No. 19

Trans World Airlines Inc., Boeing 707-331, N 769TW, accident at Leonardo da Vinci Airport, Fiumicino, Rome, Italy, on 23 November 1964. Report dated January 1966. released by the Ministry of Transport and Civil Aviation, Rome, Italy.

1. - Investigation

1.1 History of the flight

Flight 800 was a scheduled international flight from Rome, Italy to Athens, Greece. It departed the parking area at 1300 hours GMT with the co-pilot at the controls and the take-off run on runway 25 started at 1307 hours. The aircraft had reached a speed above 80 kt when the pilot-in-command noticed that the No. 4 engine pressure ratio gauge was reading 1 (zero thrust) and, immediately thereafter, the amber light indicating thrust reversal of No. 2 engine came on. Since the speed was still below V_1 for the weights and runway conditions, he decided to abort take-off and took over the controls to carry out the required manoeuvre. The tower was advised of this decision when the aircraft had reached a point 800 to 900 m after the threshold. The aircraft started to decelerate but at a much slower rate than expected, and at the same time veered strongly to the right with the result that the right landing gear was grazing the runway edge. Reverse thrust on the two right engines was reduced in an attempt to bring the aircraft back to the centre line. The aircraft continued travelling beyond the declared runway limit and struck with No. 4 engine a pavement roller which was being used for maintenance work on taxiway 16/34 in an authorized area. After travelling a further 260 m, the aircraft came to a stop with fire on board. After a series of explosions, it was engulfed in flames and completely destroyed. The accident occurred at 1309 hours GMT.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	5	44	
Non-fatal	5	15	
None	1	3	

1.3 Damage to aircraft

The aircraft was completely destroyed.

1.4 Other damage

There was no other damage.

1.5 Crew information

The pilot-in-command, aged 44, held a pilot's licence for commercial single and multi-engined land and sea planes and ratings for several types of aircraft including the Boeing 707. He had been a pilot-in-command of jet aircraft since May 1960. His last emergency procedure practice was on 16 October 1964 and his last in-flight check was on 14 October 1964. He had flown a total of 17 408 hours including 2 617 hours on the Boeing 707, of which 132 hours were flown within the last 90 days. He had not been involved in any previous accidents.

The co-pilot, aged 46 years, held a pilot's licence for commercial multi-engined land planes. His last emergency procedure practice was on 13 March 1964 and his last in-flight check was on 11 March 1964. He also had several ratings including one for the Boeing 707. He had flown a total of 17 419 hours including 1 269 hours on the Boeing 707, of which 108 hours were flown within the last 90 days. He had not been involved in any previous accidents.

The second officer, aged 41 years, also held a licence for commercial multi-engined aircraft with various ratings including the Boeing 707. He had flown a total of 9 928 hours including 1 920 hours on the Boeing 707, of which 43 hours were flown within the last 90 days.

The engineer, aged 47 years, held a flight engineer's licence for multi-engined aircraft including jets, and a rating for the Boeing 707. He had flown a total of 14 231 hours, including 1 308 hours on the Boeing 707.

All flight crew members had their last medical examination in the last six months and were medically fit with no restrictions.

The cabin crew consisted of a steward and 5 hostesses; nearly all of them had their last emergency procedures training and practice in 1963.

One extra crew member was on board.

1.6 Aircraft information

The aircraft had a valid certificate of airworthiness. All periodic checks and overhauls had been effected at the prescribed periods.

On 20 July 1964, the Kollsman EPR transducer No. 2166 was taken off from another aircraft because of a sudden falling of the reading to 1 (zero thrust). It was overhauled, checked and installed on No. 4 engine of the subject aircraft on 7 August 1964. No malfunction was reported.

The weight and centre of gravity were within permissible limits.

The aircraft carried a total of 61 500 lb of JP 4 fuel.

1.7 Meteorological information

Just after the accident a special weather report was issued at Fiumicino. The weather conditions had no bearing on this accident. The surface wind was calm (230°/3 kt), and the average visibility was good (14 km) although slightly hazy.

1.8 Aids to navigation

Not relevant to the accident.

1.9 Communications

In accordance with current procedures, the aircraft had maintained continuous radiotelephony contact with the Fiumicino tower during taxiing and for take-off clearance. All communications were conducted in the English language and in the prescribed phraseology both by the flight crew and by the tower controllers. The VHF equipment of the aircraft operated normally up to the time of the accident.

1.10 Aerodrome and ground facilities

Runway 16/34 was usable over its entire length but taxiway 16/34 was not usable because of construction work (see Figure 19-1).

The length of runway 25 from which the aircraft took off was reduced from 2 220 to 2 000 m because the threshold of runway 07 had been displaced to ensure normal traffic on the runway during resurfacing in the work area.

Class I NOTAM No. 1699 was issued on 21 September 1964, giving notice of the reduction in length of runway 25 for a period of 60 days as from 23 September 1964; a subsequent NOTAM No. 2138, issued on 20 November 1964, advised that this period had been extended a further 15 days.

At the time of the accident, a power roller was located on taxiway 16/34, 301 m beyond the declared limit of runway 25 and 46 m north of the centre line of runway 25. It was moving northward and its height above the ground was 2.65 m, which was below the 1/50 gradient of the take-off climb surface specified in the ICAO Standards in Annex 14. Another piece of construction equipment, smaller in height (2.36 m), was also on taxiway 16/34, moving northward, at approximately the same distance beyond the declared limit of runway 25. This piece of equipment was also below the take-off surface.

The surface of the runway was dry.

1.11 Flight recorders

The aircraft was equipped with a Lockheed flight recorder. The recorder was sent to the Civil Aeronautics Board in Washington for graphic and numerical transcription of the data recorded. The Boeing Company also issued a document concerning the study of transcribed data from this flight recorder.

1.12 Wreckage

The aircraft came to a stop at the intersection of runways 7/25 and 16/34, near the extension of the north edge of runway 7/25, on a heading of 250° and with the engines in line with the centre line of runway 16/34.

The main part, consisting of the fuselage, wings, tail assembly, engine nacelles, landing gear etc., was lying at the 2 250 m point (extension of runway 25).

Upon coming to a stop, the aircraft was resting on its landing gear and was still practically intact, except for the left nose wheel which had come off approximately 50 m before the stopping point, and No. 4 engine and nacelle, which were damaged by impact with the roller.

Immediately after the stop, fire and subsequent explosions destroyed and burnt the centre part of the fuselage and the wings. Following the explosion of No. 3 fuel tank and of the centre tank, several fragments of these tanks were projected into the surrounding area, and the wings and fuselage subsided on the runway pavement after collapse of the landing gear; the forward part of the fuselage dropped and rotated to the left, the centre part of the fuselage, i.e. the passenger cabin, was completely destroyed. The aft section of the fuselage, with the tail assembly structure, was considerably fire damged, particularly on the right side, but remained upright.

1.13 Fire

When the aircraft hit the power roller, fuel leaked from the vent scoop of the right wing tip and the ruptured fuel feed pipes to No. 4 engine. These leaks started the fire and a series of explosions followed. The fire then engulfed the aircraft and destroyed it.

A considerable amount of fire-fighting equipment was sent to the scene of the accident, viz:

3 water foam vehicles, 2 water tank trucks, 3 fire trucks, 1 dry chemical truck, 1 trailer truck, 1 rescue vehicle, 1 truck, 7 complete protective suits, 16 asbestos sheets and 6 rescue ropes.

Also, the following equipment was dispatched from Rome and vicinity:

8 vehicles, 1 travelling crane, 1 fire-ladder vehicle, 1 jeep, 1 radio car and 1 truck.

Fifty-three airport firemen and forty-nine firemen from Rome and vicinity took part in fighting the fire.

The airport fire-fighting squad was alerted by the tower within seconds after the aircraft came to a stop and reached the scene of the accident approximately 3:45 minutes later. The rest of the fire equipment arrived 1 minute later. Within three minutes, the fire was brought under control; after 20 minutes, the fire was practically extinguished.

For the next three hours, firemen continued to douse the aircraft with water spray in order to cool the wreckage.

The rapid intervention of the fire-fighting services permitted removal of the survivors that were in the fire area, and prevented the flames from spreading to other unexploded tanks, from which 14 400 litres of fuel were subsequently removed.

1.14 Survival aspects

The explosion of some of the fuel tanks, the most violent occurring about 20 seconds after the aircraft came to rest, and the very rapid propagation of the violent fire resulted in practically instant death to the passengers who remained in the aircraft or on the ground near it.

On the basis of statements by survivors and by other witnesses on the ground, it was established that the passengers made use of all regular and emergency exists on the left side of the aircraft, and of the cockpit exit and the forward and aft service doors on the right side as follows:

left side		right side	
crew cockpit exit	2	crew cockpit exit	1
forward exit	13	forward exit	4
emergency exit to the wing	9	emergency exit on to the wing	-
aft door exit	11	aft door exit	4

Some passengers used the escape ropes, but it did not appear that the chutes were used. The left forward door chute was destroyed by the explosion while it was being placed in position. The left aft door chute was removed from its container but could not be placed in position because of the smoke and fire.

1.15 Tests and research

Investigations, tests and analyses of the engines, parts of the landing gear and other components of the airframe and systems were conducted at Fiumicino Airport, at the Laboratories of the Military Aviation in Rome, of Alitalia at Fiumicino, of Alfa Romeo at Naples and at the FAA, TWA and Boeing Centres in the U.S.A.

It was determined that all four engines were operating until the time they were shut off by the pilot-in-command. However, evidence revealed that the following discrepancies existed in the thrust reversing system of No. 2 engine before the explosions:

- detachment of the compressed air hose of the pneumatic system for No. 2 engine reverser, through loosening of the B nut connexion to the shuttle valve.

- incorrect calibration of the microswitch in No. 2 reverse thrust gauge circuit, with travel four times less than the prescribed value.

The rules for baulked take-off on the Boeing 707/331 are based on the assumption that the pilot's reaction time (elapsing between awareness of malfunction and completion of prescribed manoeuvres) has a total value of 3.44 seconds, divided into 2 seconds of reaction time and 1.44 seconds for completion of the manoeuvre by means of the controls. This supposes that the take-off is initiated and aborted by the pilot-in-command, whereas in the present case take-off was initiated by the co-pilot but aborted by the pilot-in-command.

Since a time lapse of 3.44 seconds was considered insufficient in such circumstances, a number of tests were conducted on one of the Boeing 707/331 simulators installed at the TWA training centre at Kansas City, U.S.A., with the participation of a qualified member of the Board of Inquiry.

The results led to the conclusion that, while the reaction time in the specification is adequate in the case of take-off initiated and aborted by the pilot-in-command, it is insufficient when operations are initiated by the co-pilot and aborted by the pilot-in-command.

It was found that the average time, counted from the appearance of the amber reverse thrust warning light, for intervention by the pilot-in-command and completion of the manoeuvre (excluding application of reverse thrust) was about 5 seconds.

In the speed range from 80 to 124 kt, the flight recorder shows an average acceleration value of approximately 5 kt per second, so the speed increase in the 5 seconds preceding the peak of 131 kt had amounted to about 25 kt (not counting delayed engine response).

The speed at the time of the decision to abort can therefore reasonably be construed as about 106 kt (131 - 25).

The point at which tower personnel observed the aircraft at the moment when the decision to abort was communicated, when compared with the speed-distance chart drawn from flight recorder data, approximately confirms the order of magnitude of the speed as computed by the Board.

2. - Analysis and Conclusions

2.1 Analysis

The take-off was started by the co-pilot while the pilot-in-command used his left hand on the nose steering at the lower speeds. During the first phase of the take-off run, the pilot-in-command handled the EPR (engine pressure ratio) fine trim controls. On reaching 80 kt, the co-pilot took over the nose steering control from the pilot-in-command as prescribed in the airline's B-707 operations manual.

A few seconds after passing 80 kt, the pilot-in-command observed that the EPR reading (for No. 4 engine) was almost on the figure 1 (zero thrust).

The pilot-in-command's direct reading of No. 4 instruments, the lack of any feeling of decrease in acceleration or of yawing moment, the acceleration recording, and the technical examination of No. 4 engine all lead to the conclusion that the engine was operating normally.

Technical examination of the retrieved parts of No. 4 EPR system failed to establish the cause of malfunction.

While the pilot-in-command was checking No. 4 instruments, the amber warning light for No. 2 reverse thrust went on (these lights are designed to appear when the reverse thrust clamshell doors leave the "stowed position").

The transcribed flight recorder data showed steady acceleration and constant heading even after the warning light went on, and it was concluded that, whatever the cause of the lighting (wrong setting of microswitch, probable slight movement of clamshell doors due to pressure loss in the system etc.), the take-off thrust of No. 2 engine was largely unimpaired.

The pilot-in-command, after a quick check of the positions of the controls and faced with indications of malfunction of two engines, decided to abort take-off, a decision which was in accordance with operational procedures and was professionally correct.

The pilot-in-command later stated that he could not tell the indicated airspeed at which he took that decision because he was busy checking the engine instruments at the time. He considered, however, that this speed was between the 80 kt mentioned above and 124 kt corresponding to computed V_1; he suggested an estimated value of about 100 kt. As indicated in paragraph 1.15 above, the speed reached by the aircraft when the decision to abort the take-off was taken was computed to have been in the order of 106 kt.

The sequence of actions for discontinuing take-off was reconstructed on the basis of the pilot-in-command's statements and other testimony. Power reduction, brake application, raising of spoilers and application of reverse thrust were completed in accordance with the operations manual procedures and were adequate for aborting take-off at a speed well below V_1.

The time-distance speed charts transcribed from the recorder showed that the time taken to decelerate from 131 to 123 kt was about 9 seconds, which is considerably more than the specified time for the same deceleration. This could be explained by adding the times required to complete abort procedures, which were initially conducted without haste, to reverse the thrust (about 2.5 seconds) and to expect the increased reverse rpm of the engines with the resulting braking effect.

However, when that effect should have been felt, the deceleration did not increase and the aircraft started to yaw to the right.

The probable causes of this could have been of an aerodynamic or mechanical nature, since weather and ground conditions were excluded (3 kt wind at ground level and dry runway).

The rudder could not have spontaneously assumed an abnormal position. This was confirmed by the fact that the pilot-in-command did not mention any anomaly and that the post-crash tests revealed that the rudder hydraulic control was operating. Furthermore, if it had occurred, it would not explain the lack of deceleration after the application of reverse thrust.

Involuntary differential use of the brakes or malfunction of the brake system on the right landing gear were rejected. The well-marked tracks on the ground indicated pronounced and continuous application of left brakes whereas there were but few traces of braking on the right, thus giving proof of action to correct the yaw to the right.

Furthermore, technical examination of the parts retrieved showed that the rotating brake discs were entire, with no trace of seizing.

The persistence of the yawing effect and the simultaneous and persistently slow deceleration, led to the assumption of an asymmetry in the reversed thrusts.

The pilot-in-command declared that the reversing manoeuvre was normal and differences in the setting of the reverse controls would have only produced a slight asymmetry of thrust, resulting in a slight yaw with a deceleration almost normal.

Only an asymmetry due to malfunction of the actuating system of the clamshell doors of one of the two left engines producing forward thrust can explain both the amplitude of the yaw and the lack of deceleration.

The reverse thrust system is so designed as to exclude the possibility of an increase in rpm beyond a certain limit if the reverse controls have not been set beyond a safety position called interlock position, and full reverse occurs only if the clamshell doors are almost completely closed, so as to guarantee that the thrust will in any case be reversed; however, three cases have been recorded of technical difficulties in passing the interlock position, with resulting forward thrust.

The technical examination of the left engines revealed that the B nut that should have joined the shuttle valve to the ducts of the cylinders actuating the clamshell doors of No. 2 engine had completely separated, thus causing a total loss of pneumatic pressure in the system. As a result, No. 2 engine was developing forward thrust. In computing that thrust, the following facts were taken into account:

- the pilot-in-command reported exceptional steering difficulty due to the strong and persistent drift to the right;

- difficulties were also noted by the navigator and the flight dispatcher;

- the tracks on the runway indicated an intense asymmetrical braking action applied almost solely to the left landing gear, as well as violent corrective action applied to the nose wheels;

- the tracks of the latter showed that their vertical axis was almost constantly oriented to the left in relation to the direction of motion;

- the resulting persistent stresses caused structural failures sufficient to cause break-off of the left nose wheel, which was found about 50 m behind the point where the aircraft came to a stop;

- application of reverse thrust together with the pronounced use of the brakes (even though asymmetrical and therefore partial) should have stopped the aircraft within the declared runway limit;

- the 550 m travelled by the aircraft beyond the declared runway limit is consistent with a considerable forward force counteracted only by a partial braking action;

- the pilot-in-command stated that he had correctly switched the controls beyond the interlock position and applied full reverse thrust.

The series of computations made both in Italy and in the United States by different methods failed to establish exactly the amount of forward thrust, owing to the many variables involved. However, on the basis of the above factors, and in view of the pilot-in-command's long flying experience, it seems likely that the forward thrust developed by No. 2 engine was probably close to maximum. This would explain the exceptional efforts required of the pilot-in-command in taking corrective actions which, however, were not sufficient to avoid impact of No. 4 engine with the power roller located 301 m after the displaced end of runway 25.

At impact, the fuel feed pipes to No. 4 engine were ruptured near the high pressure pumping and fuel flow regulating system, and the electric generator of No. 4 engine was torn off. The booster pump being in operation, the fuel escaped at a rate which was estimated to be of about 30 gal/min and ignited. The generator selector switch on the engineer's panel being set on position 4, as prescribed in the operations manual, the power

was cut off from the emergency bar supplying energy to the fire warning system, when No. 4 generator separated. As a result, the fire warning system became inoperative and precluded immediate indication of fire to the crew. When the crew became aware of the fire and took remedial action, the fire had already developed beyond control. The manner in which the fire propagated was traced through evidence and it was concluded that the first explosion occurred in No. 3 fuel tank, the second explosion, which was the most violent, in the central fuel tank (No. 2 tank) and the third explosion in No. 1 reserve tank.

2.2 Conclusions

Findings

On the basis of the foregoing it was concluded that:

- the crew held the required licences;
- the aircraft had been declared airworthy;
- flight planning was complete and in accordance with regulations;
- the pilot-in-command acted in accordance with the prescriptions in the operations manual;
- on the Boeing 707/331, the information supplied by the reverse thrust system warning light regarding the position of the clamshell doors is inadequate; in the subject case, it was out of setting;
- the take-off data in present manuals apply and are valid only in the case of manoeuvres conducted by the pilot-in-command in person;
- in the manual, aborted take-off is not considered an emergency manoeuvre;
- acceleration of the aircraft was normal;
- the decision to abort take-off was taken before reaching V_1;
- the thrust reversing system on No. 2 engine was impaired, and that engine therefore continued to supply forward and asymmetrical thrust during the deceleration phase;
- it is certain that the pilot-in-command moved all four levers beyond the interlock position;
- deceleration was slower than expected and irregular;
- the aircraft was submitted to pronounced and continuous yawing moment;
- the aircraft travelled beyond the declared runway limit, thereafter hitting with No. 4 engine a power roller operating in a work area authorized in accordance with ICAO Standards;
- fuel spilled from the vent scoop in the right wing, admitting fire into the system;
- the fire warning device failed to operate;

- the explosions, which occurred very shortly after the aircraft stopped, were followed by a fire of vast proportions;

- the biggest explosion occurred in the centre fuel tank;

- the emergency exits to the wings of the Boeing 707/331 were difficult to open and use because of the seats;

- there were difficulties in using the escape chutes;

- rescue units from two different stations reached the scene approximately 3 to 5 minutes after the aircraft stopped.

Cause or
Probable cause(s)

Damage to the reverse thrust system of No. 2 engine, not discernible by means of cockpit instruments, and consisting in the disconnection of a duct with resulting lack of pressure in the pneumatic clamshell door actuating mechanism.

This malfunction allowed the development of considerable forward thrust by No. 2 engine even though the four levers were in the "reverse" position.

Rupture of fuel feed tube to No. 4 engine by impact with a power roller, and resulting ignition of spilled fuel.

Failure of surge tank drainage because of a blocked valve, forcing the fuel out through the vent scoop and permitting access of fire to the wing.

Presence of fuel-air vapour, formed in the tanks in explosive proportions, which caused the explosions when ignited.

3. - Recommendations

Operational recommendations

It was recommended that:

- airworthiness and operational standards be developed for take-offs performed by the co-pilot;

- aborted take-off procedures be included in the emergency procedures for practical purposes;

Technical recommendations

- a system be installed to indicate the successive positions of the reverse thrust clamshell doors;

- checking for tightness of all connexions in the pneumatic thrust reversing system be prescribed;

- consideration be given to a modification whereby the fire warning system would be fed in parallel by all sources of electric energy available on board;

- studies be conducted regarding systems designed to eliminate the danger of explosion in fuel systems and the entry of fire through ventilation outlets;

- the efficiency of the drainage system of the fuel surge tanks be improved;

- the emergency exits to the wings be made more readily accessible; and that a more rapid and less difficult method of use of escape chutes be developed.

ICAO Ref: AR/893

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Comments by the United States of America (State of Registry)

The National Transportation Safety Board, as the agency of primary interest in this accident at Leonardo da Vinci Airport, Fiumicino, Rome, Italy on 23 November 1964 has reviewed the Italian report and wishes to make known that it neither approves nor disapproves the report.

The United States wishes to observe that since the No. 2 reverse interlock system was found intact during the investigation, the worst possible effect from the operation of the PS4 line in the No. 2 reverse system would not negate the design safety features of the interlock system. These features, together with the clamshell door design, limit the thrust developed to safe values in the event of any single failure/malfunction in the reverse system.

ACCIDENT TO B-707-331, N 769TW,
OF TRANS WORLD AIRLINES INC.,
AT ROME, ITALY. 23 NOVEMBER 1964

LANDING CHART - ROME (FIUMICINO)

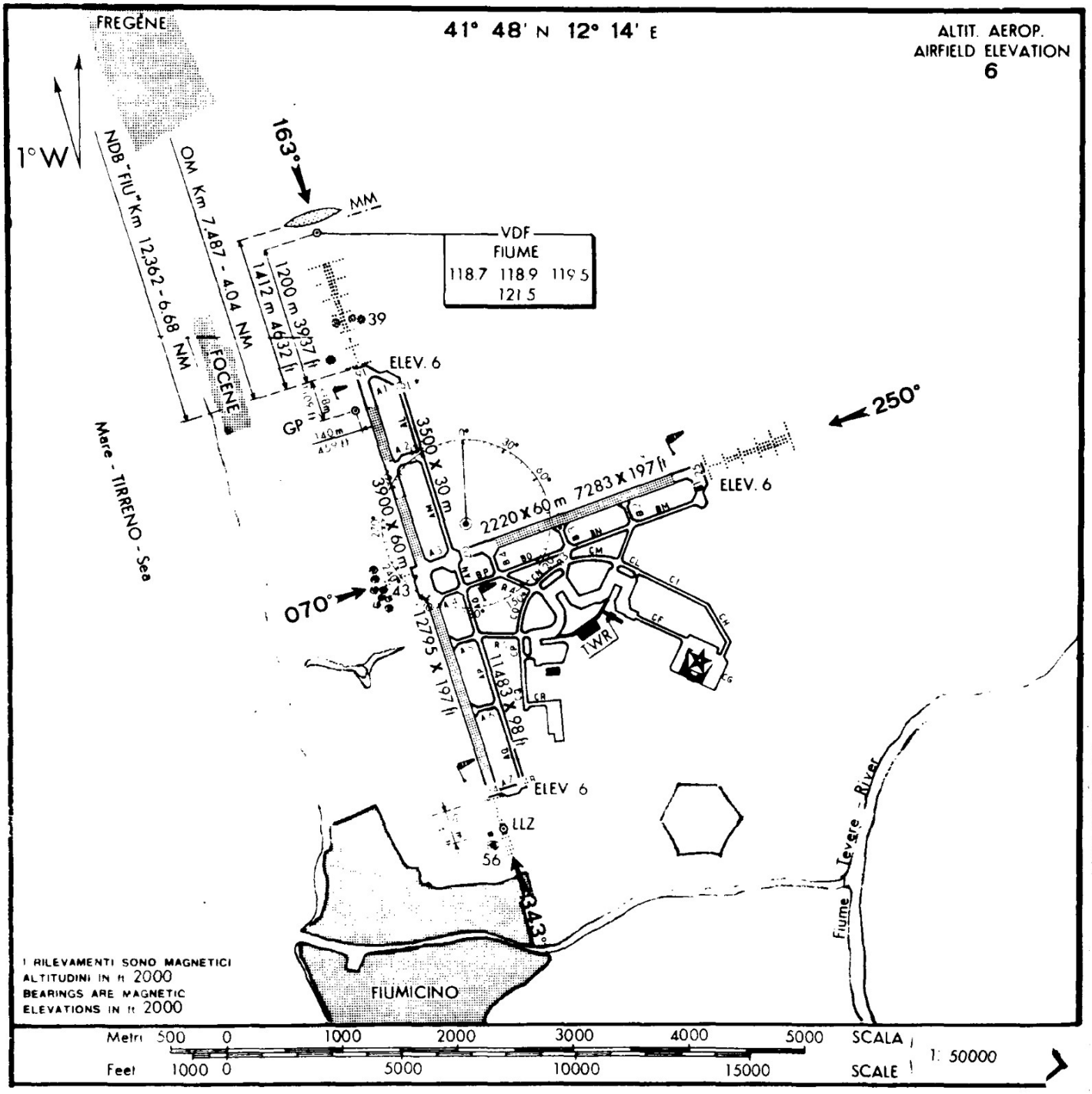

FIGURE 19-1