Incidents in Air Transport

Hydraulic Failures

N° 9
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Most public transport aircraft are designed with one or more hydraulic systems according to the level of criticality of the systems powered. Pressurization of each system can also be subject to redundancy. The procedures associated with failure are therefore adapted to the systems' architecture and their characteristics. Failures caused by defective sensors or events that are not hydraulic are more complex to identify and treat. Application of procedures can sometimes be confusing and problems of interpretation of these procedures can lead to situations not allowed for by the manufacturer..

Indication of Simultaneous Failure of Two Hydraulic Steering Systems

History of Flight

An ERJ 145 was cruising at FL 280 at a speed of 0.77 M when the autopilot disconnected. The RUDDER SYS 1-2 INOP warning appeared on the EICAS. The crew dealt with the failure by following the procedure described in the operations manual.

RUDDER SYS 1 (2) INOP

or

RUDDER SYS 1-2 INOP

Confirm the side affected

PNF - RUDDER SYS Shutoff ASSOCIATED ....OFF

Check that the only RUDDER SYS INOP message on the affected side appears on the EICAS

IF two systems fail simultaneously and the guidance operates in mechanical return mode

PNF - RUDDER SHUTOFF SYS 2 ....OFF

If the message remains:

PNF - RUDDER SHUTOFF SYS 1 ....OFF

CAUTION: ***DO NOT RE-ENGAGE RUDDER SYSTEMS IF THEY HAVE BEEN CUT OFF AUTOMATICALLY.***

IF RUDDER SYSTEMS HAVE NOT BEEN CUT AUTOMATICALLY:

PNF - RUDDER SHUTOFF SYS 1 AND 2.....ON

If the message remains:

PNF - RUDDER SHUTOFF SYS 1.......OFF

Expect a significant effort on the rudder pedals

If necessary, the two pilots should act together to control the plane

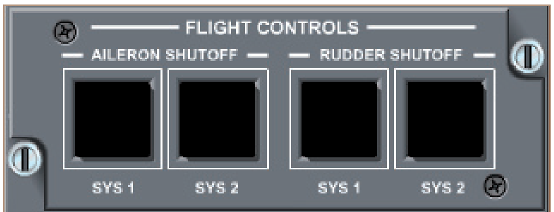
Use the ailerons to help control the yaw and asymmetrical thrust to balance the aircraft.

Avoid landing in turbulence and / or cross wind

END

Procedure from the operations manual (in green, the crew inputs)

As the EICAS message indicated that both systems were affected, the PNF stopped systems 1 and 2, in compliance with the start of the procedure. This led to control of the rudder moving to direct mechanical mode, without hydraulic assistance. The crew concluded, according to the procedure, that there was no other action. They announced an urgency situation but performed the approach and landing safely, the crosswind component being low.



Hydraulic panel

A similar incident occurred a few months later on an ERJ 135. In the latter case, the crew encountered lateral control difficulties.

Additional Information

Steering system

La gouverne de direction est actionnée par The rudder is operated by two hydraulic actuators each controlled by one of two systems of a dual system servo-control, which is itself controlled mechanically by the rudder pedals. At speeds below 135 knots, the two systems operate in parallel[(1)]. Above this speed, only system 2 is active, system 1 being in passive redundancy.

In each system of the steering control, the presence of pressure is monitored by a pressure switch. Its function is to send

[(1)] Rudder deflection is greater at low speed and requires more power to operate it.

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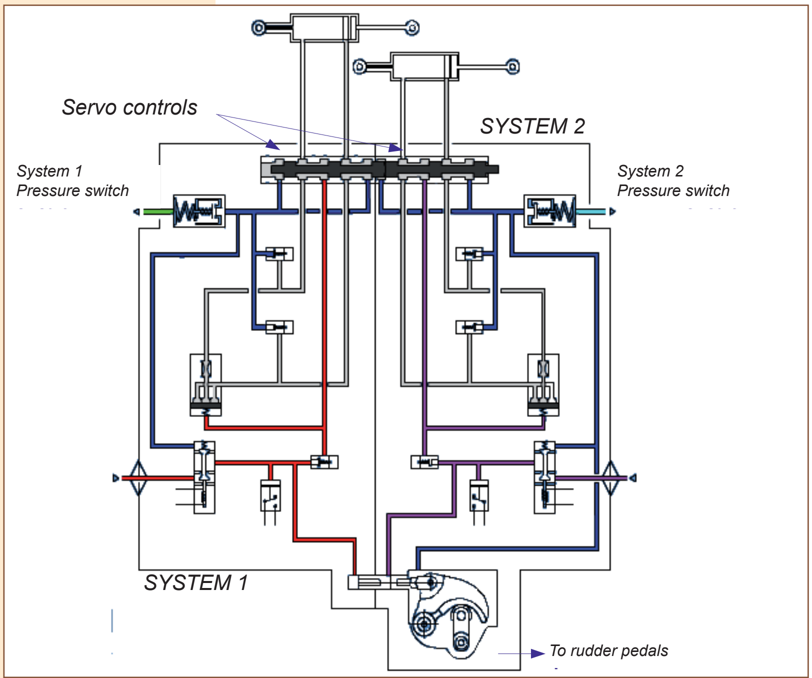


Steering hydraulic system

electric signals to generate EICAS messages relating to the steering system. Sensors also measure the pressure on the two main hydraulic systems; they are located at the level of the mechanical and electric pumps of each system. In the case of a drop in pressure in hydraulic system 2 above 135 kt, the pressure sensor of this system controls the activation of system 1 of the servo.

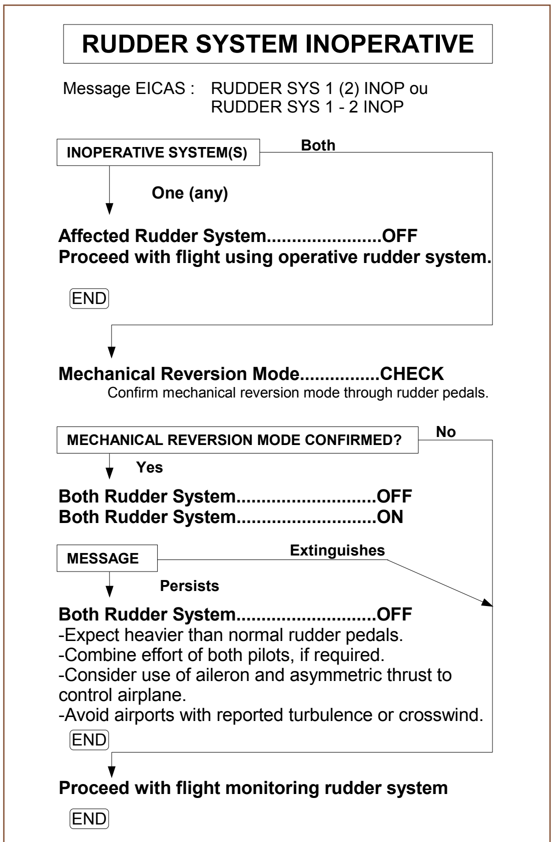
Failure of system 2 pressure switch
At a speed above 135 kt, system 1 of the actuator is normally depressurized. In case of failure of system 2 pressure switch, pressure always available in system 2, system 1 does not take over. However the SYS 1-2 INOP warning is presented to the EICAS because neither of the two pressure switches can detect pressure.

Documentation
The procedure in the operations manual was a literal translation of the flight manual.
In the QRH, a different presentation of this procedure clearly indicated to check the reality of the simultaneous loss of both systems by testing the back force on the rudder pedals. This can identify a sensor problem. The operator had reproduced the procedure in the flight manual because he thought he had to comply with an approved document.

[2] *No Technical Objection.*

Lessons Learned

Unusual procedures are mostly designed to meet real system failures. When failures are caused by the malfunction of a sensor, the application of the procedures can lead to deteriorating the system redundancy but without leading to a situation more serious than the application of these procedures in case of real failure.
The manufacturer had allowed for this case since the QRH procedure allowed doubts to be dispelled. However the flight manual procedure was less explicit. The manufacturer has since changed it to harmonize with the QRH.
The operator did not think he would be able to replace the flight manual procedure with that of the QRH. Yet, the QRH provided by the manufacturer complies with the intentions of the flight manual and can be used as it stands. In any case an operator can offer to adapt a manufacturer's published procedures. The manufacturer may give its opinion via an NTO[2], which allows the procedure to be modified after approval by the airworthiness authority of the State of Registry.



QRH Procedure

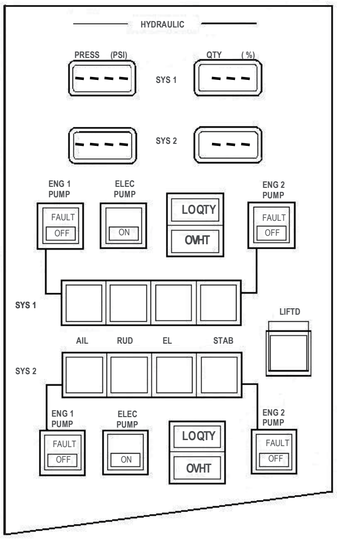
Indication of Double Hydraulic Failure

History of Event

The crew of a Fokker 100 was performing a flight from Orly. The copilot was PF.

During climb on autopilot, HYD LO QTY 1[(3)] and HYD LO QTY 2[(4)] warnings appeared at the same time on the MFDU, accompanied by loss of display of quantities and pressure on the hydraulic panel.

The crew, who had already noticed this phenomenon on the ground, suspected a false alarm and decided to delay dealing with the failure.



Hydraulic panel

A few minutes later, at the end of the climb, the autopilot disconnected. The PF took the controls and made sure they were operating correctly. The PNF started dealing with the warnings by applying the associated procedures one after another: he stopped system 1's hydraulic pumps then system 2's [(5)]. Although he had not yet finished reading the system review, STAB TRIM 1 AND 2 message appeared. He began the associated procedure.

STAB TRIM 1 AND 2

STAB TRIM 1 AND 2 .... OFF then ON

If alerts recurs:

STAB TRIM 1 AND 2 .... OFF

OPER STAB WHEEL FOR TRIM CONTROL

If no response

DO NOT SELECT HYD STAB 1 AND 2 OFF

JAMMED STAB PROCEDURE .... APPLY

STATUS

Stab trim switches inoperative.

STAB TRIM 1 AND 2 procedure

The Captain took the controls and requested clearance for a return. He started the descent by adjusting the trim system, which caused it to make a rapid pitch-down movement. The copilot, now PNF, prepared to take up STAB TRIM 1 AND 2 procedure which calls on the JAMMED STAB procedure. The latter required the use of neither the wheel nor the trim system's emergency electric engine (ALTN STAB).

The airplane slowed down as the trim system was in an out-of-trim position and control forces were becoming considerable. Shortly afterwards, the airplane started an uncontrolled descent. Vertical speed increased rapidly to reach 10,000 ft/min, the bank angle increased up to 40°. The copilot's input on the hydraulic panel enabled hydraulic pressure to be re-established in the system [(6)]. The descent was halted by a high amplitude input on the elevator control.

The crew decided to take no more account of the STAB TRIM warning and broadcast an urgency message.

They started a controlled descent and applied the procedures for emergency flap and landing gear extension. The Captain decided not to fully apply them as they required the hydraulic system 1 pumps to be put back in operation to close the landing gear doors. The airplane landed with the landing gear doors open.

Additional Information

Description of the hydraulic system

The airplane has two independent hydraulic systems. Both systems have identical design and operation but differ in their capacities and powered ancillaries.

Each system has a reservoir, two pumps driven by each engine and an electric pump[(7)] as well as a dual shut off valve and an accumulator system.

The systems, controlled from the hydraulic panel, have a nominal pressure of 3 000 psi.

Description of the elevator control system

Both elevators are mechanically interconnected; they are operated by two hydraulic servo controls,

the left one powered by hydraulic system 1, the right one by system 2. A single system is enough to operate both elevators.

The trim system is operated by a servo control powered by hydraulic systems 1 and 2. A single system is enough to operate it. In normal operation, it is controlled by the AFCAS system. If this system has failed, a trim wheel, situated on the centre panel, can be used to operate it. If there is no hydraulic pressure, it can be operated by an electric motor, controlled from the panel by the ALTN STAB switch

[(3)] *This warning appears when the quantity of hydraulic liquid in system 1 is less than 37 %.*

[(4)] *This warning appears when the quantity of hydraulic liquid in system 2 is less than 20 %.*

[(5)] *Accumulators temporarily maintain pressure in the systems.*

[(6)] *The crew indicated that they had restarted one of system 1's hydraulic pumps, which caused a jolt in the flight controls. They then immediately stopped it. They explained then starting the electro hydraulic pumps to recover pressure. The manufacturer indicated that these pumps cannot supply adequate pressure to operate the flight controls.*

[(7)] *The electric pump has a weak output and provides pressure of less than 750 psi. Its main object is to perform tests for maintenance. The use of these pumps is not allowed for in flight.*

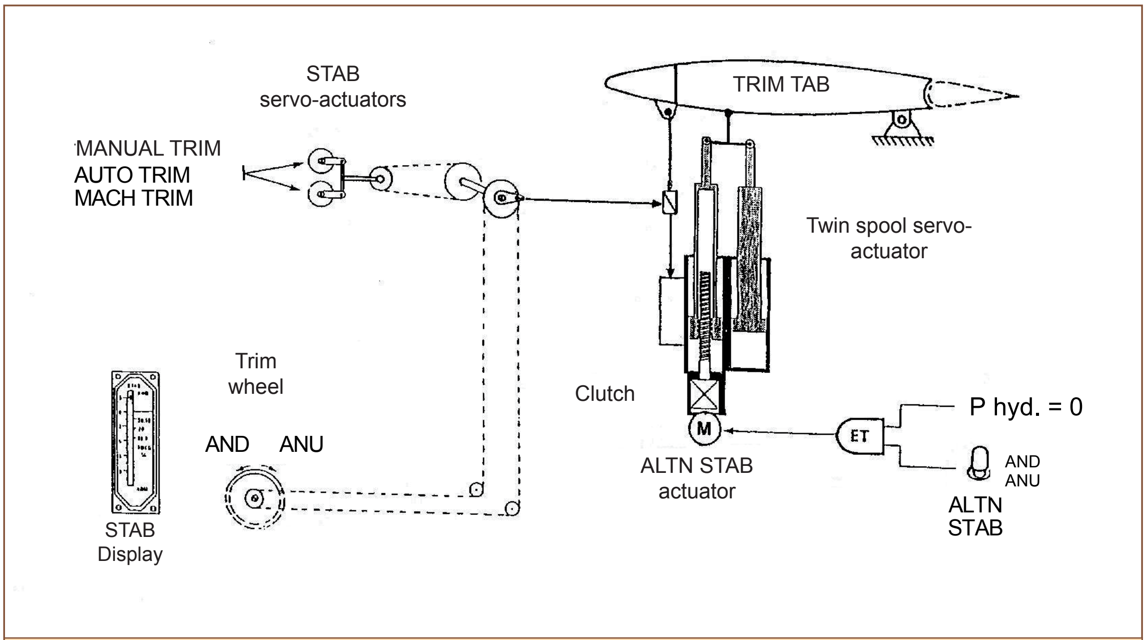


Diagram of the hydraulic system

Origin of the failure

The HYD LO QTY 1 and HYD LO QTY 2 warnings had appeared on the ground already for a few seconds on the arrival of the previous rotation before disappearing. The source of the failure was a fault in the hydraulic indication system. Erratic load was sent to the different components, particularly to the microprocessor that generates the displays and warning messages. The level of hydraulic liquid in both reservoirs was correct.

Total hydraulic loss procedure

In case of reduced pressure in both systems, a specific procedure exists, HYD SYS 1 AND 2 LO P, which provides for operating the trim system by the intermediary of the ALTN STAB. There is no HYD SYS 1 AND 2 LO QTY procedure, as the manufacturer considered this double failure highly improbable.

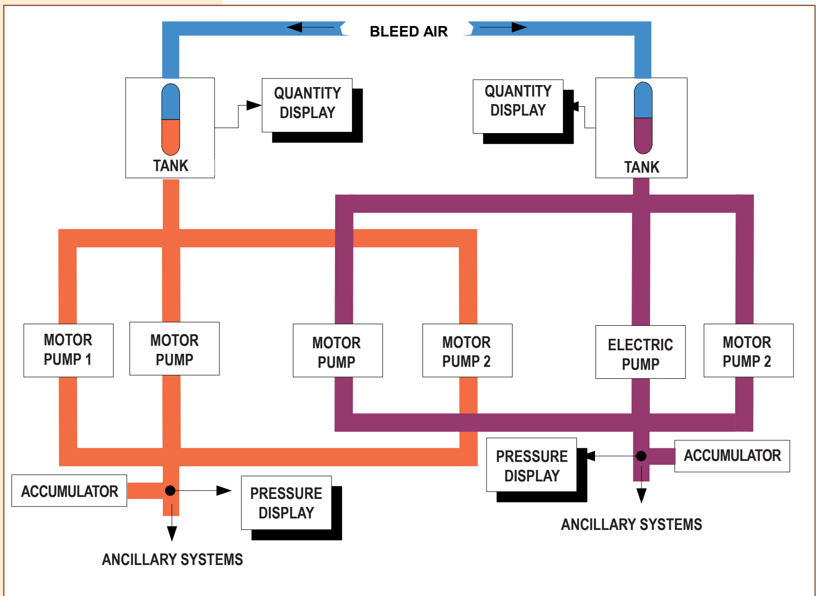


Diagram of the hydraulic system

STAB TRIM 1 AND 2 procedure

This warning is triggered when the AFCAS system is no longer able to control the trim system. This is the case when the system does not have the data required to carry out calculations or when the flight control surface does not respond (locking, major friction or servo control problem).

As the warning is triggered in case of the trim system being mechanically locked, the associated procedure forbids the use of the emergency electric mode so as not to damage the hydraulic servo control.

This warning is inhibited in case of a drop in pressure in both hydraulic systems.

Lessons Learned

The accumulated application of both HYD LO QTY 1 and HYD LO QTY 2 procedures led to the shutdown of four hydraulic pumps. The crew was not informed that it was necessary to use ALTN STAB to operate the trim system in this case. The STAB TRIM warning, adding to this worsened situation, influenced the crew's decision to not use this means to make an input on the trim system.

After the event, the operator put in place a training programme on the ground which presented the logic of this failure by considering, step by step, all the interpretations.

Although the manufacturer considered this double failure as being highly unlikely, it is still possible. It caused a sequencing of two procedures which had unexpected consequences. This led the BEA to issue a safety recommendation to the European Aviation Safety Agency aiming to clarify procedures.

Collision with a Ground Power Unit

History of Flight

The crew of an ATR42 was undertaking a flight bound for Lyon Saint-Exupéry. The Captain was at the controls.

Landing

On touchdown, while the PF brought the throttle levers to the ground idle position, the right engine LO PITCH light did not go on [8]. The PNF called out this anomaly. In compliance with the procedure, the PF did not use the reversers. The crew noticed a MASTER CAUTION [9] warning while the Captain controlled the airplane's trajectory and the copilot responded to the controller's request to clear the runway quickly.

Neither of them identified the alarms. They were unaware at that time that only the left engine's electric alternating current generator was working.

Taxiing

Once cleared of the runway, the crew tried to understand why the right engine's LO PITCH light was not on. They were interrupted by the ground controller's communication who requested them to taxi to a parking ramp that did not appear on the charts.

After several exchanges with the controller, the crew managed to locate it. They then performed

after landing actions including shutdown of Pitot heating which generated a MASTER CAUTION warning associated with an ANTI ICING on the CAP[10] warning. The crew was still wondering about the LO PITCH anomaly when they arrived at the ramp.

Ramp

Before the last turn, the Captain asked the copilot to feather the left engine propeller [11]. This feathering led to the ACW 1 generator stopping.

The main pumps of the two hydraulic systems were then no longer powered electrically.

The auxiliary pump which maintained pressure in the blue system still allowed the use of the emergency brake and control of steering on the ground (NWS). The crew, which was not aware of the deteriorating situation, wondered however about the operation of the right engine. The Captain was reassured by confirming that the three hydraulic pressure indicators indicated 3,000 psi, which corresponded to normal values[12].

It was only when the Captain activated the brakes on the ground agent's signal that he noticed that these were ineffective. The copilot called out two hydraulic pressures at 2,000 psi at the same moment and also tried to brake, in vain. The Captain touched the throttle lever to confirm their position in the ground idle setting; he was then no longer able to immediately activate the emergency brake. To avoid the walkway and the ground signalman, he steered the airplane to the right, then activated the emergency brakes, which were effective but the collision with the ground power unit could not be avoided.

The time frame was:

• four minutes had passed since landing,

• forty-three seconds had passed since the request to feather the left engine.

Additional information

Management of warnings

The sequence of detection and identification of a failure is carried out in the following way:

• MASTER WARNING or MASTER CAUTION visual warnings, associated with aural warnings, draw the crew's attention and enable them to detect a failure and to identify its degree of urgency;

• CAP visual warnings enable the origin of the malfunction to be identified (electrical, hydraulic etc);

• the upper panel visual warnings associated with each system give information on the failure and orientations on the corrective actions to take.

The MASTER CAUTION warning corresponds to an unusual situation of the airplane and mainly includes failures that have no immediate impact on the airplane's safety or conduct. It requires corrective action carried out according to crew availability.

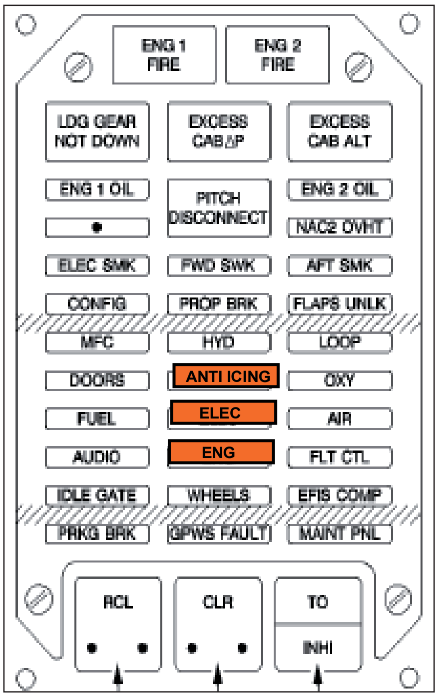
[8] The light comes on to indicate that the propeller setting angle has decreased to the full ground fine pitch position.

[9] This warning is triggered by the loss of the electric ACW 2 alternating current generator. This loss is due to the decreasing speed of the propeller rotation, following an automatic decrease in the engine rotation speed in the absence of LO PITCH.

[10] The appearance of these warnings during taxiing is familiar to crews as stopping the Pitot heating is part of the after landing actions in the operation manual. This habit led the crew not to look at the CAP attentively. The FCOM does not allow for this system to be shut down, which leaves—unless there is a malfunction—le CAP clear of any warning until the airplane stops.

[11] In order to save time during passenger boarding, the left engine can be stopped before immobilisation of the airplane.

[12] If no hydraulic system is used, the hydraulic pressure does not decrease immediately. The pressure of the green system allowing braking of the rudder pedals decreases rapidly however.



Crew Alerting Panel

Flight fine pitch on landing
If the setting angle of the propeller on the engine in question does not decrease to full flight fine pitch position when the throttle levers are positioned below the flight idle position after landing, the LO PITCH light does not come on. The MASTER CAUTION warning is then generated, associated with the ENGINE light on the CAP and the corresponding PEC[13] FAULT light. A signal is also generated to adjust the rotation speed of the engine involved to 66 % of NH.

Electric generator of ACW alternating current
Each engine drives an electric generator of alternating current which requires a minimum of 66 %[14] NP to operate.
The loss of an ACW electric generator is signalled by:
• a MASTER CAUTION visual warning,
• a SINGLE CHIME aural warning,
• an amber ELEC light on the CAP light,
• an amber ACW GEN FAULT light on the upper panel.
When an ACW electric generator is no longer driven, the associated bus bar is automatically powered by the second generator, via a tie breaker (BTC). The ACW GEN FAULT procedure specifies that taxiing must be undertaken with both engines working.

Hydraulic systems
The ATR 42 has two hydraulic systems:
• a green system, pressurized by an electro-hydraulic pump powered by the ACW 2 bus bar. It allows the extension and retraction of the landing gear, as well as normal braking;
• a blue system, pressurized by an electric pump powered by the ACW 1 bus bar. It operates the flaps, ground steering control, airscrew brake and emergency brake[15].
Only the emergency brake has an accumulator allowing the use of braking six times in case of loss of the three hydraulic pumps

Lessons Learned

During taxiing, the crew did not identify on the CAP the type of MASTER CAUTION warnings noticed during the landing roll. This non-detection may be explained by their focussing on the right engine LO PITCH[16] anomaly. Furthermore, taxiing constitutes a phase where attention is relaxed after conducting the approach and landing. This relaxation, the absence of perceptible anomalies as well as the usual presence of some warnings on the CAP during taxiing did not lead the crew to check the visual warnings or the engine instruments.
Lastly, the successive interruptions linked to radio communications during this short taxi did not leave the crew enough time to analyse the origin and consequences of the malfunction and warnings.
The analysis of this incident led the operator to modify its internal procedures which now provide for:
• the callout of the working condition of the ACW electric generator at the end of taxiing during verification of hydraulic pressure after the left engine propeller feathers;
• the suppression of Pitot heating in the actions after landing in order to comply with the FCOM keeping a warning panel switched off;
• raising Captains' awareness of the position of their right hand on the emergency brake at the end of taxiing;
• raising crews' awareness of the importance of dealing fully with failures occurring on the ground.

[13] Propeller electronic control system.

[14] In normal operation, the ACW operation is regulated for NP values between 70.8% and 100%.

[15] An auxiliary pump powered by continuous current can also pressurize the blue hydraulic system. To do this, the pressure in the system must be less than 1 500 PSI, one engine at least must be working, the landing gear lever must be in DOWN position and airscrew brake disengaged.

[16] The origin of the right engine LO PITCH light not coming on has not been determined.

Loss of Control in Hydraulic Power Failure

History of Flight

The pilot of an AS 350 BA helicopter carried out a passenger transport flight in the Paris region [17]. In transit in the Lognes aerodrome sector, the red HYD light signalling a drop in pressure in the hydraulic system came on and the associated aural warning sounded. The pilot reduced speed than announced a "real hydraulic failure" to the controller of Lognes aerodrome. He diverted to this aerodrome, situated a few minutes flight away.

The controller cleared for approach to the surfaced runway 26 in use[18]. The pilot requested permission to carry out the approach to unsurfaced runway 08 as the trajectory was more direct and using this runway enabled him to execute a running landing safely.

The pilot conducted the approach on a flat flight path. On short final, he decided not to perform a sliding landing. After slowing down, he turned left and started a movement to land on a grassy zone between the surfaced runway and the north taxiway. During this manoeuvre, when the helicopter was noticeably heading 350° close to the surfaced runway, the pilot lost control. The main blades, the nose, and then the pads touched the runway surface. The occupants, unhurt, were able to evacuate the helicopter.

Additional Information

Hydraulic system

Power assisted flying, powered by a single system, enables the load on controls to be reduced. The hydraulic system is pressurized by a pump driven by the entry shaft of the main transmission gearbox, through a flat strap. The failure of the strap caused the hydraulic failure.

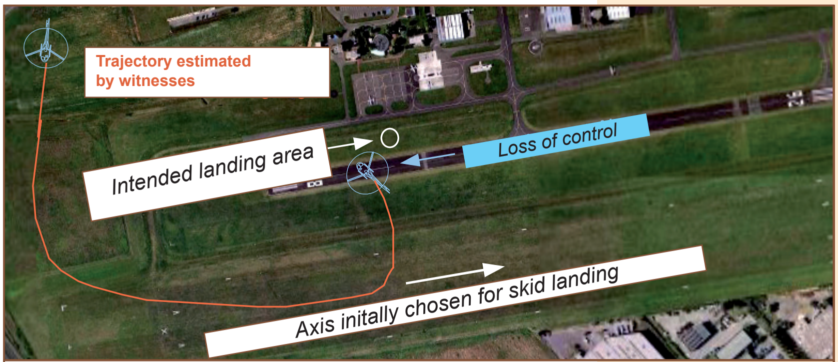
The system is also equipped with accumulators which, in the event of failure, enable power assistance to be provided during the speed reduction manoeuvre.

Procedures and training

The helicopter can still be flown in the event of hydraulic failure on condition that speed is reduced.

- Reduce the collective pitch without rushing and look for a Vi of about 40 kt to 60 kt in level flight.
- Shut down the hydraulic system on the collective pitch
Load appears in the controls.
- pull on collective pitch
- Push to the left on cyclic pitch
…
- Perform a flat approach on cleared terrain and execute a slightly running landing.

Hydraulic power failure procedure from the Operations Manual



Trajectory followed on landing

In this configuration, force required is around 3 to 5 kg on the control and collective columns and 15 to 30 kg on the rudder bar. On approach to hovering, these loads are considerably increased because of:

• reduced stability in yawing,
• increased power required for flight, particularly with a heavy weight,
• modification of aerodynamic handling caused by the change in direction of rotor airflow which produces a modification of load on the cyclic pitch control, which can be perceived as an inversion.

A pilot who must swiftly counter these effects risks not being able to adjust his inputs. That is why the emergency procedure in the event of power assistance failure allows for a flat running landing.

Pilot training and recurrent training includes exercises on failures in the hydraulic power system until landing. These exercises enable pilots to acquire reflexes and to judge the load on the controls without hydraulic power. They are generally carried out at a lighter weight.

Pilot testimony

The pilot did not notice any anomaly until the hydraulic warning was triggered. He applied the procedure by reducing speed to sixty knots, then turning the HYD CUT OFF switch on the collective pitch to stop. He felt the flight controls stiffen and was puzzled. Despite the loss of hydraulic power, control of the helicopter remained adequate. Confident of his capacity to pilot in these conditions, he decided not to continue with the running landing initially planned on the non-surfaced runway.

He wanted to reach an area where the helicopter would not block the runways and which would allow the passengers to disembark. He therefore turned gently to the left to translate towards the grassy area he had chosen.

At the time of the loss of control he had the

[17] The event occurred at the start of the flight and the helicopter weight was close to maximum weight.

[18] The wind was 240° for 4 kt.

impression of being faced with a tail rotor malfunction[19].

(19) The examinations carried out on the helicopter and its systems did not show any malfunction apart from the failure of the hydraulic pump drive belt.

Communicating Information

The manufacturer communicates information on flight safety to owners and operators via amendments to the flight manual, Service Letters and Telex Alerts. During the certification of the AS350 B3, whose weight and power had been increased compared to previous models, the manufacturer inserted the following warning in the hydraulic failure procedure: "do not attempt to perform hovering or manoeuvres at low speed. The intensity and direction of back force on the controls will change rapidly. This will result in an excessive workload for the pilot, difficult handling of the aircraft and a risk of loss of control".

> ***WARNING***
>
> ***THE FOLLOWING PARAGRAPHS REMIND PILOTS OF SPECIFIC MANOEUVRES NOT TO BE PERFORMED WITHOUT HYDRAULIC POWER, WHETHER DURING TRAINING OR IN THE EVENT OF A REAL FAILURE:***
> ***- without hydraulic power, do not try to perform manoeuvres such as a hovering, rotations using rudder bars in hover, hovering with tail wind, translation under ground effect. In fact,***
> ***in these cases, the control loads, particularly in longitudinal will rapidly vary in intensity and direction, which could surprise the pilot, delay his reaction and not enable him to take the appropriate flight attitude of the helicopter in manual.***
>
> *Extract from the Information Telex issued by the manufacturer*

This formulation was then generalised to all the flight manuals of the AS 350 family.

It had not been incorporated in the company's operation manual.

In addition, there was a Telex Alert specifically answering pilots' requests for information. This explained the dangers associated with movements at low speed without hydraulic power and indicated the manoeuvres not to be carried out, particularly rotations and translations under ground effect. The operator was not aware of this document.

The manufacturer gave access to an internet site to users who requested it[20] where all this information was repeated. Reminders were also sent by email to subscribers as soon as an update or information about the type of helicopter selected was issued.

(20) Neither the operator nor the pilot subscribed. The subscription form is available on the manufacturer's site under the heading "Technical Information Publication on Internet (T.I.P.I.)".

Lessons Learned

The pilot knew the hydraulic failure procedure and its effects on the flight controls having experimented with it during type rating, then during regular training. For safety reasons, these exercises are undertaken with only the pilot and instructor on-board and therefore with relatively light weights. The control of the helicopter in these conditions requires inputs of less magnitude than with heavy loads on the flight controls, in particular on the collective pitch. It is even possible, when the helicopter is light, to control it when hovering without too much force. However, the manufacturer's procedures and warnings are explicit and exclude proceeding to any other manoeuvre than a running landing.

During approach, the pilot estimated that the load on the flight controls remained at an acceptable level to execute movements under ground effect. However the helicopter's heavy weight and move through tail wind rapidly made control very difficult. The pilot was surprised by this phenomenon and thought it was a problem linked to the tail rotor. This showed the suddenness of the appearance of load and the difficulty of recovery in such a situation. These reasons led the manufacturer to require a running landing in these conditions.

About fifteen other similar events have occurred around the world over the past ten years. Each time, loss of control occurred when the pilot attempted a manoeuvre other than a running landing. Private users generally use the documents sent by the manufacturer directly. In the case of an operator, it is the operation manual which must not only repeat but highlight the content of the information received and its impact on flight safety. The updates are sometimes technical and interest only the maintenance workshops, and sometimes operational.

In the latter case, the information may not reach its recipient as there is still no link between technical and operational services.

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