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THE POTENTIAL ROLE OF FLIGHT RECORDERS IN AIRCRAFT ACCIDENT INVESTIGATION

DECEMBER 1966

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CIVIL AERONAUTICS BOARD
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FOREWORD

This publication is intended to provide those persons interested in aviation safety with a brief history and the possible future of the flight recorder. It provides information on how the recorder data is now being evaluated in accident investigation procedures and how additional protection and parameters can enhance accident investigation and accident prevention activities.

This paper was prepared by B. R. Allen, Director of Bureau of Safety, and John S. Leak, Chief of Technical Services Section, Civil Aeronautics Board, and presented at the Aviation Safety Meeting, Toronto, Canada, October 31, November 1, 1966, jointly sponsored by Canadian Aeronautics and Space Institute, American Institute of Aeronautics and Astronautics, and Cornell-Guggenheim Aviation Safety Center. The paper was first published by AIAA as Preprint No. 66-810, same title, and is a follow-up to an earlier CAB publication entitled, "History and Development of Flight Recorders," released March 14, 1966.

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INTRODUCTION

Admittedly, the flight recorder, which has been in operation for several years, is no panacea. It was never intended nor will it ever be an all-seeing, all knowing automaton of the type a science-fiction writer might conjure up. The flight recorder, however, has proven its value as an accident investigation tool, and it is showing its potential as an aid to accident prevention. Additionally, flight recording in the rapidly advancing state-of-the-art may become one of the greatest single boons to air management since the log book.

Because of the flight recorder's ever increasing importance in aviation, it is imperative that everyone associated with accident investigation and prevention should become familiar with this instrument, not necessarily with its mechanical and electronic features, but with its role in the investigative process, what it can and cannot do and, above all, its potential. Toward this end, this report presents a brief history of the flight recorder, how it is presently read out and to what uses the data can be put. It also discusses the need for additional parameters and what they should be, other needed improvements, and how the increasing use of recorder data can enhance accident investigation and prevention.

HISTORY

The first Civil Air Regulation on flight recorders, Amendment 100, took effect in April 1941 and required on air carrier aircraft a device that would record altitude and radio transmitter operation (on and off). The compliance date was subsequently extended three times and finally in June 1944, the Civil Aeronautics Board rescinded the requirement primarily because of maintenance difficulties and lack of replacement parts for the recorders due to the war effort.

A similar regulation was adopted in September 1947, requiring recorders in aircraft of 10,000 pounds or more to record altitude and vertical acceleration. Again, on July 1, 1948, the CAB rescinded the requirement as there were no instruments readily available of proven reliability or adequate for the intended purpose.

During the next nine years CAA and CAB studied possible requirements, met with industry representatives, and proposed amendments defining the flight recorder program.

In 1948 the French Air Safety Commission became interested in flight recorders, leading to the installation of recorders in ten aircraft belonging to Air France and TAI. The experiment aroused so much interest that TAI decided to equip all its aircraft voluntarily at is own expense.

Finally, in August 1957, CAB adopted amendments to CAR Parts 40, 41, 42 and 43. Required was the installation of flight recorders after July

1958 in all aircraft over 12,500 pounds and being operated in air carrier service at altitudes above 25,000 feet. The functions to be recorded were airspeed, altitude, direction and vertical acceleration against a base of time. At about the same time the French issued similar requirements.

In September 1959 the regulations were amended to establish a 60-day record retention period and to clarify the time period of recorder operation i.e., continuously from beginning of takeoff roll to completion of landing roll.

Many of the early major accidents of the newly introduced jet transports occurred during training operations. Much valuable investigative data was lost, or had to be sifted out by long and tedious work, because the flight recorders were not turned on. The CAB and FAA recognized that the training accident often stems from intentionally introduced problems or emergencies (dutch roll practice, flight near V_{MC}, takeoffs and landings with engines inoperative, etc.) and, therefore, provides an excellent base for implementing corrective measures. Consequently, the regulations were again amended to require operation of the flight recorder on all flights. Additionally, the regulations were extended to include all turbine-powered transport category airplanes operated by U.S. air carriers.

During the past few years several governments have either issued or have made moves toward issuing flight recorder requirements and some carriers have installed or are planning installation of recorders voluntarily. The military services have become increasingly interested in recorders for accident investigation purposes, have installed them on some aircraft, e.g., C-133 and C-141, and are planning for future planes, e.g., C-5A.

The latest action to be taken in the United States toward improvement of the flight recorder program was the recent change recommended by CAB in the Federal Aviation Regulations to relocate the recorder in the rear portion of the aircraft. It is yet too early for the CAB to offer any statistics on how much this will improve the overall flight recorder readability; however, the results of a French study may be a good indicator. In examining the post accident conditions of 51 serious accidents, including 39 total destruction cases, 3 mid-air collisions, 3 in water ranging from 5 fathoms to deep seas, 28 with fire following impact, an aft mounted recorder either was or could have been recovered in 98 percent of the accidents. Superimposed here is the fact that the recorder in this study uses a photographic process and is protected from impact and fire only by its aft location. The U. S. recorders, tested to 100g and 1100 degrees C for 30 minutes, should give at least comparable recoverability in the aft position.

CURRENT ACCIDENT INVESTIGATION ROLE

As of September 30, 1965, the Civil Aeronautics Board had investigated over 181 accidents involving aircraft with flight recorders installed. Vital information was obtained from flight recorders in 125 cases, although in 6 of these the quality and quantity of data was seriously reduced because of impact damage to the recording medium. In ten other accidents during this period recorder information was not available as follows:

Recording medium fragmented; pertinent pieces not recovered - 3 cases.

Aluminum foil medium consumed by prolonged exposure to fire - 3 cases.

Medium supply expended prior to the accident - 2 cases.

Medium not advancing - 1 case.

Recorder not turned on - 1 case.

The other 46 of the 181 accidents were of a nature such that readout was considered unnecessary (e.g., landing gear collapse during taxi, fire during engine starting, injuries to ground crew). Flight recorders have also been read out in a large percentage of the incidents investigated by the CAB, primarily those involved in turbulence.

Beyond the flight recorder's primary purpose as an investigation tool toward determination of probable cause, it has provided data for many studies conducted by NASA, FAA, airlines, manufacturers, and other groups in such areas as turbulence, airplane handling qualities, pilot techniques.

Cited below are examples of how the flight recorder has been used in accident investigation.

Case 1

A DC-8 landed with an existing hydraulic malfunction. Early during the rollout the aircraft veered off the runway, struck obstacles and burned. Examination of the readout showed a fluctuating altitude trace shortly after touchdown. This fluctuation was traced to disturbed airflow at the static ports as the result of unsymmetrical reverse thrust. Further, the airspeed and heading traces, combined with tire track information, formed the basis for an analysis which proved that the yawing rate was not possible with application of full rudder, full nose steering and full braking on one side; it required positive thrust on one side of the aircraft and reverse thrust on the other.

Case 2

The pilot of a Boeing 707 attempted to abort a takeoff near V_1. The aircraft traveled the full length of the runway, struck an obstacle and burned. The airspeed and heading traces were used as bases for an energy analysis which showed when the power was reduced, when and to what degree the retarding devices (speed brake, wheel brakes, reverse thrust) were used.

Case 3

A Viscount on a go-around pitched over sharply from less than 200 feet, crashing nose down just beyond the far end of the runway. Upon examination of the recorder readout plot, there was a suspicion that the aircraft may have struck a bluff or other obstacles under the approach, thus damaging the control system. Figure 1 shows the profile of the flight, made by converting indicated airspeed to true airspeed and ground speed, then integrated to find the geographic points under the altitude trace. The profile shows that, while the aircraft was close to the bluff, it did not strike it or other obstructions. The profile also revealed excessive airspeed for landing near and over the runway, followed by rapid deceleration, probably flap actuation, but too far down the runway for a landing. While this investigation was underway the flight recorder readout of an approach incident involving empennage rime ice led to wind tunnel tests and other analytical work. It was finally concluded that the accident resulted from empennage ice. On the basis of these developments through the flight recorder, the CAB reopened the investigation and changed the probable cause of a Viscount accident in 1958 before the installation of flight recorders.

Case 4

A Boeing 727 struck the ground short of the runway on a long, straight-in, visual approach. Figure 2 shows the profile obtained by integrating the readout and plotting the result against a terrain profile. Also depicted is the high rate of descent as the aircraft approached the airport. This information, obtained from the flight recorder, helped materially to define the flight conditions surrounding this accident and to arrive at the probable cause: failure of the captain to take timely action to arrest an excessive descent rate during the landing approach. Figure 3 shows only the final stage of this approach and, therefore, better detail of the descent path with relation to the glide slope and the runway.

Case 5

Another 727 crashed short of the airport while making a circling, visual approach in deteriorating weather. The flight recorder in this case gave the usual airspeed, altitude, heading and normal acceleration, thus giving valuable information on rates of descent, turning rates, etc. Additionally, as shown in Figure 4, it was used to recreate the airplane's track during its final moments. The first calculations were done on a no-wind basis, producing the broken line shown in Figure 4. Later, after the low altitude wind velocity and direction had been well firmed up, the wind was applied to produce the hash line. By merging this information with data gathered by the Witness Group and the ATC Group, the superimposed tracks from the several sources appear as shown in Figure 5.

Case 6

A Boeing 720 crashed after reaching about 18,000 feet during climb through a turbulent area. Before reaching the ground all four engines had separated as had the outer wing sections, the forward fuselage and the empennage. Figure 6 depicts the readout. One of the first areas of interest in this figure was the normal acceleration trace. It became evident from this trace that turbulence, per se, was not a likely candidate from probable cause. It can be seen that the early portion of the flight was conducted through far worse conditions than the latter. The Boeing Company, in a cooperative effort with the CAB, undertook several studies based on the flight recorder data. The early analog and digital studies were most helpful in demonstrating that the aircraft was intact during the initial steep climb, the pitchover and during most of the ensuing dive. The angle of attack, pitch attitude, elevator angle and stick force time histories (Figure 7) resulting from the digital computer study, coupled with the derived flight path (Figure 8) provided an excellent graphic display of the final maneuver and a clearer understanding of the problems confronting the crew. Perhaps the most significant finding was that the maneuver required (a) full nosedown trim, (b) full nosedown elevator for about eight seconds followed by (c) full up elevator about nine seconds later. This one finding was perhaps the most convincing of all in indicating an essentially intact aircraft down to a lower altitude. Still air was assumed for the study, an assumption which might first appear ridiculous; however, the excellent parametric comparison shown in Figure 8 certainly indicates that the motions must have been produced principally by elevator and stabilizer controls rather than vertical gust inputs. For gusts to have been the major generating forces for the initial negative g portion of the maneuver, their velocities would have had to be inconceivably greater than the most severe measured during the National Severe Storms Project, and would have had to persist in one direction for nearly ten seconds.

THE FUTURE OF THE FLIGHT RECORDER

For several years now accident investigators have recognized that wreckage examination is becoming less and less fruitful. In the days when the DC-3 represented the ultimate in travel comfort and speed, an inflight breakup was considered the most tedious and time consuming to investigate. Now, the investigator finds that the investigation of the inflight breakup, while far more tedious than previously, may be one of his easier investigations. This has been brought on, of course, by tremendous increases in the two energy generators, speed and mass. Additionally, the failure patterns of the newer aluminum and steel alloys do not lend themselves to quick and easy field examination.

While the art of wreckage examination is not yet dead, its prognosis is not very promising. The best medicine which can be administered is the flight recorder - not the recorder of today, but a unit which will record many parameters, be ejectable, and locatable in a wide variety of circumstances.

Many technical papers from a variety of government, airline, manufacturer and academic sources have been prepared over the past several years concerning the necessity or desirability of additional parameters. How many data sources depends on how expansively or expensively the writer is thinking. The equipment and the techniques are available for recording an almost infinite array of data to the ridiculous ultimate that the payload of an aircraft could be measured in numbers of data channels rather than tons of cargo or number of passengers. Among this vast array of possible parameters there is one group which for subsonic aircraft, has almost universal approval. This group consists of:

1. Power indication parameters, such as torque, EPR, gas temperatures and r.p.m.

2. Angle of attack.

3. Pitch attitude and/or rate.

4. Roll attitude and/or rate.

5. Yaw attitude and/or rate.

6. Longitudinal trim position.

7. Control column and/or elevator position.

8. Control wheel and/or aileron position.

9. Pedal and/or rudder position.

10. Ambient air temperature.

11. Wing flap position.

These, for a four-engine aircraft and depending on number of engine parameters selected and depending on the use of "and" or "or", could range from 16 to 36 additional data sources. While these additions would represent a 400 to 900 percent increase in data sources over those now required, they appear extremely modest when compared to the proposed recorder for the Lockheed C-5A. In addition to the parameters now recorded and those listed above, the C-5A recorder is being programmed for:

1. Thrust reverser position.

2. Fuel flow.

3. Power lever angle.

4. Cabin pressure.

5. Master Fire Warning.

6. Autopilot ON-OFF (3 axes).

7. Hydraulic pressure.

8. Takeoff cg.

9. Speed brake position.

10. Engine turbine vibration.

11. Engine compressor vibration.

12. Gross weight.

13. "Q" system.

14. Cabin and cargo smoke detection.

15. Yaw damper ON-OFF.

16. Electrical generator output.

17. Engine fire warning.

18. Engine fire bottle.

All in all, the C-5A recorder is being planned for at least 41 parameters encompassing at least 98 data points. The recording unit, which also will contain voice channels, is to be ejectable by impact, fire, emersion, or by selection. It is to be flotable and will contain a radio beacon.

To increase the data channels by more than three or four on the presently used foil-type recorder would require either extremely wide foils or the use of several separate foils. This is not practical operationally, nor is it practical in the investigator's view. What is needed in addition to "information" is "timely information." Recording additional data mechanically would serve to increase the current problems of the flight recorder specialist, e.g. shift of the medium, bent or broken stylii, and improper casette installation, and thus lengthen readout and data reduction time. During this period the investigator has been slogging through the wreckage, searching for answers he may not find.

The obvious answer for the recording of additional parameters lies in electronic recording, specifically wire or tape. It not only lends itself to compactness but also to rapid processing, using the standard digital computer from the initial readout, through calibration correction (if any) to the plotting of the data by an X-Y plotter. What now takes days with five channels could be reduced to a few hours with many channels.

The investigation of a major accident of a large aircraft now runs for several months and, where wind tunnel tests, flight tests and computer studies are required, can and does run as long as two years. Several times"second accidents" have occurred before the first could be solved. If one applies to these "second accidents" in the past the word "regrettable," he must, in terms of the 300- to 1000-passenger aircraft of the near future, apply the word "intolerable."

Perhaps the best way to assess the potential of the expanded flight recorder is to examine some past investigations in the context of having available a flight recorder record for fast readout. In some of the cases reviewed there was a flight recorder and, in these cases the potential of increased data sources is examined.

Case A

In September 1959, an Electra experienced a wing separation. The field investigation of this accident lasted for months. Experts from all parts of the industry, several aircraft manufacturers, National Bureau of Standards, NASA, FAA and CAB viewed the remains. There was unanimous agreement: The wing failed in positive overload. A flight recorder would clearly have shown that the g necessary for overload failure was not present. It would also have shown there was no dive preceding the failure, a factor over which there was much argument and many manhours expended. Recorded engine parameters would have indicated power irregularities in the No. 1 engine prior to the wing failure, and angle of attack and attitude indications would probably have reflected analyzable abnormalities. These time-consuming investigative operations could, no doubt, have been eliminated:

1. A second ground search involving 400 army personnel.

2. Searching ARTC and military records for other aircraft which might have created a near miss condition.

3. Long and expensive trajectory studies.

4. Fuel analyses.

The real tragedy of this case lies in the fact that it took a second accident five months later to provide enough additional information to solve the two accidents.

Case B

On February 12, 1963, a Boeing 720B crashed after reaching 18,000 feet during a climb through turbulence (Case 6, above). In this case a flight recorder trace was available and assisted immeasurable to the investigation, as previously discussed. The additional parameters of angle of attack and attitude, however, could have reduced by many weeks the work which went into obtaining the curves shown in Figures 7 and 8. Primary control and stabilizer trim position records would have given a true picture of how the aircraft was placed in its extreme attitude, positions concerning which crew members testified during the investigations of subsequent upset situations. The investigation could also have been shortened as follows:

1. Powerplant investigation could have been held to a minimum if the recorder had shown power information from all four engines until separation occurred.

2. The extent of airframe mock-up could have been reduced materially.

3. Many systems investigations could have been reduced in extent or eliminated.

Had this investigation been able to proceed more rapidly, many of the corrective actions, both in aircraft modification and in the operational and flying technique education and improvement, could have occurred early enough to have prevented several turbulence upsets, some of which became fatal accidents.

Case C

Preceding most of the so-called "turbulence upset" accidents in the U.S., there was an accident of a large swept-wing jet in Europe during climb after takeoff. No recorder was installed. A recorder, particularly one with expanded data sources, could have given data which was absolutely unobtainable by the investigators. Had they had flight recorder information, there is a strong possibility that even Case B, above, and all the others like it could have been averted.

Case D

A Viscount shed its wings and empennage in turbulence in 1959. Among the investigators of that accident there is no doubt that a flight recorder would have answered many questions early in the investigation. Furthermore, an expanded-parameter recorder, together with the weather and ATC packages, would have been all that was necessary to have solved the accident.

There are many more. Any investigator can review his cases and recognize in each what a recorder could have done for him and for the industry. Equipped with a good readout of the several proposed parameters, the investigating team can conclude its work months earlier. More important, positive answers to many questions are available immediately, leading to at least interim corrective measures far earlier than they occur now in many cases.

THE FLIGHT RECORDER AND ACCIDENT PREVENTION

In the past there has been much discussion over the role the present recorder could play in accident prevention if only someone would or could devote time to read out the recorders routinely. The operators argue that they do not have the manpower, and they are right. There is probably no organization which could devote, on a routine basis, the man hours necessary to read, even on a sampling basis, these numbers of tapes. However, magnetic recording, adaptable to computer equipment already in use, can eliminate this problem and make analyses relatively easy. In addition to revealing unwanted characteristics in airplane equipment (such as increased fuel consumption or decay in available power), the flight recorder could be used as a supplement to the check ride. It could show whether the crews are adhering to the flight manual and to established procedures. In very recent history one fatal accident of a jet transport on approach might have been prevented if the means had been available to detect the pilot's persistence in departing from standard, normal operation. History has recorded many such cases where the flight recorder, used as a supplement to check rides could have prevented accidents.

Several of the airlines and the military are now experimenting with the so-called "maintenance recorder" with which 20 or more channels of information are collected. The primary purpose of the maintenance recorder is, as its name implies, to enhance maintenance. It will reduce equipment down-time, reduce cost of repair work, and allow more efficient management of maintenance activities. This device is, however, by its very nature an accident prevention device. Certainly it is both cheaper and safer to remove an engine because of tell-tale warnings than to have it remove itself in flight and, in the process, break primary structure and kindle a fire.

Because the maintenance recorder, per se, and the electronic flight recorder differ in essence only in some of the recorded parameters, it logically follows that they could be merged into one. This does not mean one wire or one tape, nor does it necessarily mean one black box but, rather, one integrated recording system. Regulatory requirements concerning numbers of parameters, recording and retention times, protection, etc., are beyone the scope of this paper, but the required parameters, whatever they might be, could be triggered to one tape or wire cassette and the remaining data to another. Or by general agreement all the data, required and non-required, could be protected from impact and fire, and eventually ejectable.

CONCLUSION

The flight recorder, despite the problems it has presented and despite the numerous times it has been destroyed, has proved its worth as an investigation tool. If it had done nothing more, it has increased the investigator's confidence level, the value of which cannot be overemphasized. But it has done more, as reported in this paper. It can and must do even more. The expanded flight recorded, ejectable, locatable, and containing voice channels, could further enhance safety in many ways.

1. It could eliminate or materially reduce the costly and time consuming diving and dredging operations of water accidents. At the least it would allow the investigation to progress while these activities go on.

2. It could, in deep water accidents, provide data which now is lost forever.

3. It could furnish early data on which to base immediate interim corrective action.

ILLUSTRATIONS

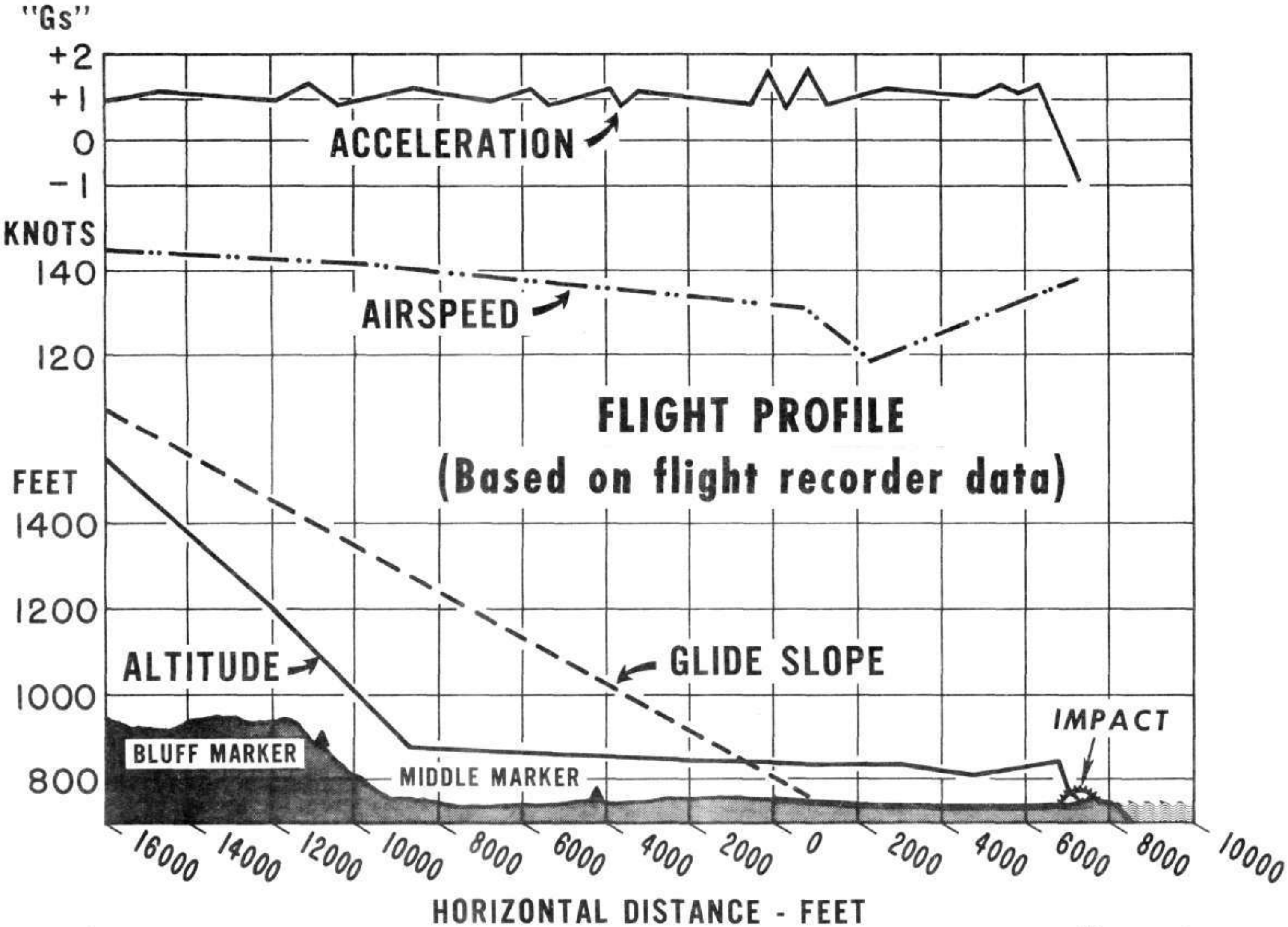
"Gs"
+2
+1
0
-1
ACCELERATION
KNOTS
140
120
AIRSPEED
FLIGHT PROFILE
(Based on flight recorder data)
FEET
1400
1200
1000
800
ALTITUDE
GLIDE SLOPE
IMPACT
BLUFF MARKER
MIDDLE MARKER
16000
14000
12000
10000
8000
6000
4000
2000
0
2000
4000
6000
8000
10000
HORIZONTAL DISTANCE - FEET

Figure 1

ATTACHMENT A

FLIGHT PROFILE

(BASED ON FLIGHT RECORDER DATA)

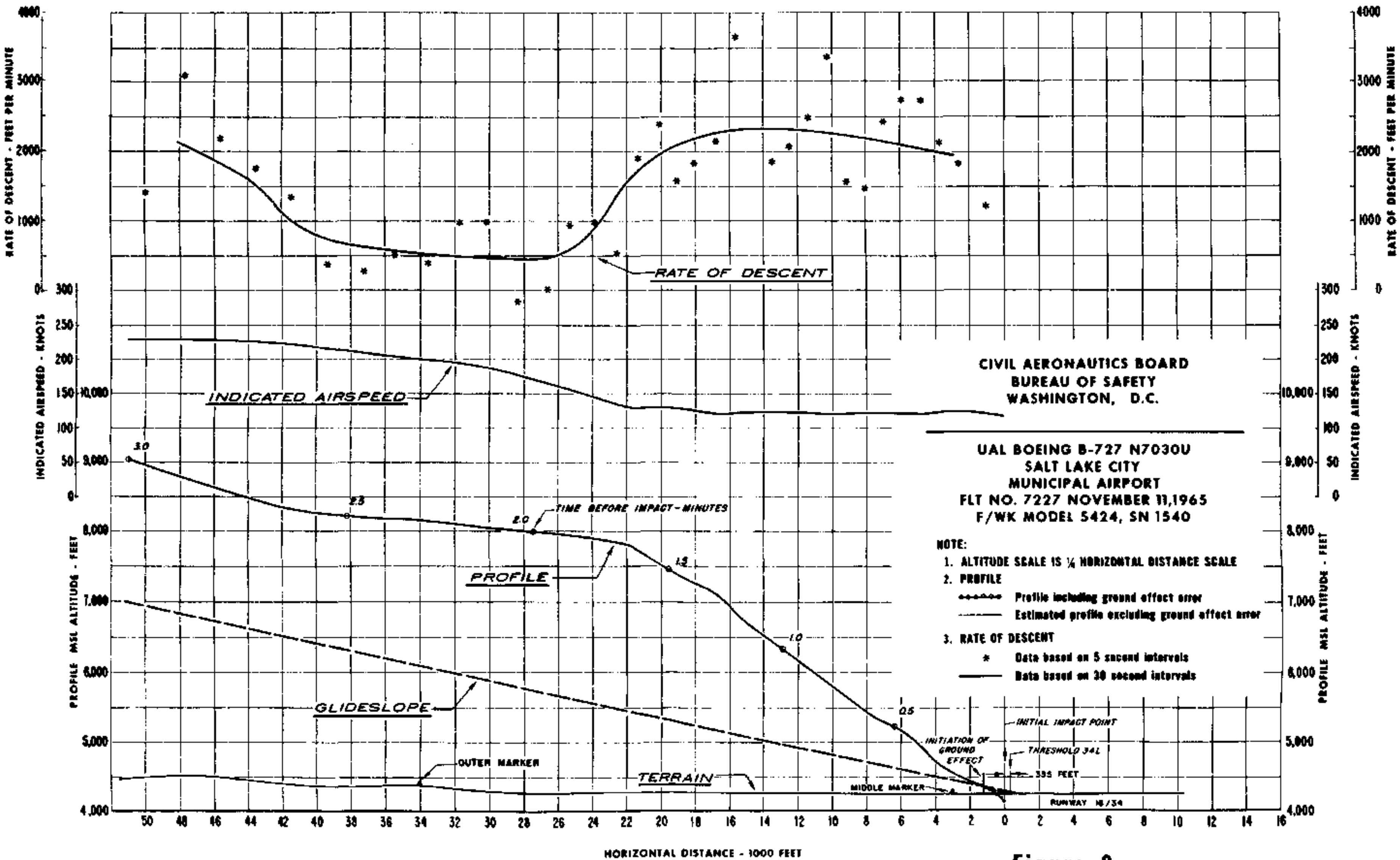

Figure 2

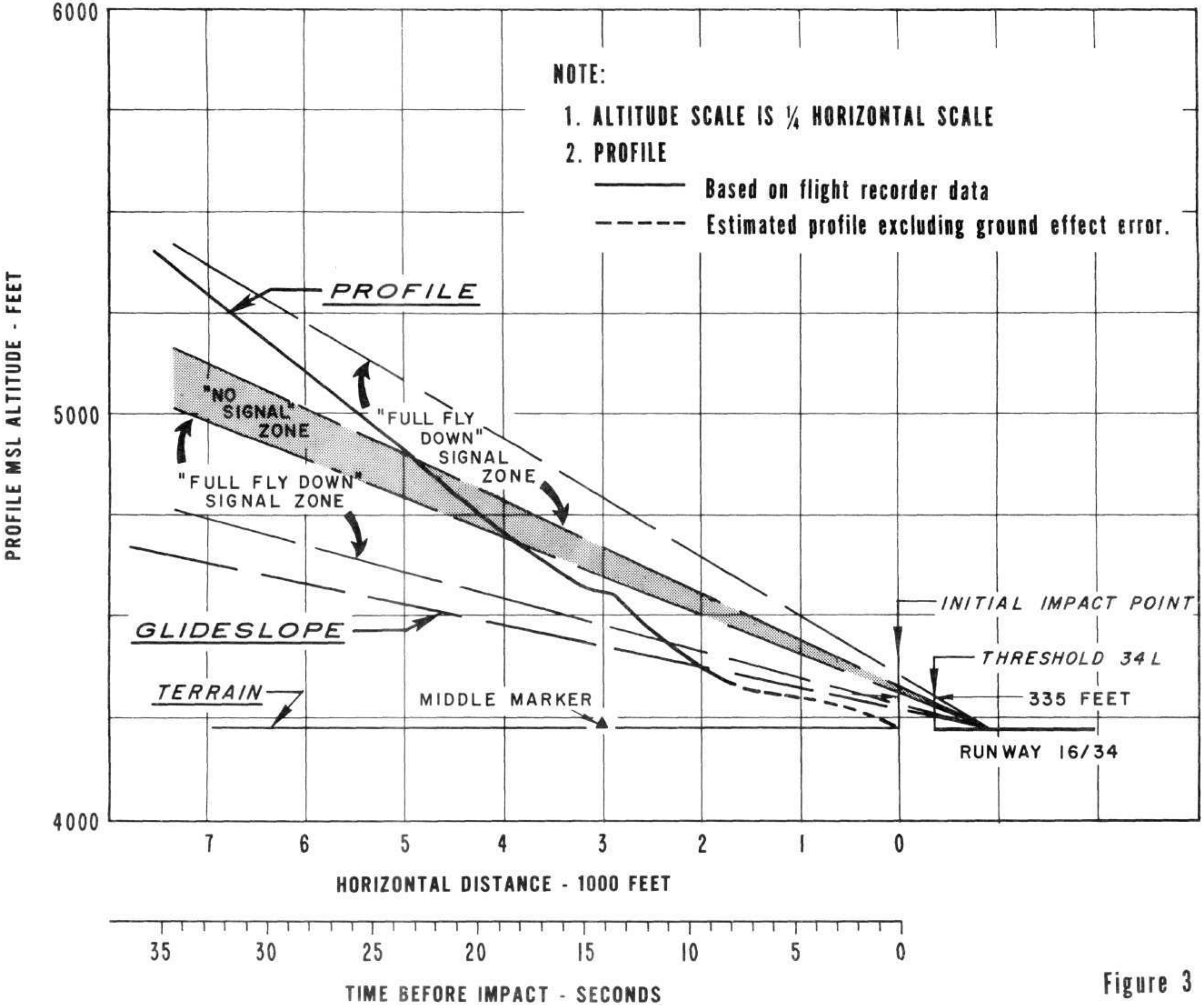
NOTE:
1. ALTITUDE SCALE IS ¼ HORIZONTAL SCALE
2. PROFILE
Based on flight recorder data
Estimated profile excluding ground effect error.
PROFILE
"NO SIGNAL" ZONE
"FULL FLY DOWN" SIGNAL ZONE
"FULL FLY DOWN" SIGNAL ZONE
GLIDESLOPE
TERRAIN
MIDDLE MARKER
INITIAL IMPACT POINT
THRESHOLD 34 L
335 FEET
RUNWAY 16/34
PROFILE MSL ALTITUDE - FEET
6000
5000
4000
7
6
5
4
3
2
1
0
HORIZONTAL DISTANCE - 1000 FEET
35
30
25
20
15
10
5
0
TIME BEFORE IMPACT - SECONDS

Figure 3

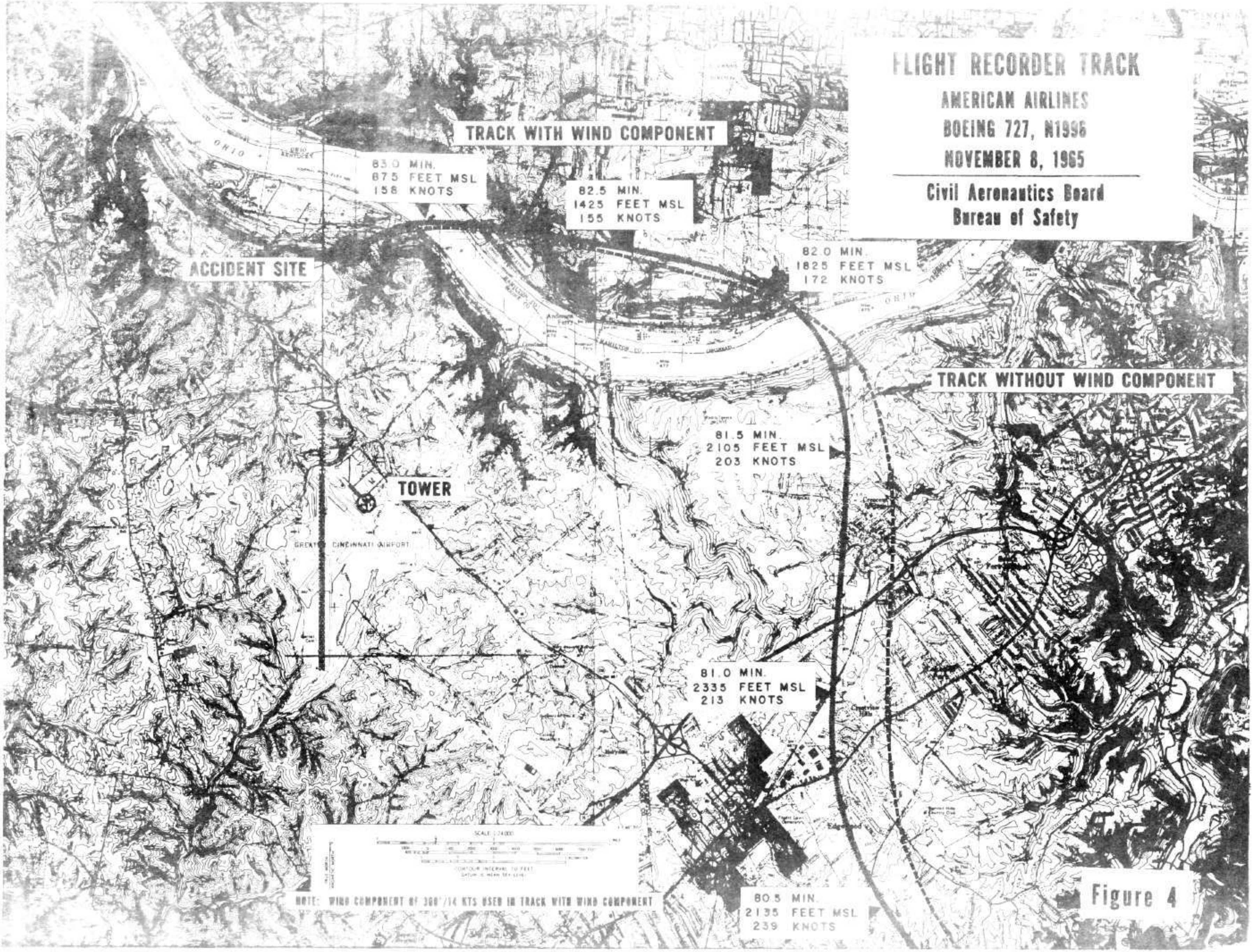
FLIGHT RECORDER TRACK
AMERICAN AIRLINES
BOEING 727, N1996
NOVEMBER 8, 1965
Civil Aeronautics Board
Bureau of Safety
TRACK WITH WIND COMPONENT
83.0 MIN.
875 FEET MSL
158 KNOTS
82.5 MIN.
1425 FEET MSL
155 KNOTS
82.0 MIN.
1825 FEET MSL
172 KNOTS
ACCIDENT SITE
TRACK WITHOUT WIND COMPONENT
81.5 MIN.
2105 FEET MSL
203 KNOTS
TOWER
GREATER CINCINNATI AIRPORT
81.0 MIN.
2335 FEET MSL
213 KNOTS
80.5 MIN.
2135 FEET MSL
239 KNOTS
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL
NOTE: WIND COMPONENT OF 300°/14 KTS USED IN TRACK WITH WIND COMPONENT

Figure 4

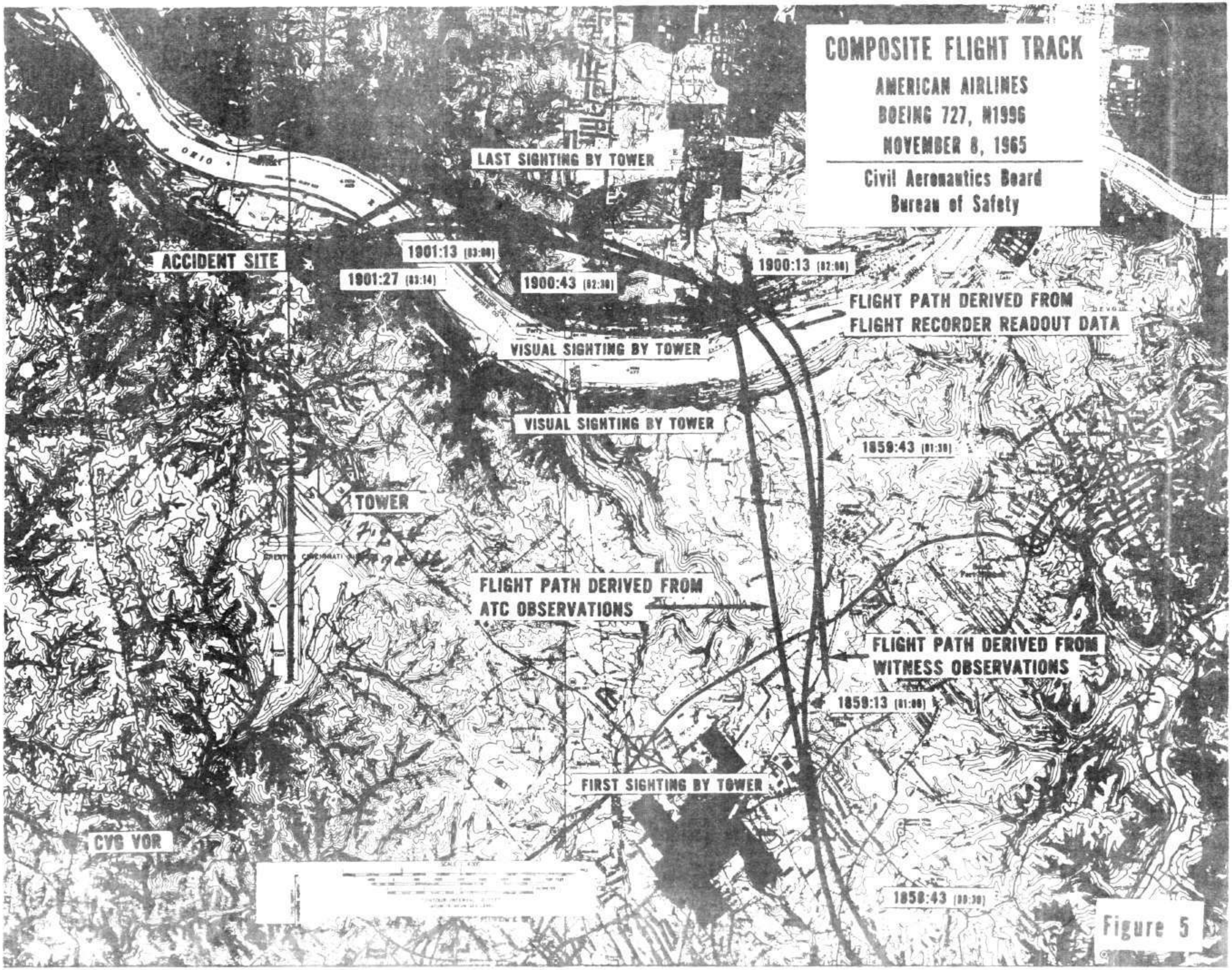
COMPOSITE FLIGHT TRACK
AMERICAN AIRLINES
BOEING 727, N1996
NOVEMBER 8, 1965
Civil Aeronautics Board
Bureau of Safety
OHIO
LAST SIGHTING BY TOWER
ACCIDENT SITE
1901:13 (03:00)
1901:27 (03:14)
1900:43 (02:30)
1900:13 (02:00)
FLIGHT PATH DERIVED FROM
FLIGHT RECORDER READOUT DATA
VISUAL SIGHTING BY TOWER
VISUAL SIGHTING BY TOWER
1859:43 (01:30)
TOWER
FLIGHT PATH DERIVED FROM
ATC OBSERVATIONS
FLIGHT PATH DERIVED FROM
WITNESS OBSERVATIONS
1859:13 (01:00)
FIRST SIGHTING BY TOWER
CVG VOR
1858:43 (00:30)

Figure 5

CIVIL AERONAUTICS BOARD
FLIGHT RECORDER DATA
NWA BOEING 720-B N724US, MIAMI, FLA., FEBRUARY 12, 1963
FAIRCHILD FLIGHT RECORDER, SERIAL NUMBER 1071

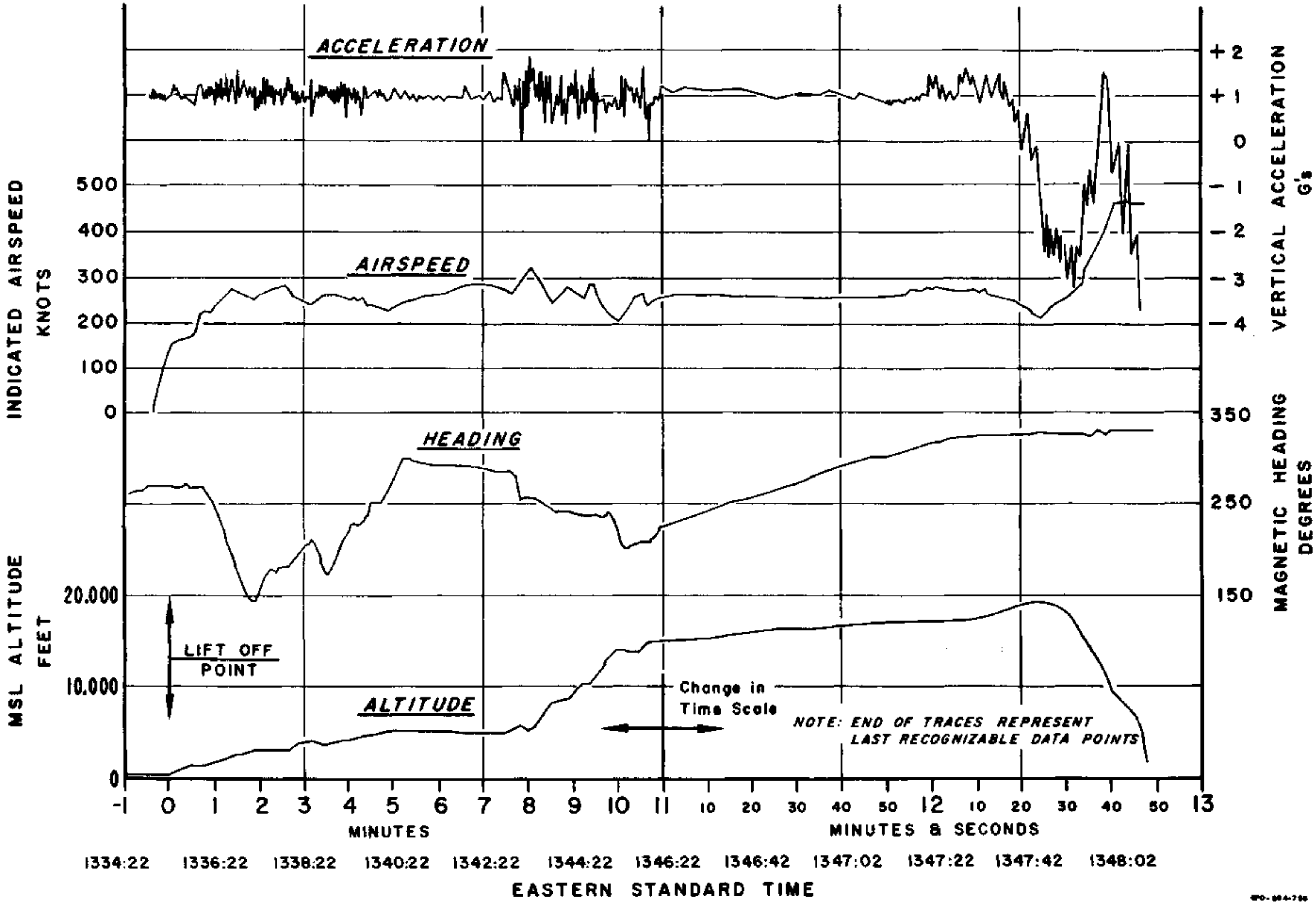

Figure 6

DATA FROM FLIGHT PATH ANALYSIS

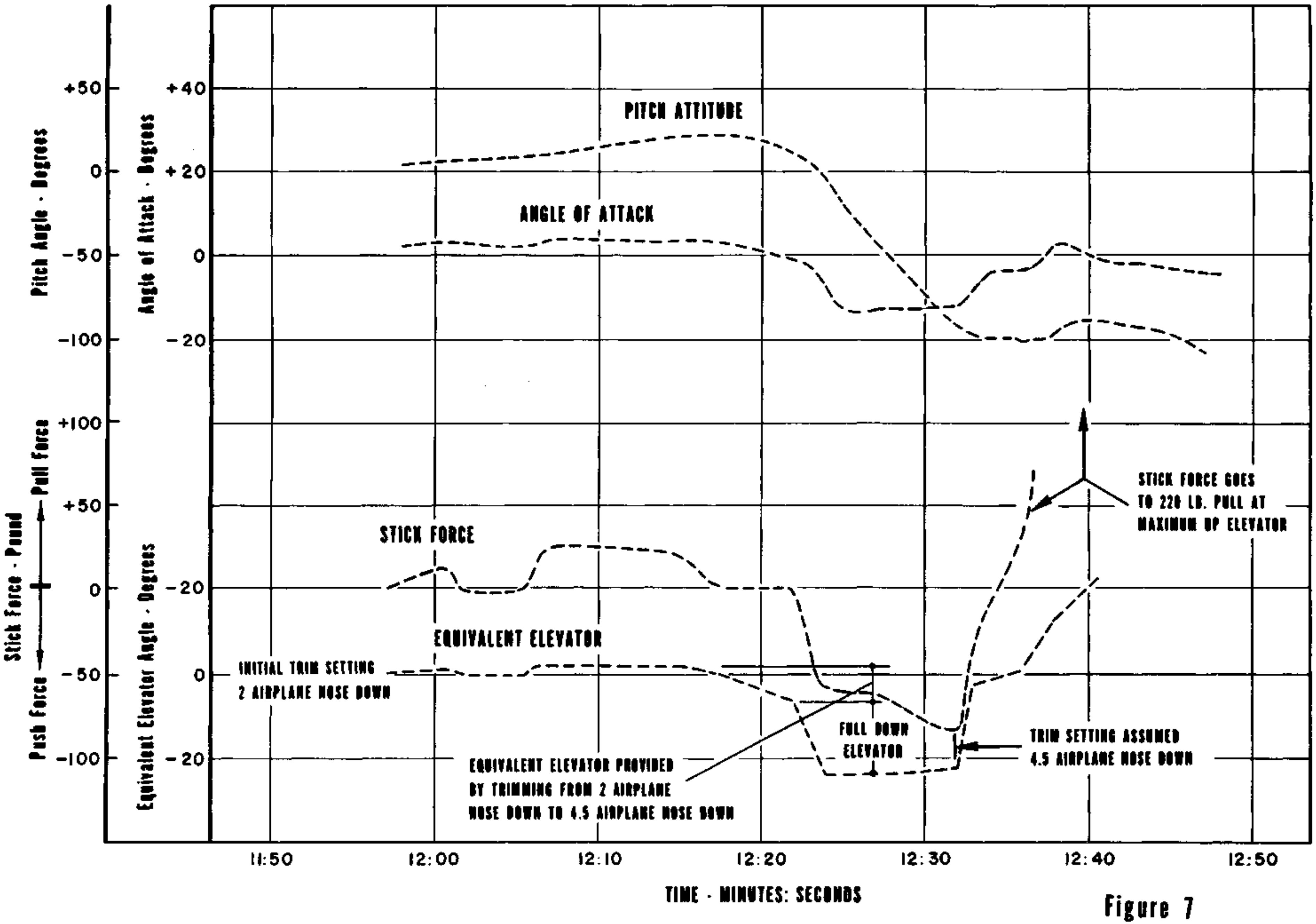

Figure 7

COMPARISON OF TRACES FROM FLIGHT RECORDER AND FLIGHT PATH ANALYSIS

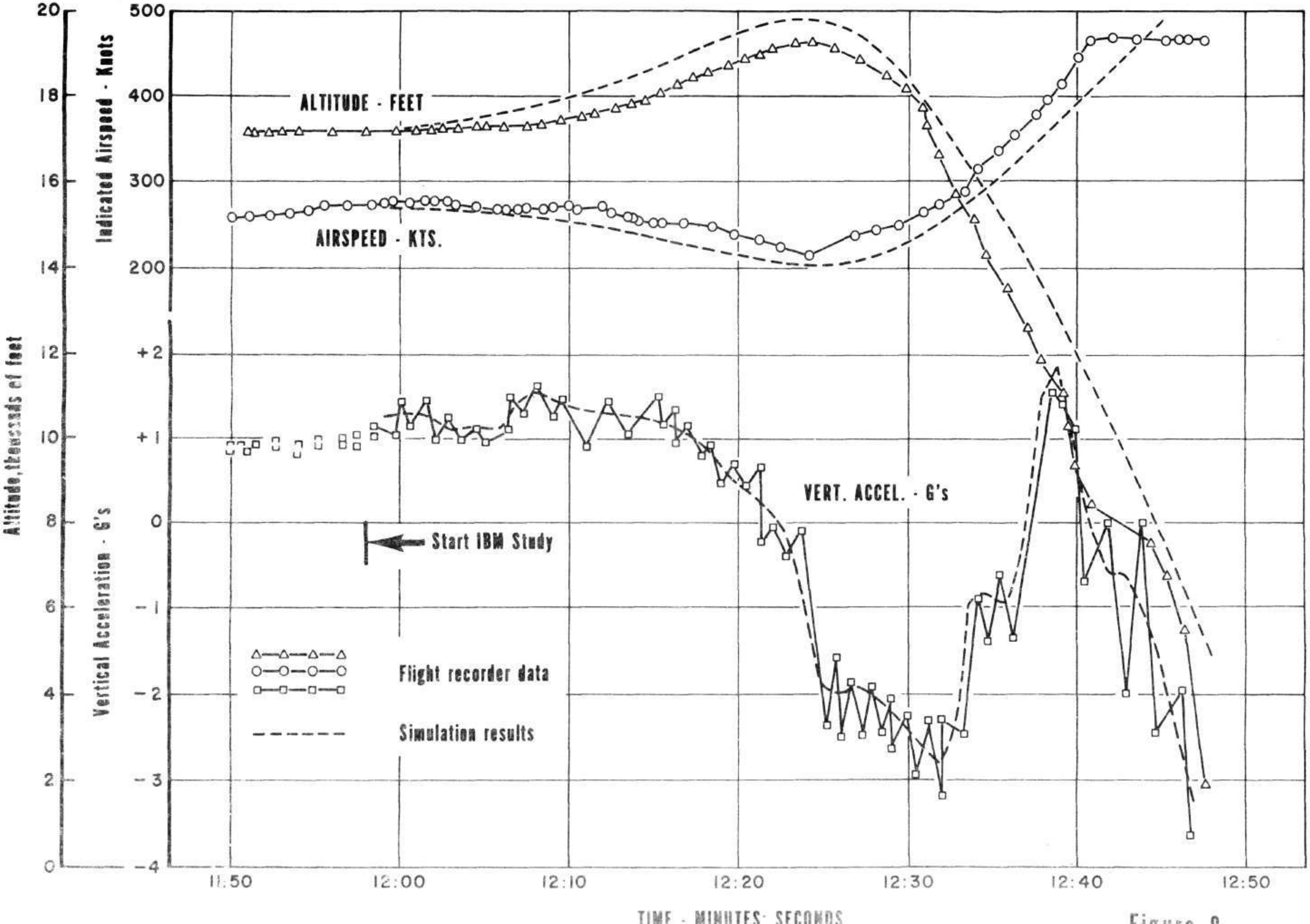

Figure 8