No. 2

Air Canada, Douglas DC-8F-54, CF-TJM, accident at Ottawa International Airport, Ontario, Canada, on 20 May 1967. Accident report, Serial No. 3395, not dated, released by the Department of Transport, Canada

1.- Investigation

1.1 History of the flight

The aircraft was on a conversion training flight from Montreal to Ottawa with three pilots on board. The aircraft departed Montreal at 1802 hours Eastern Standard Time on an instrument flight plan which was cancelled on reaching the Ottawa area. A hydraulic failure simulation was then carried out following which a touch-and-go landing on runway 32 was accomplished at 1825 hours. According to the recorded data the touch-and-go was accomplished with the ailerons in the manual mode, the flaps were raised to the 25° position during the landing roll and the ailerons were restored to the power mode during the turn following take-off while on a heading of about 260°.

After about two minutes of flight on the downwind leg, No. 4 engine was retarded to flight idle and was kept at that setting for about two and a quarter minutes. During this period an average of about 3° left wing down bank was maintained, except at a point about halfway through that period the aircraft banked slowly 18° to the left, followed by a sharp reversal to 10° bank to the right. The length of the downwind leg was consistent with a planned two-engine asymmetric landing. Power was restored to No. 4 engine just before a left turn on to the base leg was started. During that turn No. 4 engine was again retarded to flight idle, then restored to normal power. No. 1 engine was then retarded to flight idle for about 20 seconds, then restored to normal power. The flaps remained at the 25° setting. While turning on to final approach, the pilot-in-command advised the tower that he was as yet undecided whether a landing would be carried out.

When the aircraft had passed the UP beacon, about 8½ miles from the runway threshold and approximately 200 sec from impact, rudder power was selected to the manual mode and power was reduced on all four engines. No. 4 engine was then retarded to the flight idle position and the other three engines advanced to approach power. About 171 sec before impact, the pilot-in-command advised the control tower that the aircraft would be making a full stop landing. The landing gear was extended 155 sec before impact and 120 sec before impact No. 3 engine was retarded to flight idle: at the same time power was increased on Nos. 1 and 2 engines. At that time the aircraft was at a height of 1 150 ft above the ground and its indicated airspeed was fairly steady around 165 kt.

From 109 to 92 sec before impact, the aircraft turned to the right through 34° on to a heading of 337°. Power was reduced, bank applied and the aircraft returned to approximately the runway heading.

The flaps were extended to 35°, 69 sec before impact. At 54 sec before impact, the rudder was restored to the power mode for less than 6 sec and then returned to the manual mode. Through the period from 69 to 25 sec the rate of descent was relatively constant at about 700 ft/min with the aircraft tending to undershoot, and the airspeed decreasing from 163 to 152 kt.

Power on Nos. 1 and 2 engines was progressively increased from 25 sec before impact until near maximum power was reached 8 sec before impact, following which they were retarded to flight idle. A yaw to the right had started 19 sec before impact and 12 sec before impact the throttles were advanced on engines 3 and 4 and they began to spool up.

At 9 sec before impact and when some 200 ft above the ground, the left wing down condition could no longer be maintained and the aircraft entered a roll to the right. The roll rate to the right increased rapidly as did the yaw rate. The roll continued until the aircraft struck the ground in an inverted nose low attitude, 1 995 ft short of the threshold of runway 32 and 575 ft NE of its extended centre line.

The accident occurred at 1837 hours.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	3		
Non-fatal			
None			

1.3 Damage to aircraft

The aircraft was destroyed.

1.4 Other damage

There was no other damage.

1.5 Crew information

The pilot-in-command and instructor held an airline transport pilot's licence with a Class I instrument rating. He had flown a total of 19 400 hours, including 3 700 hours on DC-8 aircraft of which 89 hours were flown during the 90 days prior to the accident. His off-duty time prior to this flight was 16 hours. He occupied the right hand pilot's seat.

There were two pilots under training on board the aircraft.

The pilot in the left hand seat held an airline transport pilot's licence with a Class I instrument rating and had flown a total of 20 748 hours, including 8 hours on the DC-8 (4 at the controls and 4 in the second officer's position) all in the 7 days prior to the accident. In addition, he had 28 hours in the DC-8 flight simulator. He had flown 51 hours during the 90 days prior to the accident and his off-duty time prior to the flight was 17 hours. He occupied the left hand pilot's seat.

The other pilot under training held an airline transport pilot's licence with a Class I instrument rating, and had flown a total of 18 795 hours, including 8 hours on the DC-8 (4 at the controls and 4 in the second officer's position) all in the 7 days prior to the accident. In addition he had 28 hours in the DC-8 flight simulator. He had flown 129 hours during the 90 days prior to the accident and his off-duty time prior to the flight was 17 hours. He occupied the second officer's seat behind the right hand pilot's seat.

1.6 Aircraft information

The maintenance records for the aircraft were in order and indicated that the aircraft had been properly maintained. Maintenance Operational Check No. 9 was completed on 15 May 1967.

The aircraft had flown a total of 9 670 hours at the time of the accident, including 52 hours since the last maintenance operational check.

A tee-piece in the rudder hydraulic system, which contained a check valve and a flight recorder transducer, was last removed during the Maintenance Operational Check on 15 May 1967; the aircraft was flown for 52 hours between that date and the time of the accident. The last recorded time the part was removed before 15 May, was on 19 September 1966; the aircraft was flown for about 1 900 hours between that date and the date of the accident. The removal on 15 May was for the purpose of changing the transducer; however, the check valve was not removed from the tee-piece. It was reported that the tee-piece was re-installed in the aircraft in the same position as before removal by reference to pencil marks that were present before removal.

The weight and centre of gravity both at take-off from Montreal and at the time of the accident were within limits.

The type of fuel being used was not stated in the report.

1.7 Meteorological information

A special weather observation taken at 1845 hours (8 minutes after the accident) recorded:

> scattered cloud at 4 000 ft and broken cloud at 8 500 ft, visibility 25 miles, pressure 1015.7 mb, temperature 46°F, dew point 30°F, wind 290°/20 mph with gusts to 26 mph, altimeter setting 29.98 in Hg, clouds cumulus 2/10, alto-cumulus 7/10, pressure rising slowly.

The weather was suitable for the flight and was not a causal factor in the accident.

1.8 Aids to navigation

Not pertinent to the accident.

1.9 Communications

There were no communications difficulties.

1.10 Aerodrome and ground facilities

Runway 32 was 10 000 ft long by 200 ft wide and was serviceable for its full length and width at the time of the accident. The elevation of the runway threshold was 367 ft AMSL. All airport services including air traffic control and radio aids were serviceable and operating at the time of the accident.

1.11 Flight recorders

The aircraft was equipped with a flight data recorder which was recovered the night of the accident and transported to the Air Canada facility at Montreal by an investigator for read-out. The significant events which occurred during the last 120 seconds of flight are reproduced hereunder.

Seconds before impact	IAS Kts.	Vmc Kts.	Magnetic Heading	Roll Angle in degrees (+ is right - is left)	Roll Rate Deg./Sec.	Yaw Rate Deg./Sec.	Asymm. thrust* lbs.	Height above ground	
120	164	124	302	+ 8	0	0	11 500	1 150	
110	164	153	308	+ 3½	1½	1	16 500	1 140	Aircraft turning to right.
95	167	189	337	- 8	8½	1	20 500	1 100	Recovery from the turn was accomplished by applying left wing down aileron and reducing asymmetric thrust. The airspeed stabilized between 164 and 169 knots with a fairly steady 700 feet per minute rate of descent.
70	163	126	327	- 3	1½	0	11 500	950	
25	152	134	315	- 3	1	0	12 000	435	
20	145	138	315	0	1	3	13 500	375	
18	145	145	317	- 2	1	1	13 500	350	
17	145	148	318	- 3	1½	1	16 000	325	Yaw to right has started.
15	147	162	320	- 3½	0	1	17 000	300	Left wing held down with aileron and yaw to right continuing.
12	148	180	327	- 7	1½	1	20 000	260	
10	146	197	330	- 5	4	2	21 500	225	No longer possible to keep left wing down. Aircraft beginning roll to right.
5	131	197	345	+ 7	4	9	21 500	150	Rapidly decaying airspeed due to uncontrollable manoeuvres in the final stages of flight. The aircraft is rolling and yawing rapidly to the right.

* Asym. Thrust Lbs. - the equivalent asymmetric thrust at the outboard engine location. It represents the yawing effect of unequal power application.

1.12 Wreckage

The aircraft crashed inverted on clear, relatively level ground, in a 22° nose down and 25° left wing down attitude while the aircraft was yawing and side-slipping to the left. The wreckage was confined to an area about 420 ft long by 150 ft wide on a heading of 003°M.

Evidence revealed that the aircraft was structurally complete prior to impact with its undercarriage extended, the flaps at the 35° position and the spoilers retracted. The ailerons were in the power mode and the rudder in the manual mode at impact. No evidence of malfunction of the aileron, elevator or horizontal stabilizer systems was found and the horizontal stabilizer was at a 2 3/4° nose up setting. A tee-piece, in the rudder hydraulic system, was found to be installed incorrectly (inverted) and the check valve contained therein was faulty. Further examinations and tests were conducted (see 1.15 below). All four engines separated from the aircraft at impact; evidence revealed that they were all capable of normal operation prior to impact and rotating at the time of impact.

1.13 Fire

There was no evidence of pre-impact fire. An intense fuel-fed fire burned through the area where the engines came to rest.

1.14 Survival aspects

This was a non-survivable accident.

1.15 Tests and research

Medical investigation, including autopsies and laboratory tests, did not reveal any evidence of incapacitation of the crew prior to impact.

During laboratory examination of the rudder hydraulic system tee-piece, the check valve poppet was found in the closed position. However, it was found that the check valve had an internal wear pattern, resulting from a basic design deficiency, which allowed the valve poppet to stick open in its reverse position permitting a fluid flow in the no-flow direction. Tests carried out with the poppet placed in that position revealed that it could remain open and permit powered rudder operation with no apparent deterioration in system performance. In the power mode, a change of position of the valve from open to close would result in a locked rudder, and the rudder pedal travel would be restricted to 5/8ths of an inch, instead of the normal 3 inches. Should this have occurred in flight, the valve would have remained closed under fluid pressure and there would have been no cockpit warning or indication of the defect.

1.16 Primary Flight Controls

The elevators, ailerons and rudder were operated by dual wheel and rudder pedal controls. The horizontal stabilizer was adjustable hydraulically or electrically from the cockpit to provide longitudinal (pitch) trimming. The elevators were operated by aerodynamic boost tabs and were not powered hydraulically.

The ailerons and rudder were operated directly by hydraulic power cylinders. Their tabs were hydraulically locked in the faired position. If hydraulic power was unavailable, the tabs were unlocked automatically and the ailerons and rudder could be moved manually through the aerodynamic tabs. The ailerons and rudder could be placed in the manual mode by operation of individually marked aileron and rudder hydraulic power shut-off levers in the cockpit. Indicator lights below the Captain's instrument panel illuminated when the controls were in the manual mode.

Under hydraulic operation the rudder had a deflection of about 32° either side of the neutral position (10° or more flap extended). This provided a capability to compensate for crosswinds during take-off and landing and to counter the effect of asymmetric thrust and provided acceptable minimum control speeds. A DC-8 Study Guide prepared by the manufacturer stated that when the rudder was operated manually, through the aerodynamic tab, the effectiveness of the tab determined the amount of rudder deflection. This varied with airspeed from 10° at cruise speeds to about 20° at landing speeds. At approach speeds about half the full rudder travel was available. Adverse side-slip could further reduce available rudder deflection.

In connexion with the hydraulic mechanism of the rudder, there were a number of check valves which limited fluid flow to one direction. The function of one such valve was to keep pressure surges generated during operation of the rudder actuator from feeding back to the hydraulic pumps and sub-systems and to prevent a feedback of rudder pressure, when operating some other sub-system which would result in a momentary reduction of system pressure. If for any reason, fluid flow was cut off by this particular check valve, effective rudder control would be lost in the power mode and reversion to the manual mode through cockpit selection, would be necessary.

There was insufficient information in the Air Canada DC-8 Flight Manual to permit a safe two engine asymmetric approach in the manual rudder mode. The DC-8 Flight Manuals of four other scheduled carriers and the FAA approved flight manual were studied and the same deficiency was noted.

2.- Analysis and Conclusions

2.1 Analysis

It was considered that if the check valve in the tee-piece in the rudder hydraulic system had not been faulty, the incorrect installation involving the reversal of the tee-piece would have been noted the first time the rudder pedals were moved with the rudder in the power mode, since their travel would have been restricted to 5/8ths of an inch, rather than the normal 3 inches. This would have occurred on the first subsequent operation of the aircraft, when the controls were checked for freedom of movement prior to take-off. When examined in the laboratory the check valve poppet was found in the closed position.

Recorded data indicated that the rudder was selected to manual mode 3 minutes and 14 seconds before impact and remained in that position until 54 sec before impact when it was placed in the power mode for less than 6 sec (i.e. for only one sampling of this parameter). This was displayed in the recorder read-out by a "spike" of rudder pressure. This evidence in conjunction with read-out data obtained from a subsequent test flight during which the significant circumstances of the accident flight and powered rudder selection were simulated revealed a sharp response in the yaw rate trace coincident with the "spike" of rudder pressure. Examination of the yaw rate recorded 54 sec before impact for the accident flight did not reveal comparable oscillations in the trace. After study of the behaviour of the hydraulic pressure trace it was considered extremely unlikely that the selection indication was false. Consequently, it was considered that the check valve was in fact closed at least 54 sec prior to impact and that this rendered the rudder inoperable in the power mode. To restore rudder control the system would need to be selected to manual, as was done by the crew.

During the final circuit there were a number of deviations from a standard two engine asymmetric circuit including:

(a) the removal and restoration of power to outboard engines on three occasions;

(b) the fact that, while turning from base leg to final approach, a decision concerning the landing, had not yet been made;

(c) failure to complete preparations for the asymmetric approach on the downwind leg;

(d) selection of rudder to the manual mode;

(e) continuation of the exercise with rudder in the manual mode;

(f) speeds for the last 65 sec of flight were below the referenced minimum.

Recorded data and physical evidence established that a two engine asymmetric approach was being conducted, with rudder in the manual mode. Engines 1 and 2 were under power and engines 3 and 4 were at flight idle and the airspeeds (initially) were those recommended in the Air Canada DC-8 Manual for a two engine asymmetric approach with power rudder available.

There were progressive increases in power on Nos. 1 and 2 engines, from 25 sec before impact until near maximum power was reached at 8 sec before impact. This resulted in a substantial increase in asymmetric thrust and a very rapid increase in Vmc speed. The rudder and aileron controls would have become ineffective in rapid succession, which resulted in yaw followed by a roll to the inverted position. At 10 sec before impact the asymmetric thrust reached 21 500 lb, the Vmc speed was 197 kt, and the airspeed 146 kt.

Since Vmc speed varies inversely with available rudder deflection, it is higher in the manual mode than with power rudder. Control of the aircraft was lost when the Vmc speed exceeded the airspeed, the available rudder deflection in the manual mode being not more than 20°.

The Air Canada DC-8 Operating Manual specified that, in the power mode with 10° of flap or more extended, full rudder travel is 32° left or right. The Manual further specified that the full 32° rudder travel is only available with power rudder control. The rudder travel available in manual rudder was not specified.

A two engine asymmetric approach with the rudder in the manual mode, was not a prescribed training manoeuvre in the Air Canada DC-8 conversion course. The sections of the manual dealing with Vmc speed and three engine asymmetric approaches, contained the following note, "the three engine minimum control speeds are approximately 40 kt higher with rudder control in manual". This warning was not included in the section dealing with two engine asymmetric flight conditions. The manufacturer's flight test data established that substantially higher Vmc speeds would apply, with rudder in the manual mode on such an approach.

The section of the Air Canada DC-8 Manual dealing with two engine asymmetric approaches provided:

"(a) set up a normal initial approach with flaps set at 25° but speed 170 kt IAS;

(b) when runway assured lower landing gear, select 35° flap and reduce speed to 160 kt IAS;

(c) when landing assured select full flap, reducing speed to normal four engine flare speed;

(d) request co-pilot to neutralize the rudder trim prior to touchdown as thrust is reduced.

CAUTION: Do not attempt a two engine go-around from speeds below 170 kt IAS".

Information provided to Air Canada by the manufacturer specified the availability of powered flight controls for all two engine procedures. The Air Canada DC-8 Manual did not prohibit two engine asymmetric training procedures in the manual rudder mode.

Two possible reasons why the two engine asymmetric approach was attempted with the rudder in the manual mode were considered:

(a) for some unknown reason a decision was made to conduct the approach using manual rudder, or

(b) the closure of the check valve and resultant locked rudder in the power mode had been recognized by the crew.

The following factors relate to the first alternative:

(a) there was no training requirement for an approach in this configuration;

(b) the pilot-in-command of the flight, a very experienced DC-8 pilot and instructor, may have considered that he could cope with any situation that might arise in these circumstances.

It was difficult to rationalize the anomalies in the circuit procedures in conjunction with such a decision which in effect simulated three failures. It was less difficult to rationalize the anomalies and the decision if hydraulic rudder power was not available since:

(a) the deviations from a standard two engine asymmetric circuit, particularly the power reductions to each outboard engine, could have been to confirm that rudder power was not available;

(b) the evidence indicated that there was a deliberate movement of the rudder hydraulic power shut off lever from OFF to ON and then to OFF again 54 seconds prior to impact. There are two logical reasons for this action. Either it was done simply to check that powered operation was still available, or it represented a last minute check to see whether the rudder was still locked when in the power mode. Recorded evidence and the weight of logic support the second assumption. If powered rudder had been available the pilot could have returned the lever to the ON position and regained directional control probably as late as seventeen seconds before impact.

Despite the pilot-in-command's extensive experience and competence as a pilot, it is apparent he did not realize the potential hazards of an asymmetric approach with rudder in the manual mode. The approach was conducted initially, at airspeeds recommended in the Air Canada DC-8 Manual for a two engine asymmetric approach, with power rudder available. The decision to conduct, then continue, a two engine asymmetric approach with rudder in the manual mode constituted an error in judgement. The evidence supports the conclusion that the crew were aware of a rudder control malfunction, therefore the practice two engined approach should have been abandoned. There are, however, a number of related factors which may have prompted a decision to continue the practice approach including:

(a) The pilots under training were both very experienced, one with over 20 000 hours and the other with nearly 19 000 hours;

(b) Due to limited availability of aircraft for training purposes, traffic congestion at Montreal Airport and noise abatement restrictions in Ottawa, Saturday was frequently the only available day for completion of this phase of the conversion training programme. Failure to complete the exercise when scheduled, would probably have resulted in a 7-day delay;

(c) There are certain conditions which are desirable before a two engine asymmetric approach is planned including:

- (i) daylight;
- (ii) adequate runway length;
- (iii) reasonably strong wind without too great a crosswind component;
- (iv) reasonably smooth flight conditions;
- (v) visual flight conditions;

all these conditions existed at Ottawa on the day of the accident;

(d) The Air Canada DC-8 Manual did not clearly define:

- (i) the amount of reduction in available rudder deflection in the manual mode;
- (ii) Vmc speeds under high asymmetric power conditions with the rudder in manual;

(e) The closure of the rudder check valve would have presented a most unusual failure. The rudder hydraulic pressure gauge would have read normal and the rudder power warning light would have been out. There would have been no instrument indication of the malfunction.

2.2 Conclusions

(a) Findings

The crew was properly licensed, trained, competent and physically fit for the flight;

The aircraft was properly loaded and dispatched;

The aircraft structure, power plants and systems were properly maintained and the aircraft was suitable for the flight, with the exception of the reversal of the tee-piece, in the power rudder system and the faulty nature of the valve therein;

The weather was suitable for the flight;

The airport and associated facilities were serviceable;

The decision to attempt an asymmetric approach with the rudder in the manual mode was improper;

The information available to the crew in the Air Canada DC-8 Manual, concerning two engine operating procedures, was inadequate.

The aircraft was tending to undershoot the runway;

Control was lost when power to the left engines was increased late in the approach, at an airspeed too low for effective rudder control;

The faulty check valve closed during the flight at least 54 seconds prior to impact.

(b) Cause or Probable cause(s)

Failure to abandon a training manoeuvre under conditions which precluded the availability of adequate flight control.

ICAO Ref: AIG/048/67