CANADIAN FORCES
FLIGHT SAFETY INVESTIGATION (FSI) REPORT (FSIR)

FINAL REPORT

FILE NUMBER:	1010-12401 (DFS 2-4-2)
DATE OF REPORT:	27 Sep 04
AIRCRAFT TYPE:	CH124A Sea King
DATE/TIME:	27 1403Z/1103 R (Local) Feb 03
LOCATION:	HMCS IROQUOIS, 41 36N 051 39W (540 NM ESE Halifax)
CATEGORY:	"A" Category Accident

This report was produced under authority of the Minister of National Defence (MND) pursuant to section 4.2 of the Aeronautics Act, and in accordance with the A-GA-135-001/AA-001, Flight Safety for the Canadian Forces.

With the exception of Part 1 – Factual Information, the contents of this report shall be used for no other purpose than accident prevention. This report was released to the public under the authority of the Director of Flight Safety, National Defence Headquarters, pursuant to powers delegated to him by the MND as the Airworthiness Investigative Authority (AIA) of the Canadian Forces.

SYNOPSIS

The occurrence crew intended to conduct a deck-landing and C-6 gun training mission, flying from HMCS IROQUOIS. During the start sequence, IROQUOIS conducted a Replenishment At Sea (RAS) with HMCS PRESERVER. After approximately 45 minutes since first starting, and once the RAS was completed, the helicopter took off from the IROQUOIS' flight deck. The aircraft rose to the high hover position and then, after moving slightly aft over the flight deck, it sufferred a loss of lift, descended, contacted the flight deck heavily, and rolled over on its right side. The aircrew secured the engines and egressed from the aircraft. IROQUOIS came to Emergency Flying Stations and commenced damage control procedures, including control of aircraft fuel leaking on to the flight deck and into some of the ship's compartments. The aircraft wreckage was secured to the flight deck for transit back to Halifax. Two aircrew and one ground crew member received minor injuries.

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1. FACTUAL INFORMATION

GENERAL

The crew of Sea King helicopter CH12401 experienced a loss of lift while in a high hover over the flight deck of HMCS IROQUOIS. Unable to maintain altitude in the hover, the aircraft descended rapidly, contacted the flight deck, and rolled over after the right sponson collapsed. The helicopter was crewed by four personnel: the pilot, who was also appointed as the Maritime Helicopter Crew Commander; the co-pilot; the tactical co-ordinator (TACCO); and the airborne electronic sensor operator (AESOP).

1.1 History of the Flight

HMCS IROQUOIS, in company with HMCS PRESERVER, was conducting scheduled Work Ups while in transit to the Arabian Gulf in support of OPERATION APOLLO. The evening before the flight, the ship advanced clocks from midnight to 0100 hrs and then immediately practiced an emergency fire drill. This fire drill required the entire ship's company to be awake and active, and was completed approximately one hour later. Because the emergency fire drill had disturbed the aircrew rest schedule, the Helicopter Air Detachment (HELAIRDET) Commander cancelled the scheduled 0800 flight and allowed the next scheduled flight at 1045 to proceed.

On the morning of the flight, IROQUOIS received supplies from PRESERVER via "replenishment at sea" (RAS). This sequence required IROQUOIS to sail alongside PRESERVER's port beam for an extended period while the transfer of stores and liquids was conducted. The manoeuvre was scheduled to end prior to the 1045 launch.

The aim of the occurrence flight was to complete deck landing practice (DLP) training for the co-pilot; C-6 machine gun training for the crew's TACCO and AESOP as well as the non-occurrence crew's AESOP; and hoist training. It was intended that the aircraft recover on IROQUOIS after the DDL training in order to take on the second AESOP.

The crew briefed at 0930 and prepared for their sortie. The ship then came to Flying Stations as scheduled at 1015. While the RAS continued, the aircraft was traversed on deck at 1022 where it remained secured on deck until launch. At 1026 the co-pilot, who was in the right seat, started the number one engine, which was noted to be slow to start. The pilots indicated that this slow start with the number one engine had previously occurred on several occasions. During initial engine start, the main transmission gearbox pressure was noted to be approximately 120 PSI, which was above the normal range, but within limits for this stage of the start. The aircrew reported that this had occurred several times during this deployment; nonetheless, main transmission gearbox (MGB) pressure soon returned to the normal pressure range.

During the main rotor blade and tail pylon spread sequence at 1028, it was noted by the Landing Safety Officer (LSO) and the occurrence pilots that a wave, commonly described as a “greeny”, generated by IROQUOIS’s close proximity to PRESERVER, crested the starboard side of the flight deck and struck the aircraft fuselage. It was also noted that heavy sea spray was reaching the flight deck environment. Discussion occurred between the LSO, Sea Training Staff Air Officer (STS AirO), and STS Commanding Officer about wind conditions and the proximity of PRESERVER to IROQUOIS. The wind conditions at the time were 310ºT at 15 kts, flying course of 265ºT at 12 kts, and relative winds of Green 30º at 25 kts (one o’clock at 25 kts). Once spread, the tail and main rotor blades were observed by the aircrew to flap significantly in the wind over the flight deck.

At 1040 the number two engine was started and the main rotors were engaged. Shortly thereafter another larger wave crested the starboard side of the flight deck and again struck the aircraft fuselage. It was reported by hangar personnel that a momentary change in rotor RPM sound coincided with this wave striking the aircraft. Both pilots noted salt water on the cabin roof windows in the vicinity of the engine intakes; however, no abnormal cockpit indications were noted. The pilot then discussed his concern with the LSO about remaining on deck with the possibility of exposure to subsequent waves. During this conversation, based on a check of operating temperatures and pressures and an estimation of the amount of water seen by the pilots, the crew decided not to shut down and conduct an engine water wash.

At 1044 the pilot requested an immediate take off to leave the saltwater-laden environment. After discussion between the LSO, STS AirO and the HELAIRDET Commander, it was concluded that the aircraft would not launch under the existing wind conditions because the proximity of PRESERVER obstructed the departure flight path. The aircraft continued to take sea spray until IROQUOIS parted from PRESERVER.

With the RAS complete by approximately 1045, IROQUOIS began to turn to port to open from PRESERVER in order to reposition for a flying course that would provide better relative winds across the flight deck. The ship opened heading at 5º increments to minimize roll and wash across the flight deck. Due to sea conditions, the ship took two 15º rolls during manoeuvring. At some point post-breakaway, the pilot heard a slight buzzing sound like a piece of metal vibrating and asked the TACCO and AESOP to conduct a cabin check. The cabin check revealed nothing and the TACCO assessed that the noise heard by the pilot to be electro-magnetic interference on the aircraft’s intercom system (ICS). IROQUOIS then established itself on a flying course of 265ºT at 12 kts, with a wind of 290ºT at 19 kts, and a relative wind of Green 15º at 30 kts.

Final preparations were made for the aircraft and crew to launch with approximately 19,750 pounds all-up weight, 750 pounds below maximum. The pre-take-off check was completed and, although it was confirmed that the speed selector levers (SSLs) were at their full travel with their frictions applied, they were not guarded by the co-pilot's hands. With the pilot in control in the left seat, the aircraft then conducted a no-radio (Ziplip) take-off to the high hover. The co-pilot made a quick scan of the engine instruments and noted all temperature and pressure needles pointing up and no abnormal triple tachometer indications - all normal conditions. The co-pilot then began to provide the pilot with positional information relative to the flight deck markings (bum positioning line).

As the pilot acquired his visual references in the high hover, the aircraft drifted slightly forward. The co-pilot then provided the pilot with directional information to correct the drift. Before the co-pilot could conduct a detailed scan of engine and main gearbox temperatures and pressures, the aircraft's nose came up slightly and the aircraft moved aft and drifted left as the pilot reacted to the co-pilot's positional advisory. The TACCO then heard a loud popping or thumping noise that he described as being similar to an in-flight compressor stall that he experienced in Sep 00. The AESOP heard an intermittent noise that was different from the normal pitch and whine of the aircraft in the hover. Meanwhile, the Lifebuoy Sentry, who was stationed underneath the Flight Deck overhang of the Quarterdeck, reported hearing a machine gun-like sound. At this time, HELAIRDET personnel inside the hanger also reported hearing an unusual sound that came from the aircraft. The pilot felt the aircraft settle as observers saw it drift slightly left. The pilot then heard three beeps of the low rotor warning tone and instinctively lowered collective somewhat to preserve rotor speed (Nr). Prior to contacting the flight deck, the pilot believed that he applied full collective in an effort to cushion the landing.

After approximately 5-10 seconds in the hover and while it continued to move aft, the aircraft descended rapidly in a slightly nose-up attitude and was then seen to contact the flight deck tail wheel first at the extreme aft end of the flight deck. As the main rotor blades flexed downwards from impact forces, the main rotor tip path struck and severed the tail pylon. The nose then pitched forward forcing the main landing gear to the flight deck with the right main landing gear striking the flight deck before the left main gear. The aircraft bounced on its landing gear and then started to lean over to its right side as the right sponson began to detach from the fuselage. Personnel in the hangar took cover within its forward end and behind the main funnel uptakes.

As the aircraft tipped over on its right side, the main rotor blades contacted the flight deck, the starboard flight deck access ladder, and the aft section of the starboard flight deck netting. The aircraft leaned progressively further and further to the right, eventually coming to rest completely on its right side with the engines still driving the main rotor head. As the main rotor blades turned, they pulled the aircraft closer to the starboard edge of the flight deck, disintegrating along their full length in the process. The TACCO and AESOP braced against the motion while the pilot attempted to reach the SSLs in order to move them to the shut off position. Due to the violent shaking, it took considerable effort and numerous attempts before he could reach the SSLs and shut down the engines. Once the engines were shut down, the violent aircraft motion ceased. The right sponson had separated from the aircraft and came to rest on the starboard side of the flight deck. The tail section was severed from the airframe at the tail pylon hinge point, coming to rest on the Nulka missile launcher on the quarterdeck. The crash position indicator (CPI) activated. On hearing this signal, the pilot turned the aircraft main battery switch off so that the aircrew could hear each other inside the aircraft. Considerable debris was scattered about on the flight deck, the quarterdeck, and the starboard breezeway.

As the aircraft initially contacted the flight deck and rotor blades contacted the starboard access ladder, the STS AirO jumped down from the LSO Howdah and ran forward in the ship. After ducking down behind the Howdah console, the HELAIRDET LSO and the Flying Co-ordinator (FLYCO, a firefighter) initiated crash-on-deck procedures. The Lifebuoy Sentry, immediately upon seeing aircraft debris falling about him, proceeded forward along the starboard breezeway to seek shelter within the ship’s structure. IROQUOIS immediately came to Emergency Flying Stations to initiate damage control procedures.

After the aircraft came to rest, the crew began to egress the aircraft. The TACCO was the first to exit the aircraft and did so via the upper personnel window. Once on the ground, he indicated to the LSO that four crewmembers were alive in the aircraft. The pilot egressed via his window and used the sea anchor to climb down to the flight deck. The AESOP, who next climbed out through the upper personnel window, waited until the co-pilot had un-strapped and climbed out via the pilot’s window before both climbed down from the aircraft’s side. The co-pilot hurt his right knee upon reaching the flight deck and the TACCO hurt his thumb. All crew members were shaken by the occurrence with the co-pilot reporting that he lost awareness from the time of initial flight deck contact to the time the engines were shut down. The four crewmembers then made their way forward into the hangar where they were attended to by the ship’s Casualty Clearing Team. There was no post-crash fire. Fuel immediately began to leak from the aircraft on to the flight deck and into some ship’s compartments.

The STS Fire Fighter, who was standing in the aft end of the Hangar suffered direct trauma to his left hand as a result of aircraft debris penetrating the hangar door.

In initiating damage control actions, FLYCO attempted to activate the hangar Twin Agent Unit (TAU) and the hangar aqueous film forming foam (AFFF) system. After the primary and secondary TAU activation systems failed to initiate, the TAU hose was left on the hangar floor. It subsequently discharged and temporarily obscured everything within the hangar confines. The hangar AFFF system also failed to activate after three attempts by FLYCO; the final switch position of this system was “OFF.” As a result, the hangar saltwater hoses were then set up using inductors and cans of AFFF to foam the flight deck and aircraft. Firefighters proceeded to the flight deck through the port and starboard personnel access doors.

The 7.62 mm ammunition and smoke markers from the aircraft were jettisoned overboard and a HAZMAT team assessed the flight deck to be safe from possible radioactive material found in the Internal Blade Integrity System (IBIS).

By 1144, CH12401 was lashed secure to the flight deck and HMCS IROQUOIS secured from emergency flying stations.

1.2 Injuries to Personnel

Table 1: Injuries to Personnel

Injuries	**Crew**	**Passengers**	**Others**
Fatal	0	0	0
Serious	0	0	0
Minor	2	0	1

1.3 Damage to Aircraft

The right sponson collapsed on impact and completely detached from its mounts. All five main rotor blades sheared off at the blade root due to rotational forces on contact with the flight deck. The tail rotor blades were severely damaged. The radome just aft of the main rotor transmission housing was crushed by rotor blade contact and the tail boom was severed at the pylon hinge by rotor blade contact. The number two engine suffered external impact damage to the oil tank, outer combustion case, and other components. Considerable skin rippling and crush damage on the starboard side of the aircraft occurred as a result of aircraft rollover.

The initial assessment of aircraft damage is "A" category (Photo 1).

1.4 Collateral Damage

No significant structural damage to IROQUOIS was incurred as a result of this accident. Superficial damage from main rotor blade and shrapnel impact was inflicted on the starboard flight deck netting, starboard flight deck ladder, aft flight deck guardrail, hangar face doors, LSO Howdah, and the quarterdeck crane. The quarterdeck Nulka expendable rocket-launched hovering decoy system also received minor damage and required replacement.

1.5 Personnel Information

Table 2: Personnel Information

	Pilot	**Co-pilot**	**TACCO**	**AESOP**	**LSO**
Rank	CAPT	CAPT	CAPT	MCPL	CAPT
Age	29	35	32	30	34
Category valid	YES	YES	YES	YES	YES
Medical Category valid	YES	YES	YES	YES	YES
Total flying time	1696	396	364	897	2800
Hours on type	1397	177	157	862	1700
Hours last 30 days	10	13	9	14	11
Currency requirements valid	YES	YES	YES	YES	YES
Duty time - Day of incident	2.3	2.3	3.0	3.0	2.0
Hours sleep - Previous night	8 (interrupted)	6.5 (interrupted)	8 (interrupted)	8 (interrupted)	8 (interrupted)

The pilot last conducted single-engine (SE) hover operations training in Sep 02. Although he did receive SE training during his Operational Training Squadron (OTS) syllabus in 1998 and maintained SE currency until Jun 02, his SE currency had lapsed at the time of accident. The co-pilot had been given a cursory introduction to SE hover landing training in the Sea King during his first few OTS flights.

With the replacement of the T58-GE-8F engine by the T58-GE-100 engine, the possibility of MGB over-torques was identified during the engine upgrade integration assessment and SE training from the hover was subsequently forbidden. As a result, routine SE operations training has been extremely limited, effectively non-existent, since late 2001. However, despite this lack of viable SE training, pilot currency requirements still included the practice of (SE) training, including landings from the hover. As a result, no MH pilots had been able to maintain this currency requirement.

1.6 Aircraft Information

CH12401 embarked HMCS IROQUOIS on 24 Feb 03. As the CH-124 Mark III Sea King standard fleet upgrade was complete prior to this accident, the aircraft was equipped with General Electric T58-GE-100 engines and a 24000 series MGB (the newly upgraded versions of both). CH12401 was a “B” model that was configured for passive Anti-Submarine Warfare. It was declared fully serviceable at the time of embarkation and when it launched for the final flight.

The only noteworthy items with respect to aircraft operation noticed by aircrew were the slow-starting number one engine and a higher than normal MGB pressure of 120 PSI also during start of number one engine.

1.7 Meteorological Information

The meteorological observations taken from HMCS IROQUOIS were:

METAR: 271230Z E 15 BKN 12 SM 30026KT 01/-01
Density Altitude: -1868' (minus)
Pressure Altitude: -135' (minus)
TAF: 271230Z valid 271301Z 30025KT P6SM BKN015 OVC030 TEMPO 1418 2SM -SHSN/-SHRA OVC010

Weather information passed to Ship Air Controller:

METAR: 271315Z M 16 BKN 32020KT 12 SM 01/00 A3009
Sea State: North West 2-3 Meters
Ship's Motion: Pitch ?2?, Roll ?8-12?
Sea Surface Temperature: +14ºC

Winds passed to crew:

Flying course: 265ºT at 12 kts
True wind: 290ºT at 19 kts
Relative wind: Green 15º at 30 kts
Headwind component: 29 kts (30xCOS15º)
Altimeter: 30.06" Hg

1.8 Aids to Navigation

N/A.

1.9 Communications

Prior to any launch, communications between the aircraft, the LSO, FLYCO, and the Bridge are via the ship's ICS. Additionally, hand signals and the flight deck hangar-face trafficator lights are used to assist these communications. The accident aircraft was preparing to conduct the launch under reduced Emission Control (EMCON) policies (Ziplip launch). Ziplip launch procedures require the aircraft to maintain radio silence while the LSO utilizes the trafficator lights to provide the required communications. Ziplip procedures do not preclude radio use to identify, declare, or resolve an emergency or hazardous condition.

There were no distress calls made by the aircraft prior to the crash on deck. The LSO transmitted "CRASH ON DECK" via the ship's ICS to alert FLYCO, the Ship's Airborne Controller (SAC), the Bridge, and the Operations Room. FLYCO sounded the ship's crash on deck alarm.

1.10 Aerodrome Information

1.10.1 Flying Operations

HMCS IROQUOIS is a Guided Missile Area Air Defence Destroyer (DDH) from the 280 IROQUOIS Class. It has a hangar and flight deck located just aft of amidships. The ship has hangar capacity for two CH124 aircraft; however, it can only launch and recover one helicopter at a time. The ship is fitted with a Helicopter Hauldown and Rapid Securing Device (HHRSD) and Recovery Assist, Securing and Traversing (RAST) system. Collectively these systems are commonly referred to as "the bear trap."

To prepare for take-off, the aircraft is first traversed onto the flight deck from its respective hangar via the Rapid Securing Device (RSD). Then the number one engine is started, the main rotor blades are spread into the flight position, and functional checks are conducted. Next, the number two engine is started and the main rotor is engaged. Pre-taxi and pre-take-off checks are then completed prior to being ready to launch.

Deck landings must be made from a hover with or without the Helicopter Hauldown system, depending on deck motion. Generally, all landings are made into the RSD. Once on deck, the aircraft is secured to the deck via the RSD or with chocks and chains. Once the aircraft is shutdown, the RSD and flight deck tail guide winches are used to position the aircraft for traverse into the hangar.

Flying operations on the flight deck are controlled by the LSO from the Howdah position. The Howdah is a small cut out position in the forward starboard flight deck area. FLYCO controls flight deck fire/rescue operations from a control room that is elevated above the flight deck in the aft port hangar section.

"Relative winds" over the flight deck are defined as either red, meaning coming from the port side of the ship, or green, meaning coming from the starboard side of the ship. With red winds, departure and approach to the flight deck are made over the port side with the right seat pilot at the controls; with green winds, departure and approach to the flight deck are made over the starboard side with the left seat pilot at the controls.

It is routine procedure for destroyers and frigates to come alongside PROTECTEUR Class auxiliary oil and replenishments (AOR) ships, such as HMCS PRESERVER, to conduct RAS evolutions. The venturi effect, created by the close proximity of the two ships to one another, can commonly generate choppy seas and sea spray that often impinge on the flight deck environment.

The IROQUOIS Class destroyers conduct RAS evolutions on their starboard side, the PROTECTEUR Class's port side.

1.10.2 Damage Control and Firefighting

Hangar firefighting equipment consists of many systems. A ship-fitted system, the light water system, supplies pre-mixed AFFF to numerous fire hoses, hangar sprinklers, and the flight deck HHRSD tracking. The TAU system supplies a dry chemical fire extinguishant to one hangar hose. Both these systems can be remotely activated at the FLYCO position, at a secondary hangar location, and at other locations throughout the ship. Additionally, there are many saltwater hoses and portable hand-held fire extinguishers situated around the hangar and quarterdeck areas.

1.11 Flight Recorders

The aircraft was equipped with neither a cockpit voice or flight data recorder (CVR/FDR). This lack of onboard recording devices hindered the determination of the cause of the power loss.

All Canadian Naval ships with flight decks are equipped with flight deck video cameras and video recording devices. Because IROQUOIS' flight deck video recorder was unserviceable, the accident was not recorded.

1.12 Wreckage and Impact Information

The main airframe body came to rest on its right side on the aft end of the flight deck with the right seat pilot's window coming to rest on the starboard HHRSD. The main rotor blades were destroyed after contact with the flight deck, flight deck netting, and the starboard flight deck access ladder; only the blade roots remained attached to the main rotor hub. The right sponson and main landing gear assembly detached from the aircraft and came to rest to the right of the aircraft. The tail pylon was completely severed from the airframe body at its hinge point and came to rest on the quarterdeck-mounted Nulka rocket launcher. The tail rotor blades were severely damaged. The aircraft's interior suffered from extreme violent shaking and resulted in the pilots' instrument console partially detaching from its mounting in the cockpit. The rest of the interior was strewn with debris from aircraft insulation and mission equipment.

Extensive main rotor blade strike marks were noted on the aft starboard end of the flight deck surface. The flight deck, quarterdeck, and starboard breezeway areas were extensively covered in shrapnel.

1.13 Medical

The ship's Casualty Clearing Team immediately tended to the four aircrew members. The aircrew provided toxicological samples to the ship's Medical Officer for analysis. The blood and urine samples of all four crewmembers were sent to the Armed Forces Institute of Pathology in Washington, D.C. for analysis. Results were normal for all tested factors.

One member of the Sea Training Staff was also immediately tended to by the CCT for blunt trauma injuries to the left hand suffered from shrapnel penetration of the hangar environment.

1.14 Fire, Explosives Devices, and Munitions

At the time of incident, the aircraft was armed with 13 sonobuoys, 6 C2A1 smoke markers, and 10 boxes of 7.62 mm C-6 ammunition. Once armed, smoke markers and sonobuoys are salt-water activated. Although equipped with a self-defence suite, no chaff or flares were onboard.

There was no post-crash fire or detonation of munitions.

1.15 Survival Aspects

1.15.1 Crash Survivability

The crash was survivable. The cockpit maintained its survivable volume and was undamaged. The deceleration forces were within the tolerance level of the human body. All four crewmembers successfully egressed through either the upper personnel door or cockpit window, located on the aircraft's left side.

1.15.2 Life Support Equipment

The crewmembers' four-point harness system functioned as intended; this likely prevented further injury from occurring. Although the TACCO reported that his inertia reel functioned as intended, initial post-accident examination determined that the automatic lock test failed.

Due to the environmental conditions, the crew were wearing immersion suits. These suits are made of GORETEX material and utilize rubber neck and wrist seals. The wearing of these suits did not hinder the aircraft egress.

1.15.3 Emergency Transmitters

The AN/URT 506 (V) Crash Position Indicator (CPI) was activated on impact. Activation is through one of the following methods: hydrostatic activated switch, frangible switch, in-flight deployment, or cockpit switch. Post-crash, the CPI remained in place in its airframe mounting and commenced transmitting its signal. The pilot confirmed its operation post-crash and that no aircrew member initiated its activation. An aviation Emergency Locator Transmitter (ELT) is also carried on board. It is standard for the ELT to remain in the unarmed position until required as a backup to the CPI.

1.16 Test and Research Activities

The following items were sent to Quality Engineering and Test Establishment (QETE):

a. Airframe fuel filters, engine centrifugal fuel purifiers, and engine fuel control unit (FCU) fuel filters;

b. MGB and engine oil filters;

c. the right hand sponson assembly including airframe attachment points;

d. aircraft fuel, hydraulic fluid, engine oil, and main, intermediate and tail gearbox oil samples;

e. IROQUOIS' HELAIRDET aviation hydraulic fluid, engine oil, and transmission oil samples;

f. IROQUOIS' HELAIRDET aviation engine water/glycol wash sample; and

g. the TACCO's inertia reel.

A special inspection was conducted to evaluate the engine's SSL friction locks and the torque indicating system with respect to the phenomenon commonly referred to as Sudden Un-commanded Transient Loss of Torque (SUTLOT).

The main transmission gearbox, complete with freewheeling units (FWU), was sent to Spar Aerospace, Toronto, and both number one and number two engines were sent to ACRO Aerospace, Vancouver, for testing and analysis.

Both engine FCU's and flow dividers were sent to Columbia Industries, Portland, Oregon, for bench checks.

Aviation fuel samples from IROQUOIS and PRESERVER were sent for analysis to Defence Research and Development Canada (DRDC), Halifax, for analysis.

Technical investigations into the failure of both the TAU and hangar AFFF systems were conducted by Fleet Maintenance Facility (FMF) Cape Scott.

1.17 Organisational and Management Information

The occurrence aircraft and crew were from 12 Wing, 423 (MH) Squadron, Shearwater, NS. They embarked HMCS IROQUOIS and were in transit to the Persian Gulf in support of OPERATION APOLLO.

1.18 Additional Information

The ship's company and the aircrew involved in the accident had a significant amount of time to discuss events prior to the commencement of the Flight Safety Investigation. As a result, there was a significant amount of witness evidence contamination.

1.19 Useful or Effective Investigation Techniques

The GE-T58-100 engine is not fitted with borescope access points; this prevented any on-site inspection of internal engine components. Early indication of engine integrity would have aided the investigation.

2. ANALYSIS

2.1 General

The aircraft suffered a loss of lift while in the hover over the flight deck. Aircrew error was not identified as causal in the precipitation of this accident . The investigation therefore focussed on any possible environmental and technical factors, including the recently identified phenomenon of Sudden Un-commanded Transient Loss of Torque (SUTLOT), for the loss of this aircraft.

Although a DAEPM(M) initiative has been established to address this deficiency, it is worthy to note that CH-124 aircraft are currently not fitted with flight data recorders (FDR) or cockpit voice recorders (CVR). Had the aircraft been equipped with FDR/CVR equipment, the data would have significantly benefited the investigation by allowing the Investigation Team to quickly focus on the main problem area. Due to a lack of hard data, the team had to develop theories as to the accident's cause and then conduct a detailed analysis of each one to determine its plausibility. This process of elimination was very time consuming.

2.2 The Aircraft

2.2.1 General

Examination of all aircraft records revealed no anomalies with aircraft configuration, maintenance, or maintenance records. The aircraft was deemed to be serviceable on the day of the accident.

2.2.2 Right Hand Sponson Assembly

The right hand sponson assembly and associated airframe attachment mounts were analysed by QETE. Fractography indicated that no signs of corrosion or fatigue were evident on any components of the sponson assembly or airframe sponson attachment mounts. The fracture surfaces were indicative of typical component failure in overload conditions.

At the time of accident, IROQUOIS' pitch and roll were approximately ?2? and ?8-12? respectively. Because this was the first flight of the day and the helicopter hauldown had not yet been used, heave data from the ship's pitching motion had not yet been recorded that day. Although the ship's exact motion could not be determined at the time of impact, it is known that any ship's motion is a continuous dynamic event that is largely unpredictable. Shipboard take-offs and landings only occur during the momentary stable (quiescent) period of that ship's motion cycle. The accident aircraft was cleared for take-off during this quiescent period. Given that this period is short in duration and that once in the hover the quiescent period likely had ended, it can be said that the combination of sea state and ship's motion likely resulted in an unstable platform on which to land. Because the pilot had to land immediately and did not have the option of waiting for the stable deck period, it can be theorized that the impact of a heaving flight deck colliding with a descending aircraft could have dramatically increased vertical impact forces. Additionally, the rolling motion of the ship coupled with a possible non-level aircraft attitude could have exerted similar forces on the aircraft in the lateral plane. As a result, it is likely that the heaving and rolling flight deck motion combined with the downward and lateral vectors of the aircraft's motion adversely affected the structural integrity of the aircraft; this resulted in the right hand sponson separating under extreme loading conditions. This assessment, coupled with the technical findings, leads to the conclusion that the right-hand sponson collapsed entirely due to component overload forces generated by impact forces.

2.2.3 Fluids

Analysis of aircraft engine oil, MGB oil, hydraulic systems oil, and fuel determined that these fluids were within tolerance for all parameters and therefore suitable for aviation use.

Analysis of IROQUOIS's supply of aircraft engine oil, MGB oil, hydraulic systems oil, fuel, and engine wash fluid determined that these fluids were within tolerance for all parameters and therefore suitable for aviation use.

Analysis of PRESERVER's supply of aircraft fuel determined it to be within tolerance for all parameters and therefore suitable for aviation use.

2.2.4 MGB

SPAR Aerospace conducted a teardown analysis of MGB serial C-13, which was installed and flew for 711.1 hours on CH12401. The MGB TSO was also 711.1 hours. Inspection revealed considerable damage to the main rotor head attributable to flight deck contact. While the MGB showed no signs of external damage, internal damage was evident and also attributed to impact forces.

Due to a previous Sea King accident in 1996 in which it was thought that "freewheeling unit spit-out" may have occurred, particular attention was given to the freewheeling units associated with both engine input shafts. Analysis determined that normal wear patterns were evident and that no signs of FWU slippage, skidding, or spit-out was noted. Additionally, FWU component measurements revealed no dimensional anomalies from design specifications.

The MGB was also examined for signs of taper roller bearing wear, which has recently affected the 24000 Series MGB. No sign of this breakdown was evident in the accident MGB.

Based on these observations, it is believed that the MGB was operating correctly at the time of impact and did not contribute to the loss of lift experienced by the aircrew.

2.2.5 Torque Transmitting System and SUTLOT

2.2.5.1 General

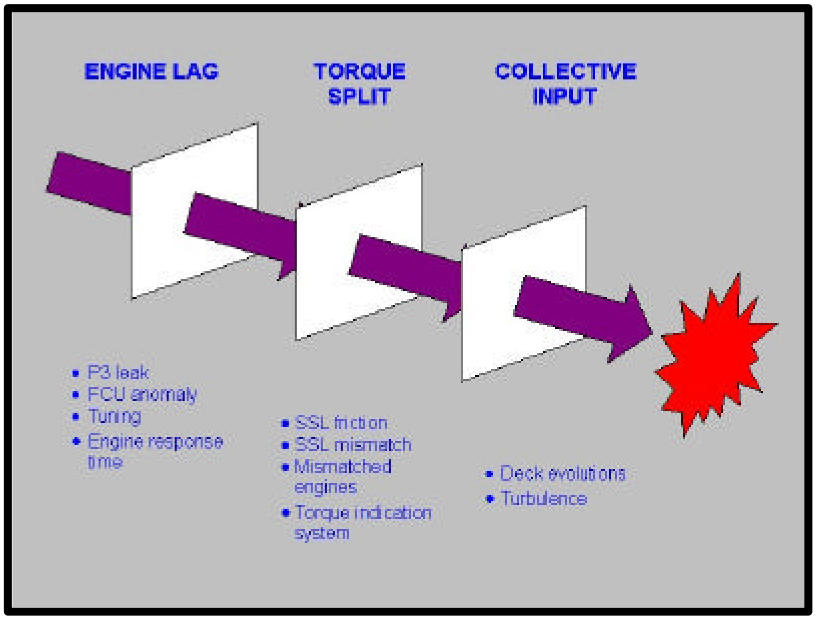
The term Sudden Un-commanded Transient Loss of Torque is used to define the cause of two Sea King occurrences (CH12434, 24 Sep 03; CH12410, 27 Oct 03) that were similar in nature to that of CH12401's loss of lift. The exhaustive technical investigation into the SUTLOT occurrences was the largest, most time consuming ever in the life of the fleet. While this investigation was under way, significant restrictions to Sea King flight operations were imposed. As the SUTLOT investigation neared its conclusion, it became evident that CH12401's accident must be looked at in light of this phenomenon.

The following discussion is not all-inclusive of the particulars to the SUTLOT phenomenon. Annex D: SUTLOT Executive Summary, provides the basic background information on this loss of torque phenomenon. This annex summarizes the findings in DAEPM(M) 11500ED-80 SUTLOT Technical Findings Report dated 26 Feb 04. The complete report identifies in detail the processes involved in the technical investigation and its subsequent recommendations; these recommendations will be actioned outside of this FSIR.

2.2.5.2 Pre-requisites for SUTLOT

SUTLOT can be summarized as the specific combination of several pre-conditions that, when combined with certain technical anomalies, created a load-sharing imbalance that allowed an un-commanded loss of torque to manifest itself, as in the case of CH12434, in a loss of lift. The conclusion of the SUTLOT technical investigation identified the following pre-requisites in Figure 1: SUTLOT Pre-conditions, in order for a SUTLOT occurrence to take place:

Figure 1: SUTLOT Pre-conditions



2.2.5.3 SUTLOT and Its Applicability to CH12401

Of the Reason's Model representation of the SUTLOT pre-conditions identified in Figure 1, not all of the components were applicable to CH12401. The following breakdown of SUTLOT pre-conditions identifies if applicability to CH12401 existed and provides a brief explanation of the pre-condition itself:

a. Engine Lag

(1) P3 Leak/Fuel Control Unit (FCU) Anomaly: NO. These anomalies could contribute to decreased engine acceleration times. No engine sub-component anomalies were noted during post-accident analysis of CH12401: P3 pressure lines and the FCUs, including throttle valve positions, were all bench tested serviceable;

(2) T58-GE-100 Engine Tuning: UNKNOWN. The number one engine tuning was found to be out of limits, as defined in the Canadian Forces Technical Orders (CFTOs), towards the decelerative stall boundary as discussed in 2.2.6.2. The SUTLOT technical investigation could not determine what impact this may or may not have had on SUTLOT susceptibility; and

(3) Engine Response Time: UNKOWN. The serviceable range of engine acceleration from 56-90% Ng is from 2-8 seconds. When two engines with large (2 seconds or more) differences in acceleration times are paired together, the possibility exists during a rapid onset of power demand (such as taking-off or waving-off from landing) for the faster accelerating engine to momentarily assume all of the load and increase its Nf by 2-3% over the other engine. This can cause the slower accelerating engine to decouple and momentarily freewheel. However, with the exception of a freewheel unit failure, this "induced freewheel effect" cannot occur when both engines are load-sharing at high power settings such as once in the hover.

CH12401's number one engine's acceleration time of 3.8 seconds was within CFTO limits. Due to accident damage, the number two engine could not be run, leaving the true value of its acceleration time unknown. As a result, the most recent repair and overhaul acceleration times for both engines were used for comparative purposes: 3.6 seconds for the number one engine (TSO 62.7 hours) and 2.9 seconds for the number two engine (TSO 89.3 hours). Given the established 600 hour engine overhaul cycle, the low TSO values of both engines, and the serviceable acceleration times of both engines during recent overhaul, it is believed that both engines were probably closely matched with one another. It therefore seems unlikely that mismatched engine acceleration times affected CH12401; however, this can't be stated with certainty and therefore the overall effect of mismatched engine response times is unknown.

b. Torque Split

The potential causes of torque (Q) splits are all closely inter-related. It must be noted, though, that both aircraft involved in the two confirmed SUTLOT occurrences had a history of Q splits and had difficulty with matching Q's. CH12401 had no such history.

(1) SSL Mismatch: UNKNOWN. SSL mismatch occurs when, although the SSLs are correctly used to match the Q indicators, one engine's Nf datum is set higher than the other's. During a shift from decelerative to accelerative power demands, this difference in Nf datums can cause the induced freewheel effect to occur. There are three causes of SSL mismatch as described below. Although the Q indicators were matched at approximately 18-20% while at flat pitch just prior to take-off, it could not be determined to what extent, if any, CH12401 had been affected by different Nf datums:

(a) SSL Friction: UNKNOWN. Consistent with 80% of a fleet-wide survey, CH12401's SSL frictions failed to meet the 14-pound pull test with values of 6-8 pounds. This may have created a situation whereby an SSL backed off from its full travel position and allowed an SSL mismatch to occur. Weak SSL frictions may also allow a pilot to inadvertently apply asymmetric thrust to the SSLs while guarding them from movement. Because the SSLs were not guarded on take-off, pilot-induced asymmetric SSL thrust was precluded from occurring. However, minute changes to SSL position, in the order of thousands of an inch in rotation, yielded significant Q deviations during SUTLOT troubleshooting. Therefore, the vibrational influence on CH12401's SSLs during the short time that it was airborne was deemed to be unknown;

(b) Torque Indicating System, Static Split: YES. Static Q split is inherent and largely due to internal errors of the Q indicator or bellows within the Q transmitter. Static Q split, when corrected for by matching both Q indicators, can establish different Nf datums even though both Q indicators are matched. CH12401's indicators were found to be slower-responding than the fleet average while showing an 8% static Q split; the fleet average was 2%; and

(c) Torque Indicating System, Transient Split: YES. Transient Q splits occur during dynamic power demands. If the engines are not allowed to return to steady state prior to re-matching the Q indicators, different Nf datums can be established. There were no Q adjustments made during dynamic power demands prior to CH12401's crash on deck. CH12401's components were found to produce up to 60% transient Q split; the fleet average was 38%. Transient Q splits can be caused by:

i. Air in the Q Transmitting System: UNKNOWN. Up to 20% transient Q split can be attributed to this. There was no established Q line purge check within the CFTOs. All Q transmitters were assumed to have had an automatic air bleed system when in fact it was found that they did not. Though this allowed transient Q splits to occur, the percentage of transient Q split apportionable was indefinable. The impact of air within CH12401's Q transmitting system is unknown since it was disturbed during pre-SUTLOT analysis;

ii. Q Transmitter Restrictors: NO. Although no percentage of Q split could be apportioned, the absence of or installation of the wrong sized or even different restrictors was found to be contributory to transient Q splits. CH12401's restrictors were correct in configuration and installation;

iii. Q Transmitter Restrictor Snubber Insert Holes: NO. Although no percentage of Q split could be apportioned, the blockage of these 0.014" holes by FOD or corrosion contributed to SUTLOT occurrences. CH12401's restrictor snubber insert holes were found to be FOD and corrosion free; and

(2) Mismatched Engines: UNKNOWN. There are two ways in which the engines can be mismatched. Firstly, because Nr is often varied in flight between generally 100% to full SSL travel, the SSLs can be inadvertently set to 103% Nr instead of full travel. This is significant because SUTLOT susceptibility increases when, if the SSLs are set to 103% Nr, the more responsive engine's SSL is inadvertently pushed forward or the less responsive engine has backed off, both of which can induce a Q split; because it was the beginning of the first flight of the day, this was not the case with CH12401. Lastly, mismatched engines can result from the cumulative effects of all the components of SSL Mismatch.

Therefore the overall effect of mismatched engines remains unknown; and

c. Collective Input

(1) Deck Evolutions: NO. One key initiator of a SUTLOT event was the dynamic application power via collective input. This was specific to the engine's requirement to rapidly accelerate from a decelerating mode, such as during an overshoot from a deck landing. There were two elements to this collective input. With significantly differing engine accelerations, the induced freewheel effect could occur during engine acceleration. Additionally, the multiple deceleration/acceleration cycles incurred during repeated deck evolutions only further emphasized the load-sharing problem: after a Q split occurred, the Q would be matched using the SSLs and would then inadvertently result in incorrectly matched Nf datums. In the case of CH12401, the engine accelerated from a low power setting on the flight deck (steady state) to a high power setting during the take-off (acceleration) and then to a lower high-power steady state setting once in the hover (slight deceleration). CH12401's loss of lift occurred after the first take-off during the first flight of the day, rather than during subsequent deck evolutions requiring multiple deceleration/acceleration cycles. Therefore, the decelerative/accelerative and divergent load-sharing processes likely did not occur; and

(2) Turbulence: NO. One in-flight condition that can be similar in nature to mismatched engines is turbulence. During turbulent flight, rapid and varying power demands are frequently made that change engine modes from decelerative to accelerative, subsequently causing the induced freewheel effect to occur. When hovering over a flight deck, especially in the low hover or with gusty winds, turbulent conditions often exist. However, once in the high hover above the hanger top, such as just after take-off, turbulent air flow reduces and results in up to a 15% reduction in required Q, thus minimizing demand for large power changes and accelerations. Once in the hover the crew of CH12401 experienced no significant turbulence associated with turbulent airflow over the hangar face.

2.2.5.4 Conclusion to SUTLOT and its Impact on CH12401

It must be noted that the above is a synopsis of the causes that have contributed to SUTLOT occurrences; the entire DAEPM(M) SUTLOT Technical Findings Report should be referred to for detailed comprehension.

Analysis has shown that CH12401 exhibited some aspects of engine lag, the first of three SUTLOT pre-conditions: P3 leaks and FCU anomalies were not factors while the impact of engine tuning and engine response times remained unknown. Torque splits, the second pre-condition, might have been evident, though only some of its components were present in mixed and unknown amounts. Although it could not be determined if an SSL mismatch occurred, its sub-components of SSL frictions (unserviceable), static Q split (unknown impact of Q transmitter and indicator) and transient Q splits (unknown impact of air in the lines; Q transmitter restrictor and restrictor snubber holes were serviceable) provided mixed analytical conclusions. The impact of engine mismatch, the second component of torque splits, also was inconclusive; however, the transient and static Q splits yielded a possibility for engine mismatch to occur. Finally, collective input, the third and final SUTLOT pre-condition, was not evident to the extent and dynamics identified in the SUTLOT investigation as being required to initiate a SUTLOT occurrence. Thus, collective input, either through pilot input or turbulence, did not adversely affect CH12401's performance.

In summary, certain elements of the SUTLOT phenomenon were found to be present in CH12401. Had the additional pre-conditions of engine lag and collective application been present, CH12401 might have been susceptible to a SUTLOT occurrence. However, the cumulative evidence presented to the FSI Team is consistent with the conclusion that CH12401 likely did not experience a SUTLOT occurrence at the time of accident.

2.2.6 T58-GE-100 Engines

2.2.6.1 General

The number one engine, serial 275055, was installed and flew for 62.7 hours on CH12401. TSO for this engine was also 62.7 hours. The number two engine, serial 275088, was installed and flew for 62.7 hours on CH12401. TSO for this engine was 89.3 hrs. On completion of the engine installations, an engine tuning test flight was conducted on 1 Nov 02; both engines were adjusted prior to declaring the aircraft serviceable. Post-accident, ACRO Aerospace conducted a teardown analysis of both engines, the results of which follow.

The engines' anti-icing systems were on at the time of accident; the systems were checked serviceable prior to launch and during post-crash analysis. No indications of severe compressor stalling were noted in either engine. The compressor sections were found to be undamaged and with slight salt accumulation which was not excessive for flight operations. Experts from both General Electric AE, the T58-GE-100 Original Equipment Manufacturer (OEM), Pratt and Whitney, and Allison/Lycoming have stated that it is common for small turbine engines not to incur any damage post-compressor.

Both engines' FCU's and fuel flow dividers were sent to Columbia Industries for bench checks. Testing showed that no anomalies existed in any component.

2.2.6.2 Number One Engine

Examination of the number one engine did not identify any damage as a result of impact forces. A minor anomaly was noted with the engine fuel settings in that the fuel flow divider was set for JP4 while the FCU was set to JP5. For operations at sea, both settings are normally adjusted to JP5. With mis-adjusted fuel settings, only engine start is affected; once an idle RPM is achieved the mis-adjustment has no effect on engine performance. The aircrew observation that the number one engine routinely took longer to start than the number two engine was partially attributable to the mis-adjusted setting on the fuel flow divider. In this case, the discrepancy between the adjustments was non-contributory to the loss of lift.

The variable geometry (VG) of T58-GE-100 engine consists of the variable inlet guide vanes and the first three of 10 stator vanes stages. The VG temperature tuning bandwidth for the engine as per CFTOs is two turns open and four turns closed from the neutral position (the “N-mark”). Post-crash examination of the VG system determined the engine to be mistuned outside of this temperature bandwidth; the stator vane actuator (SVA) piston rod-end, which controls the VG positioning, was found three turns open from the N-mark, one full turn more than the CFTO limit. The N-mark was verified to be in the correct position. The mis-tuning the VG to the open side results in a decrease of the engine’s decelerative stall margin. When the engine was delivered from ACRO to 12 Wing, the VG were rigged two full turns past the N-mark, or its most-open limit, after which it was then built up by the 12 Wing Engine Test Facility. During this build-up, no VG adjustment records were kept so it is unknown with what settings the engine was installed on CH12401. Prior to returning the aircraft to operations with this newly installed engine, an engine tuning test flight was conducted. During this test flight, the engine was found to be 30?C cool. The documented CF349 rectification indicated that the SVA piston rod-end was subsequently turned out by three full turns. The technicians involved with this engine tuning were found to be competent, experienced, and using the CFTO during this maintenance action. The technicians were also able to see the N-mark clearly so that a limit reference was clearly visible. The investigation could therefore not determine when, by whom, or why the number one engine was tuned beyond CFTO limits. Finally, the closed stop vane angle on the SVA had not been adjusted for the setting required for the T58-GE-100 engine; the closed stop vane angle does not, however, affect engine operations above 65% Ng. Both of these issues are discussed in detail in Annex A: T58-GE-100 Tuning Procedures. Although not contributory to the loss of lift over the flight deck, the mis-adjusted closed stop limit, in addition to the mis-adjusted fuel flow divider, was contributory to the slow-starting number one engine.

During post-crash test bench analysis with the accident VG settings, the engine provided acceptable power and acceleration results despite the VG tuning and the closed stop limits being out of limits. VG tuning required two full turns to the closed position to bring the engine within the tuning limit band in CFTOs.

Although a compressor stall could not be reproduced on the test bench with the mistuned settings, a slight rumble sound was noted during all phases of engine operation. Once the VG was adjusted to within the limit band, the rumble sound reduced but did not disappear. Discussion with the OEM indicated that it is possible for a serviceable and correctly tuned engine to generate a rumble-like noise during operations.

The compressor section was found to have slight, non-excessive rubbing, on the top portions of the rub strip. This rubbing was within CFTO limits.

Salt water and AFFF were found in the engine oil pump assembly. This was attributed to the damage control and fire fighting actions taken post-crash.

2.2.6.3 Number Two Engine

Examination of the number two engine identified that impact forces caused the entire engine to shift on its mounts within the engine compartment. Damage to the combustion casing precluded a test bench check of serviceability. The accessory section, including fuel system components, was installed and successfully run on a slave engine and provided full power and accelerations within acceptable limits.

Similar to the number one engine, a detailed analysis of the number two engine's VG system was conducted. The tuning test flight indicated the engine to be 15?C cool; accordingly it was documented on the CF349 that the SVA piston rod-end was turned out by 1.5 full turns. Although the VG were found to be stiff to close, the number two engine's VG was tuned within CFTO limits. Similar to number one engine, the closed stop vane angle on the SVA had not been adjusted for the new setting required for theT58-GE-100 engine. Again this only affected engine operations below 65% Ng and was not contributory in any nature to this accident.

2.2.6.4 Discussion of Engine Analysis

As the start and take-off sequences appeared to be normal, with the exception of a large amount of salt spray in and around the flight deck environment and the two reported wave strikes of the helicopter, the loss of lift over the flight deck can most likely be attributed to a drive-train malfunction. With indications of a fully serviceable MGB, acceptable aircraft fuel and fluids, and the numerous reports of a repetitive loud “machinegun-like” sound at the time of accident, the power-train malfunction can further be refined to focus on an engine as being causal to the loss of lift. There were four scenarios that could have been causal:

a. water ingestion causing engine flameout/relight;

b. engine inlet or compressor blade icing causing compressor stall;

c. compressor salt accretion causing compressor stall; and

d. number one engine variable geometry mis-tuning causing compressor stall.

In these subsequent scenarios, it must be noted that they can all exhibit the common indications of a loud popping or machinegun-like noise or a bang audible to crewmembers, a loss of drive to the power-train, and the cockpit indications of high T5, low Nf, low Ng, and low torque. In mild compressor stalls or flameout/relight sequences, damage may not occur; however, in severe occurrences, airflow reversals result in internal engine damage. In this case, an audible popping noise was witnessed by both aircrew and ground personnel. Due to the stage of flight and rapidity of onset, engine parameters were not noted; there is neither a CVR/FDR nor a health usage monitoring system to capture this information. During post-crash analysis neither engine exhibited any sign of damage other than that which was impact related. Historical engine compressor stall data was also reviewed for comparative purposes.

2.2.6.4.1 Water Ingestion Causing Engine Flameout/Relight

The aircrew noted that prior to launch, two waves struck the aircraft. The second wave was large enough for air detachment personnel within the hangar to notice an audible change in pitch of the turning main rotor blades. Both pilots saw, through the plexiglas cockpit ceiling, water pooling between the back of the Foreign Object Deflector (FOD) shield and the engine inlets. The wave also temporarily obscured the pilots' vision from the cockpit.

Examination of the engine intake area above the cockpit shows that the base of the FOD shield is mounted slightly above the cabin ceiling allowing for sufficient drainage around the FOD shield attachment points in front of the engine inlets. Furthermore, the sloping design of the cockpit ceiling can in no way inhibit the drainage of any accumulated fluids. This area is therefore efficient in draining, in a very short period of time, the significant volume of water encountered by each wave.

The engine intakes are mounted approximately eight inches above the cockpit ceiling and would therefore not allow water to flow back into the engines other than what would be forced in as a result of the initial wave strikes. With the number one engine on the left side of the aircraft, it was more sheltered from direct wave action by the FOD shield than the number two engine and thus likely did not see much water in the intake area. Furthermore, the second wave struck the aircraft 20 minutes prior to the accident, allowing ample time for water to drain from the intake areas prior to launch. Examination by ACRO Aerospace revealed a negligible amount of salt accretion in the compressor sections of both engines. Had engine water ingress been significant, salt residue would have been more evident. This indicates not only that water ingress did not occur above normally acceptable limits, but also that it was minimal in volume. Indeed, the experience of other Sea King operators has demonstrated that even when post-flight water washes are performed at ground idle power settings, the engines do not flame out despite the injection of significant volumes of water directly into the engine inlets.

Some turbine engines are equipped with continuous ignition. Continuous ignition ensures that in the event of a flame out, such as in the case of massive water ingress, the combustion chamber igniters continue to function and provide an ignition source to the fuel nozzles. Under certain conditions a repetitive flameout and relight cycle can be established, resulting in indications similar to a compressor stall, most noticeably a popping or machinegun-like noise. However, the T58-GE-100 has no auto-relight system and therefore this flame out and relight cycle could not have occurred.

In summary, it is unlikely that a sufficient volume of water was ingested by either engine to cause a flameout. Furthermore, because the T58-GE-100 does not have continuous ignition, a flameout and relight process could not have occurred. It was therefore concluded that water ingestion by either engine could not have been causal to the loss of lift.

2.2.6.4.2 Engine Inlet and Compressor Blade Icing Causing Compressor Stall

The environmental conditions just prior to the crash on deck, 1?C air temperature, dew point of -1?C, and visible moisture in the air (sea spray and waves), were ideal for the formation of both inlet and compressor icing. It was therefore necessary to determine if icing played any role in this accident as either case could lead to a compressor stall.

The engine anti-icing system provides protection for the engine air inlet section and starter fairing. The air inlet is electrically heated whereas the starter fairing, inlet guide vanes, and three starter mounting struts are heated by compressor bleed air; one starter mounting strut is continually heated by return engine oil. The engine air inlet heats up to 55?C and then cycles off, recycling on again at 49?C. Electrical heating to the inside portion of the FOD shield provides further anti-icing. These protection measures ensure that ice cannot form and subsequently shed into the engine, causing damage significant enough to induce compressor stalling.

Given the environmental conditions, the aircrew tested the engines' anti-icing systems serviceable and then turned them on prior to launch in accordance with the Aircraft Operating Instructions (AOI). Post-crash component analysis confirmed the serviceability of the number one and two engine anti-ice systems. Therefore it is concluded that engine inlet icing in either engine was not causal to this accident.

It is possible, though, that under certain conditions compressor blade icing can occur and cause airflow disruption sufficient to precipitate a compressor stall. However, both engines were running for a sufficient time (number one 45 minutes and number two 20 minutes) such that the anti-icing systems were optimally functioning. It was therefore concluded that engine inlet or compressor blade icing causing a compressor stall in either engine was unlikely to have occurred.

2.2.6.4.3 Compressor Salt Accretion Causing Compressor Stall

When operating in a maritime environment, salt is omnipresent within the atmosphere, especially when conducting hover operations over the ocean. During over-water hovering, water spray from rotor downwash and wave action is re-circulated. Consequently, Sea King corrosion control and engine performance protection measures are rigorously adhered to. Specifically, engine wash procedures are established to prevent salt accretion in the compressor section of the engine. Additionally, aircrew monitor in-flight engine performance. When engine performance degrades as a result of salt accretion, the power turbine inlet temperature (T5) increases; a maximum T5 temperature increase of 35?-50?C precludes continued flight and requires a return to base for an engine wash in accordance with the AOI. The pilots' last check of engine instrumentation just prior to take off did not indicate any abnormal increase in T5 relative to the initial T5 readings taken post-engine start and rotor engagement.

Had salt accretion progressed to the stage that airflow through the compressor section was disturbed sufficiently enough to cause compressor stalling, a much greater amount of salt residue would have been evident during engine analysis, such as found during the investigation into a compressor stall aboard HMCS CHARLOTTETOWN in Mar 96. Prior to environmental sealing of the engines for transport to ACRO Aerospace for analysis, any evaporative process due to airflow through the engines would only have removed moisture from the engines' internal components, leaving salt deposits behind on component surfaces. Detailed engine analysis noted only a negligible and inconsequential amount of salt accretion in the compressor section of both engines (Photo 2). It was therefore concluded that salt accretion causing a compressor stall in either engine did not occur.

2.2.6.4.4 Number One Engine VG Mis-tuning Causing Compressor Stall

Although the number one engine was successfully run on the test bench and met all specified power and acceleration parameters, a compressor stall could not be induced through conduct of all the CFTO-prescribed analytical procedures. The engine OEM, General Electric AE, indicated that a decelerative stall margin check should have been performed to accurately assess the engine performance. This check which simulates the most extreme stall-conducive conditions is not a CFTO procedure and could have resulted in engine damage had a severe compressor stall been induced. During test bench operation, the number one engine produced a rumble-like noise that could have been indicative of a potential compressor stall. Once the VG was correctly adjusted, though the rumble diminished in magnitude, it remained evident during all phases of operation. It is, however, possible that even in a fully serviceable and correctly tuned engine a rumble-like noise may exist during operations.

Investigative discussion involved the possible impact of airflow (ie wind) magnitude and direction on engine operations, including operations at various angles of attack. Based on Aerospace Engineering Test Establishment (AETE) flight deck certification trials and the thousands of cumulative flight operations hours in all possible environmental conditions, it is thought that the effect of airflow disruption to the engines is inconsequential provided that engines are adjusted to within design parameters and that the aircraft is operating within certified limits. The OEM could not produce empirical data with respect to engine performance outside of correctly rigged engine parameters. However, the OEM did confirm that compressor stall susceptibility increases as the stall margin decreases when the VG is adjusted open beyond CFTO limits, as was the case with the number one engine. Annex A: T58-GE-100 Engine Tuning, provides a detailed look at how this stall margin decreases with an open VG shift.

Annex A also examines the existing CFTO tuning procedure for completeness in light of investigative information provided by the OEM's Field Service Representative (FSR). This technical information identified that the current on-wing tuning does not include adjustment of the SVA feedback cable assembly. This exclusion possibly results in an incomplete procedure which can result in reducing the decelerative stall margin during transient power requirements such as those experienced during take off to the hover. When coupled with an already reduced stall margin, the possibility exists that the engine's susceptibility to stalling was quite high. A further in-depth analysis of this issue is being pursued by DAEPM(M) staff, the results of which will be reported on outside of this FSIR.

2.2.6.4.5 Historical Engine Compressor Stall Data

Due to the short time in service with the Sea King, there has been only one reported T58-GE-100 engine compressor stall; however, this was not useful for comparative purposes because of numerous dissimilarities between the two occurrences. Although the T58-GE-8F has a different variable geometry schedule compared to the T58-GE-100, both have similar stall margin characteristics; the T58-GE-100 has a somewhat improved stall margin over that of the T58-GE-8F. Because of this similarity, historical T58-GE-8F compressor stall data was analyzed.

Sea King compressor stall data from 1963 until just prior to the accident is presented in Table 3: T58-GE-8F/-100 Compressor Stall Historical Data. This data is derived from Flight Safety Information System (FSIS) entries in which it is conclusively stated or highly probable that a compressor stall occurred. There were many FSIS entries, particularly prior to 1980, that indicated a compressor stall may have occurred; however, minimal and incomplete documentation precluded their inclusion in these statistics.

Table 3: T58-GE-8F/-100 Compressor Stall Historical Data

Cause	Total	Ashore	At Sea	
Mechanical	2	2	Nil	
Non-Mechanical	18	4	14	
			Flight Deck Environment: 12	In Flight: 2
		Visible Moisture: 1	Visible Moisture (spray, waves): 8	Visible Moisture (spray, waves): 1

It is interesting to note that the vast majority of compressor stalls have occurred while operating at sea (14). Furthermore, the flight deck environment appears to be common in most reported compressor stalls, as does the presence of visible moisture, either in the form of heavy sea spray, waves, or even ship's pre-wet. Of the 10 compressor stalls involving visible moisture, all were attributed to environmental conditions.

It is obvious from Table 3 that when theT58-GE engine compressor stalls, it does so commonly while operating under the influence of ship-borne environmental conditions. However, due to insufficient historical investigative information, particularly the lack of technical data, no supportable correlation between compressor stalls and maritime operations with visible moisture present could be concluded. This lack of data correlation is further discussed in Section 2.6 Other Flight Safety Concerns.

The lack of documented compressor stalls involving the CH113 Labrador's T58-GE-100 or T58-GE-8F precluded any analytical comparison to the Sea King.

2.2.6.5 Conclusion of Engine Analysis

The investigation was unable to exclusively and with all certainty determine the cause of CH12401's loss of lift over the flight deck. However, through a process of elimination of all possible known causes, the SUTLOT phenomenon (2.2.5.4), engine water ingestion, engine icing, and compressor salt accretion were determined to have been not causal to the loss of lift. The circumstances during the critical stage of flight post-take off over the flight deck - a saltwater-laden environment, turbulent airflow, and high angle of attack of relevant airflow to engine intakes - would not likely have affected a correctly tuned engine. However, although not quantified, verified, or reproduced on the engine test bench, it is thought by QETE, ACRO, and GEAE that these factors may have adversely influenced the incorrectly tuned engine. Furthermore, it may be possible that the omission of the SVA feedback cable adjustment from the tuning procedure (Annex A) exacerbated an already stall-susceptible condition. With strong corroboration of the technical rationale by both professional and amateur ear-witnesses, it is therefore concluded that the mis-tuned number one engine VG, possibly combined with environmental factors and an incomplete tuning procedure, likely caused the engine to compressor stall and thus limit the total power available during a power-critical stage of flight.

2.3 Human Factors

2.3.1 Maintenance

The adjustments to the number one engine's VG were documented by ACRO prior to CF delivery. Once at the 12 Wing Engine Test Facility, subsequent VG adjustment documentation was not found and therefore the state of engine VG settings prior to installation on CH12401, Nov 02, could not be determined. It was found that the technicians who performed the final VG tuning, which was correctly documented via CF349, were experienced and credible when asked to describe engine tuning maintenance procedures. It was believed that they also routinely referred to CFTOs when carrying out this procedure. Although it has been known to occur infrequently, it could not be determined if further unauthorized or undocumented maintenance actions occurred. Although the investigation could determine neither why, when, where, nor by whom the number one engine was tuned beyond CFTO limits, it is evident, however, that a failure in maintenance process occurred, at some point after the installation of the number one engine on CH12401, in which the number one engine was tuned beyond limits.

2.3.2 Aircrew - General

Defence Research and Development Canada (DRDC), Toronto, conducted human factors analysis of the accident. There were no apparent spatial disorientations or associated visual illusions affecting the aircrew. Crew coordination was conducted in a standard manner during flights prior to and including the accident flight. No toxicological issues were associated with this accident. It became apparent to the Human Factors Investigation that four potential areas of concern needed further examination:

a. evidence cross-contamination;

b. circadian rhythm disruption;

c. mild sleep deprivation; and

d. the Departure Assistance Group.

2.3.2.1 Evidence Cross-Contamination

Human memory is notoriously fallible, especially memory of traumatic events. In an enclosed environment such as aboard ship, witnesses to accidents are unable to avoid discussing the event with each other. This can lead to the introduction of events during the accident that never actually occurred. Additionally, the destruction of events that really did happen can take place. Because of this, and the time lag between the accident occurrence and witness interviews, a significant amount of event reconstruction is unavoidable. Although probably not a factor affecting the witness testimony of the events of this accident, the effect of evidence cross-contamination is worth noting.

2.3.2.2 Circadian Rhythm Disruption

Circadian desynchronization or transmeridian desynchronism (TMD) is caused by irregular sleep-wake cycles combined with time zone changes. Many biochemical and physiological processes of the human body fluctuate through a period of arousal followed by a period of lowered activity. These cycles appear to be coordinated and controlled by the pineal gland which receives its cues from environmental zeitgeibers, or “time givers” such as the rise and set of the sun, local noise levels, and social events (ex: breakfast, traffic sounds). When a person travels to a new time zone or is forced to work irregular sleep-wake cycles, their biological cycles become “desynchronized” with environmental cues. The effects of TMD can include feelings of malaise, deteriorated decision-making skills, and degraded reaction times. To recover, a person must re-synchronize with local time-givers. Due to the Sea Training Staff’s workup training schedule, the accident aircrew were subject to irregular sleep-wake patterns. The early-morning fire drill coupled with the time zone change may have caused them to feel the effects of mild TMD. There were several unique events that occurred prior to takeoff that may have been responded to differently by the accident aircrew had they not been subject to TMD: the number one engine was noted as slow to start; while on the flight deck, the aircraft was struck by two waves and was subjected to a significant amount of sea spray; water was noted to be pooling on the overhead windows in front of the engine intakes; and there was an unidentified buzzing sound within the aircraft after the second wave strike. In light of these events, it is possible that TMD may have affected the aircrew during their assessment of whether or not to perform engine-related maintenance or to even continue with the launch. It is concluded, however, that although this factor likely affected the aircrew to a small degree, it could not be ascertained what impact TMD had on their performance.

2.3.2.3 Mild Sleep Deprivation

Most people require approximately eight hours of sleep during each 24-hour cycle to operate at peak efficiency. To be effective, these eight hours must be uninterrupted and of “quality” sleep (occurring during the low phase of the circadian rhythm). Sleep deprivation reduces decision-making capabilities and reaction times as well as a person’s ability to focus mentally. In this situation, with exception of the co-pilot, the accident aircrew received eight hours of sleep, albeit interrupted by the early-morning fire drill. The co-pilot reported feeling “worn out” after receiving six and one half hours of sleep. As a consequence the accident aircrew may have been experiencing a mild level of sleep deprivation.

As with the impact of TMD, it is undetermined whether or not the accident outcome would have been different had the aircrew received their full eight hours of uninterrupted sleep.

2.3.2.4 Departure Assistance Group

All IROQUOIS HELAIRDET personnel underwent the Departure Assistance Group (DAG) process. This process is an assessment of deployment suitability and determines whether or not outstanding issues (personal and professional) may potentially impact deployed operations. A “red” classification indicates that, for whatever reason (admin, social, professional or medical), a member has been deemed unfit to deploy. It is a loose definition based on the circumstances of each individual and of the particular appointment. Of the 23 personnel on the IROQUOIS HELAIRDET, only one was classified as “red,” the accident pilot. This “red” classification was contingent on the pilot completing the seven-plus month long deployment. Despite the implications of “red” DAG classification, a workable and approved solution was in place for the short term: the pilot was scheduled to remain with the detachment for a period of one month at which point a replacement pilot was to arrive. This mitigation, when factored against the initial DAG “red” classification, provided an acceptable plan. It was therefore concluded that the pilot’s DAG “red” assessment was not a factor in this accident.

2.3.3 Aircrew - Pilot Reaction to the Emergency

Based on a negative 1868’ density altitude (DA), 29 knot headwind component, and 19750 pounds all up weight (AUW), the theoretical aircraft torque required to hover 15’ over the flight deck at the time of accident was approximately 87% dual engine (72% + 15% for flight deck operations) or 174% single engine; clearly the aircraft could not have remained airborne with one engine inoperative. Any turbulence or positional corrections while over the flight deck would have required more torque. At this power-critical stage of flight, any reduction in power to the main rotor would have had immediate negative impact on the aircraft’s ability to maintain an adequate hover. The initial indication to either pilot that a power-critical event was developing was a sinking sensation as the aircraft settled towards the flight deck. Additionally, the low-rotor warning system beeped intermittently. This intermittent tone which is audible only to the pilots, indicated that Nr was at or less than 98% but above 91% when the solid tone occurs. The pilot’s instinctual reaction to the low-rotor tone, to lower the collective, increased the Nr above 98% and ceased the tone. As the aircraft neared the flight deck, the pilot raised the collective in an effort to cushion the landing. The pilot stated that he anticipated a slightly harder than normal landing. Neither the pilot nor the co-pilot could recall hearing the solid tone as would be expected if all the collective available was used for the cushion. Thus it was required to further exam the effectiveness of the pilot’s collective cushioning.

The reaction to a loss of power while in a day VFR hover, as taught by 406 Maritime Operational Training Squadron, is to initially lower the collective in order to preserve Nr; the low rotor tone may be momentarily heard as Nr droops below 98%. Then as the aircraft settles, drift and yaw are eliminated and a level attitude is established. Once ground-rush is experienced, the pilot then raises the collective to cushion the landing.

From a 15' hover, such as over the flight deck, the time to landing after a single engine failure, for example, is approximately three seconds. The average pilot takes approximately the first two seconds to correctly identify the situation and initiate a correct response. During the final second, the collective cushioning occurs before landing. During this cushioning, it could be expected to again hear the intermittent and then possibly the solid low rotor tone as all of the rotor's kinetic energy is used to slow the descent rate. The onset of low rotor tone and changes to Nr can be dependent on environmental conditions such as DA, wind, and AUW. With the winter conditions experienced at the time off accident and the rapid onset of the descent and subsequent crash on deck, it may have been possible that the low-rotor tone did not activate.

Another explanation for the low-rotor tone not activating is that a sufficient collective cushion was not used to arrest the rate of descent. Post-crash analysis showed the collective to be in the half-raised position. Due to the violent nature of the impact, this positional information is inconclusive because the collective may well have moved during the crash sequence.

Finally, the pilots may not have perceived the low-rotor tone because they were perceptually and functionally saturated. They may in fact actually have heard the low-rotor tone; however, sensory overload and task saturation during the crash sequence may have prevented them from processing the tone. Without FDR/CVR data to support anything to the contrary, it can only be presumed that the pilot reacted in accordance with his training.

Briefly, the issue of a lack of SE training currency must be also mentioned. Recency and repetition are two aspects of training that play an important role in the conduct of flight operations and reactions to emergencies. The pilot had the benefit of SE training prior to the aircraft configuration change to the Sea King Mark III whereas the co-pilot did not. Although, due to SE training restrictions in the Mark III, the pilot's last SE training was almost one year prior to the accident, therefore, he did have the benefit of previous repetitive exposure to SE scenarios. Although it cannot be conclusively determined, it is possible that the positive effect of current SE training would have provided a better skill set foundation for the pilot to draw upon during his response over the flight deck. This issue is discussed in further detail in Section 2.6 Other Flight Safety Concerns.

Based on the above discussion, and without FDR data to verify, it is concluded that the pilot likely reacted correctly and according to his training in response to the loss of lift he encountered over the flight deck.

2.3.4 Human Factors Conclusion

2.3.4.1 Maintenance

The impact of undocumented or unauthorized maintenance actions is well known. In this case an unidentifiable discrepancy between documented and actual VG settings is believed to have played a key factor in the loss of lift suffered by CH12401 over the flight deck of HMCS IROQUOIS.

2.3.4.2 Aircrew

There were several factors that may have affected the pilot's reaction to the probable compressor stall over the flight deck, though none of which could be quantifiably measured as negatively impacting his performance or reaction to the emergency: TMD, mild sleep deprivation, and a lack of recent and recurrent SE training. Without the empirical data that could have been provided by an FDR (collective position, rate of collective position change, time of collective displacement, and radalt height), the pilot's response could only be subjectively assessed. Although he stated that he felt adequately rested for flight operations, the impact of TMD and mild sleep deprivation may have affected the pilot's ability to instantaneously recognize the critical power-limited situation. This in-turn may have momentarily delayed his reaction to the time-critical situation. Additionally, the impact of evidence cross-contamination on the investigation could not be assessed. The DAG "red" assignment to the pilot was determined to be inconsequential to the outcome. It was therefore determined that the cumulative human factors impact on pilot performance was inconclusive. Furthermore, it is considered that the pilot acted correctly in response to the probable compressor stall over IROQUIOS' flight deck.

2.4 The Ship

2.4.1 Fire Fighting and Damage Control

Maritime Forces Atlantic HQ, Naval Engineering and Maintenance, conducted technical investigations into the AFFF and TAU systems. Both AFFF and TAU systems were proven serviceable prior to IROQUOIS' sailing post-accident.

2.4.1.1 Aqueous Film Forming Foam System Failure

IROQUOIS' AFFF system failed to operate when it was activated from the FLYCO position. FLYCO reported activating the system, however, the AFFF fire hoses in the hangar did not charge and were deemed unserviceable. The Technical Investigation concluded that:

a. the AFFF system was functional and could charge the fire hose when activated. There is a 35-40 second delay from the time that the AFFF system is activated to the time that the fire hoses are charged. This delay is a result of the system design and cannot be altered;

b. FLYCO was not aware of the fact that as he repeatedly depressed the button to activate the AFFF system, he was actually starting and stopping the system with every alternate push;

c. the Planned Maintenance Routines for the AFFF system were verified to be up to date and correct;

d. there was no requirement for the testing of lamp bulbs within any component of the AFFF system Planned Maintenance; and

e. all operator indication lamps on the AFFF system console in FLYCO required their bulbs to be replaced. None of the bulbs were functional; therefore, there was no indication to FLYCO that the system was operating.

2.4.1.2 Twin Agent Unit System Failure

IROQUOIS' TAU system failed to operate when activated at the FLYCO and hangar positions. The system was later successfully activated manually from the TAU compartment but was not used as part of the damage control and rescue actions. There was an accidental discharge of dry chemical in the hangar when the nozzle was kicked. The Technical Investigation concluded that:

a. the TAU system failed to activate from the pull-station locations because of problems with the pull-cable routing and configuration. The cable assemblies had to be modified to make the system functional;

b. the pull-station assemblies were significantly different and outmoded compared to the arrangement fitted to other IROQUOIS class ships;

c. the Planned Maintenance Routines for the TAU were verified to be up to date, but lacked any provision for testing and proving that the pull-stations would trip the nitrogen cylinder activation mechanisms; and

d. there were no spare nozzle assemblies in the CF Supply System to replace the one damaged in the hangar.

2.4.2 Starboard Flight Deck Access Ladder

The original configuration specification of the flight deck ladders required aluminum construction. At some unknown point in the past, IROQUOIS had steel ladders fitted while other IROQUOIS class ships remained specification-compliant with aluminum ones. This difference was noticed when a ladder from HMCS ATHABASCAN was used to repair IROQUOIS' damaged one. After assessing the damage to the ladder, it was determined that had an aluminum one been in place, the shrapnel damage to the flight deck environment and the areas in which the Life Buoy Sentry occupied would have been much more extensive, possibly resulting in increased and more severe injuries to personnel.

2.4.3 Flight Deck Video Camera

IROQUOIS' flight deck video camera system was comprised of two hangar-top mounted cameras either one of which could record video footage of the flight deck environment. In accordance with HMC Ship's Standing Orders, "if a CCTV is available, it is to record all flight operations over the flight deck." To do this, it is normal procedure for the Second Officer of the Watch (2OOW), who co-ordinates flying operations on the Bridge, to ensure that the video camera is focused on the helicopter when the ship comes to Flying Stations and that the video camera recorder (VCR) is recording. Shipboard Helicopter Operating Procedures (SHOPs) also directs that the OOW and Ship Air Controller (SAC) "must ensure that the CCTV is available and on in order to record all flight operations over the Flight Deck."

During the RAS with PRESERVER, the flight deck video camera was used by Bridge and Operations Room personnel to view the RAS evolution. Although it is required for flying operations, it could not be determined at what point, if ever, the camera was focused on the helicopter during flying stations preceding the accident. Analysis of IROQUOIS' VCR tape indicated a malfunction with the VCR. On determination of this fact, IROQUOIS was notified and indeed confirmed that the VCR was not functional. Had the flight deck camera recorded this accident, the footage would have significantly aided this investigation. Similar to CH12424 on HMCS IROQUOIS in 1996, this is the second accident on board an HMC Ship in which the critical flight deck video data was not recorded.

It was found that no routine exists within IROQUOIS' (or fleet-wide) procedures to test and ensure functionality of the flight deck camera and VCR equipment. As it is directly related to flying operations, it is likely that had control of the VCR and cameras been located within the FLYCO position, its correct aim and operation would have occurred. Furthermore, the use of a digital continuous-loop video recorder in lieu of a standard 60 or 90-minute tape would have ensured the recording of this critical flight deck event, had the system been functioning as intended.

In conclusion, the lack of application of existing orders, the lack of adequate procedures to ensure pre-use functionality, and the improper use of the flight deck video camera on HMCS IROQUOIS denied critical information to the Flight Safety Investigation.

2.4.4 Salvage and Recovery

IROQUOIS' damage control and salvage and recovery organizations performed effectively in ensuring that their actions were conducted safely and correctly. The proper securing of the aircraft to the flight deck during the two-day transit to

Halifax prevented further damage that might have made investigative processes more difficult.

IROQUOIS came alongside the Shearwater Jetty at 12 Wing, NS, for crane-off operations that were directed by the 12 AMS Salvage Team (Photo 3). Recovery to the jetty flatbed trailer was done in five phases: the attachment of crane harness assembly to the main rotor head hub; the aircraft raising to the vertical position over the flight deck; a final structural assessment of the aircraft and further photographic documentation; the craning off of the aircraft to the jetty flatbed trailer; and the securing of the aircraft to pre-positioned cradles on the flatbed trailer. The aircraft was then moved to and secured in a hangar facility for further investigation.

2.5 Aircrew Life Support Equipment

2.5.1 Inertial Reel Analysis

During post-accident analysis of the TACCO's seat inertia reel, it was found that it failed the 3G straight pull automatic lock test. A QETE investigation into this failure concluded that the inertia reel, although sensitive, was serviceable; the failure of the 3G test was most likely the result of the inertia reel locking mechanism being knocked out of adjustment during the crash sequence.

2.5.2 Immersion Suit Fire Retardancy

It is recognized that the Helicopter Operational Test and Evaluation Facility (HOTEF) project H-2002-002 Evaluation of Modified Constant Wear Immersion Suit has been initiated to address numerous issues with the current immersion suit. However, it is relevant and within the scope of this FSIR to comment on existing shortcomings.

Although there was no post-crash fire in this accident, the possibility of one occurring was quite real given the leaking fuel, onboard ammunition, the onboard pyrotechnics (flares, sonobuoys, explosive squib cartridges), and the violent crash sequence. Accordingly, the investigation examined the fire retardancy of the immersion suit used by the accident aircrew.

The constant-wear immersion suit used by the accident aircrew and by all Maritime Helicopter aircrew is of NOMEX construction. Its multiple layers, when combined with the issued liner and clothing worn under the immersion suit, provide adequate fire retardant protection. The latex rubber wrist and neck seals, however, offer no such fire protection. During the course of an aircraft egress from a post-crash fire, it is crucial that the multiple layer protection system is continuous to prevent injury. With the immersion suit, the wrists and neck are protected by only one layer, the seal itself. Furthermore, this seal is of a latex rubber construction that will melt when burned and cause significant injury.

There are several commercial initiatives that offer possible solutions to the lack of immersion suit seal fire retardancy. Mustang Survival is currently investigating a stretchable NOMEX neck seal that is mostly fire retardant. Additionally, a new neoprene rubber wrist seal is manufactured that is more fire resistant and not as flammable as latex rubber; it does burn but does not sustain flame. The wrist seals are installed in the same manner as winter jacket wrist seals. They are installed inside the sleeve and covered by the fabric of the sleeve extending to the wrist. Therefore, even if the seal is not completely fire retardant, it is protected from the heat by the immersion suit sleeve.

Given the potential for post-crash fire, the seriousness of injury, and the availability of alternate seals, it is concluded that an alternative to a single layer latex rubber neck and wrist seal is required for the constant-wear immersion suit.

2.6 Other Flight Safety Concerns

2.6.1 Single Engine Training

At the time of accident, the Sea King fleet had been upgraded to the Mark 3 variant with the introduction of the T58-GE-100 engine (more powerful than the T58-GE-8F) and the 24K MGB. At this time, single engine (SE) training had, due to the potential for MGB overtorque with the powerful –100 engine, been severely restricted and resulted in an almost two year period during which pilot SE handling skills decayed considerably. With the resolution of SUTLOT and the implementation of an engine de-topping procedure in Jan 04, the resurrection of SE training, including effective Waterbird training, has occurred. It is felt that these two in-aircraft training methods are sufficient to start regaining some of the lost SE skills since the Mark 3 upgrade, however, they represent only a portion of a complete SE training package. Annex B: Single Engine Training briefly outlines how this SE training void developed and it emphasizes the need for a training needs analysis to be completed so that a more complete SE training package can be provided. Additionally, Annex B discusses a potentially more-accurate method of using torque to compare power available to power required, rather than using SSES, to define in-flight, overshoot, and hover-flight capability.

2.6.2 Flight Safety and Maintenance Documentation

A DAEPM(M) review of eight Sea King compressor stall occurrences documented in the Flight Safety Information System from 1992-2003 showed that sufficient archived Automated Data for Aerospace Maintenance (ADAM) existed to confirm that only two T58 engine compressor stalls in fact had occurred. The data from the six remaining occurrences was inconclusive, contradictory and incomplete: insufficient maintenance action was carried out to determine whether or not a compressor stall occurred; damage to components was indicated that could not be later tracked down as having been repaired; and Flight Safety reports identified occurrence dates, yet no engine-related maintenance action had been documented for up to several weeks either pre- or post-occurrence date. This is striking in that it is essential for both databases to mutually support the findings and actions carried out. Without this, inaccurate and incomplete flight safety reporting occurs and potentially incomplete maintenance actions are carried out.

2.6.3 Observers to Flight Deck Operations

As a result of the crash impact, shrapnel from the disintegrating main rotor system punctured the flight deck hangar door and injured a Sea Training Staff observer. The crash dynamics of this accident reflect an accurate example of how helicopters can impact the flight deck and cause significant damage to not only the aircraft itself, but also to the surrounding ship's spaces. The piercing of the hangar door by several smaller, high-velocity components indicates that the hangar door potentially does not offer significant protection to hangar personnel in the event of an aircraft accident on the flight deck. Injuries to hangar personnel could be caused not only by component impact and a subsequent fire, but also by the rush of personnel to the forward part of the hangar; during the crash sequence, hangar personnel ended up tripping and stumbling over one another in an effort to get away from the crash area. As a result, it is concluded that minimum manning of hangar spaces and the restriction of non-essential observers is necessary to minimize possible injuries in the event of a flight deck accident.

3. CONCLUSIONS

3.1 Findings

3.1.1 The cause of this accident could not be definitively determined due to a lack of objective data.

3.1.2 The number one engine likely experienced a compressor stall that limited the total power available during a critical phase of flight over the flight deck.

3.1.3 Based on the information provided by the SUTLOT technical investigation, the cumulative analysis of CH12401's components was consistent with the conclusion that CH12401 likely did not experience a SUTLOT occurrence at the time of accident.

3.1.4 The number one engine was found tuned beyond CFTO limits and was susceptible to decelerative compressor stall.

3.1.5 It could not be determined who tuned the engine beyond CFTO limits.

3.1.6 The closed vane stop angles on both engines were not correctly adjusted; however, this only affected engine start.

3.1.7 The majority of compressor stalls experienced by the Sea King fleet have occurred at sea while in the flight deck environment.

3.1.8 Poor flight safety and maintenance documentation prevented the formulation of any substantiated conclusions from historical compressor stall data. This discrepancy between flight safety investigation findings and ADAM information could lead to incomplete maintenance action being conducted.

3.1.9 Although the T58-GE-100 engine tuning CFTO reflected the procedure identified in the OEM's maintenance manual, the OEM Field Service Representative indicated that the SVA feedback cable should also be adjusted during on-wing engine tuning. The omission of the SVA feedback cable from on-wing tuning potentially compounded the effects of an already incorrectly tuned engine.

3.1.10 The OEM subsequently identified that on-wing engine tuning is not required.

3.1.11 The process and validity of on-wing tuning is under DAEPM(M) evaluation.

3.1.12 The pilot's response to the loss of lift over the flight deck was in accordance with his training.

3.1.13 Although numerous aircrew human factors were present, none were contributory to the accident.

3.1.14 The potential to over-torque the Sea King Mark 3 precluded effective SE training from being conducted prior to this accident.

3.1.15 SE training in the Sea King Mark 3 decayed to the point that senior MH pilots rapidly lost their skills in handling SE scenarios while new and junior pilots relied upon their engine failure experience from basic helicopter training.

3.1.16 Some pilots use the accurate, though unauthorized, comparison of power available to power required as the determinant of SE capability rather than the traditional and certified SSES.

3.1.17 There is no clear guidance to determine pilot actions in the event of an OEI situation in forward flight, during transition to and from the hover and in the hover.

3.1.18 An accurate Training Needs Analysis remains to be completed.

3.1.19 The constant-wear immersion suit in use by the MH community has no fire-retardancy protection about the wrist and neck seals.

3.1.20 The lack of CVR and FDR equipment hindered the investigation.

3.1.21 IROQUOIS' flight deck video camera system was unserviceable and did not capture the crash on deck sequence.

3.1.22 There were no requisite video system functionality checks identified within IROQUOIS or the fleet for flight deck-equipped ships.

3.1.23 IROQUOIS' AFFF and TAU fire-fighting systems were rendered unserviceable by a combination of mechanical and personnel failures.

3.1.24 IROQUOIS' flight deck access ladders were of a non-standard metal construction.

3.1.25 Had the military-specification of aluminum been utilized, it is likely that this ladder would have shattered catastrophically and would have resulted in injuries to IROQUOIS' lifebuoy sentry.

3.1.26 IROQUOIS' flight deck hangar door did not protect all hangar personnel from shrapnel penetration.

3.2 Cause Factors

3.2.1 It is concluded that the mis-tuning of the variable geometry most probably caused the number one engine to compressor stall, thus limiting the total power available in a power-critical regime of flight.

3.3 Contributing Factors

3.3.1 It is possible that omissions from the existing CFTO engine tuning procedure allowed the number one engine's deceleration stall margin to be further reduced such that it was contributory to the probable compressor stall suffered by the accident aircraft.

4. SAFETY MEASURES

4.1 Safety Measures Taken

4.1.1 FMF Cape Scott conducted technical investigations into the failure of both the hangar AFFF and TAU systems. Deficiencies were rectified and tested fully serviceable prior to IROQUOIS' sailing 5 Mar 03. Detailed system and fleet-wide preventative measures have been implemented.

4.1.2 The IROQUOIS class lifebuoy sentry position has been relocated away from the flight deck environment.

4.1.3 IROQUOIS raised an Unsatisfactory Condition Report to document the deficiencies of the IROQUOIS class aluminum flight deck ladder. An Engineering Change was initiated by the Fleet Technical Authority to utilize steel ladders and to classify them as the requisite flight deck ladder specification. The steel ladders are in the process of being installed.

4.1.4 A functional VCR was installed to record flight deck operations prior to IROQUOIS' sailing for OPERATION APOLLO.

4.1.5 12 AMS issued SAMA Alert 03/03 to all Sea King maintenance personnel to ensure that stator vane rigging is conducted IAW CFTO specifications.

4.1.6 A local 12 Wing survey of engine VG tuning limits indicated that all aircraft were correctly tuned within CFTO limits.

4.1.7 DAEPM(M) sought OEM guidance with respect to correct tuning procedures for the T58-GE-100. This information will be used to review and update existing procedures to ensure improved performance and safety of operation.

4.1.8 The SUTLOT phenomenon has been the catalyst to the development of a single engine training procedure that has been recently implemented by 12 Wing. This training addresses a two-year gap in SE procedures.

4.1.9 The recommendations from DAEPM(M) 11500ED-80, SUTLOT Technical Findings Report, 26 Feb 04 were extensive and actioned via non-FSIR means.

4.1.10 DAR, DFS, and NRC are in the process of defining a cost-effective proposal to capture CVR and FDR data from the Sea King.

4.1.11 DFS has established an initiative to cross-reference FSIS report numbers and associated CF349 and CF543 ADP control numbers within the Performa application. Performa is a desktop database application for aircraft records that compiles CF349 and CF543 data from the ADAM and DMS systems; Performa is also used to track aircraft component issues.

4.2 Further Safety Measures Required

It is recommended that:

4.2.1 the acquisition of a crashworthy CVR and FDR capability for the Sea King is expeditiously pursued;

4.2.2 a fleet-wide routine functionality check of flight deck camera systems be incorporated into flying operations procedures;

4.2.3 a review of fight deck camera system operations be conducted with the intent of passing system control to the FLYCO or LSO positions;

4.2.4 a digital continuous loop video recorder be utilized with the flight deck camera system;

4.2.5 a review be conducted of the current procedure allowing observers to remain in the hangar area during flying operations;

4.2.6 HOTEF project H-2002-002 Evaluation of Modified Constant Wear Immersion Suit should include fire retardancy as a mandatory characteristic in the replacement of the existing constant wear immersion suit's wrist and neck seals;

4.2.6 a Single EngineTraining Needs Analysis be completed. Simulation options should also be considered; and

4.2.7 consideration be given to evaluating the use of power available versus power required for determining pilot actions in the event of an OEI situation in forward flight, during transitions to and from the hover, and while in the hover.

4.3 Other Safety Concerns

4.3.1 Although identified in 4.1.7 as safety measure taken, until the review and update of T58-GE-100 engine tuning procedures is completed this issue will be monitored by DFS.

4.4 DFS Remarks

The recent announcement of the Sea King replacement may cause a tendency to downplay the utility of the preventive measures outlined in this report as the phase out of the Sea King starts within the next few years. However, it must also be remembered that although the new aircraft will start to arrive in the near future, the CH-124 will continue to operate several more years until it is phased out and the new aircraft is phased in. Therefore, close attention must be paid to the recommendations of this FSIR so that Maritime Helicopter operations can continue within the safest environment possible for our personnel.

The technical investigation of this accident had to determine the validity of the evidence with respect to the two possible prime cause factors: a compressor stall caused by VG mis-tuning or SUTLOT. Without CVR/FDR data to exclusively support the conclusion of compressor stall or entirely refute the possibility of SUTLOT, it may be possible to debate either as causal to this accident. What must be kept in mind is that the aim of the flight safety program has been met through the identification of safety measures that will effectively deal with either potential cause.

Finally, it is clear that this accident exemplifies how the investigation process could have been streamlined had CVR/FDR data been available. This data would have allowed the investigation to focus on the root cause of the problem in a timely manner rather than painstakingly investigate multiple scenarios over a protracted period of time. The procurement of some type of CVR/FDR for the CH-124 is long overdue.

AD Hunter
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DFS

ANNEX A: T58-GE-100 ENGINE TUNING

1. GENERAL

The investigation determined that the number one engine tuning was incorrectly performed, although it could not be identified when or by whom it was done. Furthermore, the OEM's Field Service Representative (FSR) indicated in his response to DEAPM(M)'s request for technical support that the T58-GE-100 CFTO did not correctly detail the entire engine tuning procedure. Subsequent dialogue directly with the OEM reaffirmed that the current tuning procedures within CFTOs are valid, although the OEM has yet to refute the technical assertions made by the FSR in his support to DAEPM(M). This Annex explores the potential impact on an engine's performance in light of the FSR's comments. However, during recent investigative discussion, the OEM stated that on-wing tuning is not required as the SVA can be nominally set pre-installation during second or third line maintenance to allow a sufficient stall margin in all environments. The OEM also identified that on-wing tuning is not required because of the possibility that repeated on-wing adjustments increase the chance of setting the VG out of limits.

2. ENGINE TUNING

The T58-GE-100 engine variable geometry consists of the variable inlet guide vanes and the first three stages of the 10 stages of stator vanes. The engine's variable geometry (VG) is set (tuned) by adjustment of both the stator vanes and inlet guide vanes via the stator vane actuator (SVA). During the course of repair and overhaul, the initial engine tuning is done by ACRO. The engine is then built up at the field unit and run in the engine test cell where the VG can, if needed, be further tuned prior to installation in the aircraft. Once installed or "on-wing", the engine is further fine tuned to operational environmental temperatures before being declared serviceable.

The SVA is adjusted during the life of the engine when T5 temperature does not fall within limits as determined in the one point tuning check; this check identifies the Ng-T5 relationship. If this check identifies an incorrect relationship, then the SVA piston rod-end bearing is adjusted, to a maximum of two turns open and four turns closed, so that the correct Ng-T5 relationship is established within limits. When tuning the T58-GE-100, the SVA piston rod-end bearing is adjusted either in to shorten its length and thus decrease T5, or out to lengthen it and thus increase T5. This adjustment does two things:

a. it changes the angle of the VG, altering the maximum open and closed stop vane angles; and more critically

b. it also shifts the VG opening and closing schedules.

2.1 Changes to the VG Angle

The T58-GE-8F engine was phased out of service starting in 1997 when the upgrade process to the T58-GE-100 engine began. The upgrade process included modifications whereby an adjustment mark was included for reference to identify the stator vane actuating system's fully closed position on the SVA piston rod (the closed or "C-mark"); the neutral position indicator, or N-mark, was not altered during the upgrade process. The SVA piston rod is correctly aligned to the C-mark by adjustment of the closed vane stop jam nuts; this adjustment was not required on the T58-GE-8F. When correctly performed, this new adjustment ensures that the closed VG angle always returns to the requisite value of 48?. Although this modification and its use were properly documented in the new CFTO concerning T58-GE-100 engine maintenance, its awareness by maintenance personnel was poor. Specifically, it was not well known or understood that failure to properly adjust the SVA piston rod to the C-mark would result in an improperly closed stator vane position that, by not providing correct airflow ratios during the start procedure, would affect engine start and ground idle operations; the effect on engine operations below 65% Ng would be commensurate with the degree the VG angle would differ from the 48? value. Furthermore, the investigation determined that both numbers one and two engines had incorrectly adjusted closed stop vane angles. Albeit not causal to this accident, the lack of adequate training for this new engine component is significant in that it highlights a failure in the information/communication process concerning a critical aircraft component.

2.2 Shift of VG Schedules

The second and more significant impact of an SVA adjustment is that the VG schedule is also shifted. When the SVA is adjusted out, the vane angle, as a function of Ng, is more open. Alternately stated, for a constant VG angle the Ng is then lower; this is similar to a cold shift of a T2 sensor that measures inlet temperature. The reason this secondary effect on the VG schedule occurs is due to the mechanics of the feedback cable operation.

To better understand this secondary effect, first it is necessary to understand the SVA feedback cable assembly. An SVA pilot valve mounted on the engine's FCU directs fuel pressure to the open or closed side of the SVA as directed by the FCU's 3D cam. As the engine RPM increases, for example, the SVA opens the VG and thus increases the correctly scheduled airflow through the compressor. The feedback cable is moved by the SVA as it travels, sending a signal back (feedback) to the FCU pilot valve. Once the feedback signal equates to the selected position of the FCU's 3D cam, the SVA pilot valve returns to a neutral position and the SVA then ceases to open the VG.

Due to the kinematics of this system, when the SVA is adjusted and the open or closed vane jam nuts are re-adjusted to maintain the correct vane maximum or minimum angles, the resultant feedback cable position at the pilot valve is also changed. For example, if the SVA piston rod-end is adjusted two turns out from the N-mark, the jam nuts are properly re-adjusted, and no feedback cable adjustment is made, the position of the feedback cable then results in the VG opening earlier than before ie at lower Ng speeds. The effect of not making this change equates approximately to 150 RPM per full turn of the SVA piston rod-end. The reason that this is significant is that the compressor deceleration stall boundary is on the open side of the VG schedule. Therefore, the further the VG opens, the closer to the deceleration stall boundary the engine operates during a transient input, for example, when collective pitch is changed; during transient inputs, control system lags can amplify the effects on the VG. Additionally, compressor fouling by dirt or salt encrustation will also cause the stall boundary to migrate closer to the steady state VG schedule. The combination of these two conditions can significantly reduce the deceleration stall margin on the T58-GE-100 engine when the SVA piston rod-end is lengthened. In contrast to this, the opposite adjustment or shortening of the SVA piston rod-end will increase the deceleration stall margin; it is therefore not as critical an adjustment.

In accordance with the CFTO, when the engine tuning adjustment (lengthening or shortening the SVA piston rod-end) is made to an installed engine, the feedback cable is not adjusted: "a stator vane schedule check cannot be carried out on an engine installed in a helicopter. Therefore the feedback cable effective length adjustment shall be performed on an engine installed in a mobile engine test stand or engine test facility only. " However, engine tuning is routinely carried out on installed engines. The potential impact of not adjusting the feedback cable is therefore clear: when tuning the engine, particularly to the open VG side, it is crucial to also adjust the feedback cable to ensure correct and complete engine tuning. Therefore, with the number one engine incorrectly tuned towards the decelerative stall boundary, the possibility existed that, because the SVA feedback cable adjustment is not incorporated in the on-wing tuning procedure, the existing stall-susceptible condition of the engine may have been further exacerbated to the point of compressor stalling.

2.3 Other Operators

The tuning procedures of some operators outside of the Maritime Helicopter community have diverged from those identified within CFTOs: the USN H-3 fleet only tunes on-wing T-58-GE-100 engines to the closed side of the SVA (the direction of the adjustment does not affect the engine's safety margin because it does not decrease the deceleration stall margin) and the USN H-46 fleet has ceased on-wing engine tuning entirely (once the tuning is set in the engine test facility or mobile engine test stand it is left alone, regardless of OAT). This shift away from on-wing tuning was mostly driven by the propensity for incorrect SVA adjustments to be made at the rod-end bearing.

3. CONCLUSION

It is concluded that current T58-GE-100 engine VG tuning CFTO procedures are in accordance with existing OEM manuals and guidance. However, the rationale behind not completely refuting the OEM's FSR's comments has not been provided by the OEM. Until the OEM's FSR's observations are fully discounted based on technical merit, the possibility remains that, by not including the SVA feedback cable adjustment in the existing on-wing engine tuning procedure, the number one engine's already reduced decelerative stall margin could have been further reduced. Therefore, the omission of SVA feedback cable adjustment from the on-wing tuning procedure may have been contributory to the loss of lift suffered by CH12401 over IROQUOIS' flight deck. As part of an overall review of engine tuning procedures by the Sea King WSM office, ACRO Aerospace has been tasked to look at the validity of on-wing tuning with the view to eventually removing the procedure altogether as per OEM direction.

ANNEX B: SEA KING SINGLE ENGINE TRAINING

1. GENERAL

During the transition from the Mark 1 to the Mark 3, single engine (SE) operations training within the MH community began to erode until the point that it became ineffective.

2. DEVELOPMENT OF THE MARK 3

2.1 Engines

Starting in 1997, the Sea King and Labrador T58-GE-8F (the -8F) engine entered an upgrade program to modify it to the T58-GE-100 (the -100) model. This program was developed because these two aircraft fleets were the last users of the -8F engine and this relatively small market was no longer feasible to support from a logistics perspective. The resultant upgraded engines produced a minimum of 15% more power.

2.2 Main Gear Box Transmission

As the Sea King's 21,000 (21K) series MGB was deemed insufficiently robust to accept the upper limits of the upgraded T58-GE-100 engine output, a parallel yet separate program was initiated to upgrade the MGB to the 24,000 (24K) series.

2.3 Configurations

As upgraded engines and MGBs became available, three configurations (Marks 1, 2, and 3) of Sea King aircraft were developed over several years. The final configuration upgrade to the Mark 3 with the -100 engine and the 24K MGB was completed in spring 03.

2.3.1 Mark 1 (original)

This nomenclature was used to distinguish the "base-line" Sea King from the variants modified during the drive train upgrade. It should be noted that this engine/MGB configuration generally provided that the engine power output did not exceed MGB torque (Q) limits during SE profiles.

2.3.2 Mark 2 (transitional)

As the MGB upgrade program was slightly behind the relatively fast-paced engine conversion program, it was necessary to install -100 engines with the old 21K MGB until 24K MGBs became available. This configuration was not ideal because the newer engines could often exceed the Q limits of the old MGB.

2.3.3 Mark 3 (end-state)

As upgraded MGBs became available, they were installed to convert Mark 2 aircraft to Mark 3 aircraft; however, toward the end of the program it was more common to convert Mark 1 aircraft directly to Mark 3 aircraft as -100s and 24Ks became available concurrently. Ideally, this was to have happened in all cases, thereby not requiring the Mark 2 option. The last Mark 1 aircraft underwent configuration upgrading in fall 02. The Sea King fleet was completely reconfigured to the Mark 3 by spring 2003.

3. ENGINE POWER ISSUES

The "average" -100 engine produces approximately 135-140% Q, well above the maximum 21K design limit of 130%. The traditional method of conducting SE training from the 15’ hover by retarding an engine SSL sufficiently enough to disengage the engine from driving the MGB became no longer possible as the "good" engine would quickly go to topping (max power output) and spike or sustain >130% Q. This exceedence of the allowable limits would render the MGB unserviceable. In the event of an engine-topping situation in the Mark 2 (eg engine failure or flex shaft failure), the topped engine would likely exceed both the SE transient and maximum limits. This mis-match of performance and procedure was significant in that it created opposing views on the reaction to an MGB over-torque:

a. Over-torque "not an issue". Pilots that felt the 21K would not "come apart" and would plan to reduce or mitigate the higher Q, but continue flying to a suitable landing site and declare the MGB U/S after landing; or

b. Over-torque "serious". Pilots that considered the limits as absolutely critical stated that they believed the MGB would self-destruct rapidly and catastrophically; therefore, the only option was to land immediately or ditch.

The initial engineering direction to not exceed the 130% maximum Q or the 5 second transient limit was inadequate. Operator frustration ensued because, depending on a pilot’s view, loss of life and/or aircraft was probable in that:

c. the decision to fly with an imminent MGB break-up could result in an uncontrolled crash; or

d. the decision to ditch with a flyable, albeit U/S MGB, could result in the loss of aircraft and possibly life (sea state, day/night, distance from land/ship, etc depending).

In June 2000, DAEPM(M), the engineering authority, was asked to provide direction on specific emergency handling actions. This was needed because, despite the existing MGB limitations, over-torque occurrences were highly probable and potentially left aircrew to devise their own response to SE emergency situations. After 16 months (Oct 2001), almost at the end of the Mark 2 configuration phase, DAEPM(M) provided some guidance for the Part 3 Emergency Section of the Aircraft Operating Instruction (AOI) and the pilot checklist.

Although the new Mark 3 maximum SE Q limit of 150% virtually eliminated the possibility of high-end over-torque situations, the 5-second SE transient Q limit of 123-150% remained. Although only destructive testing of the new 24K MGB could provide empirical support for redefining broader transient Q limits, its expense prevented it from taking place. Thus the "traditional" practice SE sequences and exercises were precluded from occurring, particularly in the high power demand regimes such as in the hover or near Safe Single Engine Speed (SSES), until Jan 04 when the engine de-topping procedure was put in place. This procedure allows an engine to be de-topped and therefore prevents it from over-torquing the MGB during a practice SE scenario when the non-de-topped engine is taken off line. Subsequently, all the in-flight SE training, including Waterbird, has been re-instated.

4. OPERATIONAL CONCERNS

The Standard Manoeuvring Guide (SMG) states that when in visual flying conditions (VFC), the pilot has the option to conduct a flyaway and exchange altitude for airspeed, though this is dependant on ambient conditions and aircraft weight. When in instrument flying conditions (IFC), if below SSES an immediate landing is to be carried out; when above SSES with power available (PA) greater than power required (PR), a flyaway is to be attempted. However, in instances where the PA is marginally less than PR, SMG guidance requires the aircraft to be ditched even though it may have been possible to conduct a flyaway.

The current indicator for SE performance is based on airspeed. In the Mark 1, which was almost always power limited (except during cold temperature and high wind conditions with light aircraft weights), the SSES was so high (PA < PR) that in the event of an engine failure in the hover, an immediate landing was the only effective option. With the Mark 3's increased engine performance and lower SSES over the Mark 2 and Mark 1, pilots have re-evaluated the "what-ifs" with respect to improved SE performance. In the event of a loss of power situation, many pilots have begun to use Q rather than SSES as the basis of their assessment of flyaway capability despite SSES chart guidance; this is a result of the positive influence of greater PA and allows, in certain instances, a fly away when the AOI calls for an immediate landing. Airspeed measurement in the 20-30 KIAS region can be inaccurate due to instrument position error and the effects of main rotor wash induced airspeed; accurate airspeed information with the now reduced SSES is crucial when deciding whether or not to ditch. Thus Q becomes a more accurate and dynamic indicator of PA versus PR instead of SSES. Q is used by both the Royal Navy (RN) and the Royal Australian Navy (RAN) Sea King fleets and the CF's Griffon and Cormorant fleets for accurately assessing flyability in one engine inoperative (OEI) situations.

To illustrate how Q can be effectively used to identify aircraft performance, the following scenarios were constructed using a maximum SE PA Q of only 120%. Note that the SE PR to maintain a hover is exactly twice that of Dual Engine and also that on an ICAO standard day, for example, anticipated SE Q could be as high as 135-140% or more.

a. PA > PR. In the case where Dual Engine Hover Q is 58%, 116% SE would be required to hover. In this situation power in excess of the minimum Q required to hover exists and no rotor droop would occur. Therefore the current pilot checklist direction would result in an unnecessary controlled hover landing (ditching) even in IFC;

b. PA ~= PR. In the case where Dual Engine Hover Q is approximately 60%, 120% SE Q would be required to hover. In this situation the rotor would be on the verge of drooping and during a flyaway procedure, depending on pilot technique, some rotor droop would likely occur during the transition to forward flight. This then presents a situation in which the aircraft could likely conduct a flyaway with minimal rotor droop below 103%. The normal range of rotor speed (Nr) is from 91-117%;

c. PA < PR (significant). In the case where Dual Engine Hover Q is 85%, in an SE situation, 170% SE Q would be required to hover. In this situation an immediate controlled hover landing is necessary to avoid total loss of lift and an uncontrolled descent; and

d. PA < PR (minor difference). This scenario is presented last because there are several variables and "unexplored" areas of performance. In the case where Dual Engine Q is 65%, 130% SE Q would be required to hover but only 120% SE Q would be available. This would result in some Nr decay, however, it is not known at what Nr the gains of this reduced Nr and the resultant reduced induced drag offset the associated loss of lift. Aircrew who have received SE training experience in the Mark 1 are aware that the Sea King flies well at 96% Nr and can continue flying with Nr down to 92%. The newer generation of aircrew who have come on line since the Mark 3 introduction have not been exposed to this flight regime. Additionally, information with respect to Nr decay relative to the amount of PA < PR is not currently available to MH aircrew.

Within their manoeuvring guide, RN and RAN Sea King operators refer to the “Dunking Bucket” to define pilot actions at various Q settings for all stages of the transition to and from the hover. This “dunking bucket” effectively details the requisite actions for all the above-described scenarios (sub-paragraphs 4a-d). Even by simple reference to the term “dunking bucket,” it becomes clear to each RN and RAN Sea King pilot what his actions are at each phase of the transition, eliminating speculative or ad hoc procedures from developing. Although these non-CF fleets have different SSL configurations than the CH124, it is felt that this procedure would be transferable and applicable to the CH124 fleet.

5. TRAINING ISSUES

Training should closely emulate operational scenarios provided that unnecessary risk to personnel or equipment does not exist. Current SE training, including Waterbird, is effective albeit incomplete as it can only be done in the aircraft and can't accurately be applied to critical environments such as over a frigate's flight deck. It is therefore necessary that a thorough SE Training Needs Analysis be completed with the following components considered:

a. Simulator. The Sea King Operational Flight Tactics Trainer (OFTT) is not a simulator; it is more accurately described as a full-motion non-visual procedural trainer. The training mandated by CADORDs has been amended to include an increased emphasis on simulator SE scenarios, including hover, transition to/from hover, and forward flight. However, due to its limitations, the OFTT's realism was and remains questionable with respect to accurately and dynamically representing SE performance, not to mention loss of tail rotor drive, loss of tail rotor control, water operations, and autorotation scenarios. During pilot emergency sessions in the OFTT, any SE training from hover is often dismissed due to negative training impact. The OFTT often provides aircrew with indications that are inaccurate when compared to actual aircraft performance. This false knowledge transfer to the aircraft creates potentially dangerous situations;

b. Alternate Simulation. There are existing non-CF Sea King visual simulators that can provide SE performance and other non-related sequences. The CH149 community is currently seeking alternate simulation training within the UK due to a lack of national resources. The Helicopter Maritime Environment Trainer, a virtual reality based training device, has not yet been developed to the point of integration in to routine training where it may one day be used for SE training in critical flight regime environments; and

c. Flight Deck Mock-Up. Until the mid 1990's, the Flight Deck Mock-Up at 12 Wing was routinely used to provided the visual references for the training of both aircrew and maintenance personnel in the numerous flying evolutions conducted on or over the flight deck; although still in existence, it does not appear to be widely used. With respect to SE training, the Flight Deck Mock-Up was invaluable in that it provided a platform to conduct SE profile approaches and landings to a confined landing area with the safety of an open and unobstructed prepared surface. Similarly for deck landing practice, this asset should be reconsidered for inclusion into formal training syllabi.

6. FLIGHT SAFETY CONCERNS

In general, aircrew respond to rule-based procedures in several ways:

> a. Reasonable/Logical Direction. Except in few cases, most follow direction because it is sensible and has been demonstrated to be valid by previous experience; and
>
> b. Over-restrictive/Illogical Direction. Many dismiss or ignore direction based on opinion, particularly if the scenario results in an adverse outcome. For example, ditching an aircraft that is still flying with little or no rotor droop even though airspeed is <SSES is illogical. Therefore there is a predictable tendency to mitigate (ignore) the direction provided and devise a substitute procedure. This makes standardization difficult and allows the potential for the substitute procedure to be beyond the capability of the aircraft or the pilot.

Therefore, unless reasonable and logical emergency handling direction for power-critical situations is available, the potential will remain for pilots to develop their own procedures.

7. SUMMARY

The evolution to the current Sea King Mark 3 configuration negatively impacted effective SE training within the MH community until Jan 04 when a new procedure was put in place that allowed the conduct of SE training without potentially over-torquing the MGB. Given the length of time that it took to implement effective SE training with the Mark 3, coupled with the delays in providing guidance for Mark 2 operations, it is apparent that some pilots are not wholly confident of the current use of SSES to determine in-flight, overshoot, and hover-flight capability when viewed in light of the PA/PR relationships. Although the overall community proficiency with SE training will slowly re-establish itself, the outstanding issue of how to effectively train for SE situations remains. It is therefore crucial that this Training Needs Analysis be completed so that situations will not arise where pilots develop procedures based on their own abilities and perceptions of aircraft performance.

ANNEX C: PHOTOGRAPHS

Photo 1: At Rest on the Flight Deck

Photo 2: Number One Engine Compressor

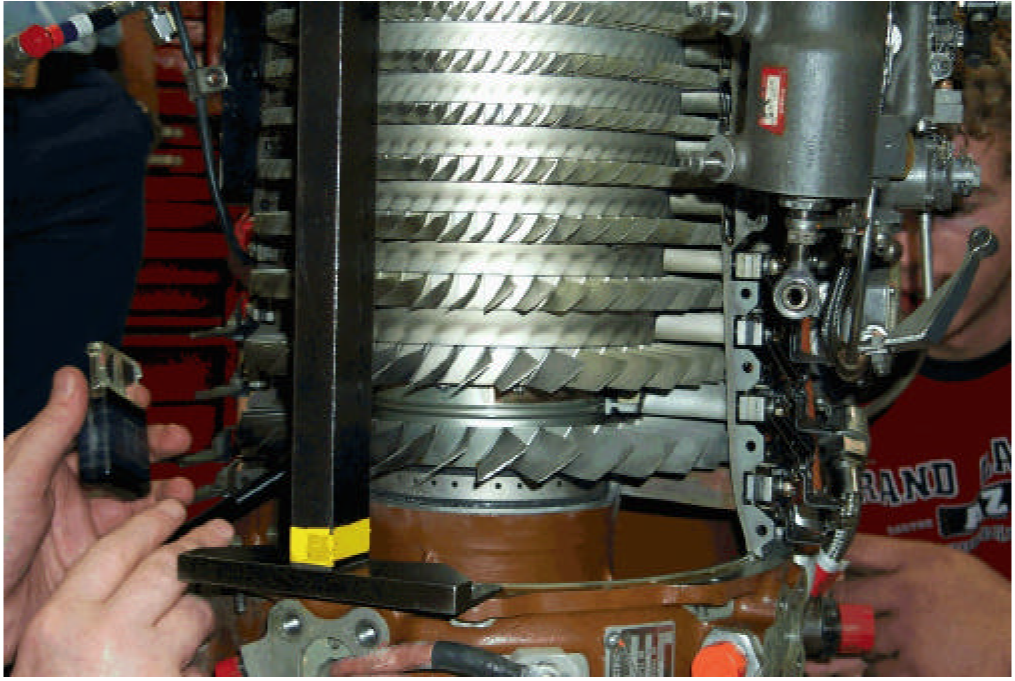

Photo 3: Salvage Operations

ANNEX D: SUTLOT EXECUTIVE SUMMARY, DAEPM(M) 11500ED-80 26 Feb 04

EXECUTIVE SUMMARY

BACKGROUND

1. Since October 2003, the CH124 Sea King helicopter community has been working to identify the cause(s) behind a phenomenon now commonly known as Sudden Uncommanded Transient Loss of Torque (SUTLOT). Two aircraft, CH12434 and CH12410, are believed to have experienced this phenomenon. A risk assessment conducted by the operational community resulted in the imposition of severe operational restrictions on all Sea King flights. A technical investigation of unprecedented magnitude was initiated.

PURPOSE

2. The purpose of the attached report is to highlight the technical findings and provide credible conclusions as to the most likely cause(s) of the two incidents.

FINDINGS

3. During the technical investigation, a series of related and non-related technical discrepancies were identified. Specifically attributed to SUTLOT as contributory cause factors are:

a. Different engine acceleration performance due to adjustments;

b. Engine Speed Selector Levers (SSLs) friction locks below specifications; and

c. Numerous faults and anomalies within the torque indicating system.

4. Both incident aircraft (CH12434 and CH12410) experienced similar but not identical symptoms. The initial theory developed to explain this phenomenon was based on the presence of three main elements (engine mismatch/torque splits, different engine acceleration performance and significant collective control input). This so called “SUTLOT Theory” has since been further supported by the two incidents’ factual technical and testimonial evidence.

5. A series of potential scenarios for each aircraft such as a main gear box slippage/spit out, fuel starvation to the engine, engine roll back, internal failure of the engine fuel control unit and a false indication problem were investigated and ruled out or deemed to be unlikely. Therefore, the emphasis of the investigation was placed on the cause and consequences of inadequate engine load sharing.

6. Based on technical findings and aircrew testimony, it is believed that due to the anomalies noted with aircraft CH12434's torque indicating system (transient and static torque splits), the aircrew (in a attempt to match torque indications) were in fact introducing a mismatch in engine power output. This, coupled with a differential in engine acceleration performance and a specific engine operation regime (wave off immediately after landing did not allow for the engines to stabilize), may have caused the engine at the lower setting to momentarily freewheel (a built in gearbox design feature to allow autorotation). This allowed a significant rotor speed (Nr) droop to a point where the aircraft lost lift. Subsequent additional rotor droop allowed the incident decouple engine to re-couple and return to normal operation. Immediately following the incident, the aircraft launched again and returned to the unit. It is believed with a high degree of confidence that the anomalies listed above caused CH12434's incident to occur.

7. Although aircraft CH12410's incident was similar to that of CH12434 in that it experienced a large transient torque split, no loss of lift was experienced. Therefore, CH12410 suffered a SUTLOT related incident of a lesser magnitude than CH12434. In CH12410's case, it is not believed that the incident engine freewheeled. It has been confirmed that CH12410's torque indicating system was giving erroneous indications and, as in the incident involving CH12434, the aircrew (unbeknownst to them), were likely inducing a mismatch in engine power output based on false torque indication. The probable reason for the extended duration of the incident in CH12410 is the debris found in the associated torque indicating system restrictor. This likely prevented a change in the incident engine indicated torque. Once the large torque split was noticed, the aircrew entered into a 'fly-away' situation where the collective input was reduced, allowing for the particle to become dislodged. The aircraft returned to unit without any further incident. CH12410's incident explanation has been provided but with a lesser degree of certainty then for CH12434.

8. Aircraft CH12426 did not suffer a SUTLOT related incident. Its torque indication system was erroneous due to an incorrect restrictor installed, creating up to 100% transient torque splits.

CONCLUSION

9. Each related incident has been thoroughly reviewed using all available technical and testimonial information. In each case, application of the SUTLOT theory explains the reported occurrences to different levels of confidence. However, all other scenarios have been ruled out or deemed extremely unlikely. The phenomenon referred to as SUTLOT can only occur if a series of specific conditions are present and coupled with technical anomalies. It is considered very unlikely that those conditions could be reproduced with a high degree of confidence in order to quantify or replicate these incidents.

10. As all identified technical anomalies/discrepancies can be easily overcome through implementation of concrete measures, it is assessed that once these corrective actions are implemented, the probability of reoccurrence of a SUTLOT incident will be reduced to “remote.”

11. Accordingly, the SUTLOT technical investigation into the two incident aircraft 434 and 410 is considered closed.

RECOMMENDATIONS

12. A comprehensive list of actions undertaken as a result of this technical investigation is available from the CH124 WSM, DAEPM (M) 3. The key recommendations derived from findings are as follows:

a. To ensure its reliability the aircraft torque indicating system must be calibrated and checked regularly for accuracy;

b. Engine acceleration performance must be reasonably matched;

c. A monitoring program for Engine/torque matching/trending must be established;

d. Engine Speed Selector Levers friction lock inspection frequency must be increased;

e. Aircrew instructions must be amended to promulgate acceptable transient and static torque splits and the requirement to perform torque matching prior to every flight;

f. Current Aircrew Order (ACO) pertaining to SSL limitations should be revised to clarify the use of max Nr during take offs and landings and flight below safe single engine speed (SSES);

g. The Sea King community must be reminded of the importance of reporting even minor aircraft anomalies, so that they can be appropriately investigated; and

h. Re-open aircraft CH12401 fight safety investigation to assess SUTLOT implications.

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