Department of Trade

ACCIDENTS INVESTIGATION BRANCH

Sikorsky S-58 G-BCRU
Report on the accident in the North Sea, Forties Field Platform 'Charlie', on 21 April 1976

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Department of Trade
Accidents Investigation Branch
Shell Mex House
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London WC2R 0DP

22 June 1977

The Rt Honourable Edmund Dell MP
Secretary of State for Trade

Sir,

I have the honour to submit the report by Mr P J Bardon an Inspector of Accidents,on the circumstances of the accident to Sikorsky S-58 G-BCRU which occurred in the North Sea on 21 April 1976.

I have the honour to be
Sir
Your obedient Servant

W H Tench
Chief Inspector of Accidents

Accidents Investigation Branch
Aircraft Accident Report No. 6/77
(EW/C559)

Operator:		Bristow Helicopters Ltd
Aircraft:	*Type:*	Sikorsky S-58
	Model:	ET
	Nationality:	United Kingdom
	Registration:	G-BCRU
Place of Accident:		British Petroleum Company's Forties Field Platform 'Charlie', North Sea
		Latitude 57° 43′ 21″ N
		Longitude 00° 50′ 51″ E
Date and Time:		21 April 1976 at 1320 hrs

All times in this report are GMT

Synopsis

The accident was notified by Bristow Helicopters Ltd (BHL) to the Accidents Investigation Branch (AIB) at 1535 hrs on 21 April 1976. The AIB informed the National Transportation Safety Board (NTSB) in the USA that the accident had occurred and invited them to appoint a US accredited representative to participate in the AIB inquiry. The NTSB did not send an accredited representative but asked that Sikorsky Aircraft be permitted to participate in the investigation, and this was done.

The accident occurred during a daytime visual flight between two platforms of the Forties Field in the North Sea. The helicopter went out of control as it was about to land on one of the platforms. It bounced on the heli-deck and fell off to crash 140 feet below on to the deck of a crane barge lying alongside.

The report concludes that the probable cause of the accident, based upon the limited physical evidence available as regards tail rotor damage, was tail rotor instability arising from some undetermined cause, which resulted in the whole tail rotor assembly becoming immediately detached.

1. Factual Information

1.1 History of the flight

G-BCRU was on a domestic non-scheduled air transport flight in daytime from Aberdeen (Dyce) Airport to the British Petroleum Company's Forties Field Platform *Charlie* via the nearby Platform *Bravo.* The helicopter landing deck (helideck) on Platform *Charlie* was of octagonal planform, the principal dimensions being 65 feet x 65 feet. The deck was 158 feet above mean sea level (amsl) and projected from the eastern face of the platform. Alongside this face lay the derrick barge *Thor* which was anchored on a northerly heading with its large crane extended out on the port beam (see Appendix A).

G-BCRU left Aberdeen at 1152 hrs, landed on Platform *Bravo* at 1303 hrs and took off for *Charlie* at 1310 hrs. Aboard were the pilot and nine passengers; one of the passengers was in the left cockpit seat and the other eight were in the cabin. After a short period circling *Charlie* to allow another helicopter to leave the helideck, the pilot checked the cockpit instruments and found all indications were satisfactory.

The wind was from 025°/14 to 16 knots and the pilot decided that because of the position of the *Thor's* crane the best approach path lay over the *Thor* on a heading of 280°M. The pilot set main rotor speed (N_R) at 100 per cent, the figure used for take-off and landing on oilrigs, and commenced the approach. The pilot stated that as the helicopter was approaching the edge of the helideck a rapid sequence of events ensued as follows: firstly he felt a strong medium frequency vibration through the yaw pedals, and then heard a rapid rise in engine speed. Next he looked at the engine instruments and saw both torque needles increasing together to over 100 per cent although collective pitch had not been increased. The helicopter then started an uncontrollable yaw to the right. The pilot assumed that there had been a tail rotor failure of some sort and attempted to set the helicopter down on the helideck. The aircraft, however, was out of control and went off the helideck in a south-easterly direction, crashing on to the deck of the *Thor* 140 feet below.

During the investigation, when it was explained to the pilot that it was important to discover if there had been any previous instances of an unusual vibration during the flight from Aberdeen, he recollected that there had been a momentary vibration through the yaw pedals as the helicopter gained translational lift on take-off from Aberdeen. The wind had been light and variable and 93 per cent N_R had been set for take-off. After the vibration disappeared the aircraft behaved normally throughout the flight until the time of the accident, including the landing and take off at *Bravo* at 100 per cent N_R and with the wind on the starboard bow. The pilot said that the vibration at Aberdeen was similar to that experienced at *Charlie,* but nothing like as severe.

The evidence of the passengers was to the effect that the flight was a normal one until the helicopter neared the edge of Platform *Charlie's* helideck when there was an abnormal and severe vibration, which two of them identified immediately as coming from the tail rotor. Some of the passengers also noticed a rapid increase in engine note. All were certain that the symptoms they noticed came before the helicopter went out of control and struck the helideck.

Eyewitness statements were to the effect that the helicopter was nearing the edge of the helideck in an apparently normal approach when pieces flew off the tail rotor at high speed, and that this was accompanied by a sudden rise in engine noise. The helicopter was then seen to bounce twice on the helideck, yawing to the right, and to fall off the south-east edge on to the *Thor.*

1.2 **Injuries to persons**

Injuries	Crew	Passengers	Others
Fatal	–	1	–
Serious	1	5	–
Minor/none	–	3	

1.3 **Damage to aircraft**

The aircraft was destroyed by the impacts on the helideck and the *Thor*, and by a post-crash fire.

1.4 **Other damage**

Platform *Charlie* and its helideck were undamaged. Multiple damage was done on the *Thor* to the main crane operator's cabin, and to deck superstructure and equipment. This damage was almost entirely caused by the impact of the fuselage and rotating main rotor-blades, but there was also fire damage to paint work on the deck and the engine room housing.

1.5 **Personnel information**

Flight crew

The pilot was the sole flight crew member. Relevant details concerning him are as follows:

Age:	26 years.
Licence:	Airline Transport Pilot's Licence (Helicopters) with Instrument Flying Certificate of Competence. The licence was endorsed for the S-58ET and was valid.
Mandatory tests:	Last Certificate of Competence on the S-58 was dated 22 December 1975. Last Route Check on the S-58 was on 22 October 1975.
Flying experience:	Total hours: 2,360
Total hours on helicopters:	2,275, of which 1,675 were on the Westland Wessex.
Total hours on S-58ET:	490.
Total hours in last 28 days:	20:35, all on the S-58 ET.
Duty time:	The pilot's duty times in the previous 7 days were well within prescribed limits.

1.6 Aircraft history

The aircraft (Serial No. 58-1092) was purchased in 1974 as one of a batch by Bristow Helicopters Ltd (BHL) from a company in the United Technologies Corporation Group. It had completed 3,130 hours as a piston engined H34A. It was converted to the civil S-58ET standard by BHL in accordance with schedules issued by the manufacturer ('E' signifies a converted aircraft to distinguish it from new built aircraft). The original powerplant was replaced by a new Pratt and Whitney PT6T-6 Twinpac installation. The helicopter came on to the British register in November 1974 and the CAA granted it a British Certificate of Airworthiness in March 1975.

At the time of the accident the aircraft had a valid certificate of airworthiness in the transport category (passenger), and a valid certificate of registration. The records show that it had been maintained to the approved maintenance schedule and it had a valid certificate of maintenance. All lifed components were within their life limitations and the application of service bulletins relevant to the tail rotor and its control system was up-to-date. However, following cases of cracking in the tail rotor gearbox intermediate casing Sikorsky Aircraft had introduced a number of modifications and revised maintenance procedures. All of these had been complied with on G-BCRU with one exception, which was a modification to introduce longer studs to the tail rotor gearbox intermediate casing to increase stud retention. The relevant Sikorsky service bulletin, number 58B35-19 dated 23 April 1975 stated, in part:

> 'Compliance. The manufacturer believes compliance to be essential and recommends accomplishment of the work outlined herein during the next tail gearbox overhaul'.

The S-58ET tail gearbox has an overhaul life of 3,000 hours. At the time of the accident G-BCRU's box had done 993 hours since the last overhaul. Thus under the terms of the service bulletin this modification was not required for more than another 2,000 flying hours.

The aircraft's control system incorporated a main rotor speed (N_R) governing system which could be set to selected speeds by the pilot through a trim switch. The BHL Operations Manual, Part 5, S-58T Operating Procedures, stated that N_R was to be set at 100 per cent in the Pre Take-Off Vital Actions, at 93 per cent in the After Take-Off Actions, and at 100 per cent in the Approach and Pre-Landing Checks.

However, in accordance with a Company instruction, 93 per cent N_R was used for take-offs and landings from non-critical sites in order to reduce vibration levels. Though this rotor rpm setting had not been formally approved for use at the time, formal approval would have been given by the CAA had it been requested.

The tail rotor is controlled through a hydraulically boosted cable system with push-pull rods connecting a rear fuselage bellcrank to the rotor. The hydraulic servo operates on the tension difference between the two cables and, as the system is a boosting system with the power piston in series with one of the cables and not a fully powered system, the yaw pedals have a direct mechanical link to the rotor blade pitch change mechanism.

The cables are rigged to a specific tension and a spring inserted in one of the cables has as its main function the tuning of the rate of the whole tail rotor system to avoid unwanted resonances. The spring also maintains the tension over a wide range of ambient temperatures.

The helicopter was equipped with a three axis Sikorsky stability augmentation system (SAS). In the yaw channel it improves dynamic stability and its authority is limited to 10 per cent of total control range.

Other relevant information is as follows:

Total hours flown:	4,123
Total hours as S-58ET:	993
Hours since last certificate of maintenance (50 hour maintenance period):	47
Total engine hours:	1,001 (No. 1) 993 (No. 2)
Maximum weight authorised:	13,000 lb
Estimated weight at last take-off:	12,447 lb
Estimated weight at time of accident:	12,397 lb
Centre of gravity range (accident weight):	129.6 inches to 146.7 inches aft of datum
Centre of gravity at time of accident:	142 inches aft of datum
Estimated fuel remaining at time of accident:	1,450 lb
Fuel type:	Jet A-1
Maximum permitted speed (sideward flight):	25 knots

1.7 **Meteorological information**

The weather at the time of the accident was:

Wind:	025° 14 to 16 knots
Visibility:	8 to 10 nautical miles
Cloud:	6 oktas strato-cumulus, base 600 to 700 feet
Temperature:	+7°C (+45°F)
QFE:	1026 millibars
Sea state:	A south-westerly sea, mean 3 feet and maximum 5 feet
Light:	Good daylight

1.8 **Aids to navigation**

Not relevant.

1.9 **Communications**

G-BCRU first contacted the BHL Forties Field Controller (based on Forties *Charlie*) at 1245 hrs and was passed the weather. At 1310 hrs G-BCRU reported that it was airborne from Forties *Bravo* for Forties *Charlie* with ten souls on board, 75 lb of baggage, 15 lb of freight and 1,500 lb of fuel. At 1318 hrs the pilot informed the Controller that he was 'landing at Forties *Charlie*'. This was the last transmission from the aircraft.

1.10 Aerodrome information

The helideck of Platform *Charlie* was positioned on the eastern face of the platform 158 feet amsl. The deck was octagonal in shape, with a distance of 65 feet between opposite faces. On the deck surface was marked a 23 feet radius landing circle for S-61 aircraft, and a concentric 13 feet radius circle for S-58 and other smaller helicopters. This landing area was covered by a 50 feet square deck net of 12 inches mesh tautly stretched. The deck surface was painted with an anti-slip, fuel resistant finish.

The BHL Operations Manual Part 2, Flight Operations, Section 2, Offshore Operations, stated:

> '1.4 OBSTRUCTIONS
>
> Further to the obstruction clearances previously stated it is recommended that an approach and take-off sector should be kept clear of all obstructions.
>
> This clear sector may be defined as an arc of 210° drawn from a point on the periphery of the recommended minimum sized flight deck, and totally including that deck. Within this area no obstructions on the structure of the installation should rise above the level of the flight deck.'

The considerable obstruction created by the *Thor's* crane within this sector was not unusual on North Sea rigs, and it was within the pilot's discretion to accept it, provided a safe approach could be made cross wind within the limitations of the aircraft, as was the case in this instance. (See Appendix A).

1.11 Flight recorders

No flight recorder or cockpit voice recorder was required or fitted.

1.12 Wreckage and impact information

1.12.1 Accident site

Wreckage was found in three separate locations: on the oil rig Forties *Charlie*, on board the *Thor*, and on the seabed at a depth of 400 feet. On the helideck some heavy rub marks and surface scratching were apparent but they were discontinuous and could not necessarily be associated with G-BCRU. The main wreckage found on the helipad comprised the tailwheel with part of its yoke, the starboard ventral aerial, parts of the passenger entry step (starboard side) and fragments of the lower attachment of the starboard undercarriage strut. There were also numerous skin rivets which appeared to have come from either the tailwheel area or the starboard mainwheel attachment area and are evidence that either or both of these parts of the fuselage structure were disrupted in the impact on the helideck. The tailwheel had pivoted fully to starboard before breaking, indicating aircraft starboard yaw at impact. A tail rotor blade pocket (the honeycomb sandwich trailing edge portion of the blade) and its leading edge tip cap (see Appendix B) were found on a walkway on the southeast corner of the rig at about 70 feet above sea level.

The mass of the wreckage was found on the barge *Thor*, lying between the main crane and the engine room deckhouse. The passenger cabin and cockpit were substantially intact but with some crumpling in the area of the yaw pedals. The engine bay, lower cockpit and forward cabin areas had been severely fire damaged. The tail cone was badly damaged by impact and the tail had broken off forward of the tail folding hinge. The tail rotor gearbox intermediate casing was found to have fractured and the whole tail rotor assembly aft of this point, with the exception of the one blade pocket found on the oil rig, was missing (see Appendices C and D).

The main rotor blades were badly bent and broken. The outer portions of all four blades were missing and this damage is attributed to the impact on the *Thor.*

The horizontal stabiliser had separated on impact and was lying with the main wreckage. The starboard main landing gear lay apart from the fuselage, separation being considered to have occurred on the helideck.

A systematic search of the sea bed around Platform *Charlie* was carried out using a manned submersible and divers operating from a bell in an attempt to find any tail rotor items, but only one major section of main rotor and some other minor debris were recovered.

1.12.2 Subsequent examination of wreckage

After the on-site inspection the wreckage was removed for detailed examination.

From the beginning of the investigation it was evident that the accident had its origin in a loss of yaw control and the investigation centred around the tail rotor and its control system. However, examination of the engines established that they had been developing high power on impact and there was no sign of an overspeed or overtemperature condition. Examination of the rest of the helicopter revealed no evidence of any pre-crash damage, failure or malfunction.

The tail rotor gearbox was found to have fractured through the intermediate casing with several attachment studs having been pulled out (see Appendix D). Examination established that the fracture was characteristic of a static overload failure.

An examination of the detached rotor blade pocket was carried out. There was so little damage to the pocket that it could not have become detached through an impact. A study of the fracture led to the conclusion that the pocket had come off in a high speed continuous tear from tip to root. The failure was not a progressive one such as would result from a bonding fault or fatigue. Specialist opinion was that a failure of this nature could only be the result of forces generated during a tail rotor flutter. Pockets damaged in a similar manner had been seen in tail rotor flutter incidents in another type of helicopter with similar blade construction, namely the Sikorsky S-61.

The tail rotor transmission shaft was still connected to the main rotor gearbox but had separated at the centre flexible coupling. One section of the shaft was deformed in a manner consistent with either over-torqueing or bending while under rotation. However only bending matched the pattern of damage to the rest of the tail cone. The transmission shaft bearings and the intermediate gearbox were free to rotate and gave no evidence of a pre-crash distress or failure.

The whole tail rotor control system from the yaw pedals to the severed actuating rod in the vicinity of the tail gearbox was available for examination. It was concluded that there had been no disconnection before the crash and no evidence of any pre-crash malfunction or maladjustment was found.

The yaw pedal damper, the tail rotor hydraulic servo, the cable tensioning spring, and the yaw channel of the SAS were studied. The pedal damper functioned correctly on a rig. The tail rotor hydraulic servo was found to be functioning correctly *in situ*. The tensioning spring operated without sticking over its whole range of movement and its behaviour was within specification.

The SAS control panel and cables were damaged by impact and fire and it was not possible to carry out a functional test of the whole system. The servo motor could be successfully motored over its range and was still capable of functioning correctly. It was considered that the characteristics of the SAS precluded the possibility of its having provided the exciting force for a tail rotor oscillation.

On completion of the wreckage examination it was concluded, on the basis of the available facts, that the only evidence of a technical failure or malfunction in the tail rotor and/or its control system (and thus in the whole aircraft) was the fracture in the tail rotor gearbox and the detached blade pocket. Specialist opinion was that these failures were consistent with a tail rotor flutter.

1.13 Medical and pathological examination

There were no medical cause factors in this accident.

1.14 Fire

The aircraft was carrying about 1,450 lb of Jet-A1 fuel in its main tanks when it crashed, the auxiliary tank being empty.

When the starboard landing gear leg broke off after impact on the helideck the forward fuel cell on the starboard side was ruptured. The helicopter crashed on the deck of the *Thor* landing on one of the fire equipment points and within feet of forty gallon drums of lubricating oil, and acetylene and oxygen cylinders stored on deck. It came to rest lying on its port side with the engine compartment severely damaged.

Soon after this impact fire broke out in the area of the ruptured tank on the starboard (top) side of the aircraft and spread on to the deck. The pilot operated the engine compartment fire extinguisher selectors. The *Thor's* crew members responded rapidly using foam, carbon dioxide and powder appliances, as well as water hoses, on the fire. Hoses were also brought to bear from Platform *Charlie.* The fire was extinguished within 10 minutes without spreading beyond the vicinity of the aircraft. It had, however, consumed the nose doors and much equipment in the nose compartment, and had invaded and badly damaged the forward end of the passenger cabin.

1.15 Survival aspects

1.15.1 Cockpit

Both the pilot (right seat) and the cockpit passenger were wearing full harnesses which were tight and locked. Both seats and harnesses held firm. The passenger, though seriously injured, was quickly helped out by two of the *Thor's* crew. The pilot was trapped by his left foot and could not be extricated until the fire had been put out. The pilot sustained a severe head injury (a depressed fracture of the skull) and the passenger had lacerations of the scalp and concussion. These injuries were consistent with them striking their heads on the overhead controls and panel and the transmission tunnel between the two seats. The pilot's skull fracture was probably caused by the rotor brake lever knob.

1.15.2 Cabin occupants

One cabin passenger lost his life; the other seven were all injured (3 minor, 4 seriously) but two could be described as being severely injured. They had trunk injuries which were consistent with them being held by their seat belts in a semi-flex position during the impacts on the *Thor.*

The cabin was arranged to seat 14 passengers, 9 on the port side seated back to wall facing sideways, and five similar seats on the starboard side aft of the main door. The dead passenger was seated in a forward port side seat.

A freight/baggage cage fixed to the aircraft forward of the main door had remained substantially intact. A liferaft, weighing approximately 130 lb, was stowed on top of the cage and secured fore and aft by a single strap. The liferaft became dislodged during the impact and was found, partially opened, on top of the passenger who later died. The dislodgement of the life raft allowed the baggage stowed in the cage to spill out.

The cabin seats were supported on a tubular frame, the lap belts being attached to the rear seat bar which was in turn attached by removable pins to reinforced strong points on the aircraft structure and braced by diagonal struts fixed to the floor. The front seat bar was supported on braced vertical struts secured by quick-release attachments on the floor. Emergency exits were through the main door and through both portside windows. On the starboard side only four of the five anchorages of the rear seat rail had been secured and these four were all damaged with the rail being partially torn from the fuselage wall. The rearmost rail attachment was undamaged and was found with the pin in place but without the rail engaged. The next attachment forward had ruptured allowing the occupant of the last seat of the bench to swing across the cabin. The other rail attachments had then failed in a forward direction without becoming fully detached.

The port side bench, unlike the starboard one, was fully secure before the crash and probably was less severely loaded in the impact. Consequently it sustained much less damage.

1.15.3 *Freight and baggage security*

At Aberdeen luggage and freight is normally loaded under the supervision of apron staff but it could not be established whether this procedure was followed on this occasion. The evidence is that when the helicopter was loaded at Aberdeen the freight compartment was filled, some suit cases were stowed under passenger seats and five light mailbags weighing 30 lb in total were lying unsecured at the front of the cabin on the port side of the baggage cage. There is a conflict of evidence as to whether or not some suitcases were also lying unsecured in the forward cabin area. At Platform *Bravo* one passenger got off taking two suitcases and two of the mailbags. Three passengers got on at *Bravo* with baggage and freight comprising a box, a steel flange, and a galvanised iron bucket together with a mop. None of this baggage or freight was secured.

The BHL Operations Manual, Part 2, Flight Operations, stated, in part:

'12.19 FREIGHT AND BAGGAGE STOWAGE

The stowage of freight and baggage on board company aircraft is the responsibility of the pilot and shall only be carried out on his instructions or under his supervision . . . .

In certain aircraft types, the random stowage of freight and baggage may sometimes impede access to liferaft/s, emergency packs and even emergency exits. As well as this, there may exist physical danger to passengers from loose items of freight or baggage in the event of a forced landing or excessive 'g' forces. Because of these considerations pilots should carefully plan the stowage of freight and ensure that it is properly secured to the aircraft. Taking into account C of G requirements, the freight compartment should be used whenever possible . . . . '

The BHL Operations Manual, Part 4, Load and Balance stated, in part:

'1.12 Securing of Cargo and/or baggage in the cabin.

All cargo or baggage other than hand baggage in the cabin of a helicopter must be secured . . . . ' and,

'1.12(3) Pilots are reminded that the ultimate responsibility for the loading of the aircraft and preparation of the load sheets is their's alone'

The BHL Operations Manual, Part 5, S-58T Operating Procedure stated, in part:

'4.5 Cargo Security

Cargo tie-down rings located in the cabin floor are stressed to withstand a 1,200 lb pull in any direction. The cargo tie-downs supplied for the securing of freight have a safe working load of 3,000 lb each. Freight should, where possible and practicable, be loaded into the baggage/freight compartment located on the starboard side forward, under the life-raft stowage. The maximum load in this compartment is limited to 600 lb.' and,

'4.6.2 Passengers Baggage

Baggage shall be stowed into the forward starboard baggage compartment. When this compartment is full baggage may be stowed under the seats.'

The oil company's platform crews include men part of whose duties are to act as the helideck attendants to facilitate helicopter loading and unloading. However these men have neither the authority nor the degree of training of the BHL apron attendant at Aberdeen heliport although, as they often supervise rotors running turn-rounds, their task is more difficult.

All oil rig staff undergo briefings on helicopter passenger flight and safety procedures before they start work on North Sea installations. Part of their instruction is that seat belts must be worn all the time they are in the helicopter; that on the S-58T freight must be placed in the freight cage or be properly secured, and that personal baggage must be stowed under passenger seats or be properly secured. They are also told that an English speaking passenger should occupy the seat next to the door and wear the headset which permits communication with the pilot so that he can tell the pilot when the cabin occupants are prepared for take-off.

In the case of the S-58T however the quality of the intercomm system was described by the pilot as being so poor as to preclude normal conversation between the pilot and the cabin.

1.15.4 *Rescue*

Once the aircraft came to rest the *Thor's* crew responded at once, fought the fire with determination and assisted the rescue from outside. Both emergency exits were opened, the door was slid back half-way, being partially obstructed by the detached tail pylon, and the access hatch from the cabin into the tailcone was removed by a passenger to allow escape through the ruptured rear fuselage.

Seven of the eight cabin passengers left through these exits, the cabin meanwhile filling with dense black smoke. The crew of the *Thor* did not realise that one passenger remained in the cabin and they then concentrated their efforts on suppressing the fire while cutting the fuselage to rescue the pilot who was in great danger from the flames. When the fire had been extinguished a crew member was able to enter the cabin and saw the eighth man at the front of the cabin covered by luggage and by the aircraft's partially opened liferaft. He was extricated alive but later died in hospital from the effects of burns. All ten men were given first aid by the *Thor's* crew, then treated by a doctor flown from a nearby ship, and later flown ashore accompanied by doctors who had come out from Aberdeen.

1.16 Tests and research

At the time of the accident Sikorsky Aircraft were about to commence a ground rig whirl test programme to investigate further the dynamic characteristics of the S-58T tail rotor. These tests were conducted on the tail rotor test stand at Sikorsky Aircraft's facility at Stratford, Connecticut, USA. The tests identified two modes of oscillation. Firstly, a collective mode which involved control system collective properties and blade pitch and flap. Secondly, a forward whirl mode which involved control system cyclic properties and blade pitch and edgewise bending.

The onset of the collective mode vibration was found to be independent of blade pitch. Although it did lead to larger gearbox stresses than the whirl mode did it was not self-exciting. The collective mode required precise excitation both in terms of frequency and amplitude and Sikorsky stated that they knew of no such source of excitation on the S-58T.

The results of the whirl mode investigation were as follows:

The standard S-58T blade with the leading edge abrasion strip was tested. In a hover condition, 89 per cent N_R and at an impressed pitch of 23 degrees nonharmonic oscillations occurred. At 93 per cent N_R the oscillations occurred at 21 degrees impressed pitch and at 100 per cent N_R they occurred at 19 degrees. Analysis of the responses showed the rotating frequency to be nominally 1.5 x tail rotor speed (1.5/rev) and the mode to be a forward whirl.

Further tests were conducted using the whirl stand blower to simulate low speed forward flight, quartering winds and right side flight. Nonharmonic oscillations were again observed. The forward flight conditions were found to be the least damped while right side flight had a stabilizing influence. At 25 knots right side flight, no nonharmonic oscillations were observed up to the 500 HP test limit. The effect of wind velocity and angle of inflow to the rotor is believed to be associated with unsteady wake effects. In right side flight, the most damped condition, the rotor operates in a well established wake and derives damping from the air mass dynamics. As the wind quarters and approaches the forward flight direction, the wake is disturbed with the result that its damping contribution is diminished. This effect would be most pronounced at low forward flight speeds.

It was also found that ambient conditions had an effect on the whirl mode boundaries. Cold day (60^{o} F) operation was found to be less damped than hot day (85^{o}F) operation. It is believed that the damping of the whirl mode decays very gradually with pitch. For this reason, small changes in parameters, or operating conditions may significantly effect the location of the boundaries. Although this ambient condition effect was important in relation to test data comparisons, there is no evidence to suggest that it had any bearing on reported cases of tail rotor vibrations. The known range of temperatures at which vibrations have been reported is 57^{o} F to 87^{o} F. Vibration free operation has regularly been accomplished at much lower temperatures – as low as -49^{o} F. Further, as temperature is reduced, impressed pitch requirement is also reduced – approximately 12 per cent over the temperature range -50^{o} F to 85^{o} F.

The rate of growth of the amplitude of the non-harmonic oscillations as impressed pitch was increased was found to be a function of rotor speed. Thus, operation at the higher rotor speed, in addition to leading to earlier onset of non-harmonic response, also increases its rate of growth.

The fact that the whirl mode occurred on the test stand precipitated an investigation of S-58 and S-58T flight test data to establish impressed pitch requirements for the flight conditions simulated on the test stand. These show that impressed pitch requirements are below those at which the non-harmonic oscillations occurred.

In summarising the whirl mode test results Sikorsky stated that they indicated that at any operational rotor speed the blade pitch required to produce non-harmonic oscillation was outside the range used in normal operation of the S-58T. Further, that the loads produced by these non-harmonic oscillations were not of sufficient magnitude to produce the tail rotor gearbox fractures characterised in reported incidents. Sikorsky stated that the tests confirmed their previous opinion that operation at lower rotor speeds resulted in later onset of non-harmonic oscillation in terms of tail rotor blade pitch angle, and also in reduced loads. On this basis Sikorsky proposed, and the FAA approved, a reduction in operational main rotor speed from 100 per cent to 93 per cent. (The CAA had already done this for aircraft on the British register.)

1.17 Additional information

1.17.1 Tail rotor instability

The phenomenon of tail rotor instability is extremely rare but has been known to occur on the S-58 and the S-61 and has been known colloquially as tail rotor 'buzz'. It is characterised by a medium frequency vibration originating in the area of the tail rotor and felt through the whole airframe and, in the case of the S-58, particularly through the yaw pedals. Factors increasing the tail rotor's susceptibility to buzz are operation at high pitch angles, high rotor speed and the direction of the relative wind (the worst direction being on the starboard bow). Poor tail rotor condition (ie unbalance or worn bearings) could also be a contributory factor. Depending on the particular conditions the buzz may simply become apparent as a momentary vibration which damps out without causing any damage. On the other hand it may become divergent and result in serious damage to the blades, possibly resulting in the stripping of blade pockets. If tail rotor pitch is decreased by the pilot immediately a buzz is detected he may be able to prevent it becoming divergent.

In about 1956 tail rotor oscillation was first noticed on the Sikorsky H34 (the military version of the piston engined S-58) which was in service in the US Army and Navy. The symptoms were described as a vibration of the aircraft, fairly violent sometimes and clearly from the tail rotor, and felt by the pilot especially strongly through the yaw pedals. There was no apparent yaw and the only damage experienced was elongation of the tail rotor fairleads and heavy indentations on the flapping hinge nylon stops.

A flight test programme was carried out but the condition was very difficult to reproduce. Over the S-58's life various modifications were introduced to eliminate the possibility of recurrence of the oscillation. Tail rotor gearbox failures of an identical nature to that seen in G-BCRU had been experienced before on the S-58T and in one case had been positively associated with an observed tail rotor flutter and yaw pedal vibration. In other cases the failure was considered to be due either to an extreme combination of load, flight conditions and vibration leading to overstressing, or a bonding failure on a blade leading to the loss of a blade pocket and large out of balance forces. The modification and inspection procedures referred to in paragraph 1.6 were introduced by Sikorsky in response to these failures and they had also conducted static load tests to determine the type of load required to produce gearbox failures with these characteristics. They concluded that this load was equivalent to that resulting from the loss of one blade pocket, or from a tail rotor vibration of sufficient magnitude and in such a direction as to duplicate the load vector that corresponds to the loss of one blade pocket.

Since the accident, there have been two further instances reported of S-58T tail rotor buzz, both in the North Sea area. One occurred during take-off on 11 June 1976 and the other on 8 February 1977 as the aircraft entered the hover prior to landing. In both cases 93 per cent N_R was being used and the buzz ceased as soon as the pilots applied a small amount of right pedal.

1.17.2 *Precautionary action taken*

Tail rotor instability was suspected as the probable cause within a few days of the accident to G-BCRU and on-site discussions between the AIB team and representatives of Sikorsky Aircraft and BHL indicated that a reduction in the maximum permissible main rotor speed towards 93 per cent N_R would be operationally practicable and would place the tail rotor in a more conservative operating range. The Civil Aviation Authority (CAA) was recommended to consider this and on 27 April they issued an interim instruction to all British operators of the S-58T, with copies to Sikorsky Aircraft and the Federal Aviation Authority (FAA). This stated that for operations below 1,500 feet density altitude at sites where the scheduled field length data was non-critical, take-off and landing should be made using an N_R of 93 to 95 per cent.

On 28 April Sikorsky Aircraft sent a telex message to all S-58T Operators advising them of the CAA action and endorsing it. The message also re-emphasised the importance of strict adherence to a Sikorsky service bulletin which called for a daily inspection of tail rotor blades for cracks, and inspection of yaw cable tension in accordance with instructions in the maintenance manual.

On 30 April Sikorsky Aircraft sent another telex message to all S-58T Operators saying that the FAA had informed them that their reduction of N_R was in direct conflict with the FAA approved helicopter flight manual and that compliance with that procedure might result in operators being placed in a position of violating applicable Federal Air Regulations. The message added that Sikorsky accordingly now advised that the reduced N_R operating procedure did not have FAA approval and that Sikorsky accordingly withdrew this particular recommendation.

After discussion between the CAA, the FAA and Sikorsky, the company was able to issue an amendment to the S-58T Flight Manual on 15 July confirming a reduction of N_R to 93 per cent.

2. Analysis

2.1 The evidence that the accident was the result of a tail rotor failure is conclusive. The investigation was therefore directed towards establishing the cause of this failure. The following possibilities were considered in depth:

(a) A tail rotor blade strike just before landing leading to vibration and failure. There was no evidence to support this possibility.

(b) A failure of the tail rotor gearbox due to static overload alone. This was a more difficult possibility to discount as there had been previous failures of this sort on the S-58T and they had all occurred with the aircraft at low airspeeds, at high weight and out of ground effect, as was G-BCRU; and although modifications and amended procedures had been introduced to prevent failures of this type one of the modifications had not yet been carried out to G-BCRU. However the sequence of events as described by the pilot and others ie intense tail rotor vibration followed by a rapid increase in engine power before the loss of yaw control, together with the condition of the stripped pocket, indicates that there was some other kind of failure before the gearbox separated.

(c) A failure of some kind in the tail rotor mechanism outboard of the gearbox which led immediately to an oscillation, the loss of at least one blade pocket and the break-up of the gearbox. As the tail rotor assembly was not recovered this possibility cannot be positively excluded. However there is no history of such failures in the S-58T nor any other aircraft on the British register.

(d) The detachment of one blade pocket (for example because of faulty bonding or skin cracking) producing vibration initiating flutter, stripping of other blade pocket/s and breaking the gearbox. While this possibility, again, could not be positively excluded two factors suggest that this was probably not the cause of the accident. They are, firstly, that Sikorsky tests established that if one blade pocket came off the out of balance force would break the gearbox within 1 revolution so allowing no time for the sequence of events described by the pilot and witnesses. Secondly, in the one S-58T accident involving the loss of a blade pocket (in this case because of a bonding failure) and for which a report is available, no subsequent pocket stripping occurred whereas in the case of G-BCRU there was a pocket stripped by aerodynamic and inertial forces.

(e) The accident had its origin in a tail rotor flutter which caused at least one blade pocket to be stripped off, with the resulting out of balance forces immediately breaking the gearbox. This was considered to be the most likely possibility for the reasons discussed below.

The sequence of intense vibration from the tail rotor and rapidly rising engine torque without movement of the collective pitch lever were stated by Sikorsky to be consistent with tail rotor instability, and three of the witnesses on Platform *Charlie* reported seeing the tail rotor 'wobble'. Further, the specialist evidence was that the manner of the pocket failure was only consistent with its being torn off by the forces generated by a severe tail rotor oscillation. While not absolutely conclusive this strongly indicates that the accident had its origin in a tail rotor oscillation which became divergent, generating forces which stripped one or more blade pockets and led to an instantaneous over-load failure of the gearbox.

The Sikorsky analysis of their whirl rig tests led them to the conclusion that of the two modes of oscillation experienced, only the whirl mode could occur on the aircraft itself. They stated that even then the impressed pitch required for the tail rotor to be vulnerable to a whirl mode oscillation was outside the range of pitch used in normal operation of the aircraft. However the tail rotor pitch angles required for the possible onset of instability are within the range available to the pilot through the yaw pedal controls, and the SAS itself has 10 per cent delegated authority in yaw. The direct application of the whirl rig test results to the S-58T remains an open issue because tail pylon dynamic behaviour was not simulated, and also because a highly tuned tail rotor system on a test rig might not be fully representative of the behaviour of a tail rotor system on an operational aircraft. Additionally, the flight conditions at the time of the accident were qualitatively those which reduced the margin in tail rotor pitch angle between normal behaviour and the onset of instability. These were:

(a) High aircraft gross weight

(b) Low forward speed out of ground effect

(c) 100 per cent N_R

(d) Cool ambient temperature

(e) Wind from starboard

Finally it should be borne in mind that there had been one substantiated case of tail rotor instability on the S-58T which is the reason why the whirl rig test programme was instituted in the first place.

It is therefore concluded that the most likely cause of the accident was a divergent tail rotor oscillation although this could not be established with certainty. There was no evidence to suggest that G-BCRU might have been particularly susceptible to tail rotor instability though some important evidence – the condition of the tail rotor assembly and the tail rotor cable tension – was not available.

If the accident was indeed the result of a whirl mode instability then the reduction in operating rpm to the 93 per cent should have made a recurrence less likely. If the pilot's evidence of the similarity of the vibration he experienced at Platform *Charlie* where N_R was 100 per cent and at Aberdeen where it was 93 per cent is valid it would suggest that the effect of restricting the main rotor speed has not wholly eliminated the possibility of tail rotor instability. This view would appear to be reinforced by the two later instances reported upon in paragraph 1.17.1. For these reasons it would be prudent to consider whether modifications to the tail rotor system should be carried out to remove entirely the possibility of instability, bearing in mind the range of pitch angle which can in fact be applied.

2.2 It is recognised that there are difficulties in ensuring that all baggage and freight is secured before each take-off when S-58's are making short flights involving 'rotors running' turn-rounds between oil rig platforms. In these conditions the pilot cannot properly discharge the responsibility laid on him for ensuring that freight and baggage are secure; he must rely on the helideck attendant and the passenger with the intercom headset.

This presupposes that both these individuals are competent to perform these duties and that there is a satisfactory method of communication between them and the pilot, which was lacking in this instance.

The head injuries to the cockpit passenger and especially to the pilot highlight the dangers inherent in this cockpit to personnel not wearing protective helmets. In accidents of similar severity to military helicopters of the same type such helmets enable the crew to escape without serious head injury. The wearing of protective helmets by the crew of military helicopters is mandatory.

2.3 The crew of the *Thor*, and the personnel on Platform *Charlie* reacted with commendable speed to an extreme emergency which arose without any warning whatever. Crew members of the *Thor* acted with great determination in immediately attacking the fire and assisting the helicopter's occupants to escape from the wreckage. They suppressed and then extinguished the fire so preventing its engulfing the surrounding oil and gas containers and protecting the pilot from being burned while they were cutting him free. Unfortunately, the *Thor's* crew did not realise that one of the passengers lay disabled almost covered by cabin contents and obscured by smoke. However the intensity of the fire in the forward cabin might have prevented this man's rescue even if his predicament had been known.

2.4 If the helicopter had been fitted with a flight data recorder a more positive conclusion as to the cause of the accident would have been possible, especially if the recorder could have provided evidence concerning the vibration which was the first sign of the impending failure. Other flight recorder data which would have been especially useful would have been flying control movements (especially of the yaw pedals and collective pitch lever), yaw SAS behaviour, engine speeds, torques and main rotor speed, and fuselage attitudes and rates (especially in yaw). It is also possible that if a cockpit voice recorder had been fitted some evidence of the nature of the vibration might have been obtainable. A trial of a flight data recorder and a cockpit voice recorder for helicopter use is due to be carried out in Sikorsky S61 aircraft operating over the North Sea during 1977.

3. Conclusions

(a) Findings

(i) The pilot's licence was valid and he was competent to carry out the flight.

(ii) The aircraft was properly certificated and had been maintained in accordance with an approved schedule. There is no evidence to suggest that it was not fully serviceable at the start of its flight.

(iii) The aircraft was being operated in accordance with the Company's Operations Manual and instructions, although the use of 93 per cent N_R for take-off from open sites had not been formally approved by the certificating authority at the time the aircraft took off from Aberdeen. However this rotor rpm setting was approved shortly after the accident so as to reduce the possibility of tail rotor system instability recurring.

(iv) The vibration that was experienced momentarily on take off from Aberdeen may have been incipient tail rotor system instability ('buzz'), in which case it is unlikely that the use of 93 N_R has effectively eliminated all possibility of tail rotor buzz, though it has most probably reduced it.

(v) The weather was not a prime factor in the accident but the wind condition coupled with the relative positions of the helideck and the *Thor's* crane dictated that the approach would have to be made with the wind from the starboard side. This, together with the cool ambient temperature, (airflow around Platform *Charlie* and the *Thor*), contributed to the reduction in the margin between normal behaviour and the onset of instability in terms of tail rotor pitch angle.

(vi) As the helicopter was about to land on Platform *Charlie's* helideck the whole tail rotor assembly became detached causing the aircraft to go out of control and crash on to the *Thor*.

(vii) It is probable that a divergent undamped tail rotor oscillation developed resulting in the loss of at least one blade pocket and the consequent break up of the tail rotor gearbox.

(viii) It could not be established whether the fact that the tail rotor gearbox had not been fitted with longer studs was a factor in its failure. However the modification was designed to increase stud retention and so was important to safety. It is considered that the time allowed for it to be implemented was excessive.

(ix) On the flight between Platforms *Bravo* and *Charlie* there was some freight and baggage in the cabin which was not secured in accordance with instructions contained in the BHL Operations Manual. Due to the configuration of the aircraft the pilot was unable to comply with these instructions during normal inter-rig operations.

(x) The crews of Platform *Charlie* and, especially, of the *Thor* acted with commendable speed and determination in extinguishing the fire and in rescuing and aiding the survivors.

(b) Cause

The probable cause of the accident, based upon the limited physical evidence available as regards tail rotor damage, was tail rotor instability arising from some undetermined cause, which resulted in the whole tail rotor assembly becoming immediately detached.

4. Safety Recommendations

It is recommended that:

4.1 In view of the doubts as to the efficiency of the N_R reduction to 93 per cent in eliminating all possibility of S-58T tail rotor instability, the Civil Aviation Authority request the United States Federal Aviation Administration to consider, as a matter of some urgency, what action needs to be taken to modify the aircraft's tail rotor system so as to prevent further instances of catastrophic instability.

4.2 The modification called for in Service Bulletin 58B 35-19 dated 23 April 1975 to introduce longer studs into the S-58T tail rotor gearbox intermediate casing be implemented as soon as possible.

4.3 The S-58T Flight Manual be amended to provide guidance as to the nature of tail rotor instability, the conditions under which it might occur, and the action that pilots can take to avoid it.

4.4 A tighter control be exercised by operators over the loading of helicopters engaged in North Sea operations.

4.5 That measures be taken to either relieve the pilot of his responsibilities for the security of cargo and baggage or, enable him to discharge these responsibilities properly himself. These measures should include an improvement to the S-58T intercomm system between the pilot and cabin.

4.6 The necessity that freight and heavy baggage be properly secured in helicopters operating in the North Sea be placarded in the cabin in the appropriate languages.

4.7 Consideration be given to a requirement that the occupants of the pilot's compartment of helicopters engaged in off-shore operations wear protective headgear whilst in flight.

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