEM). The cracks revealed features typical of overstress separation with no evidence of fatigue or other type of pre-existing cracking.

Thickness measurements were made and the wall for housing system no. 2 was below the specified range for all drawing revisions. For housing system no. 1, the measurement was either slightly below the specified range or slightly above the specified range depending on the area of the bore on which specification revision was in effect. In summary, the NTSB examination revealed that the housing walls of the tail rotor actuator control valves were slightly thinner than the specification called for. This finding had no bearing on the accident.

1.6.8 Examination of the engines

According to the FDR recording of engine parameters and the engine monitoring system (FADEC), there were no malfunctions in the operation of the engines that could have affected the flight. The engines were examined after their recovery from the sea, and no mechanical damage was found. The compressor shafts of the engines rotated relatively freely when turned by hand. Both engines were sent to the engine manufacturer in France for further investigation. As part of the examinations carried out by the manufacturer, both engines were started up and test run. No defects were found that could have affected the flight.

1.7 Meteorological information

1.7.1 General weather

The weather in the area of the accident was dominated by the northeastern part of a low-pressure system. The centre of the system was located about 150 km southwest of the accident site and moved northeast at a speed of 10 km/h. At the time the accident, there was a southeasterly surface wind (110°) at 14 kt in the area of Tallinn Bay. At an altitude of 1 000 – 2 000 ft, there was a southeasterly wind (130°) at 25 - 30 kt. Visibility was 7 - 8 km. Precipitation was light to moderate drizzling rain. The lowest cloud base of stratus and nimbostratus was at 800 – 1 400 ft. The Harku weather station registered at 12:00 hours local time (09:00 hours UTC) isolated cumulonimbus and light showers. There were no freezing temperatures in the lower layers of clouds, as the freezing level was at 9 500 ft. Moderate turbulence was forecast between the cloud layers from close to the surface up to an altitude of 4 000 ft. According to meteorological radar, the main layer of clouds that affected the flight reached from Tallinn to the island of Aegna and a few kilometers beyond.

There were no witness or weather radar reports of any special weather phenomena. There were no areas of heavy precipitation or thunderstorms. The turbulence in the cloud layers was moderate.

1.7.2 Weather reports

The weather report at Tallinn City Hall Heliport immediately before the take-off at 12:36 hours was as follows: Wind from 120° at 13 kt, visibility 5 km in light rain, some clouds at 1 000 ft, ceiling broken at 1 600 ft, overcast at 2 200 ft, temperature 14°C, dew point 13°C, altimeter setting QNH 989 hPa, QFE 989 hPa.

The weather station at Tallinn Airport (EETN) reported the following weather:

At 11:20 hours, wind from 110 degrees at 15 kt gusting to 26 kt, visibility 8 km in light rain, ceiling broken at 800 ft, overcast at 1 400 ft, temperature 14 degrees C, dew point temperature 12 degrees C, altimeter setting (QNH) 989 hPa, trend forecast no significant changes expected.

At 12:20 hours, wind from 110 degrees at 14 kt, visibility 6 km in moderate rain and drizzle, ceiling overcast at 800 ft, temperature 14 degrees C, dew point temperature 12 degrees C, altimeter setting (QNH) 989 hPa, trend forecast temporarily visibility 3 000 m.

At 13:20 hours, wind from 120 degrees at 13 kt, visibility better than 10 km in light rain, ceiling broken at 800 ft, overcast at 1 400 ft, temperature 14 degrees C, dew point temperature 12 degrees C, altimeter setting (QNH) 989 hPa, recent rain, trend forecast no significant changes expected.

1.7.3 Conditions at sea

At the accident site, the estimated wave size was up to one meter. However, it was possible that there might have been some higher swells caused by ships on the Tallinn Bay.

The temperature on the surface of the water in Tallinn Bay was estimated to be between 12℃ and 17℃. The latter temperature was measured at the Pirita beach in the southeastern part of Tallinn Bay (i.e. windward); the water temperature at Tallinn Sea Port was 15.6℃ (measurement made at 11:00 hours LT), 15.2℃ at 12:15 LT and 14.7℃ at 13:00 LT.

1.7.4 Weather necessary for creation of a waterspout

There could be two types of waterspouts: tornadic and fair weather waterspouts. Tornadic waterspouts required an unstable atmosphere. Building cumulonimbus clouds or lines of cumulonimbus clouds are normally present and it is usually present if the water surface has much higher temperature than the air above it.. Strong wind shears are also present. Fair weather waterspouts occurred when the winds are less than 6 kt.

1.8 Aids to navigation

The navigation aids had no bearing on the accident.

1.9 Communications

1.9.1 Radio communications

Before the accident sequence, all radio transmissions were clear and audible. The helicopter was in radio communications with the following stations:

Radio Communications Station	Frequency
Hernesaaren liikenne / Hernesaari Traffic	123.150 MHz
Helsinki-Malmi Tower	131.250 MHz
Tallinn ATIS, Information Hotel	124.870 MHZ
Tallinn Approach	127.900 MHz
Tallinn Linna Hall / Copterline company frequency	126.250 MHz
Tallinn Linna Hall / Automatic weather report	126.250 MHz
Tallinn Tower	120.600 MHz

There were no reported malfunctions in the radio communications. Both English and Finnish languages were used. The radio communications with Tallinn Tower were recorded by the ground facility and were transcribed as part of the investigation. The flight crew communications on the Copterline company frequency with the Copterline ground crews were not recorded by a ground facility, but any communications that took place in the last 30 minutes of the CVR duration were recorded by the CVR in the helicopter. According to the radio communications recordings and the CVR recording, the co-pilot conducted the radio communications.

On board the helicopter, the pilots used headsets and communicated with each other using the flight deck intercom system (“hot mike”). An automatic (pre-recorded) pre-flight passenger briefing was available and used in the Finnish, Estonian and English languages. Usually, the languages for the passenger briefing were chosen based on the nationality of the passengers on board each flight. In addition, a passenger address system (PAGE) was available and used by the flight crew for cabin announcements.

1.9.2 Radio panel settings

After the accident, the settings on the radio panels were found in the positions for the co-pilot to be able to transmit and receive radio communications on COM 2 (radio communications equipment no. 2). The settings for the pilot were found in positions for him to receive radio communications on COM 1 and COM 2. For the pilot, the PAGE system was found in the transmit position.

1.10 Heliport information

1.10.1 Linnahalli

The helicopter took off from the Tallinn City Hall Heliport (Linnahalli) (EECL) near Tallinn Bay. The heliport elevation was 17 ft (5 m) and the heliport was an elevated heliport. The accident did not take place at a heliport and, thus, the heliport had no bearing on the accident.

1.10.2 Radar data

The Tallinn Monopulse Secondary Surveillance Radar (MSSR) tracked the helicopter from an altitude of about 140 ft over Linnahalli heliport at 11:39:06 hours, through a climb to about 1340 ft just prior to the upset flight condition at 11:41:51 hours, and then down to an altitude of about 340 ft over the accident site at 11:42:26 hours.

The radar data was time referenced in hours, minutes, and seconds. The time interval between radar returns from the Tallinn SSR was four seconds. The OH-HCI transponder code (Mode A) was 5673. The transponder reported pressure altitude in hundreds of feet (Mode C). The pressure altitude was adjusted for the local altimeter setting to determine actual altitude. The resolution of the altitude data was +/- 50 ft.

1.11 Flight recorders

1.11.1 Description of the flight recorder

The helicopter was equipped with a Penny & Giles combined audio and flight data recorder Type 2000, MOD01, part number D51521-010-112, serial number 85579-001, manufactured in the United Kingdom. The recorder contained a crash protected solid-state memory module that recorded audio and the data parameters related to the operation of the helicopter. The recorder met the specifications in EUROCAE ED-112 “Minimum Operational Performance Specification for Crash Protected Airborne Recording Systems”.

Following the helicopter wreckage recovery from the sea, the flight recorder was located and removed from the helicopter. The recorder was read out by the manufacturer in the United Kingdom. Both the audio recording and the flight data recording parts of the recorder were well preserved.

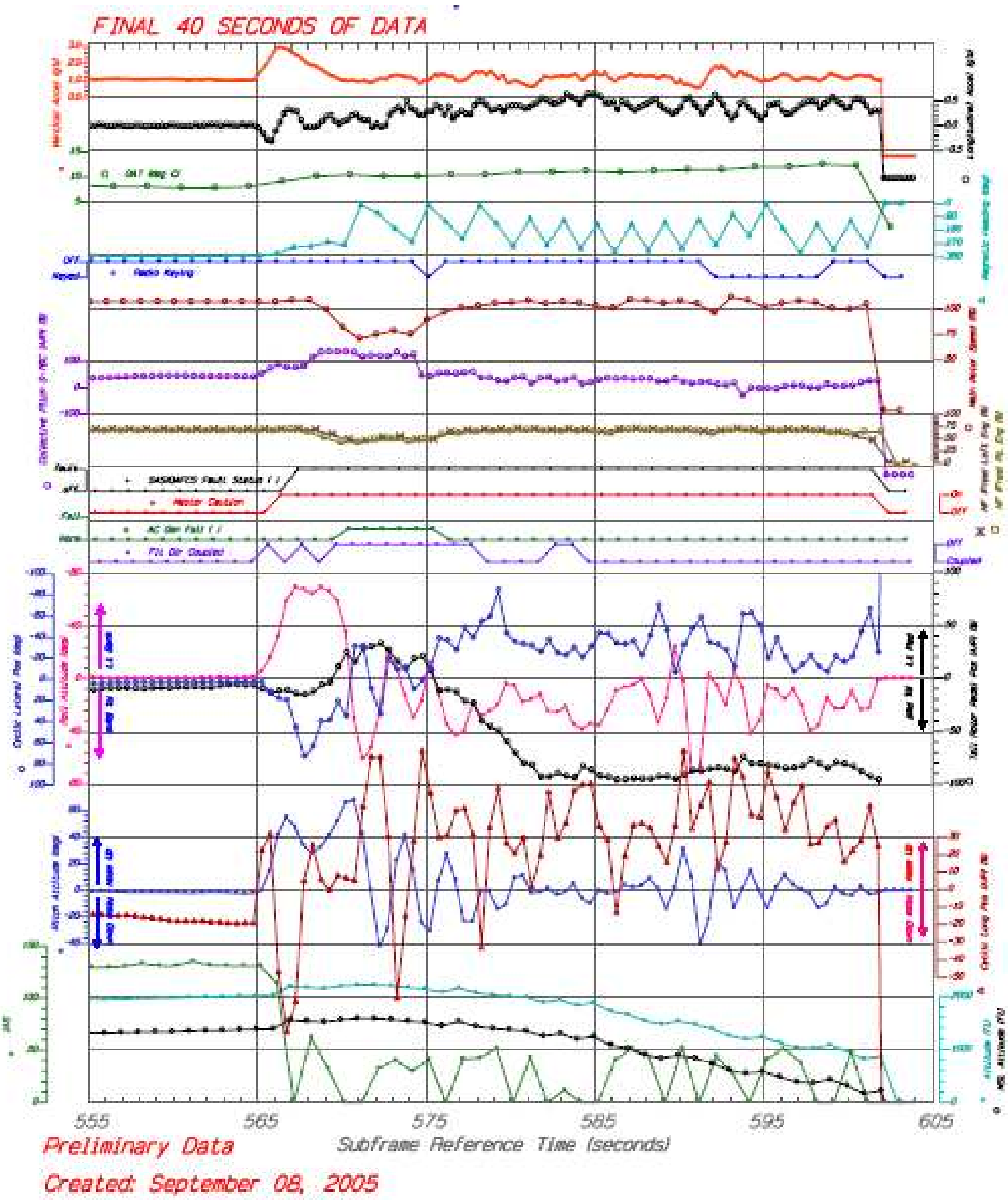

Figure 2. FDR data of the last 40 seconds of the accident flight

1.11.2 CVR and FDR synchronization

The four audio channels were manually synchronized using spectrum and audio analysis. The FDR data frame consisted of parameters sampled from one to eight times per second. Hence, a theoretical best time resolution of FDR data was 0.125 seconds, however, only the normal acceleration parameter was sampled eight times per second. It would require the normal acceleration to be time correlated to an event recorded on the CVR. Another limiting feature in the correlation between the FDR data and the CVR recording was the 30 minute duration of the CVR record versus the 33 hours of FDR data. The synchronization was achieved based on the landing gear warning signal (250 Hz intermittent signal), which was recorded on channels 2 and 3 of the CVR and the warning signal activation was recorded as an event on the FDR data.

1.11.3 The flight data recorder

The flight data recorder recorded 57 parameters. It received formatted data from a Flight Data Acquisition Unit (FDAU). The solid state memory module stored flight data from the last 33 hours of helicopter operation. The oldest data was over-written with new data, without the data recorder having means of erasing recorded data.

The FDR data (33 hours) was used extensively in analyzing the events on the accident flight and the previous flight to Tallinn, as well as analyzing events on flights and ground runs in the days preceding the accident. The airspeed distribution showed that half of the flight time was within 10% of the 155 kt Vne and 82 seconds were at or exceeding Vne, i.e. Copterline had reached or exceeded the maximum speed (Vne) certificated for the helicopter for a short time period during nearly every flight in the recording.

Distribution of FDR-recorded seconds at each knot of airspeed

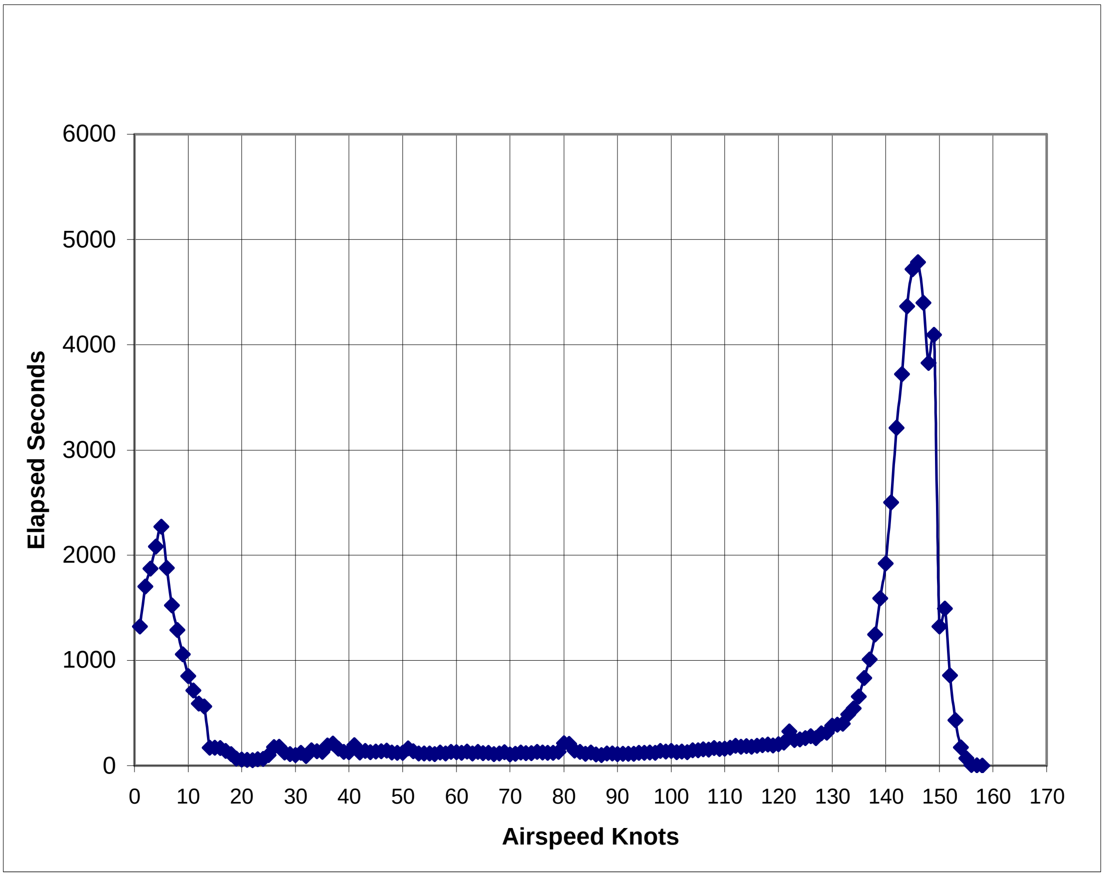

Figure 3. Airspeed distribution from the 33 hours of FDR data. Redline speed (Vne) was 155 kt.

1.11.4 The audio recorder

The CVR recorded simultaneously on four channels and stored the recorded audio from the last 30 minutes of its operation. Thus, the CVR contained recorded audio from the previous flight (from Helsinki to Tallinn), the helicopter turn-around on the helipad in Tallinn, and the accident flight.

The CVR record was used extensively in analyzing the events on the accident flight and the preceding flight to Tallinn.

1.12 Wreckage and impact information

Following the impact with the sea in Tallinn Bay, the helicopter sunk to a depth of 45 m and came to rest upside down on the seabed. The co-ordinates of the location were N 59°32.546 and E 024°43.852.

The condition of the wreckage was consistent with impact with the water in a relatively flat attitude and at a high, but not extreme, descent rate. The main rotor and tail rotor blades were broken off, and the fuselage and tail components exhibited crush damage. Otherwise the helicopter structure was largely intact.

1.12.1 Initial examination of the helicopter wreckage under water

An initial examination of the helicopter wreckage was carried out on the seabed using video recordings made by a Remotely Operated Vehicle (ROV), as well as the observations made by the divers. The quality of the video recordings was not good, because the visibility on the seabed around the helicopter wreckage was only about one meter. The helicopter was upside down and the main rotor hub had sunk into the sandy clay of the seabed. The helicopter tail rotor and the tail rotor gearbox had separated from the helicopter. They were located approximately 15 m from the main wreckage. The portions of the main rotor blades and other smaller parts of the helicopter were also found close to the main wreckage site. The tail cone of the helicopter was still attached to the fuselage, but it had marks of severe tear at the back of the fuselage. The right side windscreen was damaged and the right side cockpit door window was broken.

1.12.2 Recovery of the helicopter wreckage from the sea

The recovery of the helicopter wreckage from the sea was done using divers and a ship equipped with a crane. The divers attached straps around the main rotor hub and the wreckage. Using the crane, the main rotor head was pulled out of the sandy clay and the wreckage was turned to one side, so that the straps could be properly attached around the rotor hub and the spindles. An additional strap was attached to the helicopter's broken tail cone. The helicopter was lifted to the surface and placed on the deck of the ship.

The helicopter may have incurred some minor additional damage when it was turned around at the bottom of the sea, and hoisted up onto the ship with the tail still hanging from the main fuselage.

Photo 4. Helicopter OH-HCI recovery from the sea.

An initial inspection of the helicopter wreckage on board the ship showed that the landing gear was in the extended position. The two front emergency flotation devices had fallen out of their stowage in the nose wheel wells. They had not inflated and hung loosely. They contained tens of liters of water, which probably had leaked in through ruptures caused by the impact or during the recovery of the wreckage. The two rear emergency floats, which were attached to the inner sides of main landing gear doors, were in their stowed positions.

There was no evidence or indication of a bird strike or a collision with another object in the air. There was no evidence or indication of a separation of any part of the helicopter in the air. All significant parts of the helicopter were found at the wreckage site. All the doors and the latches (except the doors opened by divers) were closed.

1.12.3 Detailed examination of the helicopter

1.12.3.1 Main rotor blades

The root ends of all four main rotor blades were recovered still attached to the main rotor head and were primarily intact. The pocket on all four blades remained attached, consistent with the blades fracturing immediately after impact. If a main rotor blade would have separated in flight, then the vibratory loads would have shook the main gear box out of its mount. That was not the case, thus, there was no evidence or indication of a vibration of the magnitude that would have developed had a main rotor blade separated in the air.

Each of the four main rotor blades was identified by a different color: red (no. 1 and proceeding counterclockwise), blue (no. 2), yellow (no.3) and black (no. 4). A blade measured 239.75 inches in length.

The red blade remained attached to the rotor head, and was fractured at blade station (BS) 31 (blade stations were measured in inches from the blade cuff outboard). The outboard section of the red blade was recovered. It was partially fractured in an upward – aft direction at approximately BS104. An approximately three inch section of upper airfoil spar remained connected. The leading edge sheath was fractured and the trailing edge skin remained connected; however, the trailing edge was “popped” (mechanically disbanded due to sudden deceleration) and buckled from BS88 to BS116. There was a downward and aftward bend at approximately BS180. The trailing edge was popped and buckled in association with this bend from BS140 to BS196. The leading edge tip weight mounting bolt was bent aft. The tip block and weights were intact, and the tipcap was torn off in the aft direction.

The blue blade remained attached to the rotor head, and was fractured at BS60. The spar was intact outboard of the fracture at BS60. The trailing edge was popped from BS134 to BS154 consistent with sudden deceleration due to impact. The tip block and weights were intact, and the tipcap was torn off in an aft direction.

The yellow blade remained attached to the rotor head, and was fractured at BS26.5. The outboard section of the yellow blade was recovered; however, the section of the blade from BS26.5 to approximately BS113 was not recovered. The outboard section was intact from BS113 to the tip block, but showed evidence of leading edge impacts with hard objects and blue paint transfer at BS204, BS212 to BS216, and the tip. The trailing edge was popped from BS155 to 165 and BS175 to 185 consistent with sudden deceleration due to impact. The tip weight mounting bolts were bent aft. The tip block and weights were intact, and the tipcap was torn off in an aft direction.

The black blade remained attached to the rotor head to BS11, where it was fractured in an aft and upward direction. Both damper attachment lugs were damaged, the upper completely, and the lower partially separated. The outboard section from BS11 to the tip, except for the tipcap, was recovered floating on the surface close to the accident site. The blade was relatively intact with no evidence of any impact other than water. There were several areas where the trailing edge was popped (BS64 to BS80, BS98 to BS112, and BS140 to 148), which was consistent with sudden deceleration upon water impact. Several skin-to-core pocket disbands were noted in these areas. Two small skin tears were also found.

1.12.3.2 Main rotor head

The main rotor head was intact and attached to the main gear box. All four spindles remained intact. Evaluation of the inner hub arms through the upper inspection holes showed the impact marks left by the inboard ends of the elastomeric bearings, consistent with impact direction on the red, blue, and black blades, and consistent with damage opposite rotation (inertial) on the yellow blade. All four dampers were intact.

The four pitch change rods were intact and remained attached at both ends. All four pitch change horns appeared intact. Light witness marks were observed on the inboard side of the horns where they contacted the hub during extreme lag motions associated with impact. All four droop stops could be rotated freely. None showed any signs of impact with the spindles. All were found in the retracted (static) position. The flap stops rotated freely, except for the blue which was slightly stiff. None showed any signs of major impact with the spindles. All were found in the retracted (static) position.

The helicopter was fitted with a standard 3P bifilar only. According to maintenance records, the optional 5P bifilar had been removed by the operator on 6 July 2005. The 3P pins and bushings had also been replaced at that time. All weights were intact and the bifilar remained attached to the rotor head.

1.12.3.3 Tail rotor system

The tail rotor gear box output section and the tail rotor head were observed adjacent to the helicopter on the underwater video, and they were recovered separately from the main wreckage.

As with the main rotor blades, the four tail rotor blades were also identified by a different color: red (blade no. 1 and proceeding counterclockwise), blue (no. 2), yellow (no. 3), and black (no. 4). The red tail rotor blade was intact from the root to the tipcap. The trailing edge of the torque tube was popped from radial station (RS) 13 to RS25 (measured in inches from the tail rotor head centerline outboard), consistent with sudden deceleration due to impact. The blue, yellow, and black blades were not recovered. All three spars were fractured in a broom straw fashion at RS11, RS9 and RS7, respectively. The cuff boots were intact. The bonding jumpers were separated and retained on the pitch change beams.

The tail rotor gear box input and center housings remained attached to the vertical pylon. The tail rotor actuator and yaw Stability Augmentation System (SAS) actuators were visibly damaged and the tail rotor quadrant was torn away from its mounting point on the tail rotor gear box, but remained attached to the two yaw SAS actuators. The inboard rod ends of both SAS actuators were bent, and an inboard portion of the forward yaw SAS actuator had evidence of impact damage.

The tail rotor head remained attached to the tail rotor gear box output section. The tail rotor retention plates were intact, the retention nuts were installed, and the cotter pins were present. The pitch change beam was oriented correctly; the retention nut was installed and safe-tied. The red pitch change link was intact. All three other pitch links were fractured at the pitch change beam end.

There was no evidence or indications of pre-existing damage or malfunction of the tail rotor system.

1.12.3.4 Fuselage

The fuselage was damaged, but retained survivable volume. There were extensive crushing deformations on the fuselage skin on the belly. The damage was more extensive on the right side from the nose to fuselage station (STA) 215 (end of cabin), but was nearly symmetrical aft of STA 215. The right side fuel tank was compromised by hydrodynamic inward crush of the bottom airframe structure. The left side fuel tank appeared intact. The fuselage deformations were consistent with pressure damage resulting from impact with water. There was no soot or any other evidence of fire in any location.

The impact damage was consistent with the helicopter having a slight right bank and nose-up attitude, low forward speed, and moderate rate of descent along with a right (clockwise) rotation.

The airframe was intact, except for separation of the tail cone along STA 300. The tail cone remained attached to the fuselage by electrical wires and hydraulic lines. The two tail rotor control cables broke when the helicopter was lifted out of the water. As a result, there were deep cuts caused by the control cables to the lower parts of the fuselage frame. The stretching and breaking of the control cables turned the segment bell crank to the extent that a tail rotor control rod also bent.

The tail pylon showed heavy left to right damage and paint scuffs that were consistent with a main rotor blade strike extending from about STA 400 to STA 480. The tail pylon also showed extensive hydrodynamic crushing of the lower surface consistent with impact with water. The vertical pylon was damaged where the output section of the tail rotor gear box separated from the pylon. Both the left and right horizontal stabilizer panels were damaged, but remained attached. The intermediate gear box was found in place.

The left side forward chin bubble and nose radome were intact. Both right side chin bubbles, as well as the left side aft chin bubble, were shattered. The right side windscreen was completely shattered, while the left side windscreen was intact. The left side cockpit door and window were intact. The left side forward opera window and cabin door window outer panes were fractured, but the interior panes and both panes of the aft opera window remained intact.

The right side (pilot's) door was heavily damaged. The door's locking mechanism was still attached to the doorframe, although the remainder of the door was torn open. The door was split vertically along the centerline of the door. The window was fractured with the top of the pilot's headrest extending outboard beyond the window. The airframe section between the cockpit and the cabin doors was crushed inward consistent with impact with water. The cockpit canopy was fractured on the right side of the upper windscreen support. The right side forward opera window outer pane was fractured, but the inner pane was intact. The right side cabin door was also intact, with a crack in the window outer pane. The window inner pane and the rear opera window were intact.

1.12.3.5 Cockpit and flight controls

The co-pilot's space (left side) was intact. The pilot's space (right side) was compromised with damage to the forward floor structure and pedal support, the windscreen shattered and pushed slightly inward, and the pilot's seat had broken off from its left floor attachments. The pilot's seat was still attached to the floor by the right attachments, but it was free to rock in the lateral direction. The right side was crushed inward in a manner consistent with a right roll during the accident sequence.

The number one engine power control lever was near the stop position, the fuel selector was in the direct position, and the T-handle was in the full forward (ON) position. The number two engine power control lever was one inch forward of the idle position.

According to Sikorsky, the engine power controls were in the *“manual track”*, which may have been a result of the impact, and not necessarily a flight crew selection. The fuel selector was in direct, and the T-handle had been moved aft approximately three inches of the full forward position.

The landing gear handle was in the UP position, and the emergency extension handle was not activated.

Both pilots´ headphones were connected to their sockets.

On the pilot’s instrument panel the airspeed indicator needle was broken off. The altimeter setting was 29.22 inches Hg. The radar altimeter was at zero, the OFF flag was visible, and the bug setting was 175. The standby gyro indicated 135 degrees right wing down and greater than 30 degrees nose down. On the pilot’s overhead panel, the following items were ON: inverters no. 1 and no. 2, batt(ery), master start, pitot heater (right switch was ON), and master – EFIS no. 1 / EFIS no. 2 / radio.

On the co-pilot’s instrument panel, the radar altimeter indicated 195 ft and the bug was set at 450 ft. On the co-pilot’s overhead panel the following switches were ON: FSB, ANTI COLL and STROBE/POS.

To the right of the emergency flotation system switch in the cockpit overhead panel, two inverter switches were found in the *“ON”* position and the two switches for the generators next to them were in the *“OFF”* position. Photos of the cockpit panels could not be taken under water. It should be noted that the positions of switches and levers at impact may have been different from the positions in the recovered helicopter. During the recovery operation in the inverted helicopter with space constraints in the cockpit and poor visibility, the activities of the divers may have resulted in inadvertent changes to some lever and switch positions. However, the flight controls could not be moved without hydraulic pressure.

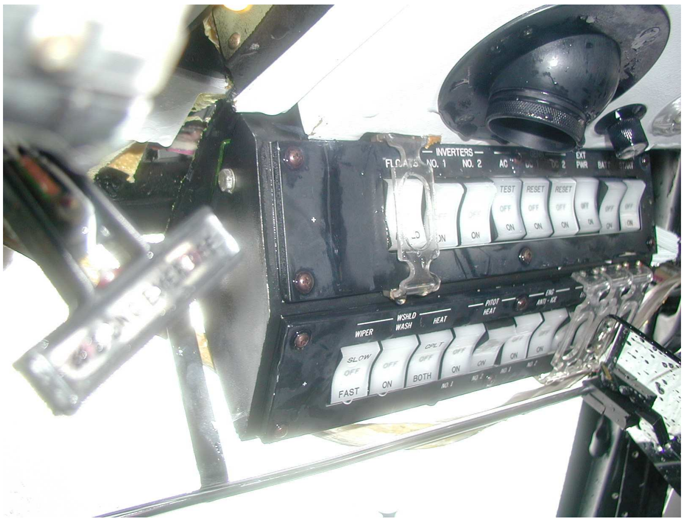

Photo 5.   Overhead control panel with the switch for the emergency floats.

(The first left one in the upper row, under protection cover)

The collective controls on both sides (pilot and co-pilot) had stopped close to a middle position. The hydraulic system selector switch on the collective on the left side (co-pilot) was found set to *"No. 2 OFF"*. The hydraulic system selector switch on the collective on the right side (pilot) was found in the middle (normal) position. A plastic cover for the engine power control switch had separated from pilot's collective control handle. The cyclic control stick on the right side (pilot) was bent slightly forward near the floor.

The tail rotor pedal mechanism on the right side (pilot) was deformed and the right pedal was in the maximum forward position. The deformations of the right pedal indicated a forward-directed force at impact. The cover plate for the trim switch on the right pedal was bent up. The tail rotor pedals on the left side (co-pilot) were not deformed and the pedals were in a position with the left pedal slightly forward. The rod (tube) under the cockpit floor that connected the pilot's and the co-pilot's cyclic controls was broken. The surfaces of the rod breakage were consistent with compression loads at impact. As a result, the pilot's and the co-pilot's cyclic controls moved independently of each other.

1.12.3.6 Landing gear

The three landing gears were in the down position at recovery, and the tires remained inflated. The landing gear handle was found in the gear up position. Damage to the landing gear doors and surrounding structure was consistent with the landing gear being up and locked at the time of impact.

1.12.3.7 Emergency Locator Transmitter

An Emergency Locator Transmitter (ELT) was installed in the tail of the helicopter. The ELT activation switch was in the "off" position, which was the normal working position during helicopter flight operations. However, the ELT was not capable of transmitting signals from below the surface of the sea.

1.13 Medical and pathological information

According to the autopsy reports for the flight crew, there was no evidence or indication that the flight crew would not have been medically fit to perform their flight duties. According to the toxicology reports for the flight crew, no evidence or traces of alcohol or psychotropic substances were found.

The autopsy reports showed a varying degree of trauma injuries for all occupants, and according to the autopsy reports, the cause of death was drowning for all occupants.

1.14 Fire

There was no fire.

1.15 Survival aspects

1.15.1 Passenger safety briefings

In the passenger terminal, a passenger safety information video was shown to the passengers before each flight. Before take-off, a pre-recorded passenger safety briefing was provided in the Finnish, Estonian and English languages. A safety information card in the English language, which included emergency evacuation procedures into water, was available for the passengers at each passenger seat location in the cabin.

1.15.2 Helicopter emergency equipment and flotation devices

The helicopter was equipped with inflatable life jackets for each occupant. The life jackets were in plastic covers and stowed in pouches with Velcro-shutters under each seat. Three loose life jacket packs were recovered from the cockpit, only two of which were probably stowed for the flight crew. The two right side life jacket packs in the front row, and two packs in the back row, were not found.

Because the calculated flight time was 18 minutes, the helicopter was always within ten minutes of the shoreline. Therefore, no life rafts were required to be carried on board according to JAR requirements.

The helicopter was equipped with an emergency flotation system, which enabled the helicopter to remain afloat if the floats were activated before an emergency landing on water. The flotation system consisted of four floats, two of which were located in the nose wheel well on each side of the nose landing gear. The two rear floats were located inside the main landing gear wells. In the event of an emergency situation requiring a landing on water, the floats were first armed and then activated by either pilot. Compressed nitrogen bottles were available to inflate the devices before a ditching or emergency landing on water.

On the center overhead panel in the cockpit, there was a *"float"* switch. In order to avoid unintentional deployment of the floats, the normal procedure required the pilots to de-arm the switch after take-off when the airspeed increased to over 75 kt for the duration of the en-route flight. When the switch was in the armed position, a warning light illuminated in the cockpit warning panel. In this configuration, either pilot could inflate the emergency floats by pressing a button on the cyclic control, which would discharge the nitrogen bottles. The time required to inflate the floats was ten seconds.

The two rear emergency floats remained stowed in their containers in the main wheel wells. The two emergency floats in the front part of the helicopter had come out of their stowage wells. They were attached to the airframe, but they had not inflated. According to the Copterline S-76 Flight Manual, the checklist for the activation of the emergency floats, listed the landing gear extension as an action item before the inflation of the floats. Nevertheless, the floats could also be inflated with the landing gear in the up position. Electrically activated explosive charges would separate the main landing gear door linkage upon deployment of the emergency floats.

Also, the pressure bottles for inflation of the floats were pressurized with compressed nitrogen and the system had not been activated. The float arm switch in the overhead panel in the cockpit was in the *OFF* position (i.e. disarmed as required in flight at over 75 kt).

1.15.3 Search and rescue operation

The air traffic controller at Tallinn Airport Air Traffic Control Tower watched the helicopter on his radar screen. He was about to communicate to the helicopter the take-off time and request the helicopter to contact Tallinn Approach on frequency 127.9 MHz.

In the information available to him on his radar screen, he noticed an abrupt change in the helicopter's heading followed by a loss of altitude. When the helicopter information disappeared from the radar screen, the air traffic controller activated a rescue operation. Also, two eye-witnesses of the accident had alerted the emergency centre. Thus, the search and rescue operation was activated within two minutes of the accident.

The port authority vessel AHTO 7 reached the accident site about ten minutes after the accident. According to the captain of the vessel, he noticed at once a small oil patch (coordinates 59° 32.684 N and 024° 43.725 E). He al so noted one of the main rotor blades in a near vertical position, protruding approximately one meter above the water, and floating slowly away from the oil patch.

At 12:55 pm the search and rescue helicopter of the Boarder Guard Aviation Group departed from Tallinn Airport. It arrived at the accident site approximately 20 minutes after the accident and began searching the area.

The Estonian Boarder Guard observations were similar to the findings by the captain of the port authority vessel that only a light trace of oil and one floating main rotor blade were found on the surface of the sea in the vicinity of the accident site. None of the occupants of the helicopter were found in the course of the search and rescue operation.

On 10 August 2005 following the accident, the Joint Rescue Coordination Centre in Tallinn (JRCC Tallinn) contacted the Maritime Rescue Sub-Centre in Helsinki, Finland (MRSC Helsinki) and requested assistance. The Finnish authorities, including the Boarder Guard and the Navy, provided rescue helicopters, a surveillance aircraft, vessels and divers that assisted the Estonian authorities in the search and rescue operations.

The wreckage of the helicopter was located on the seabed approximately five hours later by the use of a Remotely Operated Vehicle (ROV). During the next three days, divers recovered thirteen of the fatally injured occupants from the helicopter. The fourteenth victim was recovered 15 days later some distance away from the wreckage location.

1.15.4 Emergency egress considerations

The passenger seats were equipped with three-point safety harnesses. According to the divers, all passengers were located in helicopter passenger cabin.

According to the Copterline Ground Handling Manual, Allocation of Passenger Seats, passengers requiring boarding assistance were to be seated in the centre or back row of the cabin and always in one of the middle seats (seats B and C), in order to facilitate a quick evacuation in an emergency situation. The Commission noted that an elderly passenger had been seated in seat 2 D, next to the passenger cabin door. However, the Commission was not in a position to determine whether the passenger would have been capable of jettisoning the cabin door by the emergency procedure and evacuating the helicopter without assistance.

The helicopter impacted the water in a relatively high vertical descent rate, while rolled and rotating to the right. In a matter of seconds, the helicopter probably turned upside down, submerged in water and sank. The damage to the seats was consistent with relatively high vertical impact forces, such as seat pans broken in a downward direction and some seat legs pushed through the floorboard.

The flight crew seats were equipped with five-point safety harnesses. The divers reported that the co-pilot was found not strapped in the safety harness. It was likely that the pilot was not strapped in the safety harness at impact. At the impact with the water and as the helicopter was sinking, either the pilot was ejected from his seat through the side window in the right side cockpit door, or he managed to egress the helicopter through the side window.

In order to open a helicopter door by the emergency procedure, it was necessary to pull out a door lock pin, to raise the cover of the jettison handle, and to turn the jettison handle from the horizontal position to vertical. No attempt had been made to jettison the right side cockpit door or the passenger cabin doors. According to the divers, the left side cockpit door fell easily out its frame; the door lock pin had been pulled, the cover of the jettison handle had been raised and the handle had been turn to the upright position, but the door had not been pushed out.

Photo 6. S-76 Co-pilot door (left side)

Photo 7. S-76 Right side passenger door

1.16 Tests and research

1.16.1 General

As part of the investigation, tests and examinations were performed to establish the conditions of the following items:

- The engines of the helicopter were examined in order to confirm that they were in working condition. According to the examination report, the engines operated satisfactorily. There were no findings or indications of an engine failure;
- The main gear box of the helicopter was examined. No malfunctions of the main gear box were found;
- The tail gear box and intermediary gear box were examined. No pre-accident failures of the tail rotor system were found;
- The main rotor blades and their areas of separation were examined. The examination concluded that the blades had been intact until they impacted the water;
- The hydraulic actuators of the accident helicopter flight controls were tested and examined in order to assess their condition. The examination identified a failure of the main rotor forward actuator; one of the return ports of the pilot valve of the actuator stage no. 2 was obstructed by pieces of plasma coating that had separated from the coating on the pistons of the actuator; the results of the tests and examinations are described in detail in this report;
- Functional tests of a test forward actuator were carried out by simulating the documented failure, in order to determine the possibilities of uncommanded extensions. The tests showed clearly a direct relationship between the actuator stall forces and an increased internal leakage and the return port obstruction. Tests with a degraded forward actuator (similar to the actuator in the accident helicopter) demonstrated the possibility of uncommanded extension of the actuator; the results of the tests and examinations are described in detail in this report;
- An examination and functional tests of the safety belts of the flight crew were carried out. The safety belts and the locking mechanisms were intact. No deformations or indications of overload forces were found;
- An acoustic analysis of the cockpit audio recording was made in order to examine the sound characteristics and to enhance some segments of the recording. According to the acoustic analysis report, the information in the recording did not reveal any new or additional information directly related to the causes of the emergency situation;
- On the basis of flight recorder data, a graphical computer animation was developed to assist in the assessment of the attitudes and maneuvers of the helicopter;
- An assessment of the helicopter floating capability after impact and the rate at which it filled with water was made by experts;
- Computer modeling of the flight control system was used to establish a specific relationship between the motions of the main rotor actuators and the flight control movements as recorded on the FDR;

- Computer modeling of the forward main rotor actuator was used to establish the performance capability related to control, force, and velocity; and
- Sikorsky's GenHel S-76C helicopter simulation was used to establish the helicopter's response capability (1) to an uncommanded extension of the main rotor forward actuator and (2) to an encounter with a waterspout.

1.16.2 Acoustic analysis of the audio recording

The acoustic analysis consisted of speech enhancement, transcription analysis, speaker identification, and analysis of technical and aerodynamic background sounds.

For the acoustic analysis of technical and aerodynamic sounds, the rpm figures in Chapter 18 – Vibration of the Sikorsky Manual were used and translated into power settings and rpm values. Sound samples from channels 2, 3 and 4 were analysed in order to determine the changes in flight attitudes, which may not have been recorded in the FDR because of its lower sampling rate.

The audio information was transcribed in detail. Channels 1, 2 and 3 were of equal duration. Channels 2 and 3 were in synchrony as regards their speech content. Channel 1 was not in use and, thus, it did not contain any (speech) information. The channels had to be synchronized in order to establish a timeline for the audio information. This was done by locating specific sounds that were recorded simultaneously on all the active channels (2, 3 and 4).

Channels 1, 2 and 3 contained interference close to the end of the recording. After the period of interference (duration 2.57 seconds), the recording was duplicated for 3.30 seconds. The content of the duplication was identical to the content 4.48 seconds before the interference. The duplication was the result of an unsuccessful previous block writing process. According to the Penny & Giles Component Maintenance Manual, a block will take 7.128 seconds to write onto the crash-protected memory. If the writing process was interrupted, the whole block was rewritten. In this case, the duration of a successfully written block was 4.48 seconds and the duration of the interference was 2.57 seconds. The sum of these durations (7.05 seconds) corresponded approximately to one block size. Because of the interference during the writing process, the block was reprocessed from the beginning. Then the rewriting process was also interrupted, and the block ended up unfinished (3.30 seconds). There was no interference or duplication in the area channel recording.

1.16.3 Computed tomography of the flight control system components

Under the direction of NTSB, computed tomography scans and digital radiography were used to examine and document the internal configuration of the hydraulic actuators, the artificial feel and trim actuators, and the automatic flight control system actuators. Each component was examined for any signs of missing or damaged parts, contamination in the flow passageways, or any similar anomalies.

Computed tomography found and documented an obstruction by a large flake of metallic material in the hydraulic system no. 2 bypass valve, adjacent to the main control valve, in the main rotor forward actuator, as shown in Figure 5.

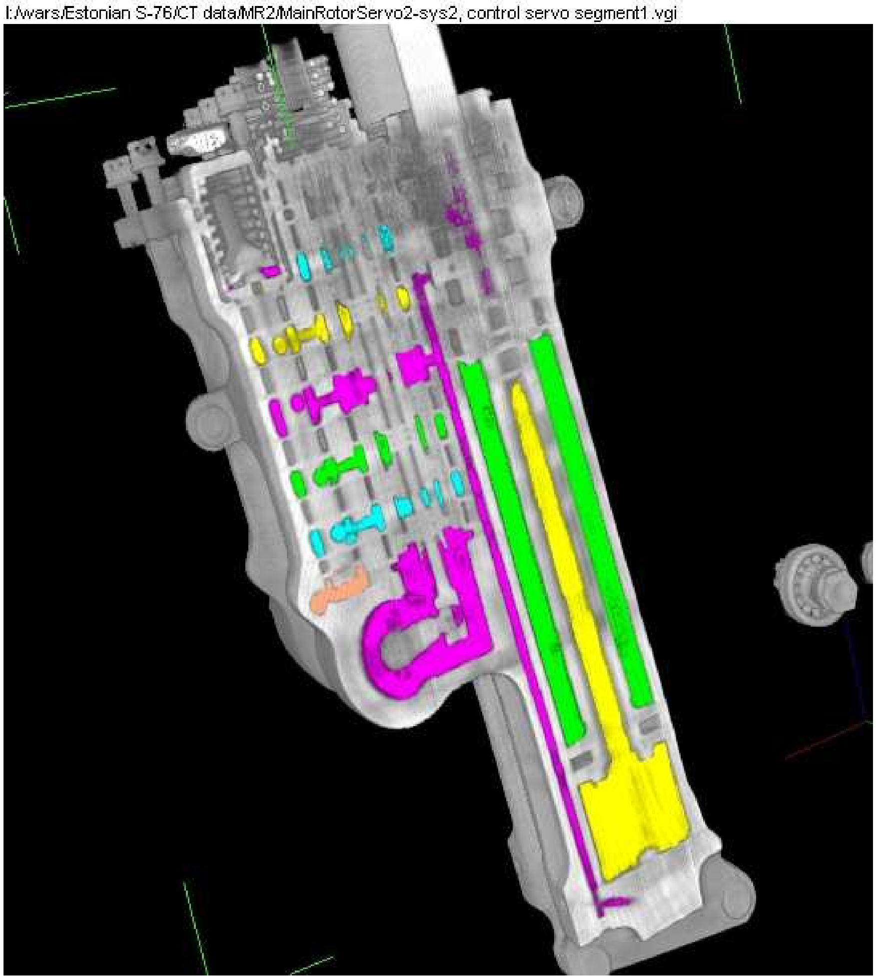

Figure 4. *Main rotor forward actuator – cross section through bypass valve, main control valve, and piston highlighting the return hydraulic passage.*

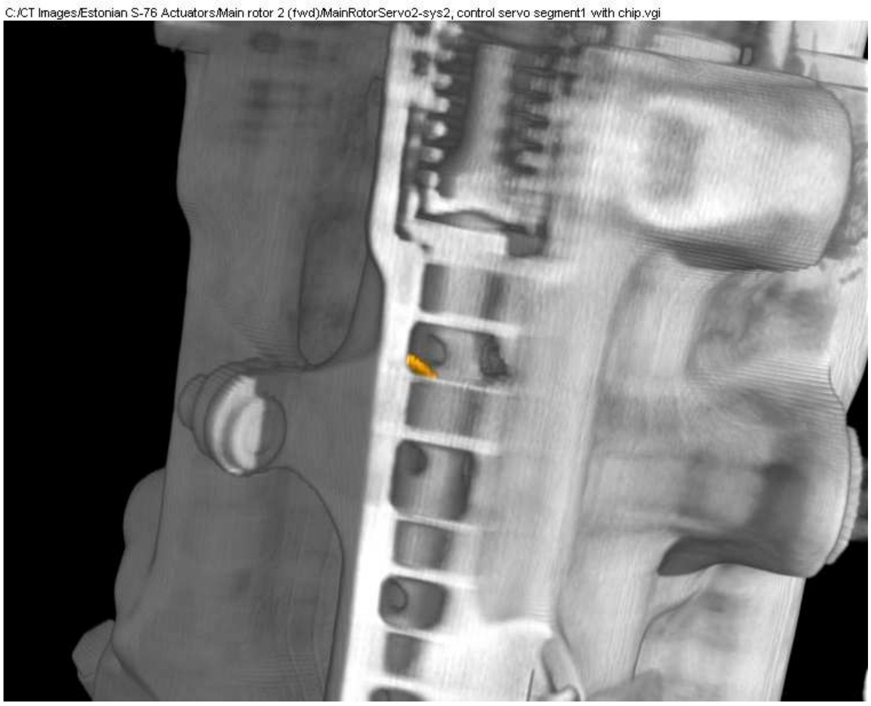

Figure 5. *Main rotor forward actuator – cross section through bypass valve showing metallic debris. (Color used for clarity only.)*

1.16.4 Examination of the main rotor forward actuator

1.16.4.1 Summary of the tests and examination of the forward actuator

The main rotor forward actuator was tested and examined under the direction of NTSB. During post-accident testing, the forward actuator failed the manufacturer's Acceptance Test Procedure (ATP). Specifically, with both hydraulic systems pressurized, the actuator would extend on command, but the retraction time to the neutral position was much slower than the test procedure specified. With only hydraulic system no. 2 pressurized, the actuator extended without an input command and would not retract when commanded. With only hydraulic system no. 1 pressurized, the actuator extended faster and retracted slower than the test protocol specified. Furthermore, the actuator greatly exceeded allowable internal hydraulic fluid leakage limits. Additionally, actuator movement was described as *"notchy"* with *"excessive resistance"*.

A subsequent disassembly of the actuator revealed the following discrepancies:

- Large pieces of aluminum-bronze plasma coating had flaked off the pistons;
- Two large pieces of plasma coating obstructed one (of two) of the return ports in the Pilot Valve of system no. 2;
- One large piece of plasma coating was found in the Bypass Valve Return Line of system no. 2;
- The piston rings showed excessive wear and the system no. 1 piston ring locks were lined up (openings approximately in the same positions on the piston); and
- In addition to the jammed Pilot Valve, many pieces of plasma coating were found in the return lines and in the hydraulic filters.

1.16.4.2 Testing of the forward actuator at HSI

The forward actuator was inspected and functionally tested at HSI in Trumbull, Connecticut, USA in accordance with the procedures in the Component Maintenance Manual 67-15-01. Visual inspection of the actuator found no external defects. Functional testing of the actuator found that it did not meet the Acceptance Test Procedure (ATP) requirements in several areas (the ATP was used for both newly manufactured and overhauled actuators).

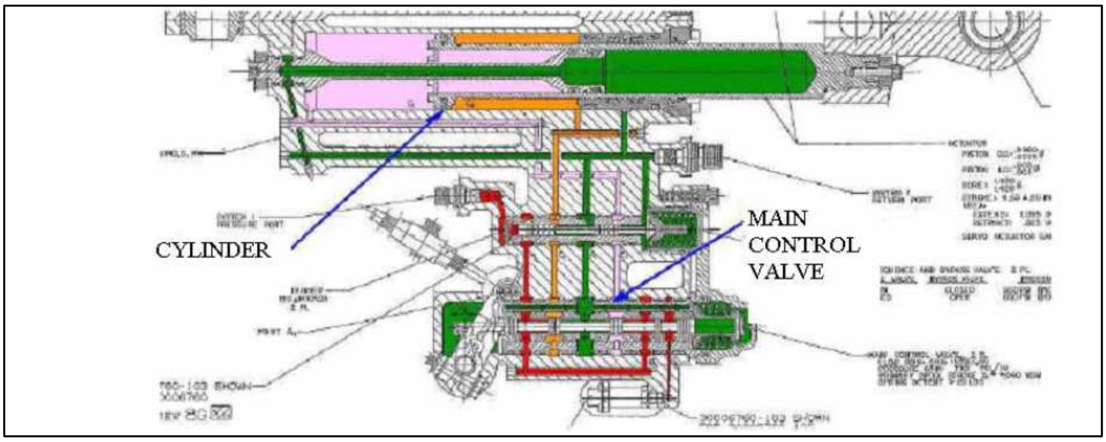

Figure 6. Main rotor actuator hydraulic schematic (one system).

The maximum allowable leakage for an in-service actuator was 725 ml/min. System no. 2 leakage at the Null position measured 2400 ml/min, and system no. 2 leakage with a hard-over Extend command measured 1800 ml/min. Also, the actuator did not remain at the full Extend position; it had a tendency to back off the stop unless force was applied to pilot input. With only system no. 2 energized, the actuator then stopped responding at the extended position and it did not retract when pilot input was moved to the full Retract position. Restoring system no. 1 and continued cycling on both systems and operation freed the restriction noted above. The system no. 1 leakage at the hard-over Retract position measured 2700 ml/min, and the system no. 2 leakage at the hard-over Retract position measured 1120 ml/min.

Piston velocity checks were performed to measure the speed at which the actuator piston would extend and retract. The piston stroke measured 4.628 inches, and the piston velocity specification was 5.0 to 5.8 inches per second. For system no. 1 and system no. 2 operating together, the Extend velocity was 6.17 inches per second, and the Retract velocity was 0.926 inches per second. For system no. 1 alone, the Extend velocity was 5.08 inches per second (which was within the specification requirements), but the Retract velocity was 3.856 inches per second. And for system no. 2 alone, the Extend velocity was 6.17 inches per second, while the Retract velocity was 0.000 inches per second – the actuator would not retract.

1.16.4.3 Further testing of the forward actuator at HR Textron

Because of the testing discrepancies identified above, the actuator was further tested at the manufacturer's (HR Textron) facilities in Santa Clarita, California, USA. Functional testing found the following discrepancies:

The internal leakage checks revealed several discrepancies: System no. 2 leakage at the Null position measured 1120 ml/min (vice the 2400 ml/min measured previously), and system no. 2 leakage with a hard-over Extend command measured 1120 ml/min (vice the 1800 ml/min measured previously). During this test, the actuator would remain at the full extend position without force being applied to the input. With only system no. 2 energized, the actuator once again stopped responding at the extended position and did not retract when pilot input was moved to the full Retract position. Restoring system no. 1 and continued cycling on both systems and operation freed the restriction noted above. The system no. 1 leakage at the hard-over Retract position measured 1160 ml/min (vice the 2700 ml/min measured previously), and the system no. 2 leakage at the hard-over Retract position measured 1350 ml/min (vice the 1120 ml/min measured previously).

When setting up for the velocity test, system no. 2 operation was achievable in the extend and retract directions, although the performance was rough. During the manual movement of the actuator, the unit was observed to suddenly *"jump"*. After this movement, the system operation was noticeably improved. When system no. 2 was in the full Extend position, an abnormal noise (hiss) was heard when the input lever was pushed to the mechanical stop. This hissing noise was indicative of hydraulic fluid flow. The internal leakage was rechecked and was found to be 1190 ml/min.

Piston velocity checks were again performed to measure the speed at which the actuator piston would extend and retract. For system no. 1 and system no. 2 operating together, the Extend velocity was 6.18 inches per second (vice the 6.17 in/sec measured previously), and the Retract velocity was 1.83 inches per second, (vice the 0.926 in/sec measured previously). For system no. 1 alone, the Extend velocity was 6.86 inches per second (vice the 5.08 in/sec measured previously), and the Retract velocity was 1.78 inches per second (vice the 3.856 in/sec measured previously). And for system no. 2 alone, the Extend velocity was 6.62 inches per second (vice the 6.17 in/sec measured previously), while the Retract velocity was 2.31 inches per second (vice the 0.000 in/sec measured previously).

1.16.4.4 Disassembly and examination of the forward actuator at HR Textron

The actuator was disassembled. The piston assembly was removed intact with the rod end still attached and the balance tubes remaining in place. The system no. 1 plasma coating at the base of the piston was chipped around approximately 25% of the circumference, as shown on Photo 8.

Photo 8. System no. 1 piston with chipped plasma coating

The system no. 2 plasma coating at the base of the piston was chipped around approximately 50% of the circumference, as shown on Photo 9.

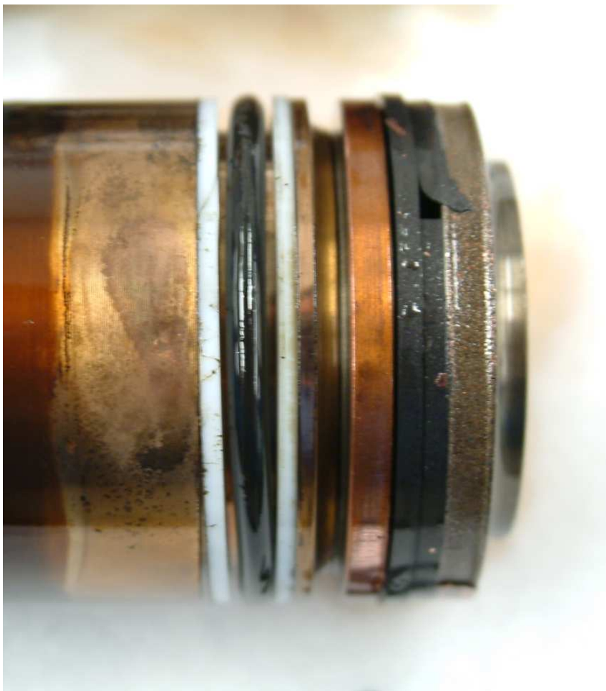

Photo 9. System no. 2 piston with chipped plasma coating

Both the system no. 1 and system no. 2 piston head seals (polytetrafluoroethylene) were severely worn, as shown on Photos 10 and 11. The system no. 2 seals were also extruded with a small piece of plasma-appearing material observed on the seal. A piece of plasma coating was observed in the bottom of the system no. 1 bore.

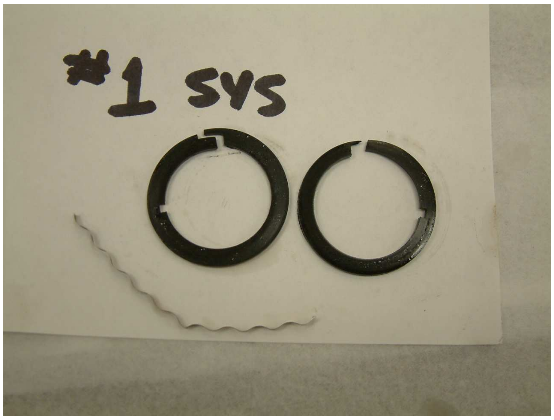

Photo 10. Worn system no. 1 piston head seals

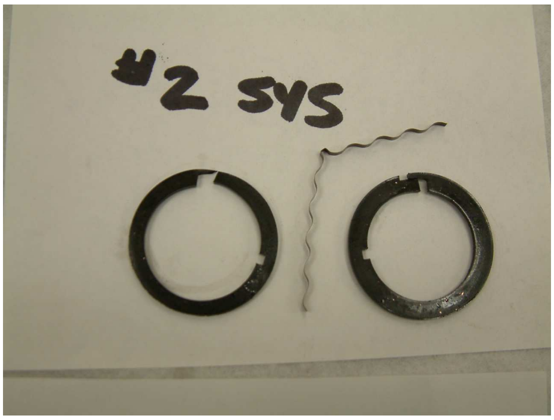

Photo 11. Worn system no. 2 piston head seals.

The piston head seals for both the no. 1 and no. 2 systems were replaced, and the actuator was reassembled for a new bench test; smooth operation was observed in both directions on system no. 1, system no. 2, and both systems together. All leakage rates were found to be within acceptable limits; system no. 1 Extend position leakage was 258 cc/min; the Retract position leakage was 236 cc/min. Piston velocity was much improved and close to normal.

Aluminum-bronze plasma coating pieces were observed inside the bypass valve chamber, and a large piece of the plasma coating was found when the bypass valve was removed, as shown on Photo 12.

Photo 12.   Plasma piece found loose in system no. 2 bypass valve

Aluminum-bronze plasma coating pieces were found in one of two C3 return slots of the main control valve sleeve, as shown on Photo 13.

Photo 13.   Plasma coating piece(s) in one of the two C_3 return slots of the secondary spool (inner sleeve. The second, not blocked C_3 return slot, is located on the opposite side of the spool and not visible on the photo.)

1.16.4.5 Examinations at the NTSB Materials Laboratory

The valve sleeves, the inner sleeves and the spools of the main rotor forward actuator were examined at the NTSB Materials Laboratory. The pieces of plasma were again observed in the C3 return port. The return port was 0.039 inch long and 0.015 inch wide. The two orange color pieces of plasma were lodged in the return port and were observed using a scanning electron microscopy (SEM). One piece was noticeably larger than the other. The end of the larger piece outside of the hole was wider than the length of the hole, and the end of the smaller piece outside of the hole appeared thicker than the remaining width of the hole with the larger piece in place, consistent with the pieces having entered the flow hole from the exterior of the inner sleeve. An energy-dispersive x-ray spectroscopy (EDS) of the plasma pieces showed a major peak of copper and smaller peaks of iron, chromium, titanium, silicon, aluminium and carbon, consistent with the plasma coating material (Metco alloy 445) used on the outer diameter of the piston adjacent to the seals.

Two pairs of piston seals from the main rotor forward actuator were examined at the NTSB Materials Laboratory. Both seal pairs displayed polishing of the outer sealing edge, extensive localized wear of this edge and one of the faces from one seal of each pair. One seal from each piston displayed localized sealing edge wear adjacent to the split, which locally reduced the radial width of the seals from nominally 0.180 inch to 0.120 inch.

Both the hydraulic system no. 1 and no. 2 seals and the sealing edges contained many embedded copper colored particles and some depressions suggestive of previous embedded particles. However, many more particles were apparent in system no. 2 seals than in the system no. 1 seals. More than 70 particles were visually identified at 20x magnification in the faces of the less worn system no.2 seal versus 27 in the less worn seal of system no. 1. Sealing edge particles were not counted.

Elemental composition of all particles was predominantly copper with a significant peak for aluminum, and various trace elements were also detected. The EDS spectra of the particles removed from the seals were consistent with the Metco alloy 445 with various contaminants.

The system no. 2 hydraulic filters and reservoir contained aluminum-bronze flakes and one flake had features with dimensions that nearly matched those of the open (as-found) return port in the hydraulic valve of the actuator (See Figures 7 and 8). The examinations found further contamination downstream of the filters in the reservoir portion of the assembly.

All aluminum-bronze particles, separated from forward hydraulic actuator pistons and found in return filters, had to pass through main control valve spool slits 0.039x 0.015 inch.

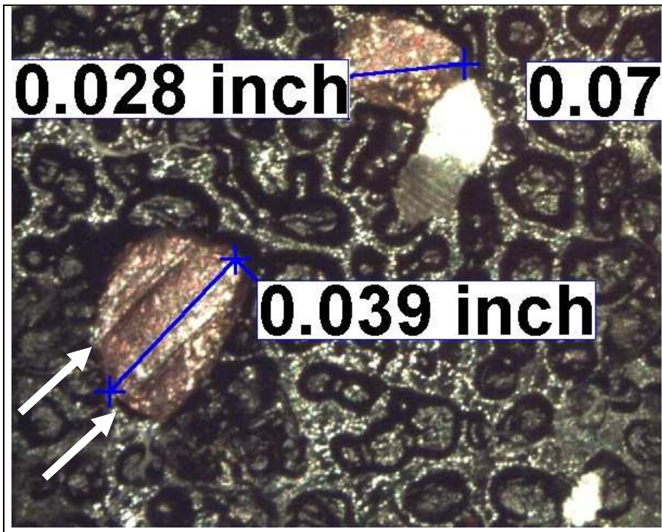

Figure 7.Aluminum-bronze flakes found in the system no. 2 hydraulic return filter. The distance between the indicated lines is 0.039 inches.

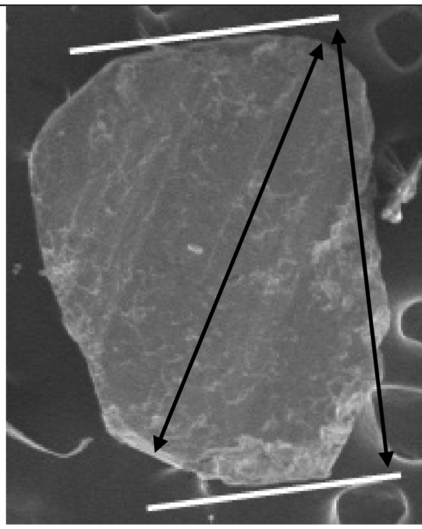

Figure 8. Scanning electron microscopic magnification of same flake. Lines show two dimensions of 0.039 inch each.

1.16.4.6 Testing of hydraulic fluid

Two laboratories (Phoenix Chemical Laboratory of Chicago, Illinois, USA and Jet Care International of Cedar Knolls, New Jersey, USA) examined samples of hydraulic fluids that were taken from helicopter components. The examinations showed that system no. 1 hydraulic fluid had a relatively small amount of copper. System no. 2 fluid samples contained 3.6 to 4.0 mg/l of calcium, chromium, copper, iron, aluminum and other contaminates. Chunk and sliver traces of metals were also found in the fluid samples from system no. 2 and the fluid was significantly darker.

1.16.5 Simulation tests with a modified forward actuator

A series of tests were accomplished on a modified main rotor actuator in order to determine the effects of obstructed actuator valve ports and leakage around the piston head.. The actuator was modified to simulate various amounts of leakage around the piston head.. In addition, various combinations of blockage of the C_3 return port were tested.

The actuators with both normal and abnormal leakage rates were tested to compare leakage rates and piston velocities. Stall force was defined as the force required to prevent piston movement. During testing, the measured stall force was the greatest load at which movement did not occur; any increase in the load above the stall force would result in movement. Piston velocity was defined as the speed at which the piston either extended or retracted, with no load applied. Unloaded velocities were measured for comparison with acceptance test data.

Stall force was observed to decrease as internal leakage increased. A blocked main control valve (MCV) port and higher leakage rates also significantly lowered the stall force. Refer to Figure 9 for example, stall force data.

Piston velocity was observed to decrease in the Retract direction as internal leakage rates increased. Piston velocity was found to increase in the Extend direction as internal leakage increased. A blocked MCV accentuated the magnitude of the velocity change in both directions. Refer to Figure 10 for example, piston velocity data.

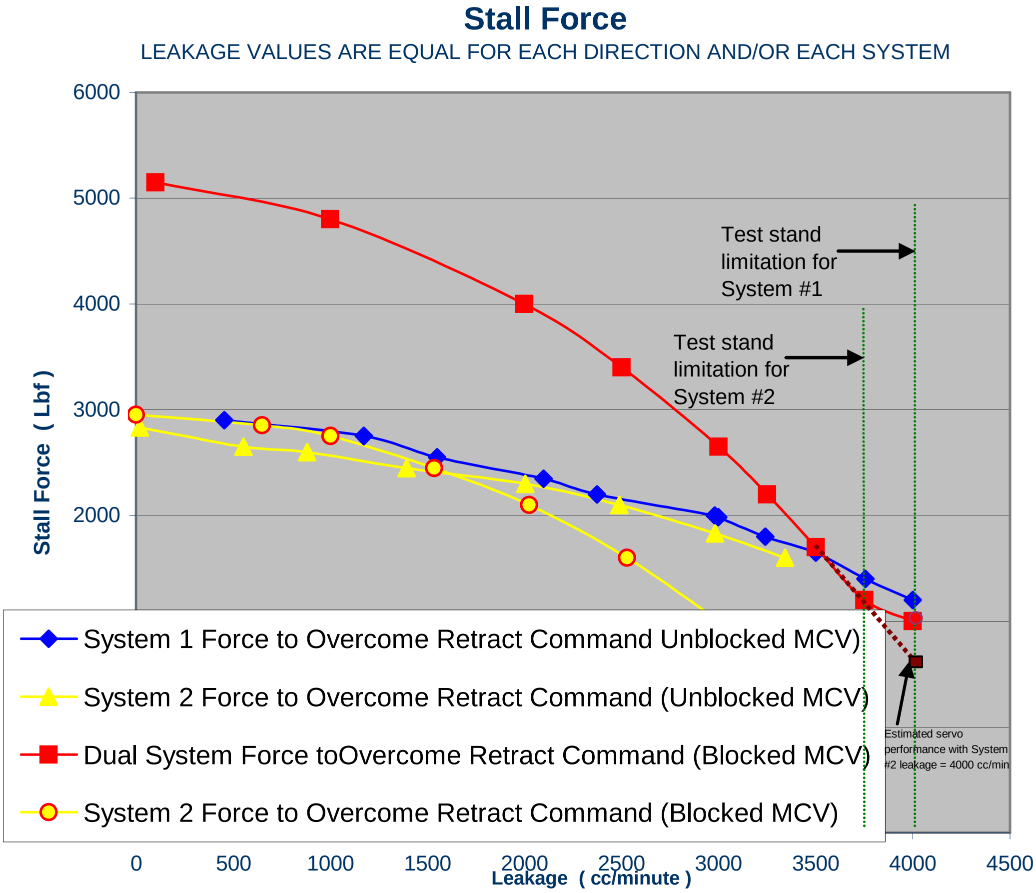

Figure 9. Stall force data

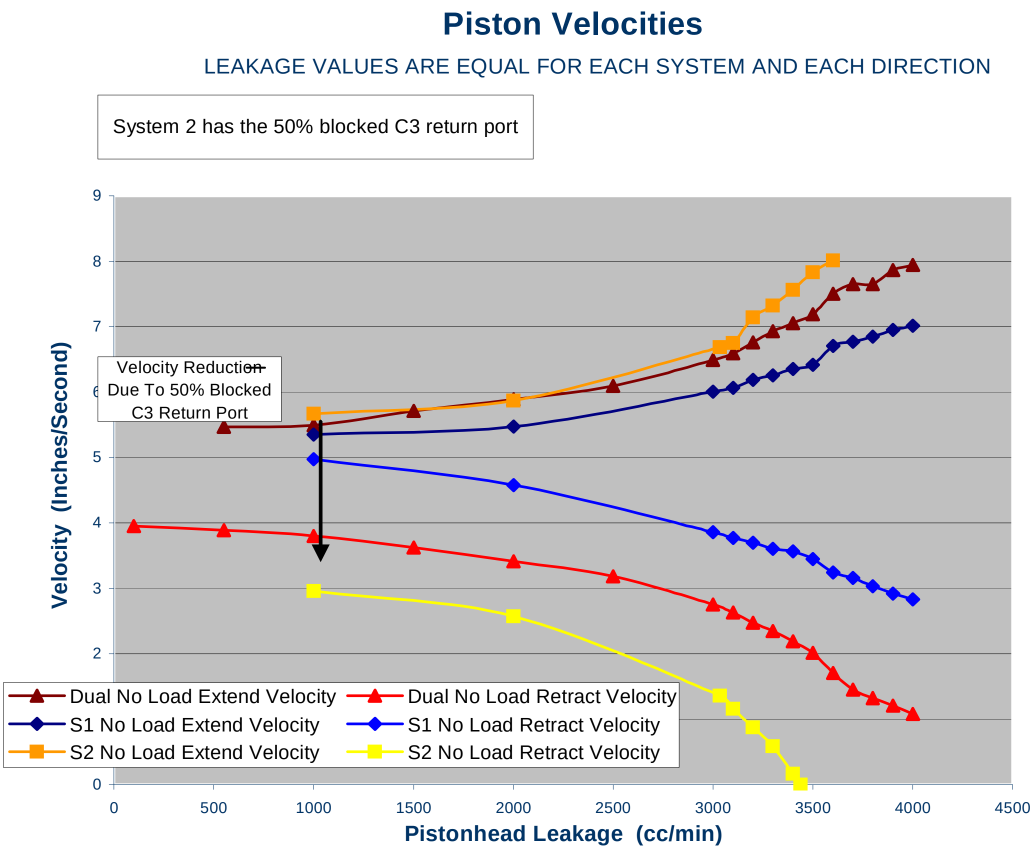

Figure 10. Piston Velocity Data

1.16.6 Actuators returned as a result of letters to the operators

As a result of the NTSB Safety Recommendations, the Sikorsky All Operators Letter (AOL) and the FAA Special Airworthiness Information Bulletin (SAIB), one HR Textron-designed actuator was found to have high internal leakage. The actuator had accumulated 2970.7 hours since its last overhaul. The system no. 1 piston was missing a circumferential piece (25-30 degrees of the diameter) of plasma coating. A copper-colored material was still present in this area, as shown on Photo 14. Additional disassembly efforts resulted in two large additional pieces flaking off, for a total of almost half of the circumference.

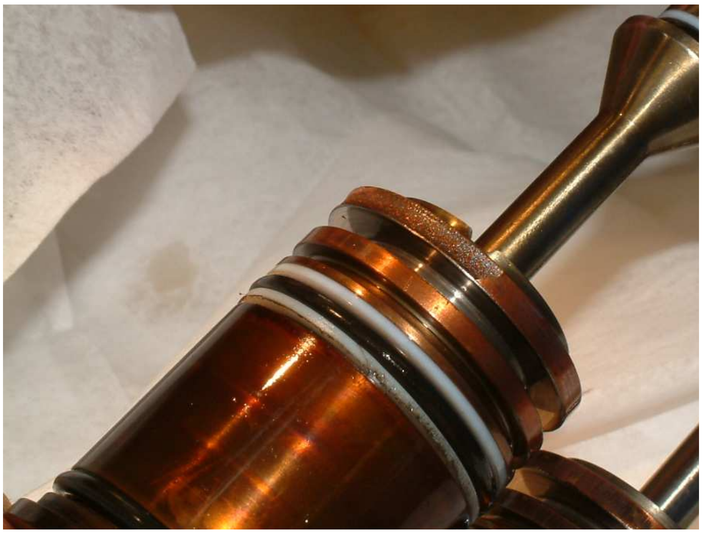

Photo 14. S/N 407 system no. 1 piston with flaked plasma. (Note! This piston is not from accident helicopter.)

The system no. 1 piston head seal on the retract side showed signs of wear with the tang on the seal breaking off during removal. The extend side seal had evidence of extrusion (small lip). A small piece of plasma was found inside the piston bore, and an additional small plasma flake was found on the secondary spool of system no. 1.

1.16.7 Modeling of the flight control system and main rotor forward actuator

At the direction of the Estonian Accident Investigation Commission, the NTSB undertook extensive modeling of the flight control mechanical system and the forward main rotor actuator. MSC.Software (MSC) provided both software and expertise to complete the modeling project.

These models were developed and validated separately and then combined into an integrated model of the helicopter control system in order to enable evaluation of accident scenarios. The modeling showed that uncommanded extension of the forward main rotor actuator movement was possible with a combination of three anomalies: nearly complete blockage of both return ports (on the piston extend path), seal leakage in the second system that exceeded maintenance limits, and flight loads that exceeded the retraction capabilities of the degraded actuator. Blockage in these ports could apply system pressure of 3 000 psi to the extend side of the actuator piston. One of the two slots of the return line C_3 of the system no. 2 main control valve spool of the accident actuator was found nearly blocked (Photo 13) and possible blockage material with dimensions of the spool open slot was found downstream of the return port (Figures 7 and 8,). Also possible blockade material was found in the system no. 2 upstream from the main control valve spool of the C_3 line in the sequence/bypass valve (Photo 12). The leakage measured in the accident actuator was about twice the required amount of leakage for an uncommanded extension as defined by the model. Potential flight loads for the helicopter speed at the time of upset were identified that could have exceeded the capability of the degraded forward actuator, as identified by the model.

Without flushing the second port, and with leakage in the opposing/parallel system, the model showed that the actuator would remain in the extended position. If the second port was cleared, the modeling identified no technical reasons that would prevent control of the helicopter from the cockpit. Sikorsky Engineering Specifications show that the actuator shall provide an output force of 5 120 lb minimum (2 560 lb per stage) at stall in the Extend direction.

Data show how actuator loads could increase with airspeed. The effect of airspeed on the loads of the forward actuator is shown in Figure 11 (with proprietary information removed).

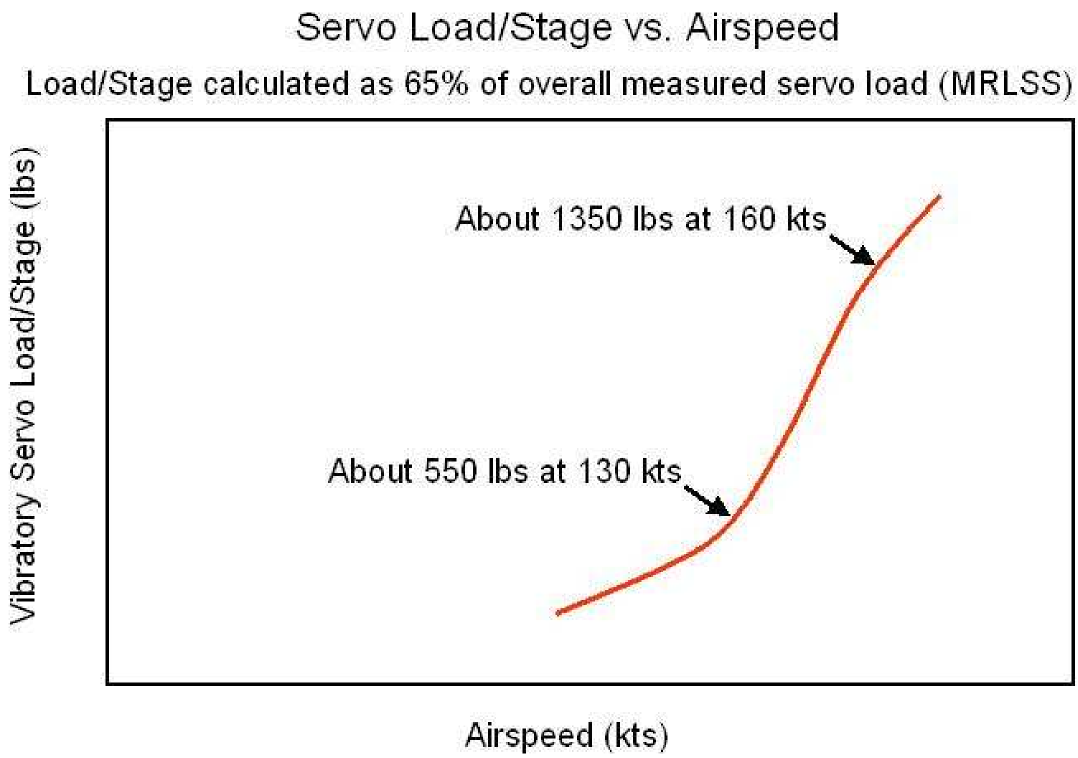

Figure 11. Forward actuator load as a function of airspeed

The airspeed and vertical accelerations from the FDR of the accident helicopter were used to produce an estimated profile of total vertical load shown as Figure 11. The total actuator load profile represented an estimate of the tension loads imposed on the actuator by the rotor blades during the initial departure from cruise flight. If the actuator were not capable of resisting the estimated force, the loads could lead to an uncommanded extension.

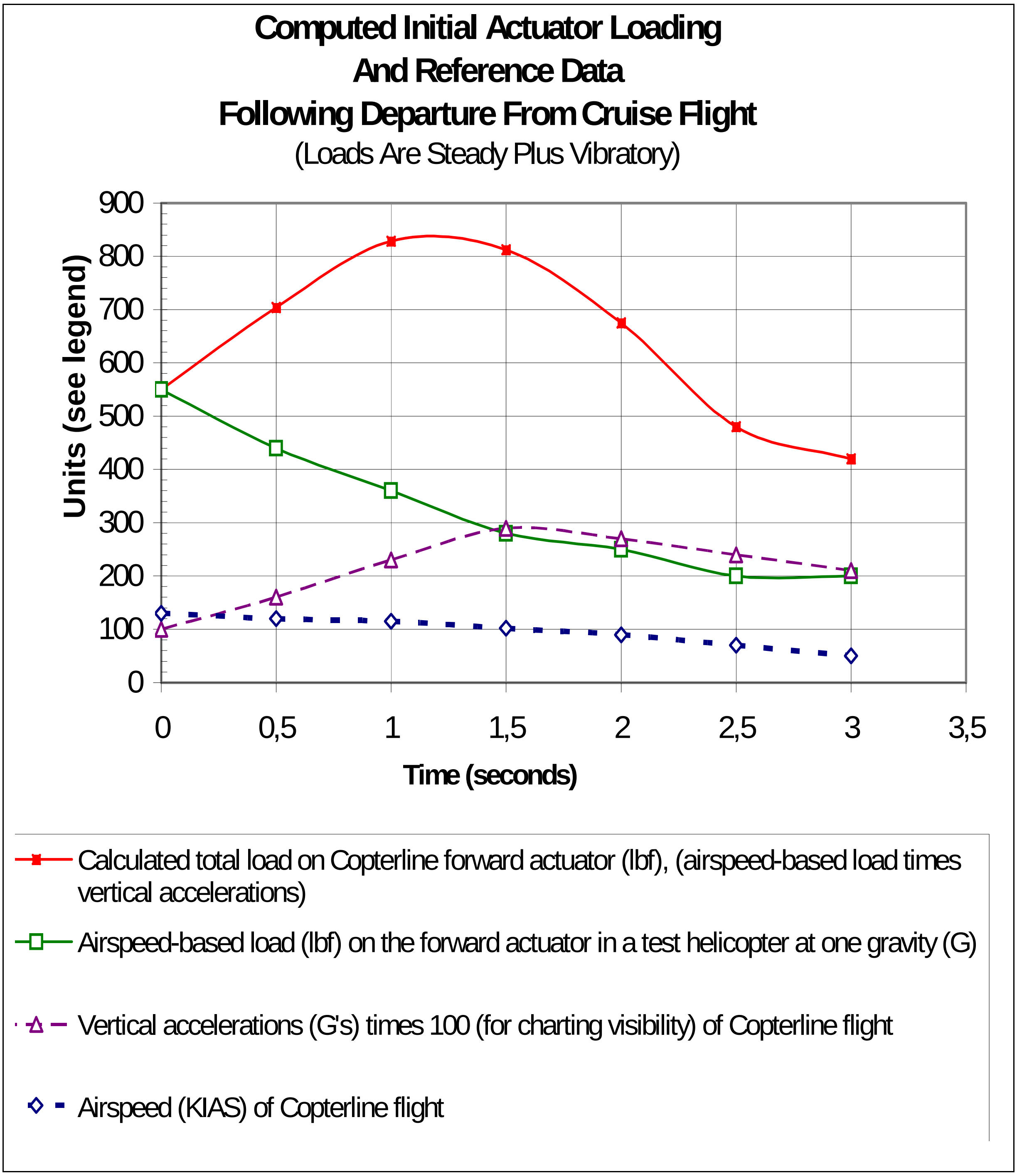

Figure 12. Integrated time history estimate for loads upon the actuator in the helicopter accident flight.

1.16.8 Helicopter simulation

At the request of the Estonian Accident Investigation Commission, NTSB aircraft performance engineers used the Sikorsky helicopter simulation model GenHel S-76C to evaluate two different accident scenarios: (1) The helicopter response to a malfunction in the main rotor forward actuator, and (2) The helicopter response to an encounter with the external winds and gusts produced by a waterspout.

1.16.8.1 GenHel desktop simulation

The simulation of the Copterline helicopter occurrence using the Sikorsky GenHel desktop simulation differed from a standard simulation in a number of ways. In both scenarios, the main rotor rpm and the torque about the main rotor shaft were produced directly with FDR data as opposed to calculating them within the simulation itself.

The simulations were considered valid for the first two seconds and diverge significantly from the FDR data after about two seconds. The reasons for this divergence were not entirely understood, but were likely rooted in the limitations and uncertainties of the simulation aerodynamic models of the main rotor, tail rotor, and fuselage under the extreme flight conditions of the accident. Consequently, the simulation effort concentrated on trying to match the FDR motions during the first three seconds of the upset. The simulation runs extended from one second before to three seconds after the initial control movements that defined the beginning of the upset flight condition. None of the simulations produce a perfect match of all the parameters recorded on the accident FDR.

The GenHel simulation represented the best engineering calculation of the performance of the helicopter. In the accident scenario, the extreme pitch and roll rates and angles introduced unsteady aerodynamic effects, more complicated rotor wake trajectories, large elastic deformations of the rotor blades, and similar complexities that were not thoroughly understood and which were not accounted for in the simulation models.

1.16.8.2 Simulation of scenario with forward actuator failure

For the forward actuator failure scenarios, the cockpit controls and mechanical control system models were not used. Instead, the main rotor blade collective and cyclic pitch angles were driven directly, using a time history of blade angles that were based on an independent control system model and simulation of the effect a failure of the forward actuator would have on the positions of all three of the actuators that control the main rotor swashplate. Effectively, the recorded collective and cyclic positions were corrected for the effects of an uncommanded extension of the forward actuator. The lateral and aft actuator extensions were determined primarily by using standard linkages and SAS inputs. The forward actuator extension was determined assuming that the linkage had bottomed out against the sloppy link and the SAS extension was modified by the forces in the linkage that would have changed the rate of the SAS input (a likely source for the illumination of the SAS fault light).

The forward actuator and flight control system was modeled and analyzed. Using the systems model, the actuator positions for the forward actuator failure scenarios were developed to be consistent with the recorded FDR flight control data.

Many of the forward actuator failure simulation results matched the character, and in most cases the magnitude, of the FDR data much better than the waterspout encounter simulations. The normal acceleration steadily increased and decreased in a smooth manner. The forward actuator failure simulations did appear to match the FDR data during the first two seconds of the upset reasonably well, given the “standard” of simulator fidelity established by comparing to flight test data.

1.16.8.3 Waterspout Simulations

For the waterspout encounter scenarios, the cockpit flight controls were driven with the flight control inputs as define by FDR data. The response of the main rotor and tail rotor collective and cyclic pitch angles were computed by flight control models. The waterspout scenarios made use of the “penetrating gust model” available in GenHel, that computed additional components of local flow velocity at each rotor blade segment based on the blade’s location in space relative to the wind field defined by the waterspout. The waterspout was modeled as a vortex with the axis of rotation oriented vertically. The vortex core had a radius of 100 ft. The wind speed at the edge of the vortex core was 89 kt and flowed tangentially to the core edge. The radial flow from the vortex center was zero. In addition, within the core, the waterspout model incorporated a vertical updraft (v_z) of 40 ft/sec. This vertical gust was sharp-edged, i.e. immediately outside the core, it dropped to zero.

The waterspout encounter simulations were run with a variety of initial positions of the helicopter, so as to survey the effects of different encounter geometries. A waterspout encounter simulation that kept the cockpit control inputs constant at their trim positions was also run in order to ascertain the relative contributions of the vortex and the flight control inputs to the overall motion of the helicopter.

The simulation results indicated that an encounter with the waterspout would increase the pitch excursion produced by the flight control inputs by only about 10º. Consequently, the results also indicated that an encounter with a waterspout, even as powerful as the one modeled here, would not likely cause the 57º-pitch excursion recorded by the FDR.

The initial yaw responses of the waterspout encounter simulations were similar to the response recorded on the FDR, although a very large yaw rate to the right developed that was not present in the FDR data. As could be gleaned from the plots of the sideslip angle and the crosswind plots, this yaw rate reversal likely resulted from the sudden change from a strong left crosswind to a strong right crosswind as the helicopter passed the centerline of the vortex. The simulated reversal in the crosswind and sideslip angle was also a likely contributor to the large reversal in roll rate that occurred in simulation but was not present in the FDR data.

The headwind and crosswind gusts produced by the waterspout simulation increased the true airspeed of the helicopter dramatically (knots true airspeed (KTAS) at over 200 kt for one run, and KTAS peak at 180 kt for another run). The FDR did not show any airspeed increase at all, but instead dropped dramatically.

The normal load factors resulting from the waterspout encounter were compared with FDR data. It was apparent that the steady increase in normal load factor as shown in the FDR data was due primarily to the cockpit control inputs, since without these inputs the vortex alone produced much smaller normal load factor deviations. While the peak normal load factor obtained in the waterspout runs was higher than that obtained in the forward actuator failure scenario, and came close to the peak recorded on the FDR, the choppy shape of the normal load factor trace did not match the smooth, ramp-like character of the FDR data. The choppiness in the simulator traces resulted from the abrupt changes in angle of attack and sideslip angle and dynamic pressure introduced by the vortex gusts, particularly as the vortex core was crossed and the updraft gust component jumped instantaneously from 0 ft/sec to 40 ft/sec. The abrupt crosswind change as the helicopter passed the vortex center also introduced choppiness into the simulated load factor data.

1.17 Organizational and management information

1.17.1 The operator (Copterline)

1.17.1.1 General

Copterline Oy had been registered as a company in 2000, although it had been operating under other names since 1990.

On 5 May 2000, the operator began scheduled passenger service between Helsinki and Tallinn with new Sikorsky S-76C+ helicopters. Copterline also operated Helicopter Emergency Medical Service (HEMS) using Eurocopter EC135 and BO 105 helicopters with bases in Oulu, Vaasa, and Varkaus in Finland, as well as other on-demand non-scheduled commercial helicopter flights.

1.17.1.2 Air Operator Certificate (AOC)

Copterline held an Air Operator Certificate (AOC) no. FIN008 for Commercial Air Transport (JAR OPS Operations) issued by the Finnish Civil Aviation Administration (CAA Finland). The latest amendment was dated 8 August 2005. The approved types of operation were passengers, cargo, and emergency medical service. The approved types of aircraft were two Sikorsky S-76C+ for the scheduled flight operations. For the other types of operation, Copterline operated four Eurocopter BO105 and seven Eurocopter EC135 helicopters. In accordance with JAR OPS 3.175, the AOC listed personnel acceptable to the authority (accountable manager and quality manager), and four nominated post holders (flight operations, maintenance management, crew training and ground operations).

1.17.1.3 Company structure

1.17.1.3.1 General

The company had a managing director (also S-76 pilot) and from 19 April 2005, an accountable manager, who had the S-76 technical type course. The flight operation department consisted of a flight operations manager, training manager, S-76 group chief, seven S-76 pilots and simulator instructor (the managing director and the S-76 group chief were included in the seven S-76 pilots; both were pilot-in-command rated). In addition, there were four part time dispatchers.

The maintenance management organization consisted of Maintenance Manager supported by S-76 Type Supervisor. There was also Type Supervisor for other helicopter types. S-76 Type Supervisor was type-rated licensed technician.

The maintenance organization consisted of Repair Station Manager, certifying staff and other persons. Repair Station Manager was the same person as the S-76 Type Supervisor. There were two additional S-76 type-rated licensed technicians, one of whom was part time. The type-rated licensed technicians had company authorization to issue Certificates of Release to Service (CRS). One licensed technician had company authorization for S-76 pre-flight inspection (PFI) approval. In addition, Copterline had eight mechanics and three part time mechanics without S-76 type-courses.

1.17.1.3.2 Flight operations

The flight operations documentation consisted of Copterline's Operations Manual (OM), which was issued in four parts: A – General / Basics, B - Flight Manual for each helicopter type, C - Routes and Heliports, and D - Training. The company also had a Minimum Equipment List (MEL) for each helicopter type and an Operator's Aircraft Technical Log Book (OATL) system.

The company's primary flight operation with the two Sikorsky S-76C+ helicopters was the scheduled passenger service route between Helsinki and Tallinn. The home base for the route operation was Hernesaari (EFHE) heliport in the southern part of Helsinki, Finland. During 2005, there was daily service on the scheduled route.

According to Jeppesen Airway Manual, presented in the Operations Manual, the minimum en-route altitude was 2 200 ft. Subsequently, 1 300 ft was approved by CAA Finland as the minimum en-route altitude for the operation. The approved departure procedures and the approach and landing procedures were VFR operations only. As the en-route flight operations were mainly conducted as IFR flights, a separate procedure to transfer from IFR flight to VFR flight had been required. The procedure included appropriate visibility and cloud base limitations. Both heliports were also equipped with an automatic weather station to support the route operation.

There was also the S-76 Group Chief, which was required by the Authority since the Flight Operation Manager had no experience on S-76 type helicopters. The S-76 Group Chief was tasked with planning the flight crew roster, usually for a month at a time. The pilots recorded their daily flight times in the log books. The company added one hour before the first flight and 30 minutes after the last flight time to obtain the daily working hours for each pilot.

1.17.1.3.3 Copterline maintenance management

In accordance with JAR OPS 3, Subpart M, the operator had an approved maintenance management system that consisted of a Maintenance Management Exposition (MME), Maintenance Program (MP) CA-HO-S76, Minimum Equipment List (MEL) for each helicopter type, and an Operators Aircraft Technical Log (OATL) system. The manuals were all in the Finnish language.

The Copterline maintenance management system had first been approved by CAA Finland in April 2000. The latest Copterline maintenance management approval /

renewal was dated 28 October 2004, the latest amendment was dated 24 February 2005, and the approval was valid until 31 October 2005.

Copterline had stated that the S-76 maintenance was carried out in accordance with the approved Maintenance Program (MP, “CA-HO-S76”). The Copterline maintenance organization accomplished the scheduled maintenance and any unscheduled maintenance including troubleshooting and defect repair. Hence, there was no outsourcing.

The Maintenance Manager was responsible for monitoring and updating the S-76 Maintenance Program, which was based on the Sikorsky S-76 Maintenance Manual. During the S-76 Maintenance Program evaluation, the temporary revisions were incorporated into the Maintenance Program. The yearly Maintenance Program evaluation also contained a reliability and Maintenance Program effectiveness analysis.

The Maintenance Management Exposition described the use of Sikorsky’s computer program HELOTRAC as Copterline’s primary maintenance planning and recording aid for the S-76 helicopters. The HELOTRAC program contained the maintenance requirements and the due lists were extracted from the database for the S-76 helicopters. The HELOTRAC database was developed during the delivery process of the Copterline S-76 helicopters. The Maintenance Management Exposition stated that the HELOTRAC program and the database was updated by a revision service. Copterline had opted for regular updates instead of an on-line revision system. Based on the revision service, the HELOTRAC database was to be updated. Copterline was responsible for ensuring the addition to the database of all part changes, modifications and service kits. Normal maintenance typically required part changes, which meant that the old part numbers / serial numbers were to be removed and the new part numbers / serial numbers of the installed parts were to be added.

The use of the HELOTRAC program was limited by username and password. The S-76 Type Supervisor was mainly in charge on the HELOTRAC database. He was responsible for updating the HELOTRAC program. The updating included flight time monitoring, new Airworthiness Directives / Service Bulletins, completed Airworthiness Directives / Service Bulletins, and defects annotated in the log books.

Copterline also required that maintenance actions and Airworthiness Directive / Service Bulletin actions be recorded in the helicopter airframe technical log book and the engine log books.

1.17.1.3.4 Copterline maintenance organization (Part 145)

Copterline held a Part 145 maintenance organization approval (FI.145.0016), first granted in March 2000 in accordance with JAR 145. The latest renewal was dated 1 November 2004 and amended on 21 January 2005. The approval schedule included maintenance on Sikorsky S-76 helicopters. The Copterline maintenance facility at Helsinki/Malmi Airport was to be used for line and base maintenance, the Hernesaari heliport for line maintenance up to 100 hours inspections, and the Linnahalli heliport in Tallinn was not approved for any maintenance activity.

The maintenance procedures and the Part 145 quality system were described in the Maintenance Organization Exposition (MOE) in the Finnish language. According to the maintenance procedures documentation, the company did not use work cards when carrying out maintenance. The scheduled maintenance was performed at the level of HELOTRAC headers.

The maintenance manager did not have S-76 type course training. Therefore, the S-76 type supervisor dealt with all the technical matters, including responsibility for any technical questions arising during the daily operations. According to the company procedures, the S-76 type supervisor printed out the required due lists for the maintenance manager for continuing airworthiness considerations and work order preparation. Then the maintenance manager issued the work order. Based on the maintenance manager's work order, the S-76 type supervisor, as the representative for the operator, was responsible for holding a pre-maintenance meeting with the repair station. The S-76 type supervisor, as the repair station manager was required to participate in pre-maintenance meetings requested by the operator. As the licensed technician with S-76 type-rating, he would normally carry out the work in accordance with the work order at the company's maintenance facility at Helsinki / Malmi Airport or at Hernesaari heliport. When the maintenance work was completed, he would sign the Certificate of Release to Service (CRS).

1.17.1.3.5 Quality system

The quality manager was responsible for the quality system under JAR OPS 3 and the Part 145 requirements. Because he had a technical background, he used a pilot as an auditor when auditing the JAR OPS 3 flight operation functions, except for the maintenance management parts. The JAR OPS 3 quality system was detailed in Copterline Operations Manual - A and the Maintenance Management Exposition. The annual quality plan included audits. There could be discrepancies at four levels: 1 - serious, 2 - medium, 3 - comment and repetitive. Corrective actions required were normally included.

The JAR OPS 3 quality system audit plan was divided into four modules; module 3 dealt with the Maintenance Management Exposition and the Maintenance Program. The scheduled audits were conducted in accordance with the audit schedule plan. Random audits were conducted for continuing quality assurance purposes, and quality inspections were done every second month. Follow-up audits were conducted when the audit had not been fully performed, when discrepancies were likely to be repeated, or when the effects of corrective actions could not be fully evaluated. Line of business audits were done in conjunction with scheduled audits (HEMS / SAR operations, off-shore flights, commercial air transport, flight training, aerial work, and scheduled routes).

1.17.1.4 Copterline quality system internal audits

1.17.1.4.1 General

As a part of the Copterline quality system, regular internal audits were carried out in accordance with the yearly audit schedule. The Copterline internal audits included, as a result of the audits, the development of a corrective action plan and due dates for each item to be accomplished.

1.17.1.4.2 JAR OPS 3 audit in 2004

In 2004, in the JAR OPS 3 flight operations audit, there were 35 discrepancies. The following items were annotated, *inter alia*:

- Auditors had not fully participated in training (time table for corrective actions had been extended twice up to 7 months);
- Quality inspections had not found a need for additional training of pilots (this discrepancy was considered unnecessary);
- The procedure to report all discrepancies to the accountable manager was not always followed;
- The occurrence reporting procedure was not clear;
- The deputy (to a post holder) arrangements were not detailed;
- The list of approved flight instructors was not updated and it was not clear how the approval had taken place;
- Three discrepancies concerning unclear training documentation;
- Errors in mass and balance calculation when preparing for flight;
- Started to use new mass and balance calculation program without appropriate approval and without training (program rejected);
- S-76 checklists were received from Flight Safety, the revision status and the procedure was not clear; and they did not match the Operations Manual – B; and
- Contaminants were found in the S-76 fuel tanks.

1.17.1.4.3 JAR OPS 3 audit in 2005 (before the accident)

In 2005 before the accident, in the JAR OPS 3 flight operations audit, there were 17 discrepancies. The following items were annotated, *inter alia*:

- The pilot meeting procedure in the Operations Manual – A was not correct;
- The Hernesaari (EFHE) to Linnahalli (EECL) route maps contained several errors;
- Pilot call-outs in Finnish and in English were in the same list;
- The duty times for some pilots sometimes exceeded the maximum;
- The pilot-in-command qualification reviews were not held and the left / right seat authorization was not documented;
- The follow-up procedure of due dates for training did not work; and
- HEMS related training was not done.

1.17.1.4.4 JAR OPS 3 Subpart M audit in 2004

In 2004, in the JAR OPS 3 Subpart M maintenance management audit, there were ten discrepancies. The following items were annotated, *inter alia*:

- The operator did not inspect the helicopter when receiving it from maintenance;

- Occurrence reporting - technical follow-up was not efficient and it was not documented;
- The company flew during the tolerance time of an inspection, although it was not in accordance with the procedure;
- There was no control procedure for initial Pre-Flight Inspection training for pilots before the issuance of authorization for Pre-Flight Inspection by pilots;
- The Pre-Flight Inspection list did not contain any JAR OPS 3 Subpart M items, such as deferred defects; and
- Maintenance Organization Exposition procedure L2.7 inspection of the maintenance work was not annotated and signed in the maintenance documentation.

1.17.1.4.5 JAR OPS 3 Subpart M audit in 2005 (before the accident)

In 2005 before the accident, in the JAR OPS 3 Subpart M maintenance management audit, there were eight discrepancies. The following items were annotated, *inter alia*:

- The pilots were not able to annotate a defect and Minimum Equipment List reference in the journey log book;
- Release to Service (CRS) was given for Pre-Flight Inspection and then CRS was referenced using *"info";*
- Two discrepancies related to errors in CRS; and
- Defect repair and component changes were done without any reference in the journey log book.

1.17.1.4.6 Part 145 audit in 2004

In 2004, in the Part 145 maintenance audit, there were 23 discrepancies. The following items were annotated, *inter alia*:

- An annual scheduled maintenance plan was not documented;
- The training in November included in the annual plan had not been performed;
- No clear procedure on how to handle items in the Hold Item List when the helicopter was in maintenance; and
- Inspections of the maintenance work were not annotated and signed appropriately in the documentation.

1.17.1.4.7 Part 145 audit in 2005 (before the accident)

In 2005 before the accident, in the Part 145 maintenance audit, there were 27 discrepancies. The following items were annotated, *inter alia*:

- A maintenance statement was filed inappropriately and with missing appendices;
- EC135 defect follow-up and analysis was not accomplished;
- There was no clear procedure for Airworthiness Directive / Service Bulletin status review for components, which were going to be installed;
- Defect repair was not signed and documented appropriately;

- Inspection tolerance was used for Airworthiness Directives / Service Bulletins, for which there was no tolerance;
- When planning the annual / 800 hour maintenance, items which had a due date in the next three months had not been placed on the work order, such as hydraulic filters;
- When planning scheduled maintenance, the person who would perform each task was not predetermined; the result of this was that the boroscope inspection was done without authorization;
- When planning scheduled maintenance, an inspection task (balancing) related to the work was not added;
- When planning scheduled maintenance, defects were not annotated on the task list; and
- Co-operation between maintenance management and the maintenance organization should have been much better (comment level).

1.17.1.5 Recurrent training in the maintenance operation

In accordance with the Maintenance Management Exposition, annual recurrent training related to the maintenance requirements, regulations and internal information had been provided. However, the maintenance manager had not taken part in this training. The recurrent training requirement concerned the licensed maintenance engineers, mechanics, as well as the management personnel, in order for them to maintain their expertise.

According to the Maintenance Organization Exposition, recurrent training at a two-year interval was to be provided in areas of employee expertise, which included type related special tools and maintenance actions. The recurrent training was also to be provided when the capability had been upgraded or there had been significant changes. The repair station manager was to follow up on the employees' knowledge and their practical capability through tests / exams. According to the training records, this had not been done.

1.17.1.6 Ground handling

Copterline had a Ground Handling Manual (GHM), dated 1 July 2005, in Finnish. The Ground Handling Manual was not required to be approved by CAA Finland. The manual contained instructions for the personnel involved in ground handling, customs, dispatching and security. The ground handling personnel handled the baggage and cargo loading and unloading.

The dispatchers were pilots, who received training in relation to their licences and pilot work in the company. In Tallinn City Hall heliport in the role of dispatcher was team leader. The dispatchers reported to the flight operations manager. Their duties were refuelling, mass and balance calculation, and weather and flight planning. The manual contained instructions for weighing the checked baggage, and the usage of standard masses for crew, passengers and hand luggage. There were also instructions on filing the flight plan and conducting the mass and balance calculation. However, there were no instructions related to the helicopter engine power margin or how to take into account the power margin when determining the maximum take-off mass.

1.17.2 Civil Aviation Administration (CAA), Finland

1.17.2.1 General

The safety oversight responsibilities and obligations of States were described by the *Convention on International Civil Aviation* (Chicago, Convention 7 December 1944). The aim was to ensure that *"… international civil aviation may be developed in a safe and orderly manner and that international air transport services may be established on the basis of opportunity and operated soundly and economically."*

Safety oversight in air transport included the responsibilities of certifying aircraft as well as the conditions of its use. ICAO Annex 6 (section 4.2.1) specified that in order to carry out its responsibilities the State of Operator was obliged to ensure that an operator *"… has the organization and means available to guarantee the safety of operations, including a method for oversight of flights, a program for training for flight crew and satisfactory provisions in terms of maintenance, and that it diligently undertake any appropriate corrective measures, where necessary."*

Safety oversight of air operators, including Copterline, in Finland rested with CAA Finland, which were to perform its duties as outlined in the Chicago Convention and the Annexes thereto.

1.17.2.2 Safety oversight audits of Copterline by CAA Finland

1.17.2.2.1 General

A significant part of the safety oversight activities by CAA Finland consisted of flight operations audits and audits of the maintenance organizations.

1.17.2.2.2 Copterline flight operations audits

In an audit of the Copterline flight operations on 10 September 2003 by CAA Finland, there were two level 1 findings, both of which consisted of multiple items. A level 1 finding was a serious deficiency that was to be rectified immediately or within a short time period. The first findings concerned the flight and duty time monitoring; and the second finding concerned the preservation, data and annotation of the Operational Flight Plan (OFP), such as fuelling, and mass and balance calculation. There were also several level 2 findings. A level 2 finding did not constitute a safety risk, but was to be rectified within a reasonable time period (within three months).

The audit also established that Copterline had used a pilot without a S-76 type rating as a co-pilot on a flight in the regular passenger route operation. The pilot-in-command was the managing director and the co-pilot was the flight operations manager.

In an audit on 13 September 2004 by the CAA Finland, there were 11 level 2 findings. The findings were divided into three groups: quality system, accident prevention and flight safety, and pilot records. Flight preparation, flight planning and training items were not inspected. The findings could be summarized as follows:

- Quality inspections were not included in the annual quality audit plan;
- Quality audits and inspections were not carried out systematically;
- Control audit was not included when handling the findings;
- Evaluation of the effectiveness of the corrective actions was not included;
- Control audit and quality inspections were not included in the instructions;
- Deficiencies in the accident prevention and flight safety reporting system;
- Deficiencies in the accident prevention and flight safety report evaluation;
- No accident prevention and flight safety system feedback; and
- Pilot licences, qualification for both seats, flight time recording for 90 days / 120 days were not updated.

Copterline developed corrective actions, which were approved by the CAA Finland on 10 November 2004.

1.17.2.2.3 Copterline flight operations audit after the accident

There was an audit of the Copterline flight operations by CAA Finland on 25 August 2005, 15 days after the accident. One level 1 finding was recorded, which concerned the handling of defects. It was noted, according to the operator's representative, that the pilots were reporting defects through unofficial means and channels, and there were no annotations or notes in the technical log sheet.

Flight preparation and planning, and passenger information had been audited on 17 August 2005 during a regular route flight. The result was no findings.

The notes by the CAA Finland auditors described that the changes in the duties (rotating post holders) led to a situation in which some necessary information was not transferred to the next post holder. The auditors also noted that the company management did not hold the required meetings, was not controlling the quality system results, and did not always act in accordance with the procedures laid down in the company manuals.

The following findings related to the time prior to the accident were made during the audit:

- There were no directives or provisions regarding the introduction of non-routine matters into the quality system;
- A representative of the company noted that pilots did not always annotate defects into journey log books;
- The quality system did not function, nor had relevant quality system training been provided; and
- The auditors found the forms concerning the simulator training in the spring of 2005 to be suspicious, and requested to be provided with the original forms.

1.17.2.2.4 Audits of the Copterline maintenance management (JAR OPS 3 Subpart M)

On 9 September 2003, there was audit of the Copterline maintenance management by CAA Finland, resulting in nine level 2 findings and one level 3 finding (a comment). Five of the level 2 findings concerned the Quality System. Corrective actions were approved by CAA Finland on 28 October 2003.

In the beginning of 2004, Copterline changed its management organization. The CAA Finland noted that:

- The number of managers was decreasing;
- There was no resource evaluation (required / available man hours);
- One person was responsible for maintenance management, repair station management, type supervisor duties, and maintenance engineer duties;
- There were six large aircraft category helicopters in operation, five different helicopter types in the repair station capability and an additional engine and C-class equipment capability;
- There were base and line maintenance at Helsinki/Vantaa Airport (EFHF) and line maintenance at Hernesaari (EFHE), Vaasa (EFVA), Varkaus (EFVR), and Oulu (EFOU); and
- There had been a relatively large number of findings during audits by CAA Finland and there were no signs of improvement. The findings were typically related to the management actions.

In an audit on 1 and 2 July 2004 of the Copterline maintenance management, the auditors recorded 17 level 2 findings. The implementation date for the corrective actions related to these findings was 26 October 2004. The following is a summary of the findings:

- Monthly technical meetings had not been held regularly (two meetings in the first half of 2004);
- There was no evidence that the monthly quality inspection for 11/2003 had been carried out;
- There was no clear procedure for how the maintenance manager was to handle changes to the PFI (pre-flight inspection) and evaluate the need for additional training;
- The record of Airworthiness Directives for BO105 was not up to date;
- Mandatory and voluntary maintenance information was not always handled in the weekly meetings;
- It was not possible to use the Maintenance Management Exposition through the Intranet as specified;
- The list of airports was not up to date;
- The maintenance coordinator duties and responsibilities had not been followed;

- Technical training (according to the plan) was not carried out, nor was the changes to the plan approved appropriately. Computer based training records did not include any evidence of changes and approvals;
- There was no evidence of the audit plan for the year 2003. The second audit for 11/2003 was missing;
- The efficiency of approved corrective actions (findings in 2003) was not evaluated as required;
- There was no systematic procedure for transferring the evidence of postponed maintenance actions to the helicopter technical journey log book;
- Maintenance Programs had not been revised as defined;
- There was no evidence that the flight safety analysis / safety group work as required;
- The Maintenance Program revision procedure related to the timetable was different for the Maintenance Program and Maintenance Management Exposition procedures;
- Documents related to continuing airworthiness, e.g. status list, time monitoring, did not contain reference information and revision status; and
- When comparing technical log book and work orders, it was obvious that defects during flight operations had not been recorded in the technical log book as required.

1.17.2.2.5 Audit of the Copterline maintenance organization (Part 145)

The last audit before the accident of the Copterline maintenance organization by CAA Finland was carried out on 28 January 2004. The auditors recorded ten level 2 findings and one level 3 finding (a comment). The implementation date for the corrective actions for these findings was 25 May 2004. The following is a short summary of the findings:

- The internal audit report system was disorganised and summaries were not prepared as defined; this was already noted as a finding in the previous audit on 6 November 2003;
- The procedure for processing findings was not followed; this was already noted as a finding in the previous audit on 6 November 2003;
- Due dates for corrective actions had not been followed; once overdue, the responsibility had not been transferred to the accountable manager as defined;
- Scheduled maintenance had been carried out at a location that had not yet been approved;
- Changes in the organization had not been revised in the Maintenance Organization Exposition;
- Company approval of a licensed maintenance engineer was done without recurrent training in company procedures; the previous company approval was due three years ago;
- The quality manager was to grant company approvals; this procedure had not been followed;

- Corrective action for the findings related to the Maintenance Organization Exposition had not been carried out even though the company had been granted an extension;
- There had been deficiencies in the identification of measurement tools and time monitoring tools, such as the maintenance of the filter of the hydraulic ground power unit had not been carried out; and
- The Maintenance Organization Exposition was lacking procedures for critical work phases, planning and the way employees were to identify critical tasks.

1.17.2.3 Weather minima limitations for Copterline IFR flight operation

On 14 May 2004, due to deficiencies, irregularities and lack of pilot skills noted on check flights, CAA Finland issued temporary higher weather minima for Copterline in IFR flight operations on the scheduled route. The temporary limitations entered into force on 20 May 2004, and were in force until the required corrective actions had been completed.

The weather minima limitations for Hernesaari (EFHE) and Linnahalli (EECL) helipads were:

- Visibility day/night 1500 / 5000 m tempo 800 m during the day
- Vertical visibility 500 ft
- Cloud base 600 / 1200 ft

These weather minima were valid for departures, the cloud break procedure and the minimum landing height.

- The required corrective actions were: All pilots involved in the Copterline route operation and all Copterline pilots flying in accordance with IFR were to receive additional training to increase their IFR flying skills. The training was to be approved by CAA Finland; and
- Copterline was to provide a recurrent training program, which was aimed at maintaining the pilot competency in IFR operations.

The basis for the temporary higher weather minima in the Copterline IFR operations was the failed check flights by some of its pilots due to poor IFR flying skills, lack of knowledge of IFR procedures and lack of helicopter type familiarity. Furthermore, the recurrent training program did not contain approved simulator training.

On the basis of a new recurrent training program and training documentation submitted by Copterline on 3 and 10 August 2004, the temporary limitations were withdrawn on 12 August 2004.

1.18 Additional information

During the investigation of the Copterline maintenance organisation and helicopters S-76 airworthiness matters also the other one S-76 aircraft (OH-HCI sister aircraft OH-HCJ) was inspected. There were discovered few examples of not authorized by manufacturer repairs on the OH-HCJ.

1.19 Useful or effective investigation techniques

1.19.1 Use of flight recorders

The helicopter was equipped with a solid state combined voice and flight data recorder which recorded selected helicopter parameters, as well as audio, into solid state non-volatile memory. The audio and the flight data recordings were read out and analyzed. The information obtained was of significant assistance to the investigation.

1.19.2 Tomography of flight control system components

Under the direction of NTSB, computed tomography scans and digital radiography were used to examine and document the internal configuration of the hydraulic actuators, the artificial feel and trim actuators, and the automatic flight control system actuators. Each component was examined for any signs of missing or damaged parts, contamination in the flow passageways, or any similar anomalies. The computed tomography was of great assistance in determining the internal conditions of the components of interest, which included the discovery and documentation of a large flake of metallic material in the hydraulic system no. 2 bypass valve, adjacent to the main control valve, in the main rotor forward actuator.

1.19.3 Modeling

At the direction of the Estonian Accident Investigation Commission, the NTSB undertook extensive modeling of the flight control mechanical system and the forward main rotor actuator. MSC.Software (MSC) provided both software and expertise to complete the modeling project. These models were developed and then combined into an integrated model of the helicopter control system in order to enable evaluation of accident scenarios.

The computer modeling was invaluable in assessing the accident scenarios and showed that uncommanded extension of the forward main rotor actuator movement was possible. Potential flight loads for the helicopter speed at the time of upset were identified that could have exceeded the capability of the degraded forward actuator, as identified by the model.

1.19.4 Simulation

At the request of the Estonian Accident Investigation Commission, NTSB aircraft performance engineers used the Sikorsky helicopter simulation model GenHel S-76C to evaluate two different accident scenarios: (1) The helicopter response to a malfunction in the main rotor forward actuator, and (2) The helicopter response to an encounter with the external winds and gusts produced by a waterspout.

The simulation established that a malfunction in forward actuator appeared to match the FDR data during the first two seconds of the upset flight condition reasonably well.

The simulation results also indicated that an encounter with a waterspout would increase the pitch excursion produced by the flight control inputs by only about 10º. Consequently, the results indicated that an encounter with a waterspout, even as powerful as the one modeled, would not likely cause the 57º-pitch excursion recorded by the FDR.

1.19.5 Human performance research and spatial disorientation

On behalf of the Estonian Commission, the NTSB initiated further research to examine reasons for the flight crew's continued right rudder application and the potential for spatial disorientation following the initial upset flight condition and throughout the accident sequence. The research was conducted by researchers at the Naval Aerospace Medical Research Laboratories (NAMRL) in USA in coordination with NTSB human performance investigators.

The research focused on the question "Why did the pilot apply and maintain full or close to full right rudder until impact?". The research established that the pilot was struggling to maintain control of the pitch and roll axes using the ADI and, likely, did not devote attention to the yaw / heading indicator. Also, the co-pilot did not draw attention to the right yaw or high angular velocity. The pilot was probably unaware of the high rotational velocity in part due to the normal physiological decay of yaw perception and, hence, did not correct for the right yaw. The results of the research were essential in establishing and understanding the human performance issues, including spatial disorientation, present in the accident scenario.

1.19.6 Computer simulation

A study of the first three seconds of the accident sequence was made (by Mr. R.W. Prouty) using a computer program to calculate time histories of rotor thrust, vertical load factors, power required, climb rate, airspeed and many other parameters.

The results correlated reasonably well with those measured by the FDR. Using the control displacements defined, the maximum recorded normal load factor of 2.9 was found possible using the airfoil data provided by Sikorsky with no modifications. The simulation program also showed that the power required during the accident sequence maneuvers was well within the capabilities of the engines.

2. ANALYSIS

2.1 General

The fact, that it was possible to use the FDR data for the occurred helicopter accident investigation, can not be overestimated.

By the FDR data the helicopter experienced the sudden pitch up and loss of control of the helicopter. The pilots probably experienced spatial disorientation which combined with the reduced controllability of the helicopter led to the impact with the sea. It was established in the investigation that the initial upset flight condition was caused by an uncommanded movement of the main rotor forward actuator.

The analysis focuses on:

- The failure mode of the main rotor forward hydraulic actuator;
- The control and performance of the helicopter after the initial upset flight condition;
- The design, manufacture and overhaul of the forward hydraulic actuator, and the safety issues involved;
- The operator organizational issues, including flight crew training, safety culture, and helicopter maintenance;
- Rescue and survival issues; and
- Weather information.

Early in the investigation, the Commission established the there was no evidence of fire, and no evidence or indication of a bird strike or a collision with another object in the air. The Commission also established that there was no evidence or indication of a separation of any part of the helicopter in the air.

Both engines of the helicopter were running without interruption and produced the torque required. The torque of the engines was evident in the FDR data. The torque changed constantly in accordance with the power required to maintain rotor speed.

According to the CVR and FDR data, there was no indication of a malfunction in the helicopter systems or components before the upset flight condition on the accident flight. Likewise, from the beginning of the upset flight condition until the helicopter impacted the water, all the recorded data (including malfunctions, cautions and warnings) was related to the uncommanded extension of the forward actuator, the unusual attitude of the helicopter, the loss of airspeed and rotor speed. The reasons for the upset flight condition were not obvious from any of the recorded parameters. However, extensive testing and examination of the hydraulic actuators, studies of the recorded data, computer modeling of the forward actuator, computer modeling of the flight control linkages, simulation of the helicopter aerodynamic performance, and comparisons to the recorded parameters provided insight into the failure and the effects of the failure of the forward actuator.

2.2 Analysis of the flight

2.2.1 Take-off and climb

The pilot was seated in the front right seat and he was the pilot flying. The helicopter engines were running during the short stop at Tallinn Linnahalli. There were no abnormal indications during ground time. No problems were reported as a result of the pre-flight checklist. The take-off was at 12:39 hours. The Tallinn MSSR radar detected the helicopter at 12:39:06 hours heading east at an altitude of about 140 ft. The helicopter then turned north and climbed over Tallinn Bay. Soon thereafter, the helicopter reached the border of Tallinn Airport Control Zone at an altitude of 1 200 ft above ground level (according to the FDR 1 900 ft standard atmosphere) and with an airspeed of 130 kt. According to the CVR record, the flight crew discussed avoiding cumulus clouds ahead by climbing to 2 000 ft or higher. About two minutes after take-off, the pilot told the co-pilot that he was going to increase power. The FDR data showed that he used the autopilot trim to increase the vertical velocity (rate of climb). It also showed the power increase at 12:41:44 hours, i.e. the collective control position moved up 5 % in six seconds. Furthermore, it showed that the airspeed and rate of climb started to increase. Also, the cyclic moved slightly forward during this time. This occurred at an altitude of 1 380 ft. In conclusion, the accident flight was normal and uneventful up to this point.

2.2.2 The initial upset flight condition

At 12:41:51 hours, seven seconds after the power increase, the longitudinal cyclic control moved aft from 60 % to 34 % in one second. Simultaneously, the collective control moved rapidly upwards from 53 % to 77 % in 1.4 seconds. It continued quickly upwards reaching 91 % in the next 0.5 seconds. Coincident with the movement of the collective and longitudinal cyclic controls, the pitch and roll attitudes of the helicopter changed rapidly. Initially, the helicopter appeared to be in an uncontrolled flight condition.

When the rapid changes in the helicopter attitude began, two seconds after the upset flight condition started, the helicopter was in the following attitude:

- The pitch rate of the helicopter reached about 60 degrees / seconds (12:41:52), and the pitch angle increased to 55 degrees nose up at 12:41:52.5;
- The normal acceleration increased from 1.0 G to 2.9 G;
- The roll rate reached – 20 degrees / second (roll to the left). The roll angle reached – 70 degrees (to the left) at about 21:41:53;
- The heading angle decreased (yaw left) from 355° (magnetic) to 290°; the heading reached 259° at 12:41:55; and then the helicopter started turning to the right.
- The lateral cyclic also moved to the right, eventually reaching 85 % at 12:41:54.

Following the initial movements in the longitudinal cyclic and the collective at 12:41:51, the initial upset flight condition lasted approximately three seconds. According to the FDR data, then ensued a series of collective, cyclic and pedal movements, which were accompanied by large excursions in pitch, roll, and yaw rates and angles. By 12:41:58, the pitch and roll angles were still undergoing large oscillations; the pitch was oscillating between 30 – 40 degrees nose up and 30 – 40 degrees nose down, roughly centered about 0 degrees (level); the roll was oscillating between 15 - 20 degrees to the left and 10 – 40 degrees to the right.

At 12:41:54, the collective again increased, reaching 100 % one second later. Coincident with the increase in collective, the engine torque increased, and the main rotor speed started to decrease, from 109 % at 12:41:54 to 71 % at 12:41:57. At 12:42:00, the collective decreased rapidly, from 95 % to 54 % in one second. Following the decrease in collective, the main rotor speed recovered.

At 12:41:55, having initially yawed to the left, the helicopter started to develop a large yaw rate to the right. The tail rotor pedals moved initially to the left, but were then displaced to the right, reaching the right pedal limit position at 12:42:08. The right pedal remained displaced, and at times close to the limit. The full right pedal displacement in the normal hovering can produce a yaw rate of about 170 degrees/second. However, the yaw rate stopped increasing and stabilized at around 100 degrees/second. There were 13 full rotations to the right before impact. It should be noted that the control power was related to the square of rotor speed, i.e. at 71 % rotor speed only 44 % of normal control authority was available.

The landing gear aural warning became audible on the CVR for a short time period. The warning had activated, because the airspeed decreased to almost 0 kt and the landing gear had not been extended. According to the FDR, a Master Caution warning signal activated and a Stability Augmentation System (SAS) Fault Indication appeared one second later. According to the CVR, there were also changes in the background sound environment that could be described as fluttering or flapping sounds

According to the FDR data, simultaneously, the autopilot (AP) and the flight director (FD) systems started a *"mode swapping"* sequence. During a four second period, the AP and the FD parameters changed between on and off (on the FDR from *"0"* to *"1"* and back at every one second sampling). This kind of AP and FD erratic behavior was observed on the FDR also for previous flights and ground runs during the week preceding the accident. The write-ups by the pilots for these events preceding the accident were *"Abnormal roll input"* and *"FD doesn't keep couplings"*.

At the initial upset flight condition, the movements of the cyclic and collective controls resulted in an abrupt nose-up movement of the helicopter, which led to a normal acceleration increase from 1.0 G to 2.9 G in 1.5 seconds. Simultaneously, the helicopter's airspeed decelerated from 135 kt to about 50 kt in five seconds. Consequently, the helicopter and its occupants experienced considerable alternating acceleration forces in several directions.

During the initial five second period of the upset flight condition, the pilot likely tried to stop the upward movement of the collective control by forcing it down. The ensuing opposite force applications between the forward actuator and the pilot pushing down on the collective likely stalled the SAS and activated the SAS fault indication.

After the initial upset helicopter started very complicated evolutions while making on airspeed about 50 KT spirals with very small radius and simultaneously rotating around its vertical axis. The main rotor stayed tilted toward center of the spirals and helicopter drifted downwind.

The attitude of the helicopter at every particular time moment related to the interaction of the different factors like:

- gyroscopic moments the main rotor and helicopter hull, which tried to level the helicopter;
- applied by the helicopter control system commands to the main rotor blade pitch settings, which tilted the main rotor rotation disc;
- gyroscopic moments of precession trying to change helicopter main rotor and hull position in direction 90° to applied forces;
- direction of the airflow on the helicopter hull.

2.2.3 Efforts to regain control of the helicopter

As a result of the considerable rate change in pitch attitude, the main rotor blades were operating well outside known flight data and likely were subjected to a driving force rather than a retarding force. The FDR showed that the main rotor RPM increased from 107 % to 109 % in two seconds, followed by a decrease to 70 – 80 % in the next three seconds for a period of three seconds. Simultaneously, the AC generator came off line for six seconds as a result of the low RPM. The main rotor RPM was recovered back to 107 % in seven seconds as the collective was reduced.

In the first five seconds following the start of the upset flight condition, the helicopter lost almost entirely its airspeed. At the same time, and in a few seconds, the helicopter climbed approximately 200 ft (to an altitude of 1 600 ft above the sea level). If the helicopter had not entered IFR conditions (clouds) before the upset flight condition, it likely did so during this climb. The helicopter was at this altitude for about ten seconds, after which the altitude started to decrease at a variable rate. When the collective was reduced, this commanded a descent. The helicopter continued in a rotation to the right and lost altitude at an average of approximately 3 000 ft/min.

During the first 13 seconds after the start of the upset flight condition, the helicopter changed pitch and roll attitudes rapidly. The attitude changes of the helicopter were consistent with the large movements of the cyclic control and the uncommanded extension of the forward actuator. Subsequently, it was likely that the flight control commands were effective, but not necessarily fully as commanded. The oscillations of the pitch attitude were within ± 40º and the oscillations of the roll attitude varied between + 10º to + 40º to the right. The amplitude of the oscillations was decreasing.

Approximately ten seconds after the initial upset flight condition, the FDR recorded abrupt collective down movement. After getting the collective control down, the pilot made a *MAYDAY* call which was recorded on the CVR and the radio keying was recorded on the FDR. However, the radio call was not transmitted from the helicopter on the Tallinn Tower frequency, because the pilot's radio panel settings (transmit selector) had been selected to transmit over the PAGE system within the helicopter.

At 12:41:59 hours, the helicopter was yawing to the right and the tail rotor pedal started to move back toward the right. At 12:42:04, the pedal moved past 60 %, and the yaw rate started to increase. At 12:42:08, the pedal reached almost full right, and the yaw rate reached 170 degrees / second to the right. At that time, the longitudinal acceleration on the pilots would have been about – 2 G, acting to push them forward out of their seats towards the windscreen.

After 13 seconds from the start of the upset flight condition, the helicopter resumed a less erratic roll and pitch attitude for the next 11 seconds. The pitch angle oscillations were less than + / - 10 degrees, centered about 0 degrees, and the roll oscillations were about + / - 20 degrees, centered about – 20 degrees. However, the helicopter continued its rotation to the right at a fairly steady rate between 150 and 170 degrees / second. The tail rotor pedal remained near the full-right position for the remainder of the flight.

At approximately 16 seconds after the initial upset flight condition, the CVR recorded the co-pilot asking *"Did we lose the tail?"*. At this point in time, the main rotor RPM increased back to normal, and the AC generator came back online. According to the FDR, after two seconds, the AP and the FD started their power-up (pre-online) sequence which lasted four seconds. A high frequency signal is recorded on the CVR, possibly altitude alert or AP back online. According to the FDR, flight director coupled (FD CPL) was connected after the co-pilot's acknowledgement and the go-around mode (GA) was connected one second later. These AP and FD mode settings remained until the impact.

The co-pilot asked again if they lost the tail, still without a response from the pilot.

Conclusion: There was no advance indication to the flight crew to precursor the upset flight condition. The flight crew were able to recognize that it was an emergency situation, but could not identify what the emergency was and why the helicopter was responding the way it was.

2.2.4 The descent

After 24 seconds from the start of the upset flight condition (13 seconds before impact with the water), the attitude of the helicopter became more unstable again and started to oscillate. The pitch attitude began to oscillate between + 31º and - 40º and the roll attitude between - 24º and + 72º. However, the amplitude of the oscillations began to decrease in the last ten seconds of flight.

Approximately ten seconds before impact, the co-pilot asked for a third time if they lost the tail. The pilot called *"Floats"*. In order to activate the floats, either the landing gear should be extended, or the emergency (explosive) landing gear door release could be used to allow deployment of the floats with the gear up. Although the landing gear was found in the extended position, further examination of the wreckage showed that the landing gear had not been deployed, since the landing gear handle was in the retract position. It was concluded that the landing gear fell out of their respective wheel wells at the impact with the water. Also, the switch in the overhead panel that armed the floats was found on the *"OFF"* position, and none of the pressurized float canisters had been activated. The nose wheel floats were found dangling from their stowage positions, but this was also the result of the impact with the sea. Therefore, it was concluded that the floats were not armed and not activated before impact with the sea.

The pilot was heard on the CVR recording specifying *"That one"*. Apparently inadvertently, the pilot had pressed the push-to-talk button (recorded on the FDR) on his cyclic control. Simultaneously, a synthetic aural warning (male voice) saying *"DH"*

(Decision height) was heard on the CVR recording. Then, the FDR showed that the left engine control lever was moved back and the no. 1 engine RPM started to decrease to zero.

It was evident that from the beginning of the emergency situation, the pilots were tremendously occupied trying to gain and maintain control of the helicopter, as well as trying to determine the reasons for the emergency situation. Initially, the uncommanded flight control movements resulting from the uncommanded extension of the main rotor forward actuator hindered the efforts by the flight crew, and subsequently, they were affected by spatial disorientation caused by the rapid changes in G forces, roll and pitch attitudes and the rotation of the helicopter.

2.2.5 The helicopter impact with the sea

Since the witnesses of the accident were situated relatively far from the accident site, the particulars of the impact with water were determined mainly on the basis of flight recorder data and by studying the damage to the helicopter. Based on the FDR data, at approximately five seconds before impact, the left engine was set to idle. The torque produced by the right engine started to increase immediately in order to maintain rotor speed. Two or three seconds before impact, the torque of the right engine started to diminish also. Impact with the water was at 12:42:28 hours. The helicopter pitch angle was approximately horizontal, there was a 20° roll to the right and the helicopter was rotating to the right with a rotation speed of one full rotation in 2.5 seconds.

The impact with the water resulted in significant structural damage. A fracture between the aft fuselage and the tail of the helicopter was consistent with the tail being forced upward relative to the fuselage. The fracture extended almost from the bottom to the top and caused the bending of the tail. One main rotor blade (the yellow blade) had struck the tail and cut off part of the tail rotor transmission shaft and its cover. The tail was also struck by the red blade, but this blade only got some traces of blue color from the fuselage.

If the main rotor blades had struck the tail while the helicopter was in flight, the separated parts of the tail would have been located much further away from the wreckage than a few meters. The leading edge of the yellow blade that struck the tail had some small but clear deformations and traces of blue color originating from the helicopter tail. Also, the blade tip weight mounting bolts were bent towards the trailing edge of the blade.

The condition of the main gear box and the nature of main rotor and tail rotor damages were not consistent with main rotor blade or tail rotor blade separation before impact with the water. Specifically, a technical expert examination (at the Tallinn University of Technology) of the main rotor blades was carried out in order to assess the causes of the separation of the main rotor blades. It was confirmed that the main rotor blades separated as a result of impact with the water. The FDR data further supported the conclusion that no part separated from the helicopter in flight. Conclusion: The main rotor and tail rotor blades did not separate during flight.

According to the FDR and the radar recordings, the helicopter moved in small spirals while tracking 320° during the last 30 seconds of t he flight, i.e. leeward with an airspeed of about 6 kt (12 m/s). The cockpit seats were located about 2.5 m in front of the helicopter (main rotor) axis of rotation and the rotation was not horizontal but a slanted (25°) motion. Thus, the motions and accelerations experienced by the flight crew were generally greater than the motions and accelerations recorded by the FDR.

Since the floats were not deployed or activated, the helicopter most likely rolled over after impact.

2.2.6 Rescue and survival aspects

An analysis was made as to why the flight crew did not deploy the floats. It could be postulated that it was possible that the co-pilot made an attempt to activate the floats, but did not succeed, possibly due to the acceleration forces from the rotation and the changes in the helicopter attitude. It was possible that while trying to press the activation switch for the emergency floats in the overhead panel, the co-pilot pressed the generator switch, which was situated next to the *"floats"* switch and which was found in the *"off"* position. There was no reason why the generators would have been switched off in this situation.

As the helicopter was not equipped with automatically (in contact with water) deploying emergency floats then helicopter did not stay on water surface.

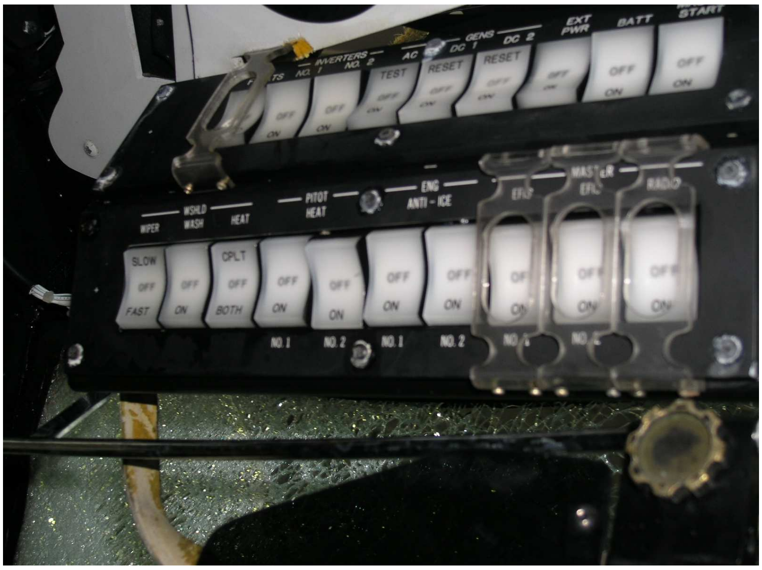

Photo 15. Overhead control panel with the switch for the floats in the upper left corner.

If floats could be inflated before the impact with water it could be that some of floats could possible be burst at impact. As floats actually were not inflated, it is difficult to assess helicopter's buoyancy after impact with water surface with floats inflated. According to an assessment by a buoyancy expert, without inflated floats and taking into account the openings in the helicopter resulting from the damage and break-up at impact, it probably took about ten seconds for the helicopter to fill with water and to sink. As the centre of gravity of the helicopter, when floating on the water, was probably higher than the waterline, the helicopter fuselage probably turned upside down, possibly as a result of the waves which were in the order of one meter high and also due to the impact forces from rotating helicopter hull.

No decreasing of the survivable volume of space for both flight crew and passengers occurred at impact with water. It was evident that egress actions had been initiated to open/separate the left side (co-pilot) cockpit door. The cover of the emergency door release mechanism had been raised, the jettison handle had been moved to the upright position, and the door lock pin had been released, but the door had not been pushed out. However, there was no evidence or indications of attempts to open any other doors in the helicopter.

2.3 Spatial disorientation of the pilots

2.3.1 General considerations

In the beginning of the emergency situation, the helicopter violently pitched up, rolled and yawed. It sustained + 2.9 G normal acceleration. The remainder of the flight sustained uncontrolled or marginally controlled flight with rapid attitude changes. Most notably, the pilot flying continued to gradually introduce full right pedal input even as the yaw rate to the right increased. It was also likely that the helicopter was in or about to climb into IFR conditions (clouds). The helicopter probably remained in IFR conditions during most of the upset flight for 15 to 25 seconds. Once below the clouds and until impact (about 15 seconds), the pilots would have minimum visual cues to aid in recovery due to the reduced visibility and limited features nearby. Furthermore, the poor response of the main rotor forward actuator to flight control inputs rendered the helicopter sluggish to flight control inputs, which undoubtedly exacerbated the situation. The series of rapid attitude changes, high acceleration loads, poor flight control feedback, and partially IFR conditions were conducive to spatial disorientation. The continuing right pedal input in the presence of high right yaw rates was indicative of the presence of spatial disorientation.

To further amplify the situation, simultaneously, there was first a turn to the left, which subsequently changed to a right turn and a rotation to the right. The combination of acceleration forces and rotation was most unusual to the pilots and it certainly affected their capacity to see and react, especially while in clouds; it likely affected and limited their perception of the helicopter’s attitude and motions. Their senses of the movements of the helicopter could have become misleading, and it was quite possible that the pilots did not sense or feel all the nuances and changes in the movements. The helicopter movements were accompanied sometimes by deceleration forces and sometimes by acceleration forces. In this environment, especially without outside visual reference, it was difficult to perceive the continuous changes in helicopter attitude, and to perceive and relate any flight control inputs to the effect of such control inputs on the changes in the helicopter attitude (i.e. the effectiveness of flight controls). Although there was a ten second period in the middle of the 37 second emergency flight condition, during which the pitch and roll oscillations had diminished, the helicopter continued to rotate to the right.

It was likely that the upset flight condition and at least the first half of the emergency situation took place entirely or at least mostly in clouds (i.e. instrument meteorological conditions (IMC) prevailed). Without the presence of a visible outside horizon reference and other outside visual cues, the pilots had to rely entirely on the flight instruments, the readability of which in the prevailing circumstances was doubtful. Once disoriented, it would have been very difficult for the pilots to regain their situational awareness.

2.3.2 Focus of tests and research

On behalf of the Estonian Commission, the NTSB initiated further research to examine reasons for the flight crew's continued right rudder application and the potential for spatial disorientation following the initial upset flight condition and throughout the accident sequence. The research was conducted by researchers at the Naval Aerospace Medical Research Laboratories (NAMRL), United States in coordination with NTSB human performance investigators.

Possibility One: Could the pilot have put the wrong (left) foot on the right pedal? In tests, pilots who performed simple arm and leg movements while experiencing increased G forces due to short radius rotation performed poorly and made errors in placement of a limb. The pilot may have pushed himself back in the seat after the collective reduced, and then when he attempted to place his left foot on the left pedal, he ended up placing his foot on the right pedal during the dynamically changing forces he was experiencing. This could explain why he not only applied full or close to full right rudder but kept the input in until impact, in order to resolve a recognized right turn that could only be compensated for through a maintained application of left rudder.

Arguing against this possibility was the relatively short period of time with neutral rudder input (approximately 1.5 seconds). Also, the constant rotation to the right would tend to displace a limb being extended to the left, not right (linear Coriolis force). Furthermore, compelling evidence refuting this possibility was a fracture to the right ankle, which was consistent with the right foot being on the right pedal at the time of impact.

Possibility two: Was the pilot aware that the helicopter was turning to the right? There was a period of right yaw angular acceleration lasting 12.5 seconds (from 12:41:54.5 to 21:42:07 hours) resulting in a rotation rate of approximately 180 degrees per second, which was maintained until impact. It was a physiological principle that the inner ear detected acceleration (not velocity), so that at constant velocity the perception of rotation (in the absence of visual confirmation of rotation) gradually decayed to zero with a time constant of 7 to 20 seconds depending on the circumstances. Thus, after a relatively short period of time at constant velocity the pilot would not perceive rotation.

For example, using a value of seven seconds for the time constant of decay, the predicted perception of yaw rotation was that the pilot would not be aware of rotation for a full ten seconds before impact. There were several reasons for using the fairly low value of seven seconds for the time constant of decay:

1. The noise and vibration associated with the accident sequence significantly degraded the ability to perceive rotation when compared with the ideal conditions used in the laboratory (minimal noise and vibration) to determine thresholds:

2. The increased resultant force on the pilot would diminish his ability to perceive angular rotation; and

3. Channelized attention to attain pitch and roll stability. The most important axes for survival were pitch and roll, both of which were provided by the single source of the attitude indicator (ADI) (whether electronically displayed on a multi-function display or via tradition instruments). Heading information was provided separately and required a gaze shift. The pilot was experiencing continuous oscillations in both

pitch and roll which could only be addressed by almost constant reference to the ADI. The dynamics of the accident sequence likely did not afford the opportunity for the pilot to develop a scan pattern that would have provided him the information concerning the high yaw velocity, especially in light of the diminished yaw perception.

The pilot was under challenging conditions with top priority to reacquire and maintain pitch and roll within safe limits. Since the helicopter was above overcast and broken layers of clouds, the pilot needed to use the ADI as his primary instrument for pitch and roll. Since he was struggling to maintain pitch and roll, there was very little time to attend to the heading indicator which would have been showing a high rate of change and would have been difficult to interpret, assuming that the pilot would have found time to devote attention resources to the heading indicator. Most likely, there were no outside visual references to provide an indication of yaw direction and that the helicopter was in a yaw to the right.

If the pilot was unaware of the right rotation due to a combination of workload to control pitch and roll, and a lack of sensory sensation of right turn, then the large right rudder input would not be of such concern in the extremis situation.

Also must not be ruled out possibility, that the co-pilot, trying to help the pilot, could interfere in some extent into controlling of the helicopter and press the left pedal.

Possibility three: Was the pilot only trying to maintain his position in his seat? As in possibility one, if the pilot’s harness was loose, he could have been pulled forward to such an extent that he might only have been attempting to maintain himself in the seat by pushing on the rudder pedal(s). With two G negative acceleration pulling him forward, it might have been necessary to push back strongly to keep him in a position where he could properly manage the cyclic and collective controls.

Conclusion: By Commission the most favorable was possibility no. 2 i.e. pilot lost situational awareness in terms of helicopter rotation due his occupation with levelling the helicopter flight.

2.4 Forward Main Rotor Actuator

2.4.1 Introduction

At the request of the Estonian Investigation Commission, the NTSB examined and tested in detail the flight controls of the accident helicopter. The testing of the main rotor forward actuator showed that the actuator did not pass the manufacturer’s Acceptance Test Procedure (ATP). The retraction of the forward actuator was much slower than required by the procedure, and in one instance, the actuator failed to retract at all. Further, the actuator had high internal hydraulic fluid leakage and very low load carrying capability.

Subsequent teardown and examinations revealed that the internal leakage was caused by the wear and deformation of the piston rings. In addition, chips of plasma coating blocked one of the return ports of the actuator valve. The poor performance of the actuator in the bench tests was attributed directly to the worn and leaking piston rings and to the blocked return port.

The actuator was modeled with blockage of one of the system no. 2 return ports and the high level of leakage of both system no. 1 and 2, as found during tests and examination. The modeling disclosed that one of the system no. 2 return ports had to have been almost completely blocked to achieve a significant decrease in the load carrying capability of the actuator.

The design and tolerances of the piston head allowed rework of the piston head. As a result of the rework of the piston head, the piston head diameter became too small and the plasma coating at the piston head separated into chips. The chips and resulting contamination led to the accelerated piston ring wear, leakage and blocked return ports. Further, inadequate maintenance and preflight practices at Copterline hindered the discovery of the poorly performing actuator.

Modeling of the actuator and flight control linkages showed that the initial flight control movements, as recorded on the FDR, were consistent with an uncommanded extension of the forward actuator. Simulation of the helicopter showed that the motion of the helicopter was consistent with the flight control movements, both being attributed to the uncommanded extension of the main rotor forward actuator.

2.4.2 Bench testing of the main rotor forward actuator

2.4.2.1 Forward actuator bench tests at HSI and HR Textron

The main rotor forward actuator was first bench tested under the direction of NTSB at HSI. The functional testing found that both system no. 1 and 2 greatly exceeded the acceptable limits for hydraulic fluid leakage. In addition, the actuator piston position would drift. Piston velocity checks also showed that actuator would extend slightly faster than allowed, but would retract very slowly or in the case of system no. 2 alone, not at all.

During subsequent testing at HR Textron, the internal leakage was still significant, but distinctly different than the leakage observed at HSI, indicating that the internal operation within the actuator was likely changing. Again, velocity checks showed that actuator retraction was slow and that with only system no. 2 energized, the actuator again stopped responding. During the manual movement, the actuator was observed to suddenly "*jump*". After this movement, system operation was noticeably improved over the level attained at HSI. However, even at the improved level, the actuator operation was still very substandard.

Finding: There were two levels of forward actuator dysfunctions seen during the bench tests.

2.4.2.2 Forward actuator bench tests with new piston head rings

When the forward actuator was disassembled at HR Textron, it was noted that the piston rings were extremely worn. The piston rings for both system no. 1 and 2 were replaced, and the actuator was reassembled. The actuator performed much better. All leakage rates were found to be within acceptable limits. Both system no. 1 and 2 piston velocities had improved and were normal, except that system no. 2 retract velocity was still slow.

Finding: Extremely worn piston head rings resulted in high internal leakage of the forward actuator and contributed to the slightly faster extend and slow retract rates of the actuator.

2.4.2.3 Effects of the blockage by the separated plasma coating

The examination of the forward actuator hydraulic systems no. 1 and 2 showed that the aluminum-bronze plasma coating around the piston heads had partially peeled off and separated in fragments. The fragments of plasma coating had travelled to the return port orifices of the servo valves. Two pieces of plasma coating had permanently blocked one of the two return port orifices of the actuator stage no. 2 main control valve (MCV) secondary spool (inner sleeve) in the actuator's retraction travel vent line. Discovered in the bypass valve no. 2 large piece of plasma coating (refer to Photo 12) could in some conditions of hydraulic fluid flow temporarily close the second return port orifice.

Finding: Permanent blockage of one of the hydraulic system no. 2 return ports jointly with temporary blocking of the second port was one of the sources of the slow retraction, and failure to retract at all in some instances, of the forward actuator in the bench tests.

2.4.3 Further actuator tests with simulated discrepancies

The tests were performed to evaluate how internal leakage and blocked return ports affected actuator velocities and stall forces. The two return ports of system no. 2 were blocked at 25%, 50%, and 75%, where 25% equated to blockage of ½ of one of the return ports. An external bypass channel simulated internal leakage. The actuator stall force was observed to decrease as internal leakage increased. The stall force also decreased significantly as the blockage of the two return ports increased. In addition, piston velocity was observed to decrease in the retract direction and increase in the extend direction as internal leakage rates increased.

Finding: Piston stall force and retract velocity decreased as leakage and blockage increased. The extend piston velocity increased as internal leakage increased.

The data gathered served as the baseline for modeling of the actuator.

2.4.4 Actuator modeling

2.4.4.1 Overview

During post-accident examination and testing, the forward actuator performed very poorly even though its performance improved at least once before the post-accident tests were completed. The post-accident capability of the actuator did not fully account for its uncommanded extension at the initial upset. Therefore, a detailed dynamic computer model of the actuator's hydraulic and mechanical capability was developed. The model was used to evaluate the post-accident performance of the actuator and to explore various conditions that could result in greater loss of actuator performance and uncommanded extension.

2.4.4.2 Actuator computer modeling

Computer modeling found that a transient uncommanded main rotor forward actuator extension was possible with a combination of three prerequisite conditions. Uncommanded extension required a combination of one system's nearly complete blockage of both return ports, ring leakage in the second system that exceeded acceptable maintenance limits, and flight loads that exceeded the retraction capabilities of the degraded forward actuator. Examination found that one of two return ports of the main control valve was almost completely blocked, and potential blockage material with dimensions of the second port was found downstream of the second port. Blockage in these ports could apply system pressure of 3 000 psi to the extend side of the actuator piston. The leakage measured in the forward actuator installed in the accident helicopter was about twice the required amount of leakage for an uncommanded extension as defined by the model. Aerodynamic flight loads that could have exceeded the capability of the degraded forward actuator were identified.

With both return ports blocked, and with leakage in the opposing/parallel system, the model showed that the actuator would remain in the extended position. However, if one of the two blocked return ports cleared, some control of the actuator could be regained. The modeling showed that the retract load capability could be reduced from greater than 5 000 lb to below 400 to 600 lb with both return ports blocked and high internal leakage.

Finding: The actuator experienced an uncommanded extension because both return ports of system no. 2 were almost completely blocked and there was high internal leakage of both systems no. 1 and 2. Some actuator performance returned when one of the system no. 2 return ports cleared.

Finding: The actuator retract load capability was reduced from greater than 5 000 lb to below 400 to 600 lb with both return ports blocked and high internal leakage.

2.4.5 Actuator piston rework – plasma recoating

2.4.5.1 Introduction

The manufacturer accepted that the actuator pistons be reworked during actuator overhaul. The HR Textron Component Maintenance Manual (CMM), Repair section required the chemical stripping and recoating of the plasma coating on the piston head at overhaul, in case if chrome plating or plasma aluminum-bronze plasma coating were assessed not satisfying. There were 13 major steps, from incoming inspection, to plasma spraying the coating, to final examination.

While it was known that there were dimensional limits on the size of the piston diameter before recoating, it was discovered in the investigation examinations that the lands of the plasma channel could get over sprayed. The over spray was thin and could be separated by lifting, thus starting the chipping process. The over spray of the lands had not been adequately addressed during design and there were no procedures in place to control over spray of the lands during the plasma coating process. For a reworkable piston the allowed diameter is between 1.416 and 1.425 inches at the edges of the trough before coating. As such, when coated and machined to final dimensions, the plasma spray coating can overlap the edges of the lands, as depicted below. In the middle of the trough the coating will still be between 0.010 and 0.0125 inch thick but depending on starting diameters it can be between 0.000 and 0.0045 inch thick at the edges. This condition is referred to as a “full width coating”.

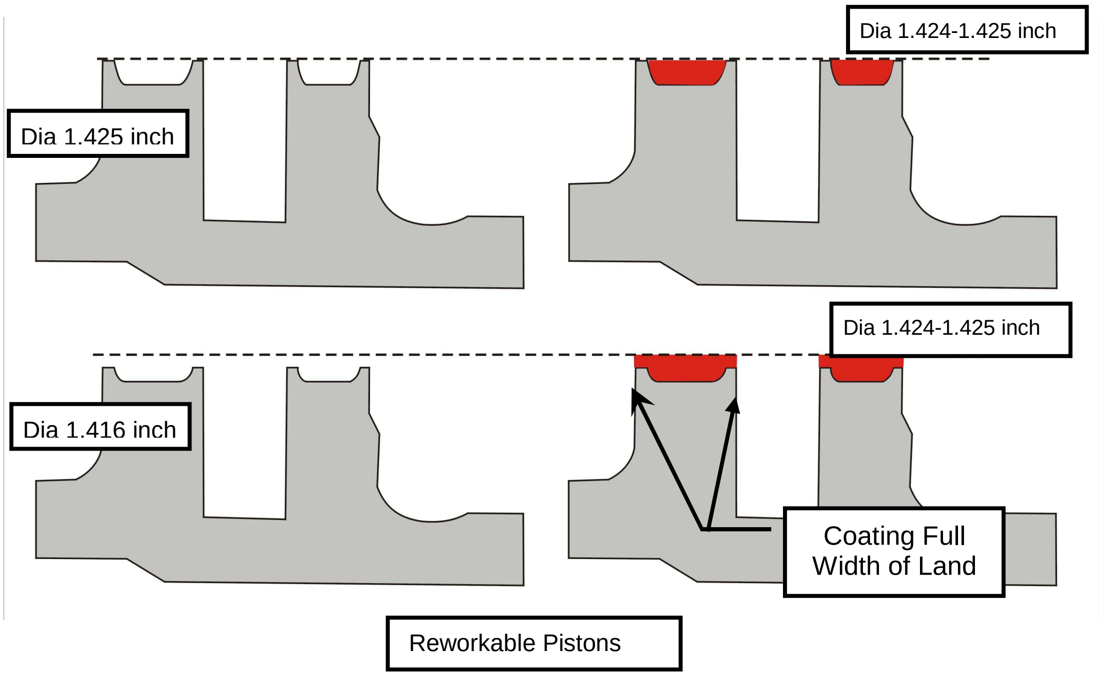

Figure 13. View of section of the piston head lands with plasma coating (red colored)

2.4.5.2 Pistons with spalled plasma coating from different helicopters

2.4.5.2.1 Examination of four spalled pistons

In all, four pistons with spalled plasma coating were found and examined. The following is a summary of the observations: the spalling was mostly adhesive but contained significant amounts of cohesive separation; all four pistons had acceptable coating metallurgical properties; the same three of four pistons displayed full width coating with relatively thick coating at the edges; the fourth piston was spalled on the shaft side land and had visible edges (did not have full width coating); the spalled areas were located in both worn and unworn portions of the pistons; the wear removed relatively minor amounts (about 0.001 inch) of material; on two of the four pistons, a large sliver of the coating was de-bonded from the piston but not detached or displaced; chipping, cracking and de-bonded coatings were noted on three of four pistons; and the accident and exemplar piston rings were worn or formed ridges at the edge of the plasma coating.

Three of the four examined pistons (including both accident pistons) had many common factors as noted above. A common cause is discussed below.

2.4.5.2.2 Mechanism for spalling and chip migration

The plasma coating eventually chipped, spalled, and cracked at the coating interface. The spalling appeared to be progressive, initiating as cracks and growing into larger de-bond areas. During the investigation it was not discovered any relation of the spalling to metallurgical properties of the coating or interface or piston wear from housing contact.

Further analysis of the observations showed that reworked pistons had an increased risk of plasma separation by mechanical forces. When new, the piston lands were full size and the groove in the outer edge of each land was sufficiently deep (cupped) to provide for better retention of the plasma coating. Further, the amount of plasma that extended beyond the radius of the piston land was relatively thin. After several reworks, the outside diameter of the piston lands was less. The smaller outside diameter of the piston lands provided for two mechanisms that aided in the separation of the plasma coating. First, the groove or cup was now shallower which provided less support for retaining the plasma. Second, the plasma was over sprayed around the outer edges of the piston lands, directly exposing it to additional mechanical forces during operation, making it more susceptible to mechanical lifting and separation. The over sprayed plasma would also produce larger particles or chips. Post accident measurements of the pistons plasma coating indicated up to 0.0129 inch (0.324 mm) thickness of the plasma coating.

As evidenced by the pieces of coating found in the actuator and the bypass valve, relatively large pieces of plasma coating could exit the piston land area. The pieces from the bypass valve showed marks from being trapped between the piston lands and the actuator wall and gradually working out into the system. The as manufactured piston-to-housing clearances of an actuator was 0.0045 to 0.006 inch diametrical (0.00225 to 0.003 inch per side) and would not allow a full thickness of the plasma coating (total depth from surface to bottom of cup) to exit the piston head area, even with the piston fully deflected to one side of the housing. However, as the piston land edge diameters of the pistons wore and decreased to minimum, only a small side deflection of the piston would allow full thickness plasma coating pieces to exit the piston cup area. At the minimum piston land diameter (1.416 inch) at overhauls, there was a 0.014 inch diametrical clearance (0.007 inch per side) between the housing and the piston.

Small (less than 0.003 inch) or thin particles of plasma coating could escape the piston at any time. These particles were probably relatively benign. Many small particles were found embedded into the piston rings, and some were found in the hydraulic return lines and in the return filter and ports of both systems. Large particles that could block ports and holes could only escape when the piston edge diameters were reduced toward the minimum.

The loss of the plasma coating could also affect ring performance. In a new condition, the piston land supported the side of the ring. However, as the piston land diameter decreased and the coating was lost, the unsupported portion of the ring could increase up to 0.007 inch per side. The decreased ring support would allow for greater side deflection of the ring, increasing wear and leakage. The wear edges on the accident rings were not square to the faces, supporting the premise of ring wear under deflection.

Finding: Loss of material from the edges of the piston lands during multiple reworks and over spray on the piston lands were the cause of the worn piston rings and the chipping of the plasma coating that caused the blockage of the return ports of system no. 2, and this led directly to the failure of the forward actuator.

The Commission considered that the above described plasma coating flaking was a serious safety issue. Following coordination a few months after the accident, NTSB issued safety recommendations, detailed in part 4 - Safety recommendations of this report.

As a result of the Commission's findings and concerns, and HR Textron's review of the available information, HR Textron prohibited overhaul of the pistons.

Finding: After the accident, rework of the actuator pistons was prohibited in order to eliminate plasma coating separation or to limit the size of plasma chips if the coating did separate.

2.4.5.2.3 Plasma Tech procedures

Maintenance records indicated that Plasma Technology Inc (Plasma Tech) applied the plasma recoating on the overhauled pistons of the forward actuator on the accident helicopter. Review of the plasma spraying procedure revealed that there were a number of provisions listed in the manufacturer's specification that were not accomplished.

The HR Textron Component Maintenance Manual (CMM) specified that, as part of the overhaul process, the plasma coating on the actuator rod be stripped and replaced per AMS 2437 specification with *"15 % aluminum bronze (Metco Inc. Alloy 445)"*. Because Metco 445 was not a 15 % aluminum bronze material, the CMM and rework drawings incorrectly identified Metco 445. In addition, AMS 2437 did not list Metco 445 or any similar materials. However, AMS 2437 did allow other coating systems to be specified by the purchaser.

Plasma Tech procedures did not directly follow AMS procedures in that no cup or bend test were performed, no production parts were tested and only one set of samples were tested. However, Plasma Tech did conduct bond strength tests on each lot, and these tests could be considered substitutes for the cup/bend tests. Additionally, size limitations and the possibly destructive nature of tests on production parts would prevent their testing. However, there did not appear to be reasonable justification for not performing two sets of quality tests per lot as outlined in AMS 2437.

A more serious deviation from the AMS specification was that the lot containing the pistons from the forward actuator on the accident helicopter was not plasma coated in a continuous operation and spanned more than one work shift. The completion dates for the two pistons were three days apart. By AMS and most other quality standards this would have necessitated additional qualification tests.

Plasma Tech also used a Honeywell (Garrett) process specification, GPS 3227-2 Type XVII, as an additional quality control document. While this document contained acceptable technical information, it was not mentioned in any HR Textron documents. Its use as *"approved data"* for FAA purposes may be questionable.

The location and manner for marking reworked pistons changed in year 2000, yet, the accident pistons were not marked in the new prescribed manner, but were marked in the older style.

Even though there were discrepancies in the Plasma Tech procedures, there were no indications that the accident pistons were reworked in a technically unacceptable manner and the separation of the plasma coating was not attributed to procedures in place at Plasma Tech.

2.4.5.3 Number of reworks of the accident pistons

According to the maintenance records, the pistons installed in the forward actuator in the last overhaul had been in service for 24 100 hours. At piston overhaul usually also plasma coating was replaced. The stripping of the aluminum-bronze plasma coating on the pistons during overhaul was necessary if plasma coating or chrome plating needed replacing. If plasma coating of the accident pistons was stripped in each overhaul (after 3000 hours), it could be assumed that there had been at least seven or eight reworks of the pistons of the forward actuator of the accident helicopter. However, according to Sikorsky, the pistons were not reworked more than three times.

2.4.6 Maintenance intervention

2.4.6.1 Internal actuator leakage

In post-accident testing, the forward actuator had excessive internal hydraulic fluid leakage due to extremely worn piston head rings. The excessive leakage was a key factor in the malfunction of the actuator.

If the actuator had been tested for leakage as described in the manufacturer's recommended maintenance procedures, the leakage could have been discovered and the actuator replaced. Although the piston head pistons rings had been in use for 2 276 hours, there was no record that the leakage test had been performed, nor was there any clear indication that such a test was contemplated or planned.

Copterline stated to the Commission that they were aware about 2250 hours leaking test, but due to the obvious need to replace the actuator with new one, decided to use 10% extension time i.e. 225 hours and to replace the forward actuator during the next 100hours inspection. By Copterline's explanation the cause for forward servo intended replacing was discovered actuator's lower spherical bearing play, what was increasing toward not allowable limit. But no record or document was presented to the Commission confirming this mentioned intention, except documentation about purchased by this moment new main rotor hydraulic actuator.

Also no documented approval or decision to defer performing of the internal leakage test task was provided to the Commission.

The overdue of this 2250 hours internal hydraulic fluid leaking test task was found to be 26 flight hours versus to the recommended test period of 2250 flight hours.

Finding: The excessive leakage of the forward actuator could have been discovered if the manufacturer recommended maintenance procedures had been followed.

2.4.6.2 Dark and contaminated hydraulic fluid

The recovered hydraulic fluid in system no 2.was dark and contaminated. The deterioration of the fluid could have been discovered by precise routine maintenance and analyses in conjunct with excessive filter changes (ref: Para 2.8.3 and Sikorsky MM 29-00-00).

Copterline maintenance should have sent the dark fluid sample to an independent laboratory for to analyse the source and level of the contamination and perform the flushing procedure as required. Flushing procedure 2, which have to be proceeded after contamination (MM 29-00-00 page614, item (29) (b)), includes as follow: “Do a patch test of fluid samples taken from return ports of servos during servo test. Replace any servo producing contaminants”

The mechanics should have determined the reason for the dark fluid, corrected the problem and replaced the dark fluid with clean fluid. Such maintenance actions would have likely led to the discovery of the leaking forward actuator. The condition of the fluid post-accident showed that a routine maintenance patch test should have further disclosed unacceptable levels of contamination. The primary source of contamination was from the separating chips of plasma coating and high wear of the piston rings. Maintenance practices at Copterline were not sufficient and adequately executed so that the presence of fluid discoloration or contamination would have been detected. Thus, the reason for the dark and contaminated fluid was not detected.

Finding: The hydraulic fluid was contaminated beyond acceptable levels. Copterline’s maintenance did not find the contaminated hydraulic fluid through its maintenance practices and missed an opportunity to discover the leaking forward actuator.

2.4.6.3 Unbalanced hydraulic pressure

Post-accident ground testing and subsequent teardown of the forward actuator revealed that both system no. 1 and 2 piston rings were worn and leaked. Although the leakage in each system was significant, the difference between the two systems was not great. The Sikorsky S-76 flight manual contained an operational check to identify an unbalanced hydraulic pressure within the flight control system at engine start. A similar procedure was described in the S-76 maintenance manual. The procedure required the pilots to switch off first one hydraulic system and then the other, watching for a change (referred to as a ”stick-jump”) in the positions of the flight controls. Such a jump would indicate a difference in hydraulic pressure between the systems and repair would be required before further flight.

The FDR data showed that the stick-jump test had been performed only three times during the previous 14 engine starts. However, given the condition of the actuator during post-accident testing and examination, it was not likely that the flight control check required at engine start up would have disclosed a stick-jump.

2.4.6.4 Summary of Copterline maintenance actions

Copterline missed several opportunities to discover the unhealthy actuator. An actuator leak test and meticulous attention to hydraulic fluid patch tests should have been sufficient to alert Copterline´s maintenance to the leaking forward actuator.

2.5 Flight control movement, linkage, and modeling

Ground tests and the kinematic model of the flight control linkages established a direct correlation between the flight control movement and the extension of the three main rotor actuators. The tests and modeling showed that the motions of the pitch, cyclic and collective as recorded on the FDR could be achieved by the sudden extension of the main rotor forward actuator. In addition, the FDR did not record a continuous, constant position of the flight controls. The modeling showed that the flight controls and/or actuators were not jammed.

Finding: The flight controls and main rotor actuators were not jammed.

2.6 Performance simulation

The Sikorsky helicopter GenHel S-76C simulation was used to explore the aerodynamic effects of an uncommanded extension of the forward actuator or the effects of an inadvertent encounter with a waterspout. GenHel provided adequate fidelity to evaluate each scenario. As noted above, modeling of the flight control system provided a time history of actuator extensions that were used as inputs for the simulation.

The magnitude and character of the pitch, roll, heading, and load factor excursions computed by the simulator in the actuator malfunction scenario consistently matched the FDR-recorded excursions more closely than did the excursions computed by the simulator in the waterspout encounter scenario.

The motion of the helicopter encountering a waterspout without the flight control inputs showed that the waterspout was relatively benign. The headwind and crosswind gusts produced by the waterspout increased the true airspeed of the helicopter dramatically (KTAS at over 200 knots for one run, and KTAS peak at 180 knots for another run). The FDR did not show any airspeed increase at all, but instead a significant drop. Further, the addition of the waterspout produced erratic and choppy normal load factor calculations whereas the uncommanded actuator upset simulation produced a smooth normal load factor calculation that was much like the data recorded on the FDR.

The motion of the helicopter could only be reasonably matched by simultaneously using both the waterspout simulation and the extreme flight control inputs. The extreme flight control inputs were the dominant factor in the upset and would have been completely counter-intuitive to the pilots.

Finding: The uncommanded extension of the forward actuator provided a good match of the FDR data. An encounter with a waterspout did not provide a match.

Finding: The uncommanded extension of the forward actuator was consistent with the initial abrupt and unusual movement of the cockpit controls, since the failure can “back drive” the cockpit controls and cause initial movements such as those recorded on the FDR. Conversely, intentional abrupt control inputs, as recorded on the FDR, that appear unprovoked and exacerbating an encounter with a waterspout was most unlikely.

Finding: Testing and simulation showed that the helicopter was responding normally to the actuator motions, although the actuator motions were not normal.

2.7 Flight control analysis related to Federal Aviation Regulations (FAR)

Some of the flight control characteristics, potential failures, and annunciations, which were examined by the computer modeling, were also addressed by the Federal Aviation Regulations (FAR), as follows:

1. *Section 29.141, General, stated that the rotorcraft must –*

(b) Be able to maintain any required flight condition and make a smooth transition from any flight condition to any other flight condition without exceptional piloting skill, alertness, or strength, and without danger of exceeding the limit load factor under any operating condition probable for the type, including –

(3) Sudden, complete control system failures specified in Sec. 29.695 of this Part;

The computer modeling found that during a transient failure, loads at the collective and cyclic (that would have to be overcome by the pilot to maintain control of the helicopter) could exceed 400 lb.

2. *Section 29.397, Limit pilot forces and torques stated that the limit pilot forces for stick controls were 100 lb fore and aft, and 67 lb laterally.*

The computer modeling found that during a transient failure, loads at the collective and cyclic could exceed 400 lb.

3. *Section 29.671, General, stated that [c] a means must be provided that will allow the pilot to determine that full control authority was available prior to flight.*

Blockage of the first port would change the authority of the flight controls by altering the rate of travel that the main rotor actuator had in one direction. The Sikorsky Maintenance Manual did not contain a specific test for detecting blockage of a port, and port blockage was not detectable by pilots during pre-flight checks.

4. *Section 29.672, Stability augmentation, automatic, and power-operated systems, stated that*

a) *A warning which was clearly distinguishable to the pilot under expected flight conditions without requiring the pilot's attention must be provided for any failure in the stability augmentation system or in any other automatic or power-operated system which could result in an unsafe condition if the pilot was unaware of the failure. Warning systems must not activate the control systems.*

Cockpit annunciations were provided for jamming of a MCV and for low hydraulic pressure. The S-76 design did not provide annunciations for blockage of hydraulic ports or internal leakage.

b) *The design of the stability augmentation system or any other automatic or power-operated system must allow initial counteraction of failures without requiring exceptional pilot skill or strength, by overriding the failure by moving the flight controls in the normal sense, and by deactivating the failed system.*

The computer modeling found that during the transient failure, loads at the collective and cyclic could exceed 400 lb.

c) *It must be shown that after any single failure of the stability augmentation system or any other automatic or power-operated system, the rotorcraft was* *safely controllable when the failure or malfunction occurs at any speed or altitude within the approved operating limitations.*

(1) The computer modeling of a potential failure in the accident flight represented a transient attitude excursion in approved instrument flight conditions.

(2) An attitude excursion near the surface would be required to clear before the pilot could regain control.

5. *Section 29.695, Power boost and power-operated control system.*

   a) *If a power boost or power-operated control system was used, an alternate system must be immediately available that allows continued safe flight and landing in the event of –*

   (1) Any single failure in the power portion of the system;

   c) The failure of mechanical parts (such as piston rods and links), and the jamming of power cylinders, must be considered unless they are extremely improbable.

The section did not address blockage of hydraulic ports.

The Commission was not in a position to analyze and assess to what extent the possibility of a blockage of the two hydraulic ports, and subsequent maintenance of the flight condition, was taken into account in the helicopter design criteria in relation to the relevant FARs. Therefore, the Commission recommended that Sikorsky, the FAA and NTSB undertake a study to this effect.

2.8 S-76 maintenance

2.8.1 Maintenance performed

The maintenance and repair station actions related to the helicopter OH – HCI performed by Copterline were collected from the aircraft technical log, sections 2 and 3, journey log book, aircraft maintenance log and maintenance records (work orders and information printed from the HELOTRAC maintenance management program data base). Further evidence and clarifications were obtained in interviews with relevant personnel.

The accident occurred on 10 August 2005, at 6256 total flight hours, and with technical log #15391 in use. On 9 August 2005, a 15 h inspection had been performed at 6253 flight hours and per technical log #15389. Furthermore on 9 August 2005 at 6251 flight hours, the following action had been taken *“Ground wire of No.2 primary 26v xformer re-soldered, tested function satisfy” (technical log #15387)*. By the explanation of the Copterline relevant personnel this ground wire re-soldering solved problems with autopilot what were switching AP2 off line in all flight from the 6. of August 2005. By opinion of the Commission some of mentioned AP problems could also be related to the decreasing of the main rotor forward actuator performance.

On 6 August 2005, there were three flights for which the pilot-in-command did not clear the *"defect"* column with *"NIL"* (6251 flight hours and technical log #15386). Earlier on 6 August, there had been a write-up (technical log #15385 at 6248 flight hours) *"No.2 AHRS off line + AP2 off line + several error codes…did not come back ON-line. Additional clarifications on separate paper"*. No actions were taken before next flights. Later, a comment was added *"See log #15387"*, which was the re-soldering of a ground wire.

On 5 August 2005, a 25 h inspection was performed at 6244 flight hours (technical log #15385).

On 28 July 2005 at 6237 flight hours (technical log #15382), a test flight was performed, but the maintenance records did not state the reasons for the test flight, nor the results of the test flight.

On 27 July 2005 at 6235 flight hours (technical log #15380), the action taken was annotated as *"50 h inspection carried out"*. However, there was no work order reference and open defects without actions. It appeared that this entry could have been a duplicate CRS with technical log #15364 from 26 July.

Earlier on 27 July 2005 at 6228 flight hours (technical log #15373), there was a log remark *"#2 FD U/S, #2 AP not engaged"*. There was no record of any action taken. On the day before on 26 July at 6220 flight hours (technical log #15367), there was an annotation in the log *"FD2 does not hold couplings….2E18 / 2E39. Abnormal roll input from serie roll actuator !!"*. There was no record of any action taken. Earlier on 26 July 2005 at 6219 flight hours (technical log #15364), a 25/50 h and engines 50/50 h inspections were recorded.

On 25 July 2005 at 6215 flight hours (technical log #15360), an annotation was made in the technical log *"FD2 does not keep couplings … error code 2E18 / 2E30"*. There was no record of any action taken.

On 22 July 2005 at 6207 flight hours (technical log #15353), a 15 h inspection was recorded. On 16 July 2005 still at 6207 flight hours (technical log #15352), *"CVR/FDR unreliable"* had been annotated in the technical log. The action taken was *"FDR/CVR replaced"* with Certificate of Release to Service dated 20 July 2005.

On 15 July 2005 at 6205 flight hours (technical log #15352), the remark was *"Eng #2 / module 1. Three chips found during 30 hours"*. The maintenance actions recorded were *"Module 1, Eng #2 replaced. Test run OK.* In addition, the DC Generator #2 carbon brushes were found worn; the generator was replaced; and the main rotor damper (yellow) leaked; the seal was replaced.

On 8 July 2005 at 6203 flight hours (technical log #15350), 5-P bifilar was removed, 3-P bifilar had maintenance, the worn nose gear tire was replaced, and the broken main rotor blade tip end (leading edge side) was replaced. Track and balance was performed and the subsequent test flight was OK.

On 4 July 2005 at 6197 flight hours (technical log #15342), *"Eng #2 chip"* was annotated in the technical log. The recorded action was *"Chip detector inspected, cleaned, one thin hair"*. On 3 July 2005 at 6191 flight hours (technical log #15337, there was a 15 / 25 h inspection. On 1 and 2 July 2005 at 6180 flight hours (technical log #15327), *"Eng #2 chip"* was annotated and the action taken was recorded as *"Chip detector inspected",* and a 15 h inspection.

On 1 July 2005 at 6174 flight hours (technical log #15320), *"AHRS No.1 U/S"* was annotated and the action taken was recorded as *"AHRS #1 replaced"*.

In the last two weeks of June 2005, the helicopter had the yearly 12 months maintenance at 6167 flight hours (technical log #15313. The maintenance documentation mentioned (25 / 50 /) 100 / (300) / 500 /900 / (1250 h) 12 months, and eng 50 / 500, although the Certificate of Release to Service did not mention all these inspections. Furthermore, without any defect remarks in the technical log, the following additional actions were taken: YAW 2 actuator is *"jamming"* in flight, replaced; and YAW 1 actuator u/s, replaced.

On 15 June 2005 at 6150 flight hours (technical log #15924), there was no defects recorded, and no comments or results of two test flights. The actions taken consisted of *"Hyd syst 1 / 2 Filter Replaced, system test OK"*. After a test flight, there was a ground test with the hydraulic ground power unit, result OK, and then another test flight. The reasons for the replacement of the hydraulic filters and the system tests were not annotated. According to the Sikorsky maintenance procedures, the hydraulic filters were to be retained for contaminant inspection, and when contamination was found, a hydraulic system flush was required. There was no evidence that the hydraulic flushing procedure was performed.

2.8.2 Last 50 hour inspection of the helicopter on 26 or 27 July 2005

There were two Certificates of Release to Service from the last 50 hour inspection / scheduled maintenance of the helicopter before the accident, technical log pages #15364 and #15380. One release to service was entered on the log sheet with incorrect work order reference and date. The work order found from maintenance organization documents was not filled properly. The release for service was signed, but the individual items have not been signed off. The other release to service service with different date in an other log sheet did not have any work order reference and it was not released properly. Based on the log sheet date, this released inspection was completed approximately nine flight hours overdue. The updates to HELOTRAC database were also found done erroneous. The date complied did not correspond with flight hours entered.

Conclusion: There were deficiencies in the documentation of performed maintenance actions.

2.8.3 Hydraulic system filters

According to the maintenance records, from 26 August 2004 to 10 August 2005, the hydraulic system filters were changed, as follows:

Date	**Helicopter flight time, Log Sheet Number or Work Order Number**	**Hydraulic system 1.** **Filter changes**	**Hydraulic system 2.** **Filter changes**
26 Aug 2004	5314 hours Log no. 14489		Filters changed No reason mentioned
8 Nov 2004	5590 hours Work Order no. 822	Return, (popped out) *"button extended"*	Pressure / return No reason mentioned
5 Feb 2005	5783 hours Work Order no. 845	Pressure / return No reason mentioned	Pressure / return No reason mentioned
15 June 2005	6150 hours Log no. 15294	Pressure / return No reason mentioned	Pressure / return No reason mentioned

Except for Nov 2004, there was no reason given for the other hydraulic filter changes. The maintenance program did not contain a specific replacement interval for the hydraulic filters; the filters were changed based on the hydraulic system contamination analysis. Although there was no reason given, it should be assumed that there was either a contamination indication (popped out) or a contamination found in connection with inspection/maintenance.

Whatever the reasons were for the filter changes, the Copterline maintenance manual contained specific requirements for contamination analysis and flushing of the hydraulic system, including the hydraulic ground power unit. No such actions had been recorded in the maintenance documentation. It could not be determined whether no action had been taken, or whether action had been taken but not recorded.

According to the maintenance records, on 15 June 2005, the hydraulic filters were changed at the Hernesaari heliport and a Certificate of Release to Service was issued. The documentation did not contain a reason for the filter changes, and the subsequent system tests and flight tests were not described. The helicopter was test flown to the Copterline maintenance base at Helsinki/Malmi Airport, where the hydraulic system was re-tested using the hydraulic ground power unit. A new Certificate of Release to Service was issued. The maintenance documentation only made a reference to generic hydraulic maintenance. It was not possible to determine the reasons for the maintenance and the maintenance actions taken, as there was no work order and no inspection lists.

Conclusion: Copterline was not documenting its maintenance actions, as required in its approved maintenance management system (JAR OPS 3, Subpart M) and by its maintenance procedures (Part 145).

2.8.4 Checks of hydraulic fluid contamination level

As part of the two annual inspections (February 2005 and June 2005) performed in the last six months prior to the accident, the contamination level of the hydraulic system was documented as having been checked. The checks were signed off by initialling the task listing.

In the inspection in February 2005, a Patch Test Kit tester was used to determine the contamination level of the hydraulic fluid. The procedure using the Patch Test Kit required the colour of the patch sample to be compared to the colours in a reference table in order to determine the contamination level. The indicator patches were stored with the maintenance documentation (work order no. 845); however, the result (contamination level) was not recorded as required by the procedure (MOE 2.13.2). However, the hydraulic filters had been changed, but there were no record of the hydraulic systems having been flushed.

As part of the investigation of the accident, the test patches stored for approximately ten months from hydraulic system no. 2 were compared to the colours in the reference table. It was determined that the test patch colourization indicated a hydraulic fluid contamination level equal or exceeding level 5, i.e. contaminated. However, there was no information available as regards to the validity of the colour of the test patches approximately ten months after the sample had been taken, i.e. could the colourization of test patches change with time.

Had the test patches been determined to indicate a hydraulic contamination level below acceptable, the maintenance manual required that a flushing procedure be performed, and that laboratory samples for contamination analysis be taken from the helicopter hydraulic systems, as well as from the hydraulic ground unit.

The last annual inspection (work order no. 922) was completed on 30 June 2005, 89 flight hours prior to the accident, at helicopter total time 6167 flight hours. According to the maintenance documentation, a check for hydraulic system contamination was performed. The action item task in the due listing was signed off, but the result of the test (contamination level) was not recorded, and the test patches were not saved.

There were four hydraulic system filter replacements in a year of operation (August 2004 to August 2005). The average time between filter replacements was approximately 280 flight hours.

2.8.5 Actuator leakage test

According to the Copterline S-76 maintenance program, the Sikorsky Maintenance Manual, chapter 5-10-00, *671530F/L/A Note 1.(a), an internal leakage test (MM 67-15-00) was to be performed after 2250 hours of *“running”* time (flight time) of the main rotor actuators (part number 76650-09805). The main rotor forward actuator had been mounted on helicopter OH-HCI the entire time since its last complete overhaul. The actuator reached 2250 hours of flight time on 27 July 2005 (at helicopter total 6230 flight hours). At the time of the accident on 10 August 2005, the forward actuator had been in service for 2276 hours.

The internal leakage test had not been done, nor could the reference to the leakage test task as a maintenance action, be found in accident helicopters Maintenance Status -listing. The actuator internal leakage test did not have an individual task code, because the test reference was contained in the manual as a note under task *671530F/L/A (Note 1. (a))

Furthermore there was also another reason why the task would not have appeared on the HELOTRAC`s due-listing; when the actuator was installed in the helicopter, the part number information of the actuator had not been appropriately inserted in HELOTRAC programme.

It should be noted that the purpose of the task to perform an internal leakage test at 2250 flight hours was not to detect flaking of the plasma coating from the pistons.

After the accident, Sikorsky updated HELOTRAC task 671530F/L/A for the HR Textron 76650-09805 series main rotor actuator overhaul. Subsequently, a new specific task for internal leak test was introduced (T-Rev5-136 dated 1 Nov 2006).

Following the tests of the actuators after the accident, NTSB issued a safety recommendation to FAA that an Airworthiness Directive for internal leakage tests of the actuators be issued. Subsequently, Sikorsky issued a recommendation for internal leakage tests of the actuators, and announced that the actuator pistons will be modified.

2.8.6 Defect reporting and maintenance actions

According to the interviews conducted by AIB – Finland, the S-76 type supervisor was the primary contact person to whom pilots orally reported defects. It was possible that the maintenance manager and some of the S-76 type rated licensed maintenance engineers were not informed of about the defect status, the problems in the helicopter during the period before the accident and the corrective actions taken. Hence, they may not have been looking for possible defects or event history annotated on earlier log book pages. It was evident that the full scope of defects, error messages and malfunction trends was not clear to most of the S-76 maintenance engineers.

The investigation found that some of the S-76 pilots did not always annotate defects in the technical log, as required by the company procedures described in the relevant manuals. There appeared to have been an informal process of avoiding the annotation of defects in the technical log and instead conveying the defects orally to the maintenance organization. An examination of the maintenance actions in scheduled maintenance frequently dealt with issues that must have existed earlier during flight operations. Nevertheless, they had not been annotated in the technical log as defects, and the flights were signed off by the pilot-in-command with *“NIL”* defects.

The defects were annotated in the maintenance documentation work orders and log pages. Some, but not of all of this defects were entered into HELOTRAC monitoring program. Also not all of those defects were found listed in defect statistics for reliability analysis. There were a number a discrepancies and substantial differences between defects listed in different documents. The result of the informal oral reporting process was that not all technical personnel were fully aware of the defect situation and it was not possible for a maintenance engineer to comprehend and remedy all the defects in the helicopter by studying the technical log. The same situation was likely to have existed from one flight crew to the next.

From 7 July 2005 until the accident helicopter has flown only 52 hours but by the FDR had many maintenance actions on it, even no proper fault isolation was recorded. Only faults concerning AP and SAS system were recorded by pilot into OH-HCI technical journey log book. No more remarks from other company S-76 pilots. In the last two weeks prior to the accident, from 25 July 2005 onwards, several technical journey log book annotations had been made related to malfunctions of the autopilot and the flight director.

Also the pilot-in-command of the helicopter on the accident flight had described to a friend concerns related to very brief moments of *"frozen"* flight controls during at least two previous flights. According to the annotation in the technical log, the pilot referred to a separate sheet of paper in which he had described the defects that occurred and the error messages related to the autopilot and the flight director. It appeared likely that the description of the defects on a separate sheet of paper was not made available to all S-76 pilots. As regards the Copterline maintenance organization, there were no documented maintenance actions taken in response to the annotations in the technical log book and the description of the defects on the separate sheet of paper. There was no documented evidence of systematic fault analysis and fault isolation. It was evident that the maintenance organization could not reproduce the anomalies, and did not transfer them to the *"Hold Item"* list. Although the autopilot and the flight director disconnects / malfunctions continued and the reasons for the anomalies in flight controls could not be established, the flight operation with OH – HCI continued.

On 9 August 2005, a day prior to the accident, the Copterline maintenance organization made the following entry in the technical log book: *"CRS: No.2 Primary 26V Xformer ground wire repair re-soldering"*. The maintenance action documentation contained a generic electrical system reference, 24-22-00. In the investigation, it was established that the work entailed a fairly extensive fault isolation as result of the annotated problems related to the autopilot and the flight director. According to interviews some components may have been interchanged during the fault isolation tests. However, there were no maintenance documentation describing the actions taken, there were no test results or test protocols, and it appeared that the view of the maintenance personnel was that the defects related to the autopilot and the flight director had been solved and the corrective action taken (re-soldering of the ground wire of the No.2 Primary 26V Xformer). Nevertheless, no annotations were made in the technical log book regarding corrective action taken in response to the open defects annotated for the autopilot and the flight director.

Conclusion: Copterline was not documenting its maintenance actions, as required in its approved maintenance management system (JAR OPS 3, Subpart M) and by its maintenance procedures (Part 145).

2.9 Copterline flight operations

2.9.1 Recurrent flight training and proficiency checks

The Copterline recurrent flight training programme and required proficiency checks were detailed in the Operations Manual (OM), Part D – Training. The Copterline flight operation, including the flight training and the proficiency checks, were the subject of regular safety oversight audits by CAA Finland.

The type rating conversion training and the recurrent training were subjects of numerous audit findings between 2001 and 2004. It was noted that the check flights were partially incomplete because not all emergency situations could be safely simulated. It was subsequently agreed that the ATPL (H) renewal check flights be flown on simulator, and it was recommended that at least every second company proficiency check flight also be flown on simulator. From 2003, a S-76 simulator was used at the training facilities of Flight Safety International in USA.

In 2004, some Copterline pilots had unsatisfactory check flights and shortcomings in proficiency. CAA Finland required additional training for the pilots concerned. It was noted that there were variances in the experience level and career backgrounds of the Copterline pilots engaged in flying the scheduled passenger service routes, and some had limited experience in a two-pilot instrument flying environment.

All Copterline pilots flying the scheduled passenger service routes had at least eight hours of flight training every six months using a FNPT 2 trainer or a S-76 simulator.

The Commission was informed that CAA Finland found that the simulator instructor was not IR/ME/MP rated as required, and some IFR procedure training programmes may not have been included in the recurrent simulator training sessions in May 2005. These findings were the subject of a separate investigation by CAA Finland.

In view of the above, nevertheless, the Commission noted that the deficiencies in the Copterline flight operation as documented in audits by CAA Finland from 2001 to 2004 appeared to have been subject to appropriate corrective actions. Similarly, the shortcomings found by CAA Finland in the flying proficiency of some of the Copterline pilots (including the co-pilot) in early 2004 had resulted in the provision of additional training. The Commission noted that the co-pilot had successfully passed the check flights in May 2004 and thereafter, and the co-pilot's performance had been rated satisfactory as co-pilot (left seat), both as PF (pilot flying) and PNF (pilot-not-flying).

Furthermore, the Commission noted that the pilot-in-command had joined Copterline in May 2005 with a significant amount of experience in piloting larger helicopters. The Commission further noted that the there were no discrepancies or unsatisfactory findings by the CAA Finland related to the training provided to the pilot-in-command by Copterline for the S-76 type rating and the Copterline pilot-in-command training for the scheduled helicopter flight service from May to July 2005.

2.9.2 Flight and duty time limitations

In section 1.5 above, it was established the pilot had flown 47:20 hours in the month of August 2005, and 102:15 hours in the month of July 2005, of which 94:10 hours were after 11 July 2005. Thus, the pilot's flight time in the last 30 days was 141:30 hours.

The Commission noted that Copterline was conducting its flight operations in accordance with its approved Operations Manual. According to the Copterline Operations Manual (OM), Part A – General / Basics, Chapter 7.3. – Flight and Duty Time Limitations, 7.3.1 – General Limitations, the maximum flight time in any calendar month was 100 hours. Section 7.5. dealt with situations which exceeded the flight and duty times in unforeseeable circumstances, such as exemptions granted by the Flight Operations Manager in case of compulsory ambulance flights, and search and rescue flights. Such situations were to be recorded together with detailed reasons. No such exemptions had been recorded relevant to the pilot and the time period concerned.

Furthermore, the Commission noted that the CAA – Finland Aviation Regulation OPS M3-2 (Flight and Duty Time Limitations) also required that the maximum flight time in any calendar month shall not exceed 100 hours.

Of concern to the Commission was that the pilot had accumulated 141:30 hours in the last consecutive 30 days, which exceeded with a significant amount the 100 hour limitation as required to be measured per calendar month. The Commission noted that the flight and duty time limitations were safety related and were aimed at preventing pilot fatigue. The uneven distribution of the flight hours of this magnitude within two consecutive calendar months, resulting in 141:30 hours in the last 30 days, was of significant concern. In the view of the Commission, a regulatory principle to measure flight time in any consecutive 30 days, rather than calendar month, would probably be preferable from a safety point of view in order to prevent pilot fatigue.

The Commission noted that much of the pilot's flight time was accumulated on the scheduled route between Helsinki and Tallinn. The average flight time on the route was 18 – 19 minutes. To reach over 140 hours in a 30 day period, would require the pilot to fly eight to nine round trips, 5:20 – 6:00 flight hours per day, and six days a week. The Commission considered these circumstances to be conducive to pilot fatigue, and even more so in short haul helicopter operations, as compared to fixed wing aircraft operations.

Regarding flight and duty times, the Commission considered the possibilities for pilot fatigue. As stated above, the pilot had flown 141:30 hours in the last 30 days. The Commission concluded that the possibility of the presence of fatigue for pilot could not be ruled out. The Commission also noted that even if there would have been some degree of fatigue present that did not have any bearing on the initial upset flight condition. However, it might have affected the pilot in the attempts to re-gain control of the helicopter.

2.9.3 Flight crew performance and CRM

The pilot had considerable helicopter flight experience as a professional helicopter pilot with the Finnish Board Guard, which operates under civil flight rules, when he joined Copterline on 1 May 2005. He received company training in accordance with the company flight training and flight check programme contained in the Copterline Operations Manual (OM), Part D – Training. The comments / evaluations by the flight instructors and check pilots for the pilot's training and check flights were generally positive and above average. The Commission noted that the pilot's performance was rated above average, that he had considerable helicopter pilot flying experience (over 7 000 hours), and that his flying experience on the Sikorsky S-76 type (173 hours) was limited.

The co-pilot had over 30 years experience in civil aviation, first as private pilot (aeroplanes) followed by CPL (A) and CPL (H), and ATPL (H). The Commission noted that the co-pilot had had unsatisfactory check flights in 2002 – 2004, mainly with comments related the IFR procedures, IFR approaches and CRM. These deficiencies, documented in 2003 and early 2004, were initially of concern to the Commission as the Commission noted that the accident sequence would have called for good flight crew coordination and CRM, and piloting partly in IMC in order to re-gain control of the helicopter. The Commission further noted that CAA Finland had required Copterline to introduce corrective measures, including additional training in early 2004. Subsequently, since May 2004, the co-pilot had successfully passed the check flights and his performance had been rated satisfactory as co-pilot (left seat), both as PF (pilot flying) and PNF (pilot-not-flying). Therefore, the Commission was satisfied that the corrective measures taken and the additional training in early 2004 had rectified the situation, as evidenced by the satisfactory check flights in May 2004 and thereafter.

The Commission noted that the co-pilot also had considerable helicopter pilot experience (over 7 600 hours).

Regarding CRM issues and flight crew coordination, both pilots had about the same flight hour experience, although the co-pilot was approximately 15 years senior to the pilot. However, in view of the pilot's long career in the military type organization (Finnish Board Guard), the Commission believes that the pilot had both the training and experience to maintain a pilot-in-command structure and authority. There were no indications of the co-pilot not accepting his position as a co-pilot in the company. The Commission noted that Copterline had a CRM programme with refresher training for its pilots. The Commission also noted that the co-pilot had received comments in check flights related to crew coordination and CRM. The Commission believes that the crew coordination and CRM was satisfactory at least in normal flight operations. According to the CVR recording, the flight crew was relaxed and the atmosphere in the cockpit was one of friendly co-operation.

The Commission noted that the pilot and the co-pilot had flown together as a crew for 21:20 hours, all of which within the last 30 days, and determined that the pilot and co-pilot were probably reasonably familiar with each other, and their individual habits in normal operation of the S-76 in the service between Helsinki and Tallinn.

The Commission also noted that CRM did not have any bearing on the initial upset flight condition. The Commission did not have evidence to determine whether the flight crew was able to maintain CRM and flight crew coordination, or whether CRM in the demanding emergency situation could have affected the attempts to re-gain control of the helicopter.

Also the Commission noted that even the FDR and CVR data was available, it was not sufficient to assess pilot actions and all the CRM matters, necessary for creating full picture of the event. To help the investigation in such kind of accidents crash protected video recordings from cockpit will be very useful.

2.10 Events prior to the accident

2.10.1 General

The Commission was able to document some events in the days, weeks and months before the accident related to the helicopter OH-HCI, which involved faults that may or may not have been related to hydraulic system contamination and uncommanded extension of the main rotor forward actuator. These events are described below.

Furthermore, there were numerous indications, including FDR data from the previous five days preceding the accident, of significant periods of maintenance activities, fault isolations and test flights. However, very few of these maintenance activities were annotated and described in the Copterline maintenance records. Apparently, these fairly extensive maintenance activities must have been undertaken for a reason, such as a known or suspected problem with the helicopter, which was not documented.

2.10.2 Event on 15 June 2005

The AIB – Finland interviewed a witness (aircraft maintenance mechanic) that was located in a trailer close to the heliport (Hernesaari). He had observed test runs of the Copterline helicopters in the early hours of almost every morning. In the early morning of 15 June 2005, he noticed that the sound from the helicopter was quite different from before. He looked outside and saw the main rotor disc flopping excessively. In his opinion, one can not achieve such movements by using the flight controls. Then the pilot shut down the engines, and went inside, apparently to speak with the maintenance personnel. He came out again and started the engines. The movements were again as excessive as a moment earlier. The pilot shut down the engines and the helicopter was taken inside the hangar.

The witness was not sure whether it was later the same day or a few days later that the helicopter was test run and test flown extensively. This time, he did not observe any unusual sounds or main rotor disc movements; everything appeared to be working properly.

2.10.3 Event on 26 July 2005

Fifteen days prior to the accident, the pilot encountered an event with the same helicopter involving presumably DAFCS failures / autopilot malfunctions. The pilot provided a written occurrence report to Copterline. In the report, he listed the problems as follows:

- FD2 unable to perform coupled flight in any mode longer than 10 – 20 seconds; and
- FD1 can occasionally perform coupled flight even if error code 2E18 is occurring frequently.

The pilot stated that the problem occurred in both ATT and SAS modes, but mostly in ATT mode (hands off flying). He listed the cockpit indications and his observations as follows:

- FD caution light flickers constantly in pilot’s EADI;
- Constantly 2E18 LVC error code in the AL-300 display (LVC – Line Voltage Compensator Failure);
- Often 2E39 error code (Roll Series Actuator failure);
- Sometimes 2E38 and 2E30 error codes (Yaw Series Actuator / Yaw Trim failure); and
- AP2 disengaged every two – three minute.

The pilot further described the tests he made. He observed the Roll Actuator Position Indicator panel (API display), which displays the position of the rods of The Series Actuators in reference to their centered positions.

1. ATT mode + NO FD coupling
   - Level flight 1 300 ft / 145 kt;
   - Roll API indicator shows occasionally sudden disturbances in Roll position for both series actuators even in calm weather; and
   - Momentary difference in series actuators position.
2. ATT mode + NO FD coupling + standard turn
   - 15 degree bank turn to check actuators movement;
   - Cyclic FTR switch pressed during maneuvering;
   - Both API indicators did not show same position – sometimes big difference;
   - API indicator moved in the opposite direction of the turn which is correct, because it shows the series actuators relative position at that time before it is automatically centered;
   - AP2 stayed occasionally in centered position “stuck” or moved only partly in the same direction as AP1; and
   - THIS TEST SHOULD BE DONE AGAIN TO CONFIRM THE MOVEMENT OF SERIES ACTUATORS.
3. ATT mode + FD coupled flight
   - FD2 unable to perform coupled flight for more than 10 – 20 seconds; and
   - Constantly 2E18 error code + disturbance in API – Roll display.

The pilot wrote that “DAFS ground test Level 1 + 2 must be performed before next flight and possible error codes recorded”.

He also recorded “other indications in DAFCS”, as follows:

Code 2E38 + 2E30

- Vi 120 kt / level flight / trimmed attitude;
- When changing TQ input (+ or -) 10 – 15 % with hands and feet on the cyclic and pedals, the inclinometer “ball” DOES NOT STAY CENTERED !!! The helicopter goes slightly out of trim approximately ¾ of a ball in both directions;
- IS THE YAW TRIM BAD AND UNABLE TO KEEP THE PEDALS IN TRIMMED POSITION ??; and
- PEDALS MOVE – CREEP DURING GROUND OPERATION WITH AUTOPILOTS OFF BUT ALL TRIM SWITCHES ON – WHY ! (Bad trim ?).

The pilot lastly recorded four questions as follows:

1. Do we have a problem with the no. 2 Roll Series Actuator (bad actuator) or IS IT in the information input / output that controls the actuator (LVC failure, bad component) ??;
2. Why do we also get YAW actuator and trim error codes;
3. Do we have two malfunctions at the same time (Roll and Yaw) !!!; and
4. It started with the YAW trim error codes and the Roll problem came weeks later.

It was obvious from this written report that the pilot had noted the DAFCS and autopilot problems on several flights prior to the flight on 26 July 2005 for which he filed the report.

Two days later, on 28 July 2005, the technical log contained an entry of a test flight. However, no reasons for test flight and no results of the test flight were included in the Copterline documentation.

2.10.4 Event on approximately 6 August 2005

The AIB – Finland interviewed a witness (helicopter avionics mechanic) and provided the following information to the Commission. According to witness, the pilot had discussed with him a few days before the accident. The pilot had been concerned about an undetermined fault that had occurred during a flight a few days earlier, apparently on a test flight at level flight or in a slight turn close to the Helsinki / Malmi Airport. The helicopter had abruptly pitched up and the control stick moved aft and jammed. Initially, the pilot had tried forcefully, but had not been able to push the control stick forward. However, the situation lasted for only a very short time before the pilot could move the control stick again and gain control of the helicopter, but the helicopter attitude had changed considerably in that short time frame. The witness and the pilot had discussed the possibilities of a malfunction in the autopilot system or the hydraulic system, as well as a possible mechanical problem.

According to the witness, the pilot further told him that there had been something similar a few days before a scheduled maintenance. The pilot had explained that everything had been checked in scheduled maintenance and the hydraulic system had been test run several times but no faults or malfunctions had been found.

2.10.5 Analysis of FDR data prior to the day of the accident

In the analysis of the FDR data, it was found that there were several occurrences before the accident flight involving the AP and the FD disengagements or mode changes (connect – disconnect) in the 33 hours of data recorded. In view of several technical write-ups involving AP and FD discrepancies and maintenance actions taken in the time period preceding the accident, the recorded AP and FD events prior to the accident were examined.

The available FDR data started on 5 August 2005, and the recorded data was synchronized with the information in the helicopter log books and the maintenance records. No significant discrepancies were found between the FDR data and the activities recorded in the log books. The FDR data period before the accident flight consisted of:

- 18 hours 22 minutes of flight time;
- 9 hours 48 minutes of ground runs; and
- 4 hours 45 minutes of tests without the engines running (maintenance, repair, fault isolation).

The FDR data showed three significant periods of testing when the engines were not running. In the beginning of the data, before a flight on 5 August, there was a 1 hour 51 minute data segment of ground testing, which included several AP and FD systems mode changes. The helicopter log books confirmed that from 28 July to 5 August there were no flights.

The second period of ground testing with the engines not running was a period of 25 minutes on the evening of 5 August or in the morning of 6 August.

The third period of tests, 1 hour 38 minutes, occurred prior to 9 August. Log book page 15 387 showed a repair action on 9 August as *"#2 primary xformer ground wire re-soldered"*. The log book showed that from 5 to 9 August the helicopter had been flown with AP 2 not engaged. From 9 August, both APs and FDs were used again on all flights.

Flight control and actuator servo system tests included a stick jump test, which was to be performed after every engine start. The purpose of the stick jump test was to check, is there any differences in performance of the two hydraulic sides of the actuators. According to the FDR data, stick jump tests had been performed on the helicopter three times during 14 engine starts in the last four days prior to the accident.

Conclusion: Copterline pilots were not performing the stick jump test after every engine start.

2.10.6 Analysis of FDR data from 10 August (prior to the accident)

In the morning of 10 August before the flights, there were tests with the engines running. The FDR data showed 2 minutes 30 seconds of tests with 68 – 80 % main rotor RPM, 3 minutes 5 seconds using 107 % main rotor RPM, 3 minutes 30 seconds using 45 – 50 % main rotor RPM, and over 1 minute again using 107 % main rotor RPM. During these tests, the FDR data showed three SAS Fault indications accompanied with flight control movements (uncommanded, presumably stick jump test performed). The FDR also recorded a 2 minute 30 second AC generator off-line period. In addition, the FDR recorded numerous radio communication keyings during the period of tests.

On the flight preceding the accident, from Helsinki to Tallinn, the FDR recorded Master Caution and SAS Fault Status set without any mode changes in the AP or the FD; however, after two seconds, AP 1 disconnected, the cyclic (longitudinal) position changed from – 15 % to – 5 % in one second, and the normal acceleration momentarily increased from 1.0 G to 1.2 G in one second. The pilot commented to the co-pilot *"oh, a small turbulence"*.

2.11 Company safety culture

Provisions and procedures, at least in writing, were contained in the relevant Copterline company manuals for occurrence / incident / event / defect reporting, quality control and maintenance actions required. However, it was not at all clear whether the company adhered to the standards set forth in the manuals. Furthermore, these procedures did not emphasize the benefits of a proactive approach to safety management, including the fundamentals of a company incident reporting system and effective problem solving based on such reports. Defect reporting in a company in which a positive safety culture was fostered and valued would have been characterized by:

- Employees, pilots and management were encouraged to voice safety concerns and report defects / incidents; and
- When safety concerns were reported, they were analyzed in depth and appropriate action was taken.

More importantly, the procedures did not clearly and definitively outline the role and responsibility of management in managing safety at the company and maintaining a positive safety culture. Particularly illuminating was the picture of a company in which defect reporting and its role in safe operations were not encouraged and taken seriously. Actually, there were indications that defect reporting was not to be done in Copterline, or at least not to be documented in any official logbook.

The Commission's review of the available audit reports from 2004 - 2005 showed that many findings had to be repeatedly addressed by the auditors, and often the Copterline corrective actions were delayed, insufficient or incomplete. The company appeared to be scrambling to piece together paperwork to meet the requirements.

The Commission noted that an examination of the maintenance documentation showed that the results of measurements, which were required by a maintenance instruction, were usually not annotated in the maintenance documentation. If there were several possibilities, the procedure/method used was not indicated in the documentation. Regarding storage control and traceability, part numbers of removed parts or equipment were not always annotated in the documentation. Furthermore, it appeared that occasionally a broken or unserviceable part/equipment was removed from a helicopter and replaced with the part from another helicopter, thus, no records were produced for the storage control system.

Furthermore, the Commission noted that Copterline pilots were not performing the stick jump test after every engine start, as discussed above.

The Commission noted with concern the events described above in the days, weeks and months before the accident, the very limited defect reporting by some pilots in Copterline, and the deficiencies in maintenance described above, including the shortcomings in defect/fault analysis. The Commission believed that the above deficiencies suggested an underlying pressure to continue the flight operation with the helicopter (OH-HCI) without having established that it would be positively safe to do so, in particular after the 26 July 2005 event, which was quite well documented by the pilot. There appeared to be little regard to several indications and events which involved flight control and flight control systems problems as a possible precursor or indication of a serious technical problem with the helicopter in the days and weeks prior to the accident.

Conclusion: All of the above were indicative of the absence of a company safety culture and a firm commitment to safety by Copterline management and many of its personnel.

2.12 Analysis of the weather conditions

The eyewitness who usually could observe the helicopter's flight from his home on the western coast of Viimsi peninsula stated with conviction that the helicopter was not visible at the time when he heard the unusual helicopter sounds (probably the sound created by the rotor blades rather than the engines of the helicopter). He then saw the helicopter emerging from the clouds. When the eyewitness first heard the sounds, the helicopter was probably about 4 km away, i.e. it took about ten seconds for the sound to reach the eyewitness.

The eyewitness's statement that the helicopter emerged from clouds was consistent with the estimated cloud base (approximately 1200 ft) and the comment by the pilot after passing that height to add some power. The flight crew had discussed the avoidance of possible cumulonimbus clouds. It was likely that pilot wanted to add power in order to minimize the time of penetrating the clouds. Pilots usually tried to avoid cumulus clouds that were hidden within stratus clouds.

Although the weather conditions were not conducive to the formation of air columns similar to waterspouts, the investigation commission considered the possibilities of the formation of swirls similar to waterspouts. According to the studies made by meteorologists, there were no possibilities for meteorological conditions which could have caused the upset flight condition. The weather forecast was for only slight showers. Because of the relatively low temperature, there was not enough steam in the air mass, the condensation of which could have produced energy and a higher temperature which would have been required for the vertical formation of clouds in a rising air mass. Also the water surface had low temperature and it did not create temperature contrast, necessary for unstable atmosphere.

At 12:32 hours, approximately at the time the helicopter arrived inbound over Tallinn Bay, the meteorological radar did not show any clouds that could have produced precipitation. A thicker cloud layer with the possibilities of precipitation was over the coastline when the helicopter made the approach to Tallinn. It moved to the Tallinn Bay area while the helicopter was on the ground at the Tallinn Linnahalli heliport. The investigation commission did not obtain any information of strong rain showers or whirlwinds, although the coastal area was densely populated and numerous passenger ferries traversed Tallinn Bay. None of the eyewitnesses reported seeing any kind of weather phenomena that would be consistent with a waterspout.

Furthermore, it was unlikely that an encounter with a waterspout would initiate a master caution for a SAS fault. The SAS fault was consistent with an uncommanded extension of the forward actuator and resistance to the movement of the collective and pitch cyclic controls.

Conclusion: Based on the witness accounts, weather reports and the extensive simulation work, the possibility of a water spout encounter was ruled out.

2.13 Copterline flight planning considerations

The Commission considered it essential to limit the investigation to issues directly or indirectly related to the accident flight. There were a number of issues discussed with AIB Finland, which related to the Copterline flight operations, including the determination of power margin and the route flight time calculation based on a cruising speed equivalent to Vne. High cruising speed resulted in operating conditions which were in the range of a high vibration regime. It was agreed that these issues be separately documented, as necessary, by AIB Finland in its further discussions with CAA Finland and Copterline.

Intentionally blank

3. CONCLUSIONS

3.1 Findings

3.1.1 Helicopter

- The helicopter had a valid Certificate of Airworthiness;
- The helicopter mass and the centre of gravity were within the prescribed limits;
- There were no indication of a malfunction in the helicopter systems or components before the upset flight condition occurred;
- There was no indications of an in-flight or post accident fire;
- Both helicopter engines were operating without interruption and produced the torque required;
- There was no evidence or indication of a separation of any part of the helicopter in flight; and
- There was no evidence or indication of a collision with another object, or a bird strike, in the air.

3.1.2 Main rotor forward actuator

- Testing of the main rotor forward actuator showed that the actuator did not meet the manufacturer's Acceptance Test Procedure (ATP); the retraction of the actuator was much slower than required and in one instance, the actuator failed to retract at all;
- The forward actuator had high internal hydraulic fluid leakage and very low load carrying capability;
- The internal leakage was caused by the wear and deformation of the piston rings; in addition, the system no. 1 piston ring locks were lined up (openings approximately in the same positions on the piston);
- Large pieces of aluminum bronze plasma coating had flaked off the pistons;
- Two large pieces of plasma coating obstructed one (of two) of the return ports in the Pilot Valve of system no. 2; the blockage of one of the two return ports was the source of the slow retraction, and failure to retract at all in one instance, of the forward actuator;
- One large piece of plasma coating was found in the Bypass Valve Return Line of system no. 2;
- In addition to the obstructed Pilot Valve, many pieces of plasma coating were found in the return lines and in the hydraulic filters;
- The design and tolerances of the piston head allowed excessive rework of the piston head; as a result of the excessive rework of the piston head, the plasma coating at the piston head had separated into chips; the chips and resulting

contamination led to excessive piston ring wear, internal leakage and blocked return ports;

- During the rework of the piston head, an over spray of the plasma coating of the piston head lands had not been adequately addressed during design and there were no procedures in place to control the spray of the lands during the plasma coating process; and
- After the accident, rework of the actuator pistons was prohibited in order to eliminate plasma coating separation or to limit the size of plasma chips if the coating did separate.

3.1.3 Computer modeling and performance simulation

- The computer modeling showed that the actuator load capability was reduced from greater than 5000 lb to below 400 – 600 lb with both return ports blocked and high internal leakage;
- The computer modeling of the flight controls showed that, following the initial upset flight condition, the flight controls and the main rotor actuators were not jammed;
- The uncommanded extension of the forward actuator provided a good match of the FDR data; an encounter with a waterspout did not provide a match;
- The uncommanded extension of the forward actuator was consistent with the initial abrupt and unusual movement of the cockpit controls, since the failure can "back drive" the cockpit controls and cause initial movements such as those recorded on the FDR; and
- Testing and simulation showed that the helicopter was responding normally to the actuator motions, although the actuator motions were not normal; the flight performance achieved was consistent within the known capabilities of the simulator and was reasonable when the known capabilities were exceeded.

3.1.4 Flight crew

- The pilot was properly licensed, qualified and medically fit for the flight in accordance with existing regulations;
- The co-pilot was properly licensed, qualified and medically fit for the flight in accordance with existing regulations; and
- The pilot's flight time in the month of July 2005 was 102:15 hours (maximum flight time in any calendar month was 100 hours); his flight time in the previous 30 days was 141:30 hours.

3.1.5 Operator (Copterline)

- Copterline held a valid Air Operator Certificate;
- Copterline had a maintenance management system in accordance with JAR OPS 3, Subpart M, which was approved by FAA-Finland;
- Copterline held a Part 145 maintenance organization approval by CAA-Finland;
- The approved maintenance programme required that the helicopter was to be maintained in accordance with the manufacturer's maintenance procedures;

- Inadequate maintenance and pre-flight practices hindered the discovery of the poorly performing main rotor forward actuator;
- The forward actuator had accumulated 2276 hours; in accordance with the manufacturer's maintenance manual and Copterlines approved maintenance programme, CA-HO-S76, a leakage test had its due-time at 2250 hours; there was no records that the leakage test had been performed, nor were there indication in Copterline documentation that such a test was deferred or planed;.
- The excessive leakage of the forward actuator could have been discovered if Sikorskys maintenance manual had been followed;
- Copterline had not properly included the internal leakage test in its maintenance monitoring programme;
- The hydraulic fluid was contaminated beyond acceptable levels; Copterline maintenance did not find the contaminated hydraulic fluid through routine maintenance practices;
- An actuator internal leakage test and cautious attention to hydraulic fluid patch test should have been sufficient to alert Copterline maintenance to the leaking forward actuator;
- Hydraulic filters had been fairly frequently changed; the Copterline maintenance documentation did not list any specific reasons; there was no evidence that the hydraulic flushing procedure was performed;
- Copterline was not documenting its maintenance actions, as required in its approved maintenance management system (JAR OPS 3, Subpart M) and by its maintenance procedures (Part 145);
- There were witness accounts of irregular events preceding the accidents (15 June, 26 July and approximately 6 August 2005); there were evidence of Copterline maintenance actions and tests, but there were no maintenance documentation describing the actions taken, the test results or test protocols;
- There were indications of the absence of a company safety culture and a firm commitment to safety by Copterline management and many of its personnel; and
- There were indications that defect reporting was not encouraged by Copterline management, or at least was not to be documented in any official logbook.

3.1.6 Flight operations

- In the beginning of the emergency situation, the helicopter abruptly pitched up, rolled and yawed;
- It sustained + 2.9 G normal acceleration;
- It was likely that the upset flight condition at least the first half of the emergency situation took place entirely or at least mostly in clouds (IMC prevailed);
- Without the presence of a visible outside horizon reference and other outside visual cues, the pilots had to rely entirely on the flight instruments, the readability of which in the prevailing circumstances was doubtful;
- Following the upset flight condition, the poor response of the main rotor forward actuator to control inputs rendered the helicopter sluggish to flight control inputs;

- The continuing right pedal input in the presence of high right yaw rates (rotation) was indicative of the presence of spatial disorientation;
- The FDR showed that the helicopter had reached or exceeded the maximum speed (Vne) certificated for the helicopter for a short time period during almost every flight in the five days preceding the accident; and
- The FDR showed that the stick-jump test had been performed only three times during the previous 14 engine starts.

3.1.7 Weather

- The witness accounts that the helicopter emerged from clouds was consistent with an estimated cloud base at 1200 ft, i.e. the upset flight condition likely occurred in IMC at approximately 1400 ft;
- Based on the witness accounts, weather reports and the extensive simulation work, the possibility of a water spout encounter was ruled out;
- There were no possibilities for meteorological conditions which could have caused the upset flight condition; and
- The meteorological conditions (IMC) could be assessed like contributory factor on after initial upset recovery of the helicopter flight.

3.1.8 Survivability

- The helicopter emergency floats were not activated;
- The helicopter impacted the water in a relatively high vertical descent rate, resulting in a varying degree of trauma injuries for all occupants;
- It probably took about ten seconds for the helicopter to fill with water and to sink;
- There remained enough survivable volume for all occupants after impact:
- It was evident that egress actions had been initiated to open the left side cockpit door; however, there was no evidence or indications of attempts to open any other doors in the helicopter;
- The search and rescue operation was activated within two minutes of the accident; however, there were no possibilities to rescue any of the occupants of the helicopter; and
- According to the autopsy reports, the cause of death was drowning for all occupants.

3.1.9 Safety oversight

- A review of the audit reports from 2004 and 2005 showed that many findings had to be repeatedly addressed by the auditors; often Copterline corrective actions were delayed, insufficient or incomplete; Copterline appeared to be scrambling to piece together paperwork to meet the requirements;
- The Copterline maintenance management system, maintenance organization and approved maintenance program were well documented and clear; however, the maintenance practices and the related annotations in the documentation showed frequent deficiencies;

- The flight operations of the Copterline was subject to CAA-Finland restrictions due to violations of regulations. The CAA-Finland found also discrepancies in flight training and in the defect reporting;
- The safety oversight activities of CAA-Finland were not sufficient to reveal the large number of safety deficiencies in Copterline, especially in maintenance. The audit findings did not generate more detailed inspections to all the related areas of the operations, thus leading in non-complete picture of the company's safety culture.

3.2 Causes

The Aircraft Accident Investigation Commission determined that the cause of the accident was the uncommanded extension of the main rotor forward actuator and subsequent loss of control of the helicopter. Contributing to the uncommanded extension and the actuator was the separation of the plasma coating on one of two actuator pistons and the operator's failure to detect the internal leakage of the main rotor forward actuator.

Intentionally blank

4. SAFETY RECOMMENDATIONS

4.1 Interim safety recommendations made in the course of the investigation

4.1.1 On 17 November 2005, the NTSB issued an urgent safety recommendation to the FAA that the FAA "Require Sikorsky S76 helicopter operators to: 1) conduct an immediate internal leakage test of all main rotor actuators with more than 500 hours since new and/or overhaul; 2) conduct subsequent recurring tests at a period not to exceed 500 hours; 3) report the test results to the Federal Aviation Administration and/or Sikorsky; and 4) correct any problems as necessary." (NTSB Safety Recommendation A-05-33 through -35).

4.1.2 On 13 December 2005, Sikorsky Aircraft Corporation issued a letter to all S-76 Operators (Sikorsky Aircraft Corporation CCS-76-AOL-05-2001). This All Operators Letter (AOL) reminded operators that, "Chapter 5-10-00 of the S-76 maintenance manual recommends a leakage test be performed at 2250 hours on part number 76650-09805 series servos in accordance with section 67-15-00, paragraph 2." The AOL further stated, "Should any operator perform a leakage test and find that the servo exceeds the permissible leak rate, please report the instance to your Sikorsky Field Service Representative". The AOL also provided a shipping address for actuators that exceeded the published leakage rate.

4.1.3 On 16 December 2005, the FAA issued a Special Airworthiness Information Bulletin (SAIB) alerting the owners and operators of S-76 series rotorcraft of a possible excessive actuator leakage situation in the main rotor actuators (FAA Special Airworthiness Information Bulletin SW-06-15). The SAIB recommended that operators perform the leakage tests outlined in the Sikorsky AOL.

4.1.4 On 2 May 2006, the FAA issued a Notice of Proposed Rulemaking (NPRM) (FAA Docket No. FAA-2006-24587; Directorate Identifier 2006-SW-05-AD). This NPRM proposed adopting a new airworthiness directive (AD) for Sikorsky Aircraft Corporation (Sikorsky) Model S-76A, B, and C helicopters. This AD would require inspecting all installed HR Textron main rotor actuators for a high rate of leakage and also inspecting for contaminated hydraulic fluid. The AD would also require reducing the time-in-service (TIS) interval for overhauling the actuators.

4.1.5 The NTSB Safety Recommendations A-05-033 through - 035 are classified by NTSB as Open – Acceptable Response.

4.2 Additional safety recommendations

4.2.1 As described in section 2.7 above, the Commission believes that a further study would be required to determine to what extent the possibility of a blockage of the two hydraulic ports, and subsequent maintenance of the flight condition with nearly Vne speed and high vibration conditions, was taken into account in the helicopter design criteria in relation to the relevant FARs. This recommendation is addressed to the FAA, NTSB and Sikorsky.

4.2.2 As described above, the Copterline flight operations, maintenance management system, maintenance organization and approved maintenance program were well documented and clear; however, the actual practices and performed processes showed frequent deficiencies and deviations from the requirements and approved documented procedures. The scheduled route operations with helicopter is relatively rare in Europe. This kind of operation sets more demanding requirements to the operator, especially to small organization.

a) It is recommended that Copterline would perform a detailed evaluation of all areas of its operations and resources to ensure that they will meet the requirements set for safe operations. Also the requirements set by the nature of this operation should be carefully evaluated. Further, the Copterline is recommended to ensure that the shortcomings listed throughout this report are duly taken into account.

b) It is recommended that Copterline ensure the establishment and maintenance of a positive company safety culture, including the encouragement of incident and defect reporting, analysis of reported safety concerns, initiation of safety actions as appropriate, and the introduction of relevant safety culture training (as included in safety management system training); and

c) It is recommended that CAA-Finland would ensure that operations of all companies under its supervision would be evaluated thoroughly enough in order to form a complete picture of the safety of the operations. CAA-Finland should ensure that it has the required resources and knowledge to be able to fulfill its supervisory role and also to guide operators to develop acceptable level of safety. The CAA-Finland should also ensure that it has proper procedures in place to intervene, if necessary, to the operations of company when there is enough evidence of safety deficiencies.

4.2.3 It is recommended that FAA and EASA will introduce the means requiring fitting helicopters operating on regular passenger flights with floats automatically inflating in contact with water.

4.2.4 Commission also recommends that FAA or EASA will introduce a requirement for deployable ELT for helicopters operating on passenger flights over water.

4.2.5 To aid flight safety and also accident investigation, the Commission recommends that the FAA and EASA implement the use of crash-protected cockpit image system on helicopter operations that carry passengers for hire.

The Aircraft Accident Investigation Commission:

Taivo Kivistik

Tõnu Ader

Oleg Harlamov

Mati Iila

Jaanus Ojamets

Toomas Kasemaa

Tiit Kaurla

Aleksander Dintšenko