No. 9

Trans World Airlines, Inc., Boeing 707, N-742TW, accident at the Greater Cincinnati Airport, Erlanger, Kentucky, U.S.A., on 6 November 1967. Report File No. 1-0029, dated 11 September 1968, released by the National Transportation Safety Board, U.S.A.

## 1.- Investigation

### 1.1 History of the flight

TWA Flight 159 was a scheduled domestic flight from New York to Los Angeles with an intermediate stop at the Greater Cincinnati Airport. It departed the ramp at Cincinnati at 1833 hours Eastern Standard Time. As it was approaching runway 27L for take-off, Delta Air Lines, Inc., DC-9, N-3317L, operating as Flight DAL 379, was landing.

As DAL 379 was completing its landing roll, the crew requested and received clearance for a 180° turnaround on the runway in order to return to the intersection of runway 18-36 which they had just passed. After turning through approximately 90°, the nosewheel slipped off the paved surface and the aircraft moved straight ahead off the runway during which time it became mired. The throttles were retarded to idle, and power was not increased again.

At 1839:05 hours as DAL 379 was in the process of clearing the runway, TWA 159 was cleared for take-off. The local controller testified that before TWA 159 began moving, he observed that DAL 379 had stopped. He stated that although DAL 379 appeared to be clear of the runway, he requested confirmation from the crew who replied, "Yeah, we're in the dirt, though." Following this report the controller stated "TWA 159 he's clear of the runway, cleared for take-off, company jet on final behind you." Take-off performance had been computed as $V_1$ 132 knots, VR 140 knots, $V_2$ 150 knots.

In fact DAL 379 was stopped on a heading of 004° and located 4 600 ft from the threshold of runway 27L with its aft-most point being approximately 7 ft north of the runway edge, the aft-most exterior lights located on the wing tip and the upper and lower anti-collision lights being approximately 45 ft from the runway edge.

The crew of TWA 159 did not have DAL 379 in sight when they commenced the take-off roll. The co-pilot was performing the take-off and the pilot-in-command drew his attention to DAL 379 as the aircraft appeared in their landing lights - they could see that it was off the runway by some 5-7 ft.

As TWA 159 passed abeam of DAL 379 the co-pilot experienced a movement of the flight controls and the aircraft yawed. Simultaneously there was a loud bang from the right side of the aircraft. The last airspeed he had observed was 120 knots and assuming that the aircraft was at or near $V_1$, and that a collision had occurred, he elected to abort the take-off. He stated that he closed the power levers, placed them in full reverse, applied maximum braking, and called for the spoilers which the pilot-in-command operated.

Directional control was maintained but the aircraft ran off the end of the runway, rolled across the terrain for approximately 225 ft, to the brow of a hill, and became airborne momentarily. It next contacted the ground approximately 67 ft further down the embankment, the main landing gear was torn off and the nosewheel was displaced rearward, forcing the cabin floor upward by approximately 15 in. The aircraft slid down the embankment and came to rest on a road approximately 421 ft from the end of the runway.

The accident occurred at approximately 1841 hours, in darkness.

1.2 Injuries to persons

| Injuries | Crew | Passengers | Others |
|---|---|---|---|
| Fatal | | 1 | |
| Non-fatal | 2 | 8 | |
| None | 5 | 20 | |

1.3 Damage to aircraft

The aircraft was substantially damaged by the ground slide and subsequent fire.

1.4 Other damage

None.

1.5 Crew information

The pilot-in-command, aged 45, held an airline transport pilot's certificate with ratings in the Martin 202/404, Lockheed Constellation, Boeing 707/720 and airplane multi-engine land. His FAA first-class medical certificate was issued on 9 May 1967 with no limitations and his last proficiency check was completed on 22 September 1967. He had flown a total of 18 753 hours including 1 532 as pilot-in-command and 4 672 hours as co-pilot in Boeing 707 aircraft. He had been off duty for 18 hours prior to this flight.

The co-pilot, aged 26, held a commercial pilot's certificate with airplane single and multi-engine land, instrument and flight instructor ratings. He also held a flight engineer's certificate with ratings for reciprocating engine and turbojet engine powered equipment. His FAA first-class medical certificate was issued on 26 October 1967 with no limitations and his last proficiency check was completed on 21 July 1967. He had flown a total of 1 629 hours including 830 hours in Boeing 707 aircraft. He had been off duty for 18 hours prior to this flight.

The flight engineer, aged 39, held a flight engineer's certificate with ratings for reciprocating engine and turbojet engine powered equipment. He also held a commercial pilot's certificate with airplane single engine land and instrument ratings. His FAA first-class medical certificate was issued on 4 April 1967 without limitations and was still valid as a second-class medical certificate at the time of the accident. His last proficiency check was completed on 30 January 1967. He had flown a total of

11 182 hours as a flight engineer including 5 444 hours in Boeing 707 aircraft. He had been off duty for 18 hours prior to this flight.

Also aboard were four hostesses who had all completed their last emergency procedures training within the past four months.

1.6 Aircraft information

The aircraft had been maintained in accordance with Federal Aviation Administration requirements.

The aircraft was serviced with kerosene and had a computed take-off gross weight of 212 231 lb, which was below the maximum allowable take-off weight of 218 500 lb. The computed centre of gravity was 28 per cent, which was within the allowable range of 14 to 31.5 per cent MAC.

1.7 Meteorological information

The 1800 hours Weather Bureau surface weather observation for the Greater Cincinnati Airport was:

> Measured 7 000 ft overcast, 15 miles visibility, temperature 34°, dew point 19°, wind 190°/5 kt.

1.8 Aids to navigation

Not relevant to this accident.

1.9 Communications

There were no reported problems with communications.

1.10 Aerodrome and ground facilities

Runway 27L is 7 800 ft long and 150 ft wide, of concrete construction. At the time of the accident, the runway surface was dry, and the high intensity lights were on.

1.11 Flight recorders

DAL 379 was equipped with a United Data Control Model F 452 Flight Data Recorder and a Fairchild Model A-100 Cockpit Voice Recorder. Both were recovered in satisfactory condition. However, although the Cockpit Voice Recorder was undamaged and the quality of recorded voice transmissions was good, the radio transmissions after the flight had completed the landing roll were extremely weak, although intelligible with maximum amplification during the read-out. This was due to the fact that the pilot-in-command had instructed the co-pilot to activate the bulk erase feature in view of the profanity used when the aircraft became mired.

TWA 159 was equipped with a Lockheed Aircraft Service Model 109C Flight Data Recorder and a Fairchild Model A 100 Cockpit Voice Recorder. Both were recovered in satisfactory condition.

Since the Flight Data Recorder did not reflect the take-off roll initiation point, the record was presented on a graph with a time scale of 70 sec which included a period of time preceding the take-off through that point where the traces became aberrant. The airspeed trace began increasing at a relatively uniform rate from approximately 10 to 15 kt at 21 sec, to a maximum of 145 kt at 61 sec. At this point, the airspeed decayed to 140 kt in 1 sec, to 111 kt in the next 2 sec, and finally decreased to 59 kt where it became aberrant at 70 sec. The heading of approximately 270° was relatively constant until 61 sec at which point it shifted momentarily to 265° and then returned to 270° at 64 sec. The vertical acceleration trace also remained fairly constant until 66 sec at which point accelerative forces were recorded ranging between +0.3g and +2.2g. The altitude trace varied between a low of 790 ft just prior to the maximum airspeed and a high of 930 ft which was recorded during the period of peak vertical acceleration forces.

The readability of the transmissions on the Cockpit Voice Recorder was good.

In order to evaluate the performance of TWA 159, and to obtain a clearer understanding of the events surrounding the take-off, a correlation of the flight data and cockpit voice recordings was made. The time base for this correlation was predicated on 80 kt, and the callout of that airspeed, occurring simultaneously. Other occurrences were measured in time from this point and plotted on a common time scale.

The Cockpit Voice Recorder-Flight Data Recorder airspeed curve was then compared with a predicted performance curve provided by Boeing (See Figs. 9-1 and 9-2). This comparison, utilizing the take-off clearance as a time reference, revealed an apparent disparity between the predicted and recorded performance of the aircraft in both the acceleration and deceleration phases of the take-off. Further study of the evidence prompted selection of the engine noise reaching its highest peak as the time reference for the take-off roll initiation point. This resulted in closer comparison of the two airspeed traces at the higher, more accurately recorded values, and still provided exceptional correlation with the physical evidence. In addition to the time base reference point, there were three other factors affecting the compatibility of the predicted and recorded performance. First, the airspeed values during deceleration were apparently depressed due to static position error induced by disturbed airflow while reverse thrust was utilized. Second, the airspeed values depicted by the flight recorder in the lower regimes, below 80 kt, tended to be less accurate than at the higher values. Third, the flight recorder tape drive system was malfunctioning. While this had no effect on the airspeed values recorded, it did result in irregular tape advance prior to the accident, and may have caused some minor distortion of the time scale during the take-off.

The final Cockpit Voice Recorder-Flight Data Recorder correlation indicated that the first reference of the crew to the position of DAL 379 occurred at approximately 115 kt. At this point, TWA 159 had progressed about 3 350 ft along the runway in 31.5 sec. Five seconds later, at 4 400 ft (200 ft prior to passing DAL 379) the flight reached $V_1$ (132 kt). The Cockpit Voice Recorder indicated that this speed was not called during the take-off. Acceleration continued as TWA 159 passed DAL 379 at approximately 135 kt, the sound of a "pop" was recorded at 139 kt, the sound of the engine power cut was at 143 kt, and finally the airspeed peaked at 145 kt. During this time interval, between 36.5 sec and 40.5 sec, the flight travelled approximately 950 ft and was then 5 350 ft from the take-off roll initiation point. The airspeed then dropped in the next second to 140 kt. At 42.5 sec the sound of engine power resumed, followed at 43 sec by the command of the co-pilot for spoilers. At this point, the aircraft was approximately 5 900 ft down the runway and a marked increase in the deceleration began. The sound of impact began at 7 575 ft.

1.12 Wreckage

During the ground slide, the fuselage upper structure ruptured just forward of the wing root, and the right wing failed inboard of No. 4 engine. Engines Nos. 1 and 2 partially separated and engine No. 3 separated from the wing structure.

The clamshell doors for all engines were in the reverse thrust position and the fuel controls were in the "maximum reverse" position.

1.13 Fire

Ground fire occurred in the area of the right wing separation and the Nos. 3 and 4 engines. The two firemen on duty at the airport responded with the crash truck and a rescue vehicle. The fire captain instructed the crash truck driver to park the truck approximately 75 ft from the fire area, and they, along with two off-duty airport employees, began foam application with the turret nozzle and a side line. Nearby volunteer fire departments with two additional trucks responded and aided in extinguishing the brush fires in the area.

1.14 Survival aspects

This was a survivable accident, although one of the eleven injured occupants died four days after the accident.

The forward galley door and aft main door were both opened by the assigned hostesses, but they were unable to inflate the slides before being forced from the aircraft by passengers. The hostess assigned to the main passenger loading door was unable to open it due to buckling of the cabin floor. After determining that there were no passengers in the area, she jumped from the forward galley door, which was approximately 7 ft above the ground. The aft galley door was opened by the assigned hostess, but she closed it because of the fire on the right side of the aircraft. She then assisted people to the aft main loading door and exited when no one else was in sight. This door sill was about 20 inches above the ground. The left aft overwing exit was opened and utilized by two passengers.

After closing the fuel shutoff valves, the flight engineer proceeded to the forward main loading door, attempted to help the hostess there, and then instructed her to go to the forward galley door. After a few moments he followed her, but finding no one in the area, he returned to the cockpit to make certain that the other crew members had escaped. He then exited through the pilot-in-command's sliding window which was approximately 10 ft above the ground. The co-pilot went directly to the forward galley door and carried a crippled woman to safety. The pilot-in-command also went to the forward galley area and inflated the slide at that door. Although the slide was doubled back under the aircraft, two or three passengers utilized it for descent to the ground. When no one else was seen or heard, the pilot-in-command left the aircraft through the galley door.

Emergency lighting within the cabin was reported as satisfactory. Several oxygen masks were hanging down and the chain locks on 84 of the drop-down tables failed to restrain the tables in the stowed position.

1.15 Tests and research

At idle power the JT8D-5 engines installed on DAL 379 produce the following jet exhaust:

| Distance (feet) | Temperature (degrees) | Velocity (feet/second) |
|---|---|---|
| 82 | 97 | 55 |
| 63 | 108 | 75 |

The distances selected correspond to the centre line of the Nos. 3 and 4 engines respectively of TWA 159 assuming that it was taking off along the runway centre line.

The effect of the ambient atmospheric conditions and the jet exhaust on the JT3C-6 engine installed on TWA 159 was studied by Pratt and Whitney. It was concluded that the combined effects of the temperature and velocity of the JT8D exhaust could have caused a compressor stall in the JT3C-6 engine resulting from the flow disturbance at the engine inlet. Additionally it was stated that, under the conditions of the accident, one could not think of any other factors which would have generated a compressor stall, and that a short duration high power stall of this type may not even be reflected in the engine instruments.

## 2.- Analysis and Conclusions

### 2.1 Analysis

When the position of DAL 379 was queried by the tower, the co-pilot estimated from a cursory glance that their aircraft was clear of the runway. The Board considered that an airline crew in these circumstances should have determined with absolute certainty whether or not the aircraft was physically clear of the runway either by opening the cockpit windows to get a better view, or even by utilizing the air stairs to make an "on the spot" determination if that were necessary. The crew should also have advised the tower immediately that the aircraft could not be moved any farther without assistance.

The Board recognized that there was no definitive standard, in terms of distance, to judge whether or not the aircraft was clear of the runway and recommended that the FAA establish, and appropriately publicize to pilots and controllers alike, meaningful standards of safe clearance from runway edges for aircraft, as well as for ground-based vehicles, which will permit reasonable assurance to all concerned that no interference with flight operations on the runway will be caused by the presence of such movable obstructions. It considered that such standards of safe clearance should take into account not only the aircraft as an "obstruction", but also the fact that jet exhaust from a parked or moving aircraft perpendicular to the operating runway may well create the type of hazard (compressor stall) encountered here even though the aircraft is more than a given number of feet "physically clear" of the runway.

In this connexion the FAA issued a report "Effect of Jet Blast - AC 150/5325-6, April 1965" which contains a quantity of valuable information as to velocities of jet engine blasts at varying levels of thrust and at varying distances, and forms a usable base from which meaningful conclusions in this area might be derived. Despite the known facts about wind velocities generated by the thrust of jet engines, no official cognizance had been

taken of them in terms of the environment they create under circumstances akin to those present in this case.

The Air Traffic Control aspects of this accident were reviewed. The controller because of his physical relationship to the location of DAL 379 (low angle of vision, night-time distance, etc.), was unable to determine by himself the distance from the closest extremity of the aircraft to the runway edge when the aircraft stopped moving and was therefore obliged to request the assistance of the crew who were in a better position to make this critical assessment. Their reply that they were clear of the runway, no matter how determined, was the critical factor influencing the controller and the Delta crew's remark ".... we're in the dirt, though," was not in itself sufficient to cause the controller to cancel the TWA 159 take-off clearance since there is no prohibition against taxiing aircraft out of such areas. No other indication of their own situation was communicated to the tower until about 4 seconds prior to TWA 159 passing the immediate rear of DAL 379 when the latter crew stated ".... we're stuck in the mud." It was considered that the provision of additional equipment such as Airport Surface Detection Equipment (ASDE), and/or the establishment and following of certain procedures for airport traffic control would have materially reduced the probability of this occurrence.

The final consideration bearing on the accident was the actions of the pilot-in-command and co-pilot of TWA 159. The aircraft passed behind DAL 379 at a speed of approximately 135 kt, and the jet blast perpendicular to its path generated a short duration compressor stall in the No. 4 engine. Although the stall resulted in a loud noise and the jet blast apparently moved the flight controls, the performance capabilities of the aircraft were not affected. However, the co-pilot, believing that his aircraft was physically damaged by a collision and that it might not be capable of flight, elected to abort the take-off. It was the opinion of the Board that his decision to abort the take-off, regardless of the airspeed, was reasonable under the circumstances. The co-pilot reduced power on all engines at 143 kt, 1 sec after the sound of the compressor stall. As the airspeed peaked at 145 kt his next action was to call for assistance in holding the yokes forward, preparatory to the application of reverse thrust. His command was given 1 sec after the power was reduced; however, the actual reverse thrust was not applied for an additional 2.5 sec. During this 4.5 sec interval, the only decelerative device applied was the brakes, and their effectiveness was appreciably reduced because the spoilers were still retracted. One-half second later, or 5 sec after the stall occurred, the co-pilot called for the spoilers which should have been extended as soon as the power was reduced. The pilot-in-command was surprised when the abort occurred, and though he stated that he assisted the co-pilot with the braking effort, he did not extend the spoilers on his own initiative. Once the spoilers were extended, a sharp increase in braking effectiveness was indicated by the rapid deterioration in airspeed. However, there was insufficient runway remaining in which to stop the aircraft.

The significance of the crew's slow implementation of the abort procedure was apparent from the Boeing performance data (see Figs. 1 and 2), which showed that the total accelerate-stop distance of the aircraft was approximately 6 560 ft for an abort-decision speed of 132 kt and approximately 7 850 ft for an abort-decision speed of 143 kt. Although this data indicates that the overrun was inevitable, it was noted that had the abort been executed properly the aircraft would have stopped either prior to the brow of the hill (225 ft from the runway end) or at least would have arrived there at a sufficiently reduced airspeed so that it would not have become airborne again as it did and damage to the aircraft would have been greatly reduced.

This analysis illustrated that the outcome of any attempted abort is heavily dependent on the pilot's knowledge of the proper sequence in which actions must be taken, especially when the abort is executed at velocities near $V_1$ and the stopping distance is limited. The company manuals indicated that aborting a take-off at high speed is potentially dangerous, and should not be attempted unless an actual engine failure occurs prior to $V_1$. Such a position could not only have misled and prejudiced the pilot and his thinking toward aborted take-offs, but also failed to consider the likelihood of other emergencies which would require an abort. Additionally, the second item on the aborted take-off procedure checklist was "Extend spoilers and apply reverse thrust". Although this provided the correct sequence, it failed to stress the importance of a proper sequence or the consequences of either delayed or improper actions by the crew. The Board believed that the circumstances of this accident dramatized the need for a major reappraisal of the current training manuals and instruction provided by all airlines. It was considered that a new, positive approach toward abort procedures, with amplification and clarification of such procedures, including safety margins provided and the need for prompt and proper sequencing of each action, was needed.

In connexion with a reappraisal of abort procedures, the Board believed that a reassessment and clarification of the respective duties and responsibilities of the pilot-in-command and co-pilot during critical phases of flight would be in order. It is a common practice among airlines for the pilot-in-command and co-pilot to alternate piloting the aircraft on various legs of a flight when several stops are made en route. In such instances, the co-pilot often makes the take-off and subsequent landing, although the pilot-in-command is still in command of the aircraft and may elect to "take over" from the co-pilot when the situation may warrant or dictate such action.

Assuming that the "pilot-in-command" concept is effective even under circumstances such as those involved in this accident, when the co-pilot is flying the aircraft, the pilot-in-command must be alert and in position to counteract actions of the co-pilot which are not in accordance with his own best judgement. The assumption that a pilot-in-command can effectively countermand a decision of the co-pilot to abort a take-off may be worth re-examination since it is at least arguable that the virtually split-second action required for implementation of the abort procedure near $V_1$ dictates that the pilot at the controls should also have the final decisional authority with respect to an abort.

## 2.2 Conclusions

### (a) Findings

The aircraft was airworthy and properly certificated.

DAL 379 was mired 4 600 ft from the take-off end of runway 27L, and the aftmost part of the aircraft structure was approximately 7 ft from the runway edge.

The local controller was unable to determine without assistance whether DAL 379 was clear of the runway. The crew of DAL 379 should have made a greater effort to ascertain their position with respect to the runway and should have been more explicit in reporting their exact circumstances to the controller.

Although the phrase "clear of the runway" was generally construed by pilots and controllers to mean that a runway was available for unrestricted use, there was no definitive criterion, in terms of distance, against which to judge whether such clearance exists, nor was there any standard which takes into account the effect of the exhaust from jet engines.

The pilot-in-command of TWA 159 failed to announce $V_1$.

TWA 159 sustained a compressor stall in the No. 4 engine as it passed behind DAL 379 due to the jet blast from the idling engines of DAL 379 and the co-pilot, believing his aircraft had collided with another plane, aborted the take-off.

The abort procedure was not accomplished in the correct sequence, nor was it completed in a timely manner.

The take-off was aborted beyond $V_1$, and the overrun was inevitable.

(b) Cause or Probable cause(s)

The Board determined that the probable cause of the accident was the inability of the TWA crew to abort successfully their take-off at the speed attained prior to the attempted abort. The abort was understandably initiated because of the co-pilot's belief that his plane had collided with a Delta aircraft stopped just off the runway. A contributing factor was the action of the Delta crew in advising the tower that their plane was clear of the runway without carefully ascertaining the facts, and when in fact their aircraft was not at a safe distance under the circumstance of another aircraft taking off on that runway.

## 3.- Recommendations and Corrective Measures

1. The Board recommended that the FAA establish, and appropriately publicize to pilots and controllers alike, meaningful standards of safe clearance from runway edges for aircraft as well as for ground-based vehicles which will permit reasonable assurance to all concerned that no interference with flight operations on the runway will be caused by the presence of such movable obstructions. Such new standards should take into account the effect of the exhaust from jet engines.

2. The Board believed that the circumstances of this accident dramatized the need for a major reappraisal of the current training manuals and instructions provided by all airlines with a view toward a new, positive approach toward abort procedures. Such an approach should include an amplification and clarification of such procedures, including safety margins provided and the need for prompt and proper sequencing of each action.

3. The Board believed that a reassessment of the respective duties and responsibilities of the pilot-in-command and co-pilot during critical phases of flight was in order. In so doing, the "pilot-in-command" concept should be re-examined with respect to its applicability in situations where time may not permit the pilot-in-command to countermand effectively the decision of a co-pilot who is flying the aircraft.

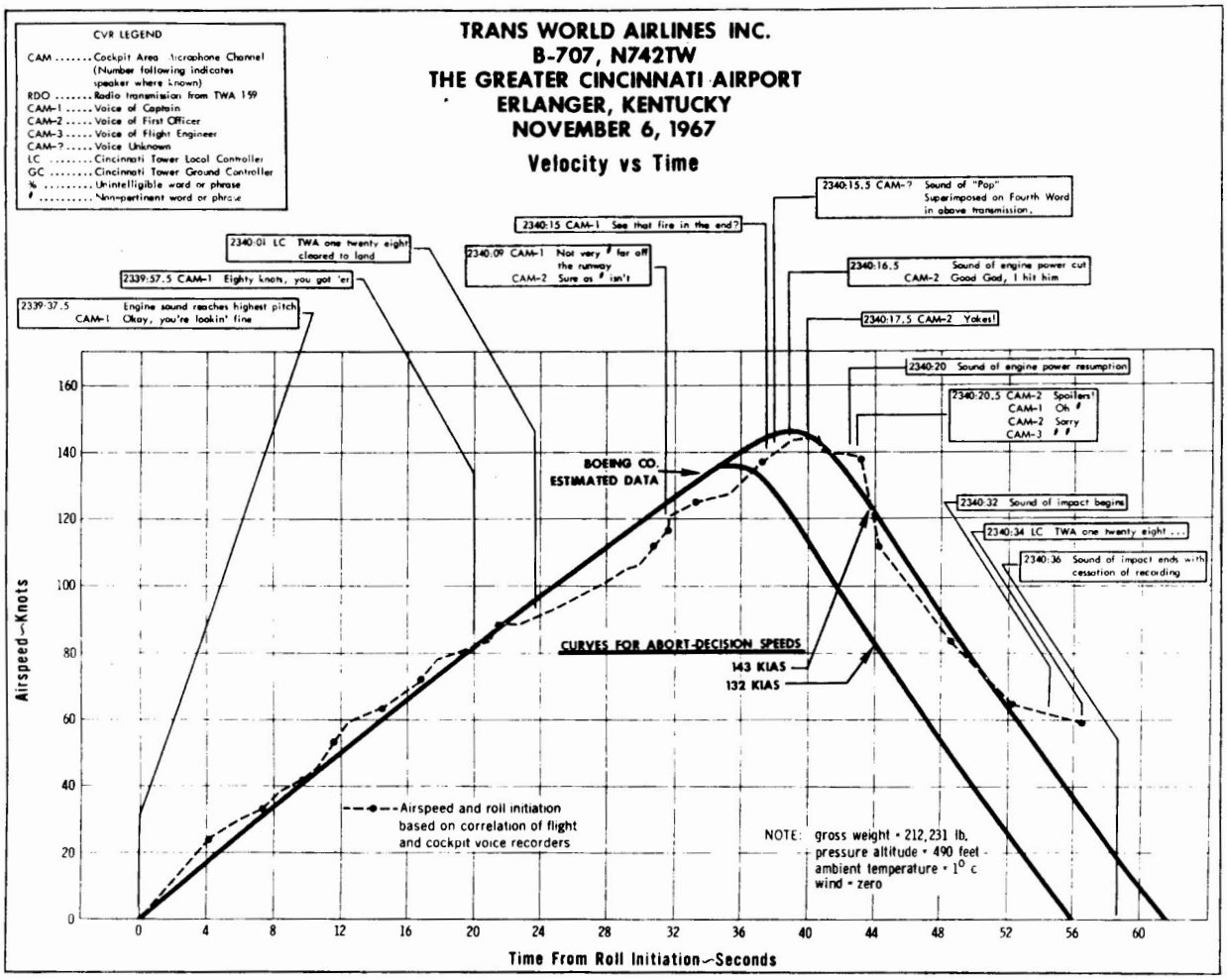
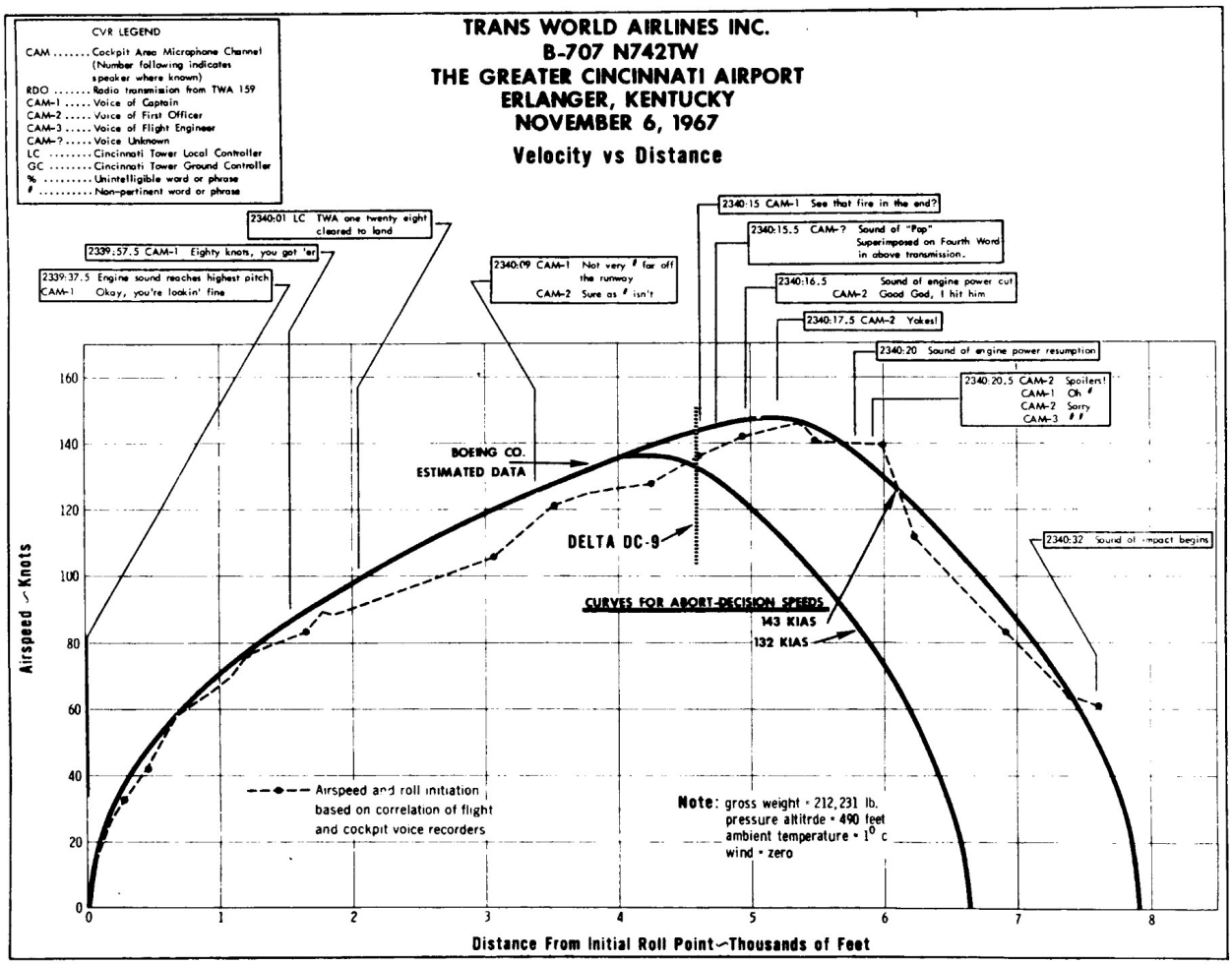

CVR LEGEND
CAM ..... Cockpit Area Microphone Channel (Number following indicates speaker where known)
RDO ..... Radio transmission from TWA 159
CAM-1 ..... Voice of Captain
CAM-2 ..... Voice of First Officer
CAM-3 ..... Voice of Flight Engineer
CAM-? ..... Voice Unknown
LC ..... Cincinnati Tower Local Controller
GC ..... Cincinnati Tower Ground Controller
% ..... Unintelligible word or phrase
# ..... Non-pertinent word or phrase
TRANS WORLD AIRLINES INC.
B-707, N742TW
THE GREATER CINCINNATI AIRPORT
ERLANGER, KENTUCKY
NOVEMBER 6, 1967
Velocity vs Time
2340:15.5 CAM-? Sound of "Pop" Superimposed on Fourth Word in above transmission.
2340:15 CAM-1 See that fire in the end?
2340:01 LC TWA one twenty eight cleared to land
2340:09 CAM-1 Not very # far off the runway
CAM-2 Sure as # isn't
2340:16.5 Sound of engine power cut
CAM-2 Good God, I hit him
2339:57.5 CAM-1 Eighty knots, you got 'er
2339:37.5 Engine sound reaches highest pitch
CAM-1 Okay, you're lookin' fine
2340:17.5 CAM-2 Yakes!
2340:20 Sound of engine power resumption
2340:20.5 CAM-2 Spoilers!
CAM-1 Oh #
CAM-2 Sorry
CAM-3 # #
BOEING CO. ESTIMATED DATA
2340:32 Sound of impact begins
2340:34 LC TWA one twenty eight ...
2340:36 Sound of impact ends with cessation of recording
CURVES FOR ABORT-DECISION SPEEDS
143 KIAS
132 KIAS
Airspeed and roll initiation based on correlation of flight and cockpit voice recorders
NOTE: gross weight = 212,231 lb.
pressure altitude = 490 feet
ambient temperature = 1° c
wind = zero
Airspeed—Knots
Time From Roll Initiation—Seconds
0
20
40
60
80
100
120
140
160
0
4
8
12
16
20
24
28
32
36
40
44
48
52
56
60

Figure 9-1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2340:20 Sound of engine power resumption
2340:20.5 CAM-2 Spoilers!
CAM-1 Oh #
CAM-2 Sorry
CAM-3 # #
2340:32 Sound of impact begins
BOEING CO. ESTIMATED DATA
DELTA DC-9
CURVES FOR ABORT-DECISION SPEEDS
143 KIAS
132 KIAS
Airspeed and roll initiation based on correlation of flight and cockpit voice recorders
Note: gross weight = 212,231 lb.
pressure altitude = 490 feet
ambient temperature = 1° c
wind = zero
Airspeed — Knots
Distance From Initial Roll Point — Thousands of Feet
0
20
40
60
80
100
120
140
160
1
2
3
4
5
6
7
8

Figure 9-2