NASA CONTRACTOR REPORT

NASA CR-2751

ESTIMATES OF THE LOW-LEVEL WIND SHEAR AND TURBULENCE IN THE VICINITY OF KENNEDY INTERNATIONAL AIRPORT ON JUNE 24, 1975

W. S. Lewellen, Guy G. Williamson, and M. E. Teske

Prepared by
AERONAUTICAL RESEARCH ASSOCIATES OF PRINCETON, INC.
Princeton, N.J. 08540
for George C. Marshall Space Flight Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • OCTOBER 1976

1. REPORT NO. NASA CR-2751	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE Estimates of the Low-Level Wind Shear and Turbulence in the Vicinity of Kennedy International Airport on June 24, 1975		5. REPORT DATE October 1976 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) W. S. Lewellen, Guy G. Williamson, and M. E. Teske		8. PERFORMING ORGANIZATION REPORT # M-183
9. PERFORMING ORGANIZATION NAME AND ADDRESS Aeronautical Research Associates of Princeton, Inc. 50 Washington Road Princeton, New Jersey 08540		10. WORK UNIT NO. 11. CONTRACT OR GRANT NO. NAS8-31380
12. SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Washington, D. C. 20546		13. TYPE OF REPORT & PERIOD COVERED Contractor Report 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This report was prepared under the technical monitorship of the Aerospace Environment Division, Space Sciences Laboratory, Marshall Space Flight Center.

16. ABSTRACT

A study was conducted to estimate the type of wind and turbulence distributions which may have existed at the time of the crash of Eastern Airlines Flight 66 while attempting to land at Kennedy International Airport on June 24, 1975. A number of different wind and turbulence profiles are predicted for the site and date of the crash. The morning and mid-afternoon predictions are in reasonably good agreement with magnitude and direction as reported by the weather observer. Although precise predictions cannot be made during the passage of the thunderstorm which coincides with the time of the accident, a number of different profiles which might exist under or in the vicinity of a thunderstorm are presented. The profile that is most probable predicts the mean headwind shear over 100 m (300 feet) altitude change and the average fluctuations about the mean headwind distribution. This combination of means and fluctuations leads to a reasonable probability that the instantaneous headwind shear would equal the maximum value reported in the analysis of the flight recorder data.

17. KEY WORDS Wind shear Wind profile Turbulence Atmospheric boundary layer	18. DISTRIBUTION STATEMENT Category 02

19. SECURITY CLASSIF. (of this report) Unclassified	20. SECURITY CLASSIF. (of this page) Unclassified	21. NO. OF PAGES 46	22. PRICE $ 3.75

For sale by the National Technical Information Service, Springfield, Virginia 22161

FOREWORD

The motivation for the research reported in this document was to estimate the type of wind and turbulence distributions which may have existed at the time of the crash of Eastern Airlines Flight 66 on June 24, 1975, at Kennedy International Airport. Conditions that afternoon were strongly affected by the passage of a thunderstorm over the area. The public hearing held by the National Transportation Safety Board attributed the accident to severe wind shear. To specify the appropriate boundary conditions before the time of the accident, the Aeronautical Research Associates of Princeton model of turbulence in the atmospheric boundary layer was used. The current operational mode of the model is limited to either unsteady one-dimensional flow or to steady two-dimensional flow parabolic in one direction. The boundary conditions called for at the top of the boundary layer are the velocity components and the potential temperature gradient as a function of time. The thunderstorm in progress while Flight 66 was attempting to land caused considerable uncertainty as to the upper boundary conditions which should be applied to the boundary layer program. For this reason, results are given for several different boundary, ambient, and thunderstorm conditions. The types of distributions which are compatible with the known meteorological conditions in the vicinity of Kennedy International Airport on June 24, 1975, are shown in terms of altitude profiles for velocity, temperature, pressure, and macroscale variation. Conclusions resulted from the study relative to how consistent the model is with the known conditions at the time of the crash.

This research was conducted by Aeronautical Research Associates of Princeton for the National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Huntsville, Alabama, under the technical direction of Mr. Dennis W. Camp and Mrs. Margaret B. Alexander of the Space Sciences Laboratory. The support for this work was provided by Mr. John Enders of the Aeronautical Operating Systems Division, Office of Advanced Research and Technology, NASA Headquarters.

TABLE OF CONTENTS

Page

SECTION

I. INTRODUCTION.. 1

II. ANALYSIS... 2

Boundary Conditions.. 2

Ambient Conditions Without the Influence of the Ocean......... 4

Ambient Conditions With the Influence of the Ocean............ 11

Influence of the Thunderstorm.................................. 11

Estimates of Conditions at 2005Z............................... 23

III. SUMMARY AND CONCLUSIONS...................................... 38

LIST OF REFERENCES... 38

LIST OF TABLES

TABLE		Page
1	TEMPERATURES AND WINDS OBSERVED AT JFK ON JUNE 24, 1975........	6
2	SUMMARY OF INPUT CONDITIONS FOR COMPUTER RUNS AND KEY TO FIGURES..	39

LIST OF ILLUSTRATIONS

Page

FIGURE

1 Sketch of Coordinate System Showing the Orientation of the Geostrophic Wind.. 3

2 Altitude Profile of Potential Temperature Distribution at 1200Z on 24 June and 0000Z 25 June 1975......................... 5

3 Altitude Profile of Mean Wind (u) Parallel to the Runway at 1400Z as Predicted by the Model for z_o = 0.5 m (Run 1) and z_o = 0.1 m (Run 2); Positive u is from 31 Degrees............... 7

4 Profile of Mean Wind (v) Perpendicular to the Runway at 1400Z as Predicted by the Model for z_o = 0.5 m (Run 1) and z_o = 0.5 m (Run 1) and z_o = 0.1 m (Run 2); Positive v is from 301 Degrees.. 8

5 Profile of Mean Wind (u) at 1800Z as Predicted by the Model for No Thermal Wind Gradients and For z_o = 0.5 m (Run 1) and z_o = 0.1m (Run 2); Positive u from 31 Degrees.............................. 9

6 Profile of Mean Wind (v) at 1800Z and Predicted by the Model for No Thermal Wind Gradients and For z_o = 0.5 m (Run 1) and z_o = 0.1 m (Run 2); Positive v from 301 degrees...................... 10

7 Profile of Mean Wind (u) at 1800Z as Predicted by the Model for a Thermal Gradient Simulating a Sea Breeze Condition; z_o = 0.5 m (Run 3) and z_o = 0.1 m (Run 4).................................. 12

8 Profile of Mean Wind (v) at 1800Z as Predicted by the Model for a Thermal Gradient Simulating a Sea Breeze Condition; z_o = 0.5 m (Run 3) and z_o = 0.1 m (Run 4).................................. 13

9 Profile of Mean Wind (u) at 2000Z as Predicted by the Model for a Thermal Gradient Simulating a Sea Breeze Condition; z_o = 0.5 m (Run 3) and z_o = 0.1 m (Run 4).................................. 14

10 Profile of Mean Wind (v) at 2000Z as Predicted by the Model for a Thermal Gradient Simulating a Sea Breeze Condition; z_o = 0.5 m (Run 3) and z_o = 0.1 m (Run 4).................................. 15

11 Profile of Mean Wind (u) at 2000Z as Predicted by the Model for a Thermal Gradient Simulating a Storm Passing to the North of the Airport; z_o = 0.5 m (Run 5)................................. 17

FIGURE | Page

12 Profile of Mean Wind (v) at 2000Z as Predicted by the Model for a Thermal Gradient Simulating a Storm Passing to the North of the Airport; z_o = 0.5 m (Run 5) 18

13 Radar Picture Taken from Atlantic City Showing the Position of the Storm with Respect to JFK Prior to the Crash 19

14 Profile of Assumed Pressure Gradients (Solid line is used for Runs 6, 7, and 8; Dashed line is used for Run 9) 20

15 Profile of Mean Wind (u) at 2000Z as Predicted by the Model with the Pressure Gradient Set to Simulate a Storm Overhead; z_o = 0.5 m (Run 6) 21

16 Profile of Mean Wind (v) at 2000Z as Predicted by the Model with the Pressure Gradient Set to Simulate a Storm Overhead; z_o = 0.5m (Run 6) 22

17 Profile of the RMS Values of the Vertical and Headwind Velocity Fluctuations at 2000Z as Predicted by Run 6; z_o = 0.5 m 24

18 Profile of Mean Wind (u) at 2000Z as Predicted by Run 7 (z_o = 0.5 m) and Run 8 (z_o = 0.1 m) Using the Same Pressure Gradient as Run 6 but Different Stability Conditions 25

19 Profile of Mean Wind (v) at 2000Z as Predicted by Run 7 (z_o = 0.5 m) and Run 8 (z_o = 0.1 m) Using the Same Pressure Gradient as Run 6 but Different Stability Conditions 26

20 Profile of the RMS Values of the Vertical and Headwind Velocity Fluctuations at 2000Z as Predicted by Run 7 27

21 Profile of Mean Wind (u) at 2000Z as Predicted by Run 9 Using the Dashed Pressure Gradient in Figure 14 and the Same Stability Conditions as Run 6 28

22 Profile of Mean Wind (v) at 2000Z as Predicted by Run 9 Using the Dashed Pressure Gradient in Figure 14 and the Same Stability Conditions as Run 6 29

23 Profile of the RMS Values of the Vertical $(\overline{w'w'})^{1/2}$ and Headwind $(\overline{u'u'})^{1/2}$ Velocity Fluctuations at 2000Z as Predicted by Run 9 30

FIGURE | Page

24 Flight Recorder Data as Obtained from Reference 6.......... 31

25 Estimates of Horizontal and Vertical Wind Profiles from Boeing Analysis of Flight Recorder Data (References 6 and 10).. 32

26 Profile of Turbulence Macroscale Variation for 2000Z Predicted by Run 6.. 34

27 Contours of Constant Values of the Mean Wind Component u as Predicted (Run 10) by a Two-Dimensional Unsteady Simulation of a Downdraft Imposed Upon the Boundary Layer (Dashed line indicates a possible 3 degree flight path through the field).. 35

28 Possible u Components of the Wind Encountered Along Flight Trajectory (Shown on Figure 27) With the Bars Denoting RMS Values of Fluctuations About the Mean Value................ 36

29 Possible Vertical Component of the Wind Encountered Along Flight Trajectory (Shown on Figure 27) with the Bars Denoting RMS Values of Fluctuations About the Mean Value... 37

ESTIMATES OF THE LOW-LEVEL WIND SHEAR AND TURBULENCE IN THE VICINITY OF KENNEDY INTERNATIONAL AIRPORT ON JUNE 24, 1975

W.S. Lewellen, Guy G. Williamson, and M.E. Teske

SUMMARY

A number of different wind and turbulence profiles are predicted for Kennedy International Airport at different times on 24 June 1975. The morning and mid-afternoon predictions are in reasonably good agreement with wind magnitude and direction as reported by the weather observer. Although precise predictions cannot be made during the passage of the thunderstorm which coincides with the time of the accident, a number of different profiles which might exist under or in the vicinity of a thunderstorm are presented. The profile that is most probable predicts a mean headwind shear of 15 m/sec (30 knots) over 100 m (300 ft) altitude change with average fluctuations about the mean headwind distribution of 2 m/sec (4 knots). This combination of means and fluctuations leads to a reasonable probability that the instantaneous headwind shear would equal the maximum value of 7.2 m/sec (14 knots) in 2.5 seconds as reported in the analysis of the flight recorder data.

INTRODUCTION

At 2005 Greenwich time (4:05 p.m., EDT) on 24 June 1975, Eastern Airlines Flight 66 crashed while attempting to land at Kennedy International Airport. The public hearing held by the National Transportation Safety Board considered wind shear to be a significant factor in the accident. The purpose of this report is to estimate the type of wind and turbulence distributions which may have existed at the time of the crash, using our A.R.A.P. model of turbulence in the atmospheric boundary layer.

Details of our planetary boundary layer (PBL) model are given in references 1 - 4. A review of the model along with results of varying the parameters which govern the boundary layer flow is given in a companion report (ref. 5). The only details of our planetary boundary layer model which will be repeated here are those which deal directly with specifying the appropriate boundary conditions to simulate conditions prior to the time of the accident. Conditions at JFK on the afternoon of 24 June were strongly affected by the passage of a thunderstorm. This thunderstorm caused considerable uncertainty as to the upper boundary conditions which should be applied to the boundary layer program. For this reason, results will be given for several different scenarios. Comparisons with analysis of flight recorder data are made to select the most likely conditions existing at the time.

ANALYSIS

Boundary Conditions

The current operational mode of our model is limited to either unsteady one-dimensional flow or to steady two-dimensional flow parabolic in one direction. The boundary conditions called for at the top of the boundary layer are the velocity components and the potential temperature gradient as a function of time. At the surface, the value of the effective aerodynamic roughness z_0 and either the surface temperature or the surface heat flux are needed. The location of the site at 40.7°N latitude determines the coriolis parameter. In addition to these conditions, it is possible to simulate some horizontal spatial inhomogeneity by applying pressure gradients which may vary with vertical height to simulate thermal winds. Initial conditions on the variables are required to completely specify the problem.

The meteorological chart of the 850 millibar pressure (ref. 6) level for the eastern United States for 00z (Greenwich time), 25 June (8:00 p.m., EDT, 24 June) shows a spacing of approximately 370 km between the 1590 m contour and the 1560 m contour. This corresponds to a geostrophic wind of approximately

$$v_g = \frac{1}{f\rho}\frac{dp}{dx} \approx \frac{30\text{ m} \times 9.8\text{ m/sec}^2}{(.922 \times 10^{-4}\text{ 1/sec})\ 370\text{ km}}$$

$$\approx 8.6\text{ m/sec}$$

The orientation of the contours is such as to yield a wind direction from approximately 300°. The motion of the thunderstorms prior to the accident, as observed by radar from Atlantic City, indicates that the geostrophic wind may have been slightly stronger and a little more from the west four hours earlier. We will use a value of 10 m/sec from 285°. The orientation of the geostrophic wind with respect to Runway 22L, along with the coordinate system to be used, is given in figure 1.

The upper level potential temperature gradient is set equal to 0.003°C/m which appeared on both the 1200z, 24 June, and 00z, 25 June, thermodynamic charts (ref. 6). Both of these curves (see

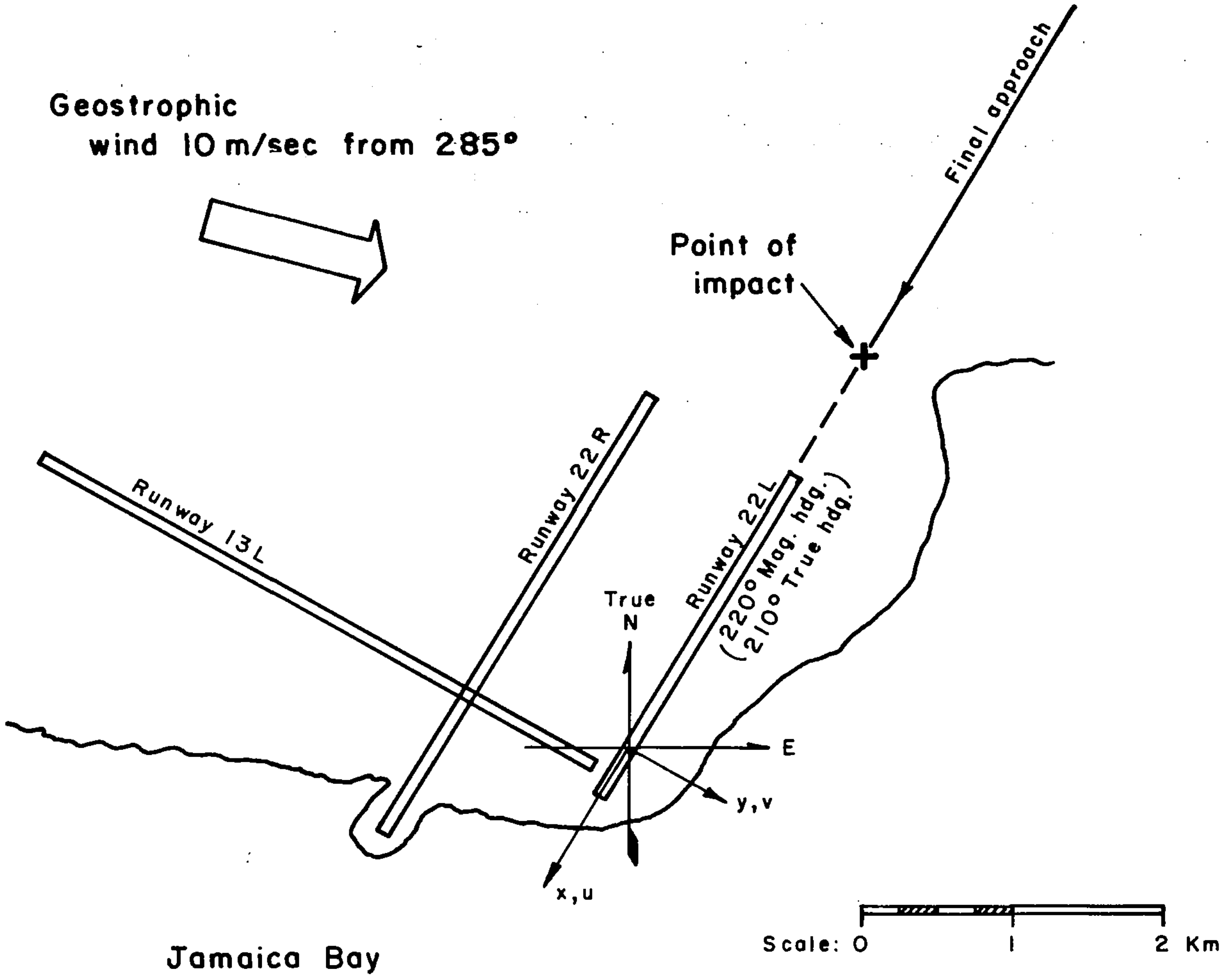


Figure 1. Sketch of coordinate system showing the orientation of the geostrophic wind

fig. 2) also show a local inversion of approximately 4°C over a 100 m altitude change near the surface. The morning curve shows this occurring between approximately 300 and 400 m altitude, while the evening curve shows it occurring between approximately 1 and 100 m altitude. The low-level stability inherent in these profiles is such that the surface value of the temperature may rise to 31°C (88°F) as recorded by the weather observer at JFK at approximately 1800z, without making the profile unstable. The "surface" temperature as recorded by the observer is given in Table I. Above 400 m, the air is conditionally unstable since it is moderately moist.

The effective aerodynamic roughness z_o of the surface in the vicinity of JFK is dependent upon wind direction. We will use two values, $z_o = 0.1$ m and 0.5 m, to demonstrate the effect of this parameter and to bracket the expected values.

Correct modeling of the development of spatial inhomogeneities such as the sea breeze would require a two-dimensional unsteady model. However, partial simulation may be accomplished by applying a pressure gradient within the boundary layer which is different from that which balances the geostrophic wind at the top of the boundary layer. We will do this to simulate the sea breeze and the thunderstorm.

The initial conditions for the first run are not known since no detailed wind and turbulence profiles are available. Therefore, we start the run at midnight the night before so that the results for the day in question are relatively insensitive to these initial conditions. Later runs are started with initial conditions obtained as predictions for conditions at specific times by other runs.

Ambient Conditions Without the Influence of the Ocean

Figures 3 through 6 show the wind profiles obtained by running our program (Runs 1 and 2) with a steady geostrophic wind of 10 m/sec from 285° with the surface temperature variations as a function of time given in Table I. Here the wind components are broken up into that parallel to runway 22L (u) in figures 3 and 5 and perpendicular to the runway (v) in figures 4 and 6. Thus, u is from the direction of 31° and v from the direction of 301°. The profiles are given for two times, 1400z and 1800z, and for two values of z_o.

The profiles predicted for 1400z are fairly consistent with the recorded values of 5 m/sec (≈ 10 knots) from 240°. But the afternoon profiles are significantly different from that reported even before the approach of the thunderstorm.

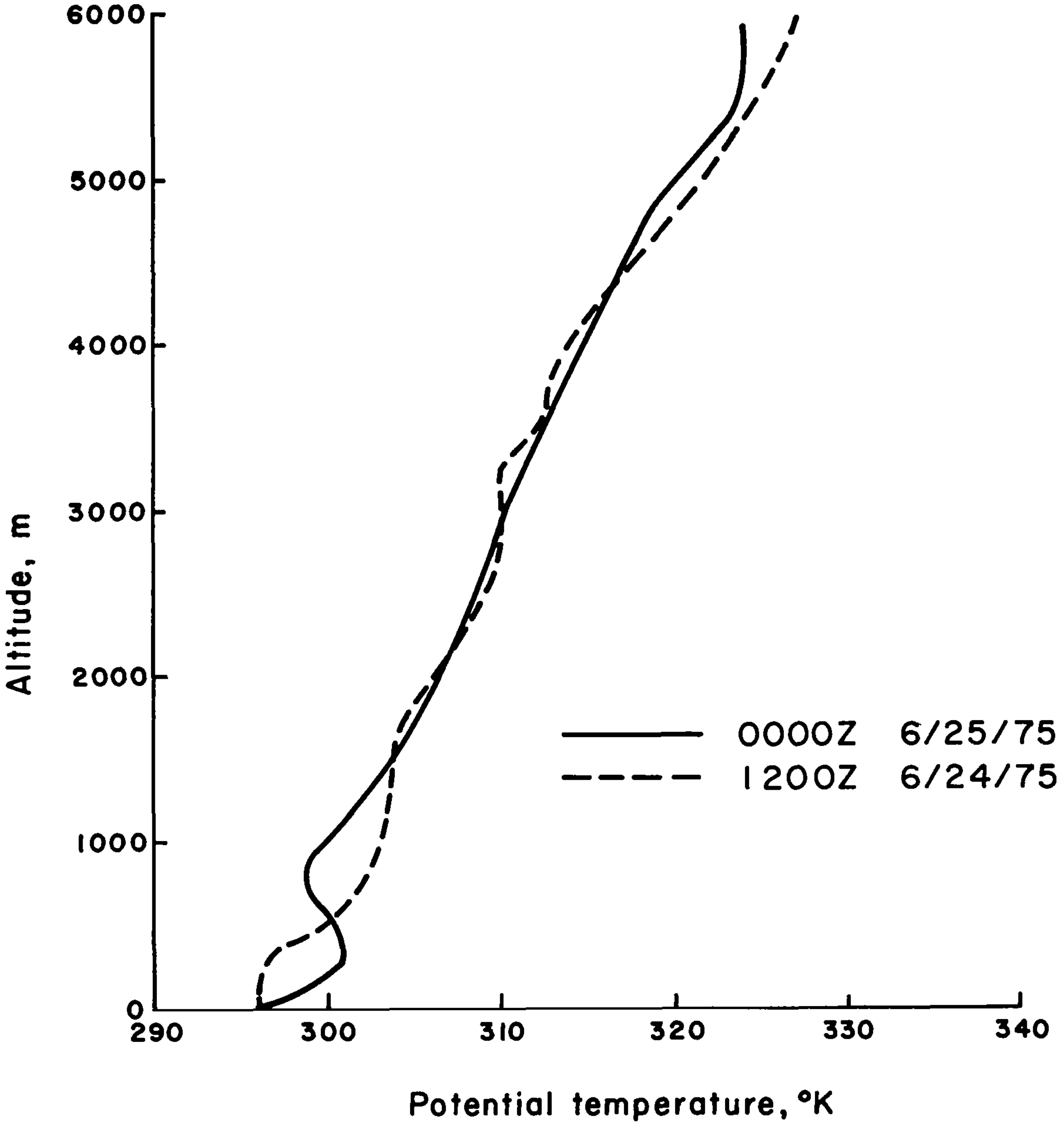


Figure 2. Altitude profile of potential temperature distribution at 1200z on 24 June and 0000z on 25 June

TABLE I

TEMPERATURES AND WINDS OBSERVED AT JFK ON 24 JUNE 1975 (REF. 6)

Time, Greenwich	Wind		Temperature, °C	Dew Point, °C
	Speed, m/sec	Direction, deg.		
0651	5.14	240	22.2	19.4
0751	5.65	230	21.7	19.4
0851	6.17	240	21.7	19.4
0951	5.65	230	21.1	19.4
1051	5.65	230	21.1	19.4
1151	5.14	230	22.8	20.6
1251	5.14	240	23.9	20.0
1351	5.14	240	25.6	20.6
1451	6.69	240	26.7	21.7
1551	7.20	240	28.9	22.2
1651	6.69	230	30.6	22.8
1751	6.17	180	27.8	22.8
1851	7.72	190	27.2	21.7
1950	3.09	300	25.0	21.7
2002	3.60	210	-	-
2006	2.06	100	25.6	21.1
2025	4.12	10	-	-

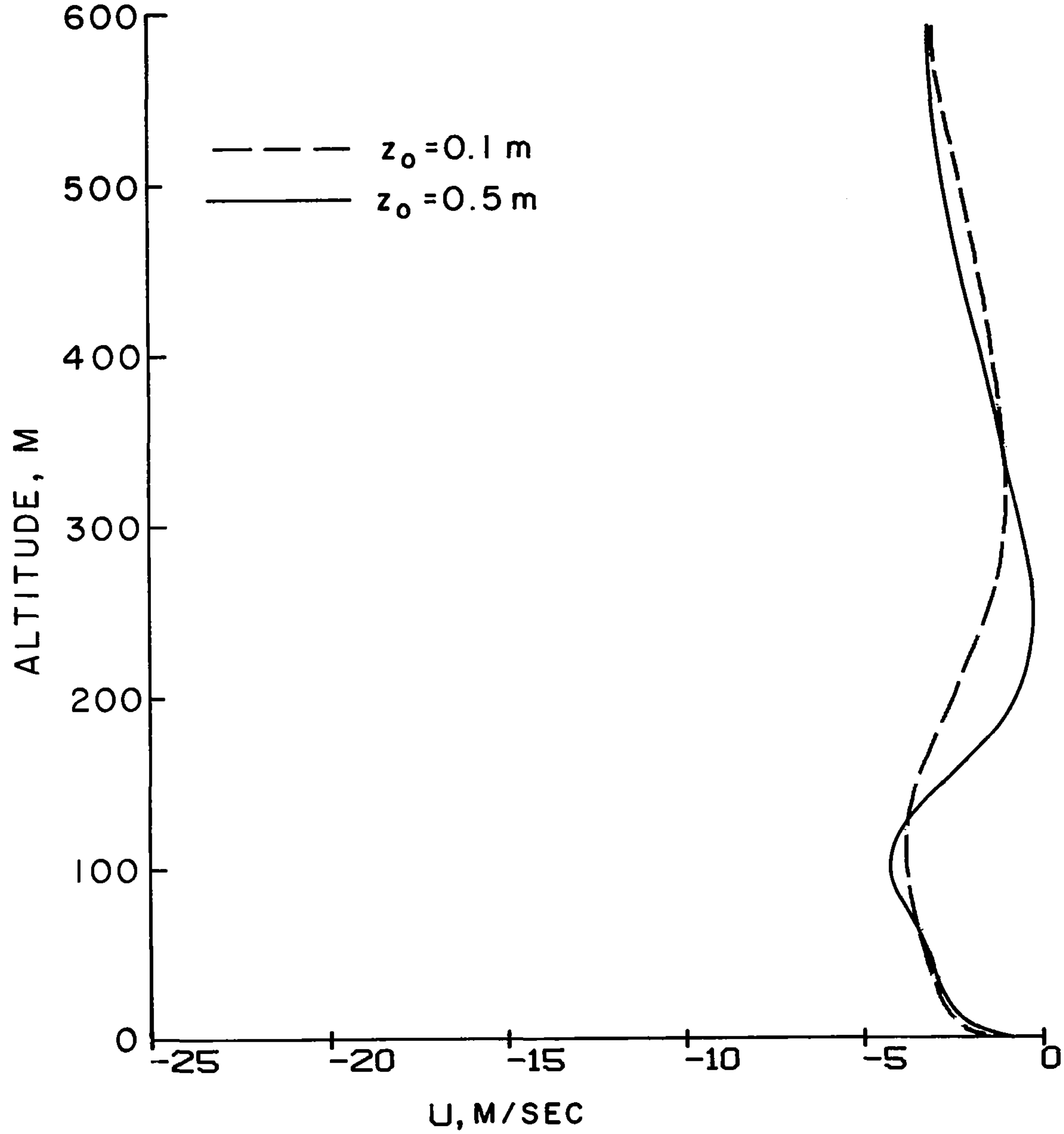


Figure 3. Altitude profile of mean wind (u) parallel to the runway at 1400z as predicted by the model for z_o = 0.5 m (Run 1) and z_o = 0.1 m (Run 2); positive u is from 31°

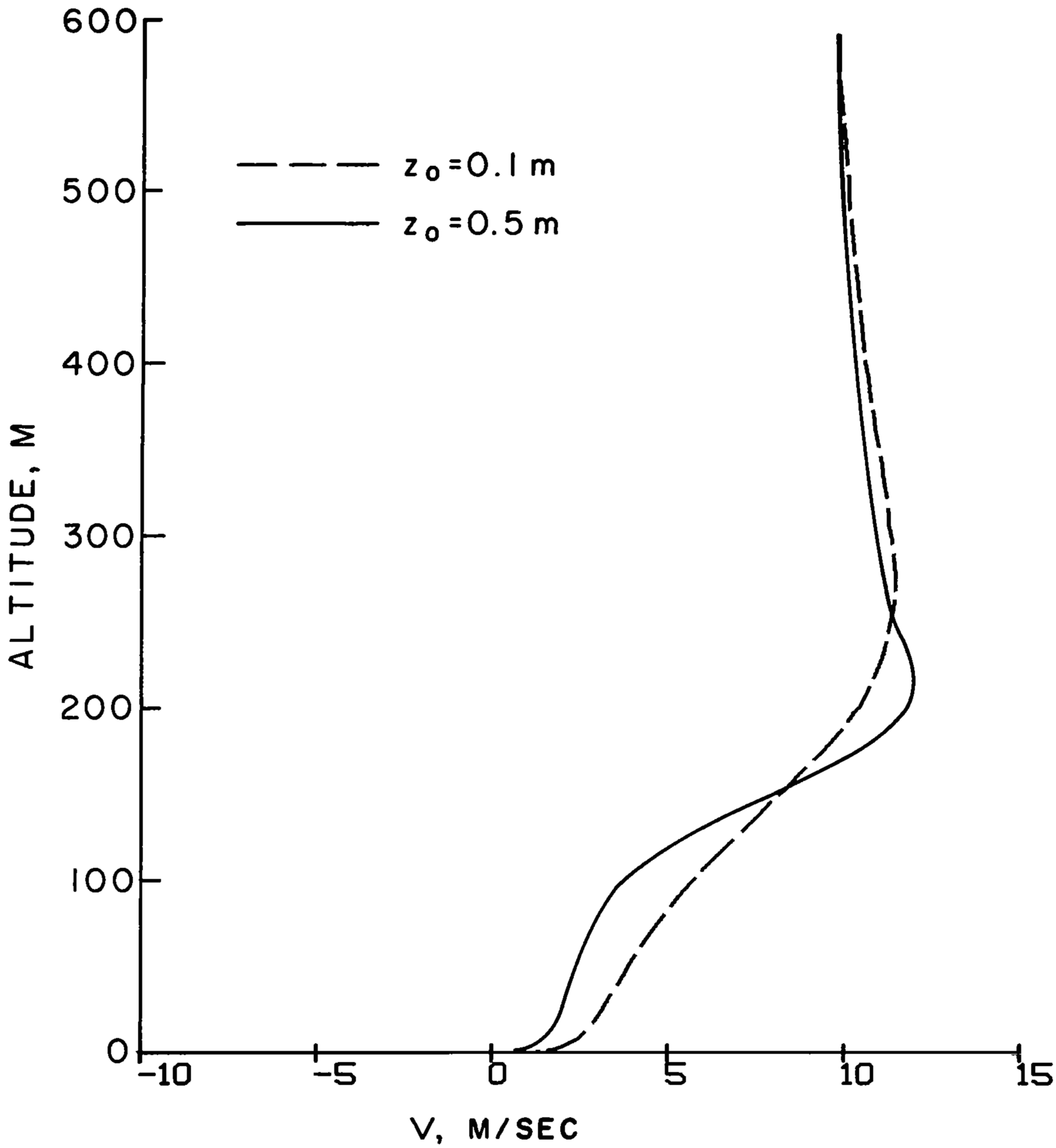


Figure 4. Profile of mean wind (v) perpendicular to the runway at 1400z as predicted by the model for z_o = 0.5m (Run 1) and z_o = 0.1 m (Run 2); positive v is from 301°

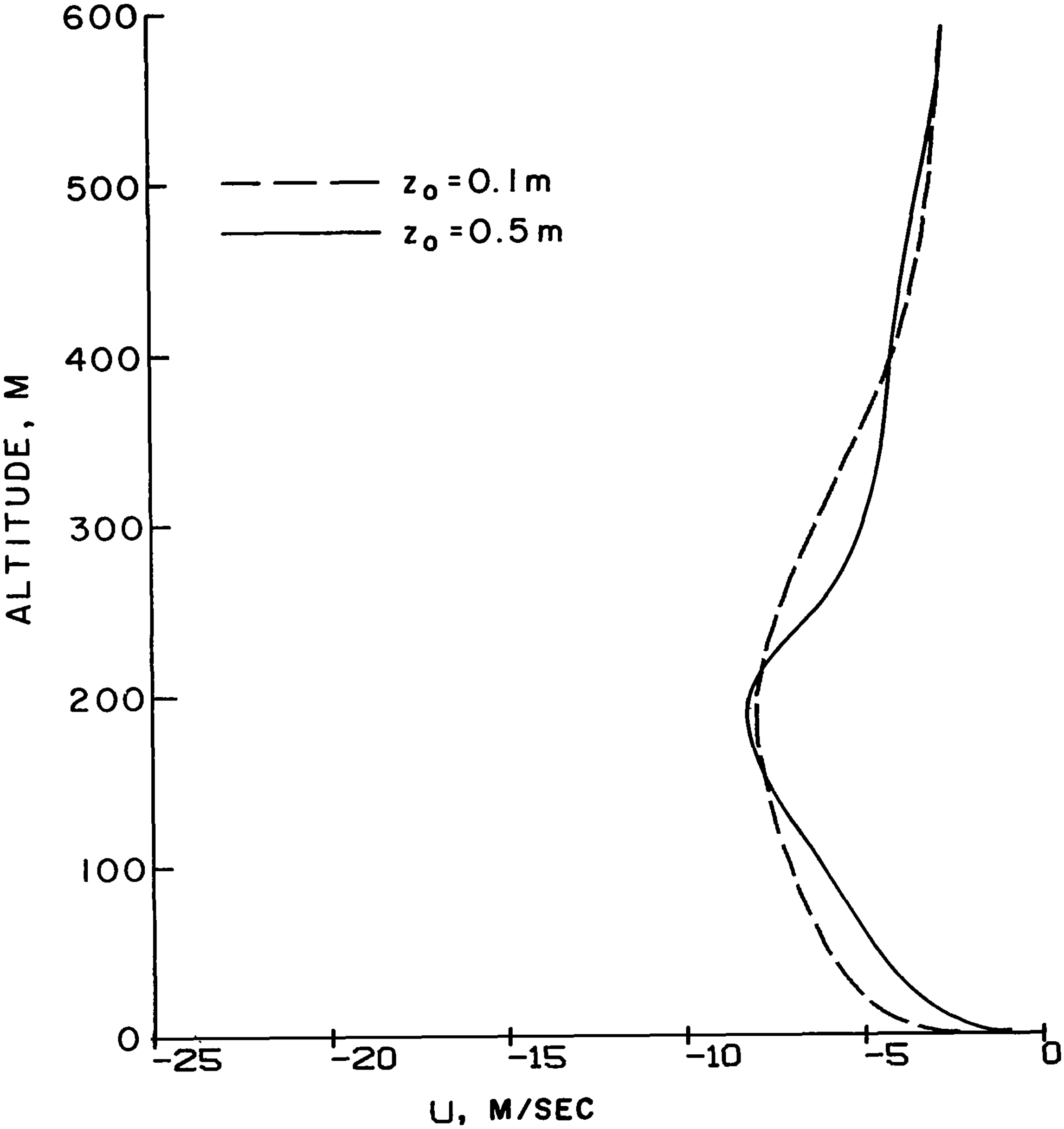


Figure 5. Profile of mean wind (u) at 1800z as predicted by the model for no thermal wind gradients and for $z_0 = 0.5$ m (Run 1) and $z_0 = 0.1$ m (Run 2); positive u from 31°

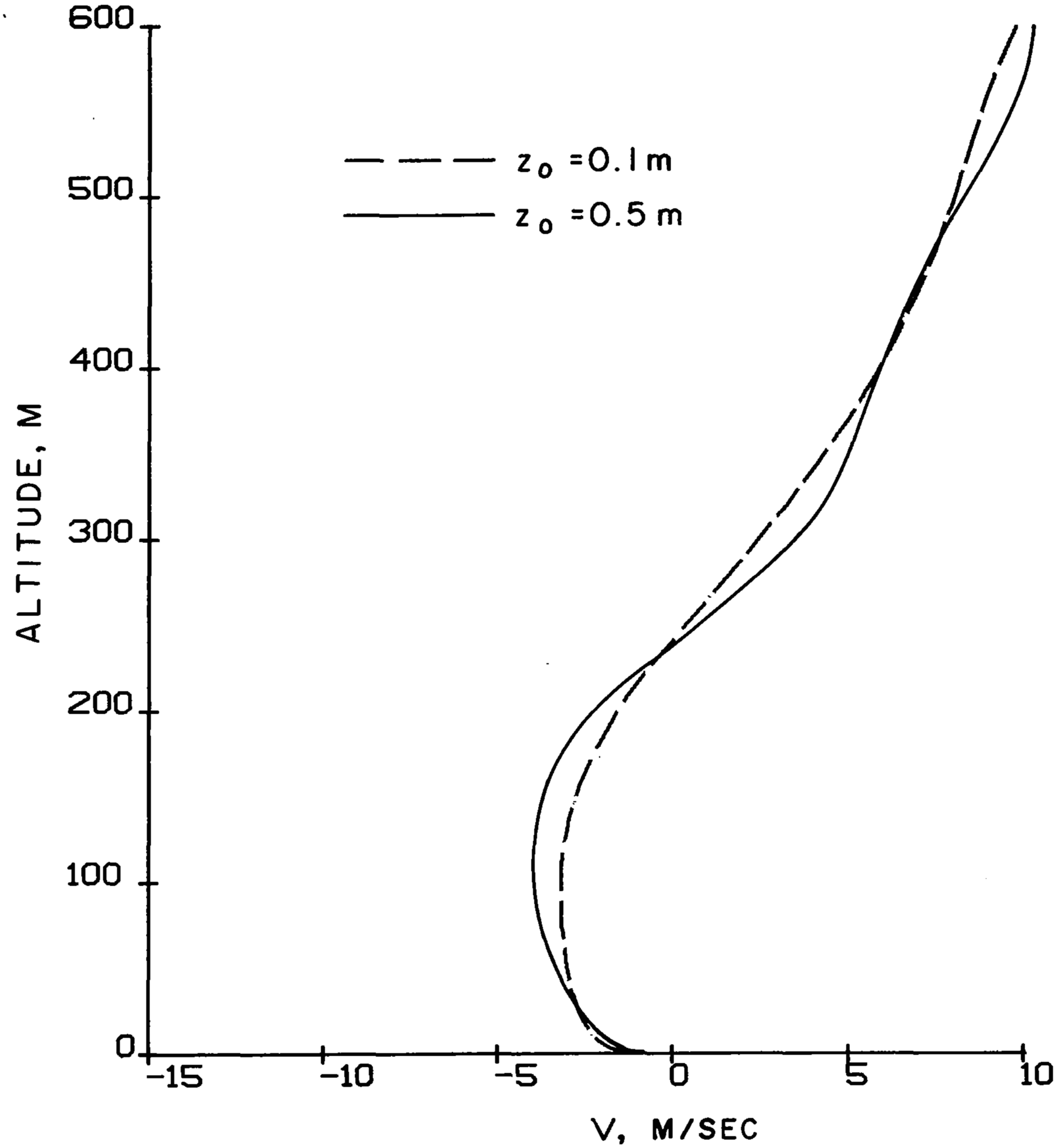


Figure 6. Profile of mean wind (v) at 1800z as predicted by the model for no thermal wind gradients and for $z_o = 0.5$ m (Run 1) and $z_o = 0.1$ m (Run 2); positive v from 301°

Ambient Conditions With the Influence of the Ocean

The ocean surface temperature was considerably colder than the land surface temperature on 24 June, so it is natural to expect a sea breeze to develop. The effect can be approximately simulated by applying a vertical gradient in the geostrophic velocity due to the horizontal thermal gradients (ref. 7). There is very little thermal gradient apparent on the 850 millibar chart. However, the surface temperature of the ocean was approximately 10°C less than the afternoon value for the air over the land. It thus appears that the horizontal temperature gradient should be limited to the boundary layer.

To simulate this sea breeze condition, we will assume a fetch of approximately 100 times the boundary layer thickness is required for the coastal boundary layer. This gives a distance of 50 km over which to spread the thermal gradient. Also, since we wish to apply a constant temperature gradient, we will take 5° as the average difference between the temperature in the marine boundary layer and that over the land. This yields a horizontal thermal gradient equal to 10^{-4} °C/m below 500 m. This temperature gradient is assumed to be directed from 120°.

Figures 7 and 8 give the velocity profiles obtained at 1800z for Runs 3 and 4. The speed and direction at 50 m are quite close to that reported by the observer at 1751z. He reported 6 m/sec from 180°. The boundary layer is relatively thin, consistent with the slightly stable conditions existing at the time.

Figures 9 and 10 give the velocity profiles predicted at 2000z if the sea breeze thermal is allowed to act uninterrupted until that time. This is quite different from the velocities observed at that time. Over a 15-minute interval beginning 9 minutes before the hour, the observer reported winds of 2 to 3.5 m/sec, first from 300°, then from 210° and from 100°. The wind field is highly influenced by the thunderstorm at this point.

Influence of the Thunderstorm

The detailed structure of the turbulence and wind profile within a thunderstorm is beyond the scope of the present one-dimensional program. However, we can approximate the influence the thunderstorm is expected to have on the atmospheric boundary layer. A thunderstorm is usually composed of several convective cells driven by condensation and evaporation. Updrafts are driven by the release of energy as water condenses out of the rising moist air. Concurrent downdrafts are driven by the evaporative cooling of rain falling through unsaturated air. At low levels, doppler radar shows that downdrafts predominate in a typical convective storm (ref. 8).

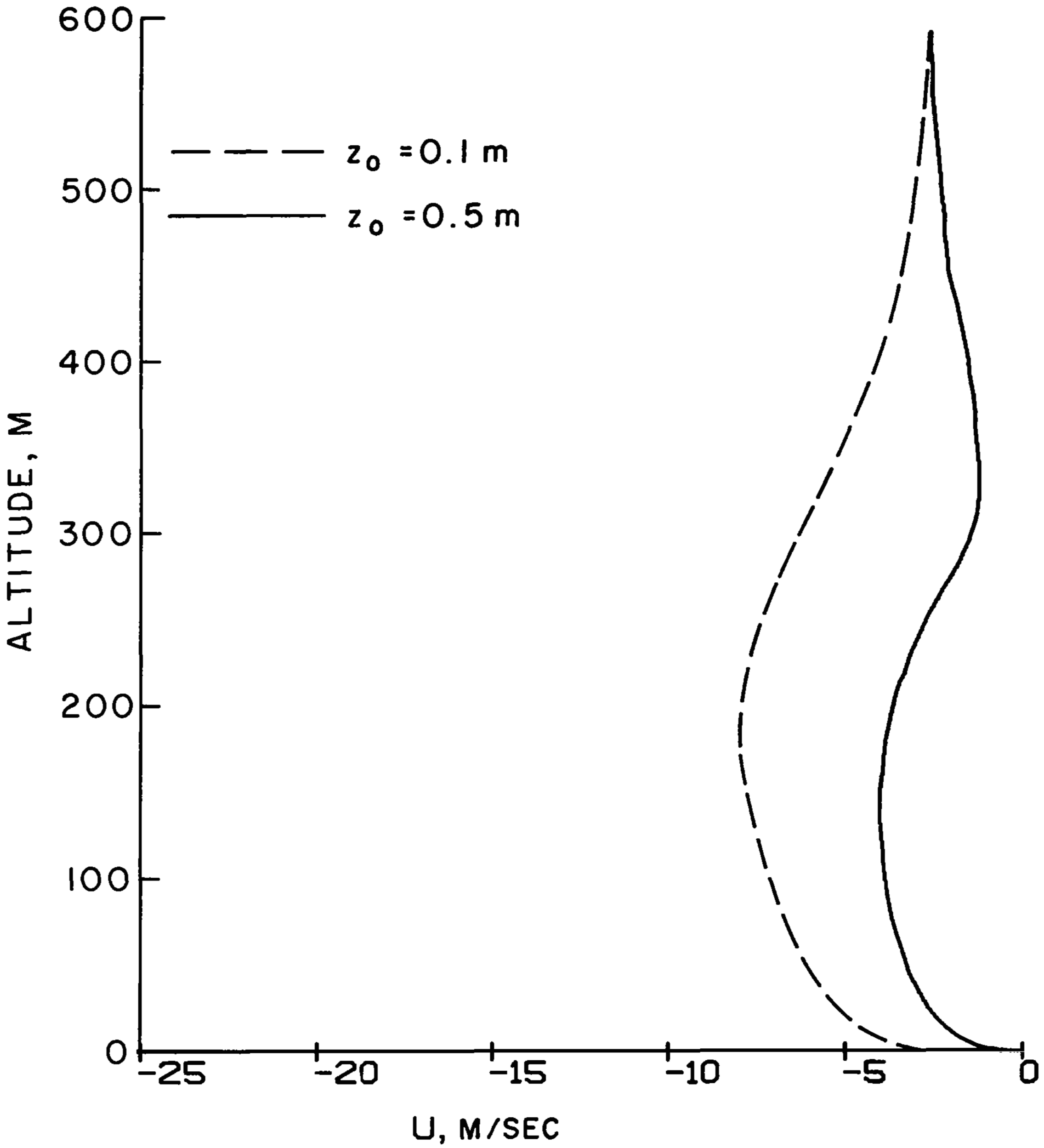


Figure 7. Profile of mean wind (u) at 1800z as predicted by the model for a thermal gradient simulating a sea breeze condition; z_o = 0.5 m (Run 3) and z_o = 0.1 m (Run 4)

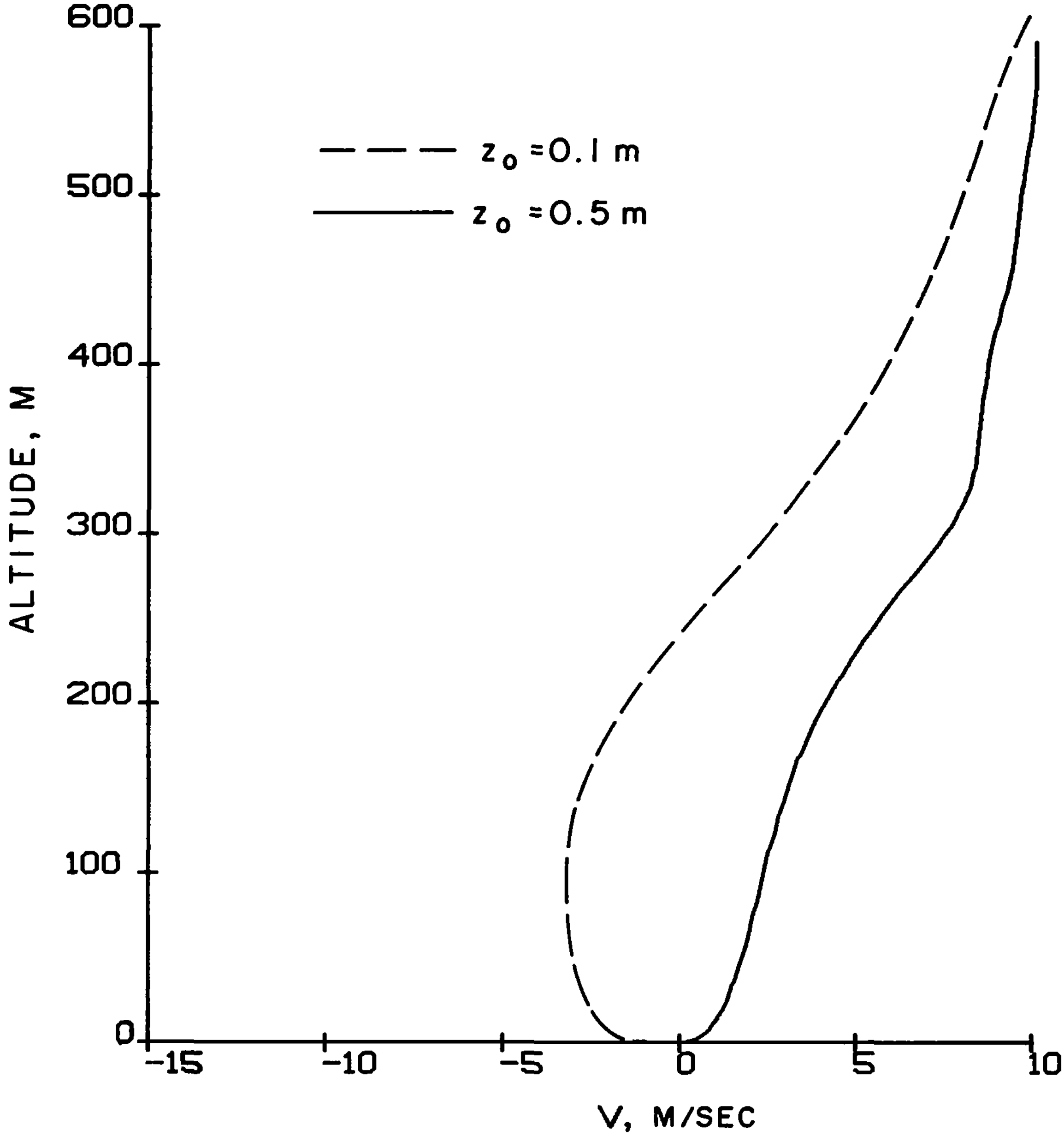


Figure 8. Profile of mean wind (v) at 1800z as predicted by the model for a thermal gradient simulating a sea breeze condition; z_o = 0.5 m (Run 3) and z_o = 0.1 m (Run 4)

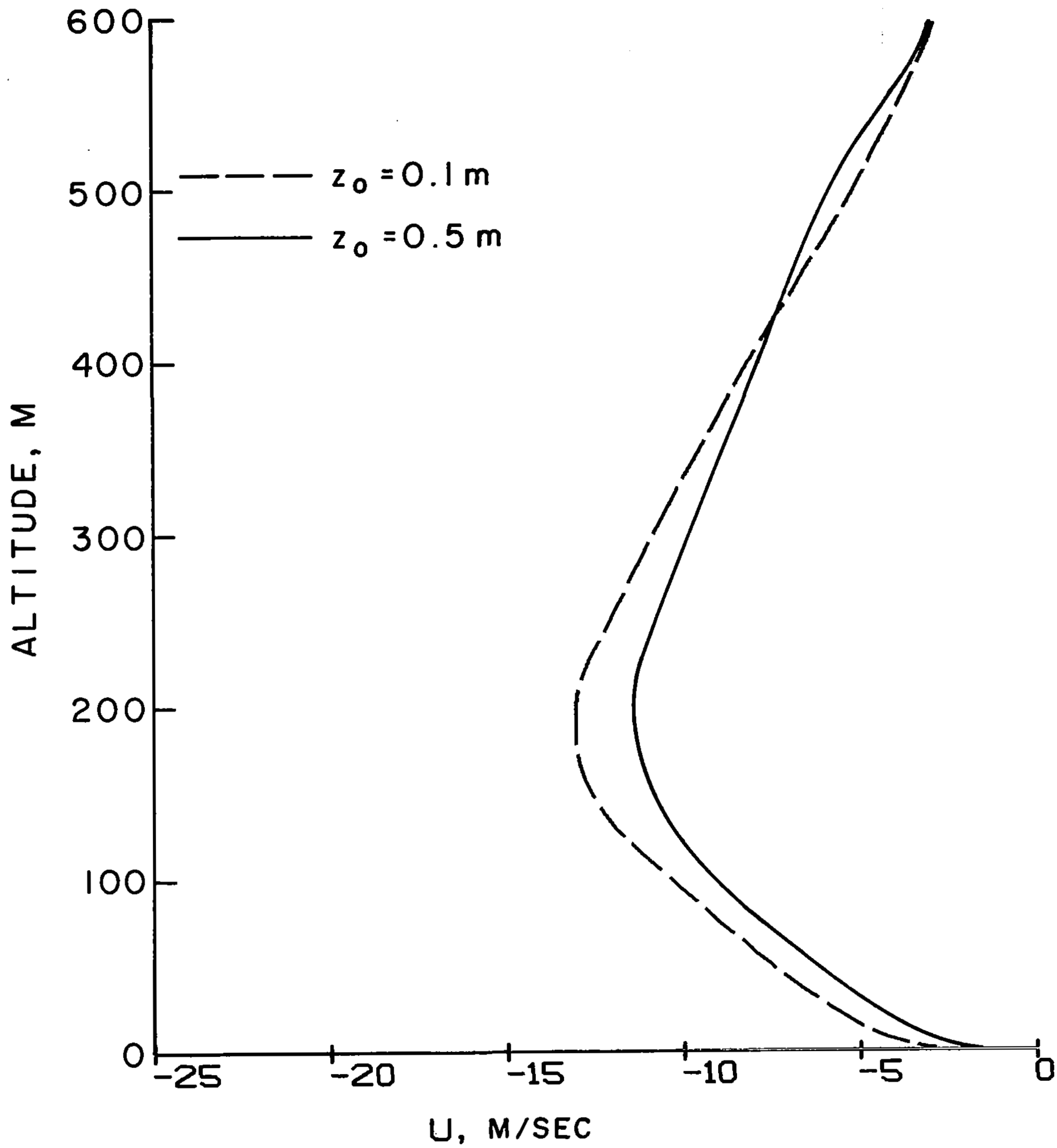


Figure 9. Profile of mean wind (u) at 2000z as predicted by the model for a thermal gradient simulating a sea breeze condition; z_o = 0.5 m (Run 3) and z_o = 0.1 m (Run 4)

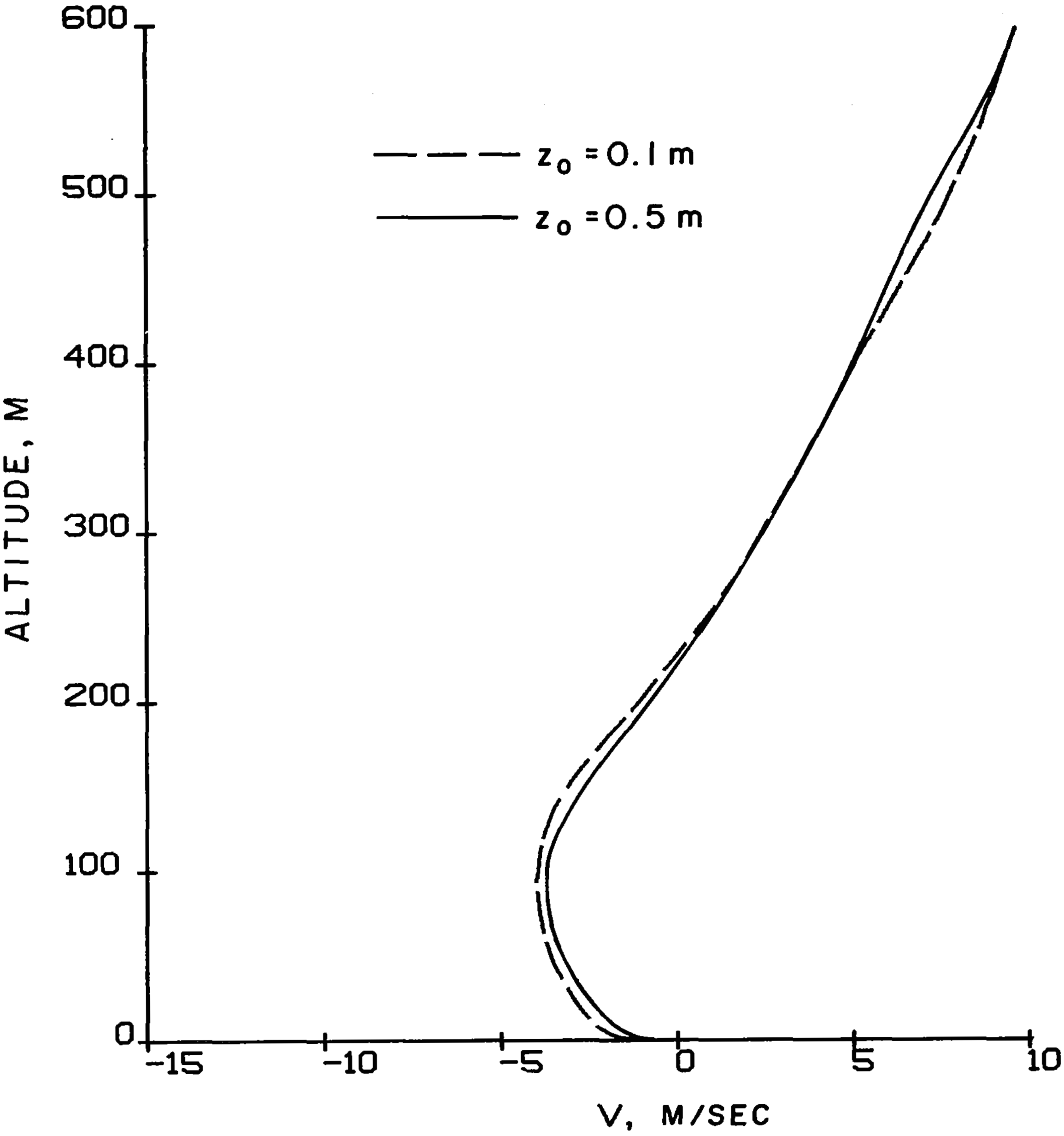


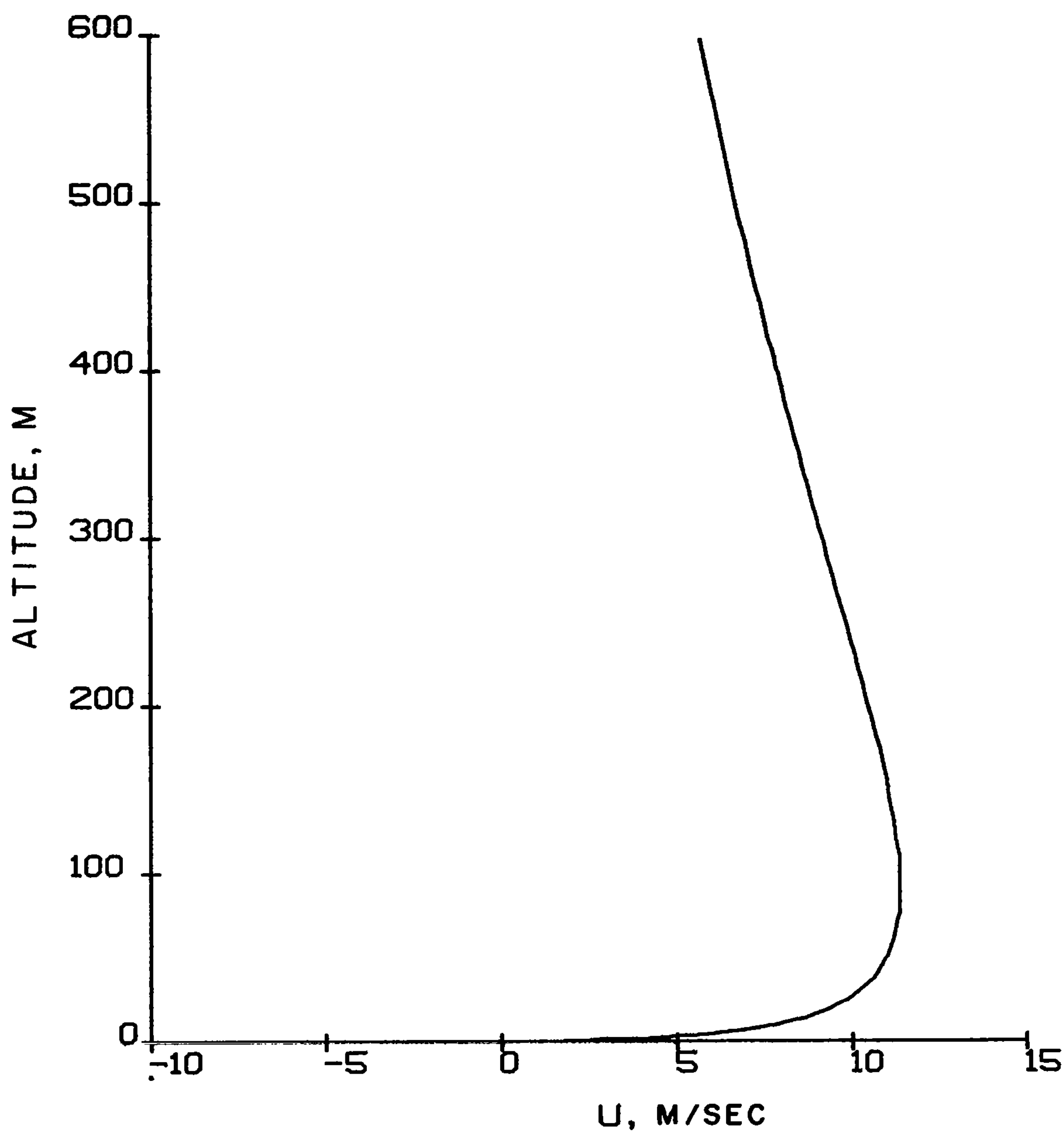
Figure 10. Profile of mean wind (v) at 2000z as predicted by the model for a thermal gradient simulating a sea breeze condition; z_o = 0.5 m (Run 3) and z_o = 0.1 m (Run 4)

The lower level air in the storm may be cooled to the ambient dew point as rain passes through it. At 1900z, the dew point temperature was reported to be 5°C below the ambient temperature. If this temperature difference occurs over a distance of approximately 10 km, then it yields a horizontal temperature gradient of approximately 5×10^{-4} °C/m. By different combinations of the pressure gradients resulting from the temperature gradient and that resulting from the turning of the downdraft at the surface, it is possible to partially simulate the influence of the storm on the boundary layer.

Figures 11 and 12 show the velocity profiles resulting from applying a temperature gradient of 5×10^{-4} °C/m from 30° for 45 minutes, corresponding to the storm passing to the north of the airport. Our early analysis of the radar picture at 1932z from Atlantic City indicated that this might be a likely scenario. The u velocity profile in figure 11 represents the velocity behind a local storm gust front. Since the velocity gradients within this front may be expected to be of the same order in both the vertical and horizontal directions, it appears that the transition from profiles like that given in figure 9 to that in figure 11 would occur over a distance of approximately 1 km (i.e., in approximately 15 seconds for an aircraft traveling at 72 m/sec (140 knots)). At 100 to 200 m altitude, this would result in the aircraft passing through a strong wind shear varying from approximately 10 m/sec tailwind to a 10 m/sec headwind (i.e., approximately 20 m/sec wind shift).

This strong shear could cause serious difficulty for a landing aircraft. However, these were not the conditions prevailing at the time Flight 66 was landing. Comparison of the radar pictures from Atlantic City shows that three individual storms which were in the vicinity of JFK at 1932z have merged as they moved southeast, and they appear as one continuous storm on the picture taken at 2002z (reproduced as fig. 13). Thus, JFK is influenced as much or more by the storm developing overhead as it is by a passing storm. At 2005z, the time of the crash, the storm appears to be directly over the approach to runway 22L.

In an attempt to simulate this, we have applied the pressure gradient shown in figure 14 to the profiles obtained from Run 3 at 1945z. This is the type of pressure gradient that may result from the combination of the downdraft stagnation at the surface acting to accelerate the boundary layer and the thermal gradient in the edges of the storm, forcing strong vertical changes in the pressure gradient. The value of $\partial^2 p/\rho \partial z \partial x$ below 150 m of .0002(sec^{-2}) corresponds to roughly a horizontal temperature change of 5°C in 1 km. The maximum value of $\partial p/\rho \partial x = 0.2$ m/sec corresponds to imposing a downdraft of approximately 5 m/sec and approximately 500 m width. The velocity profiles resulting from running with this pressure gradient distribution for 1000 sec are given in figures 15 and 16.



'igure 11. Profile of mean wind (u) at 2000z as predicted by the model for a thermal gradient simulating a storm passing to the north of the airport; z_o = 0.5 m (Run 5)

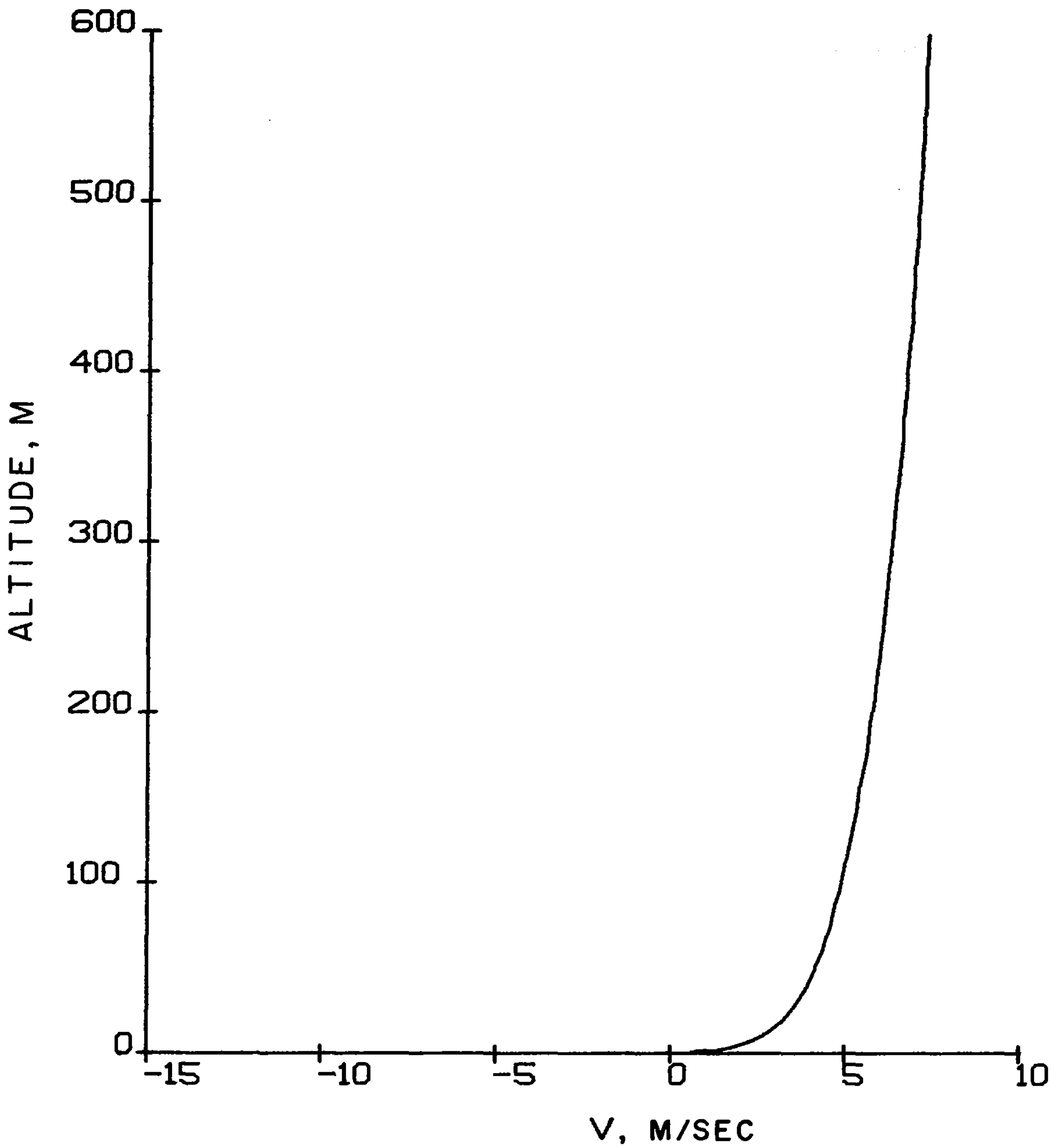


Figure 12. Profile of mean wind (v) at 2000z as predicted by the model for a thermal gradient simulating a storm passing to the north of the airport; $z_o = 0.5$ m (Run 5)

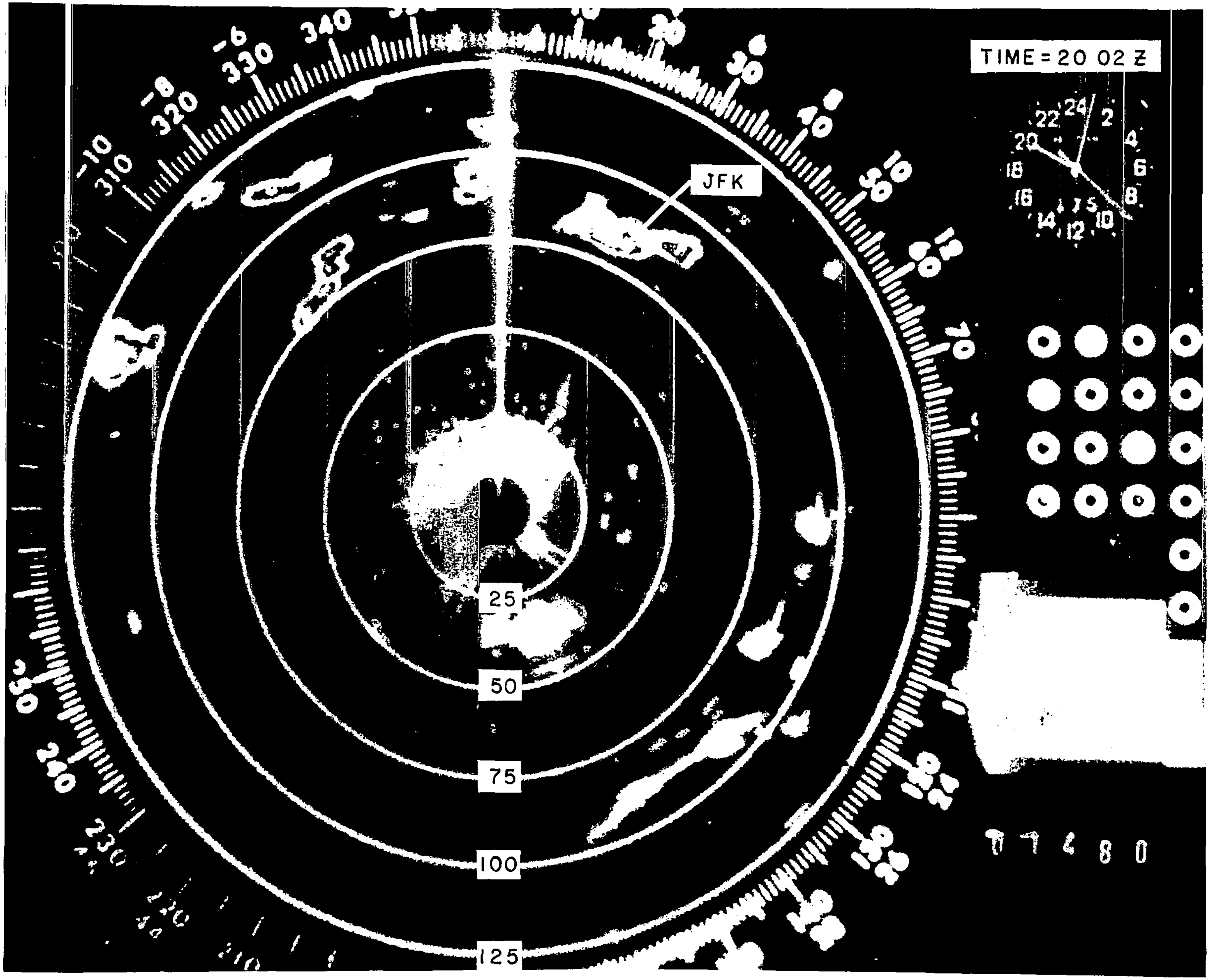


Figure 13. Radar picture taken from Atlantic City showing the position of the storm with respect to JFK just prior to the crash

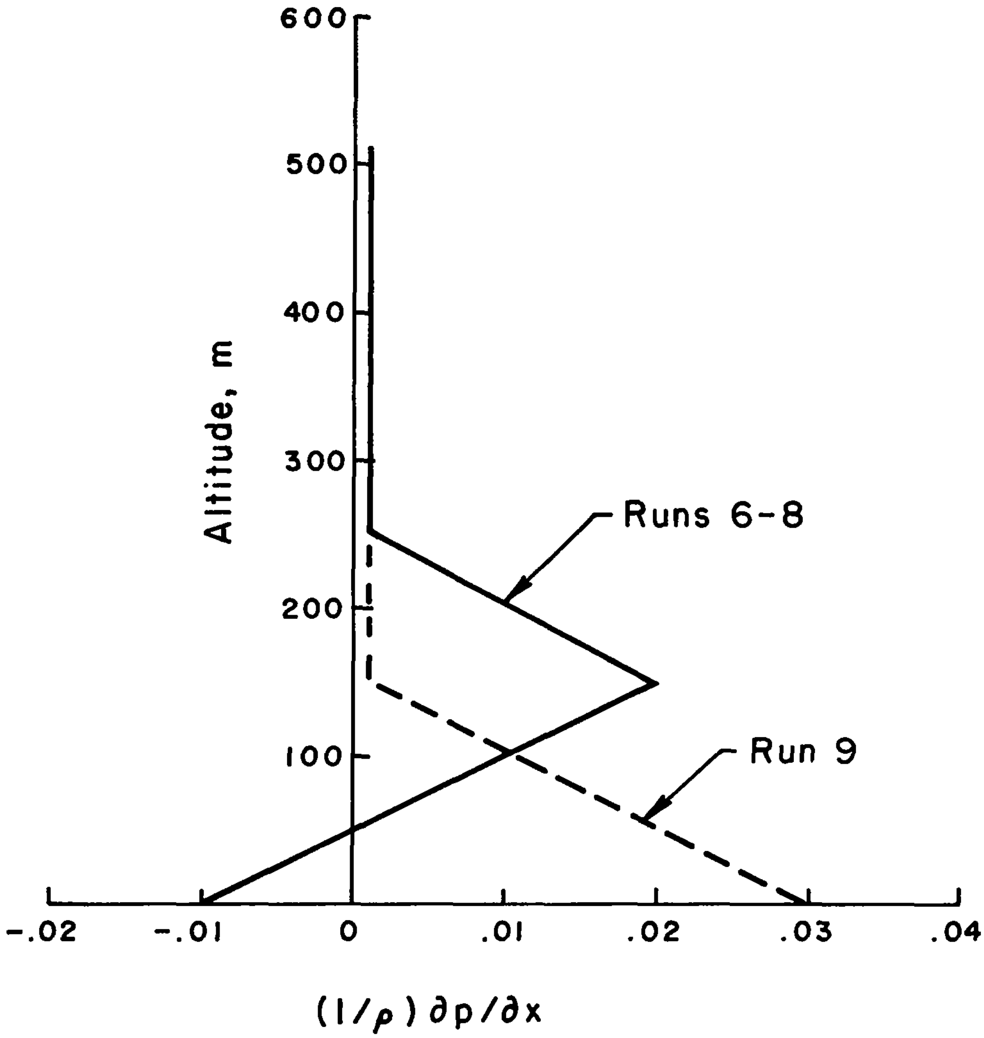


Figure 14. Profile of assumed storm pressure gradients (solid line is used for Runs 6, 7, and 8; dashed line is used for Run 9)

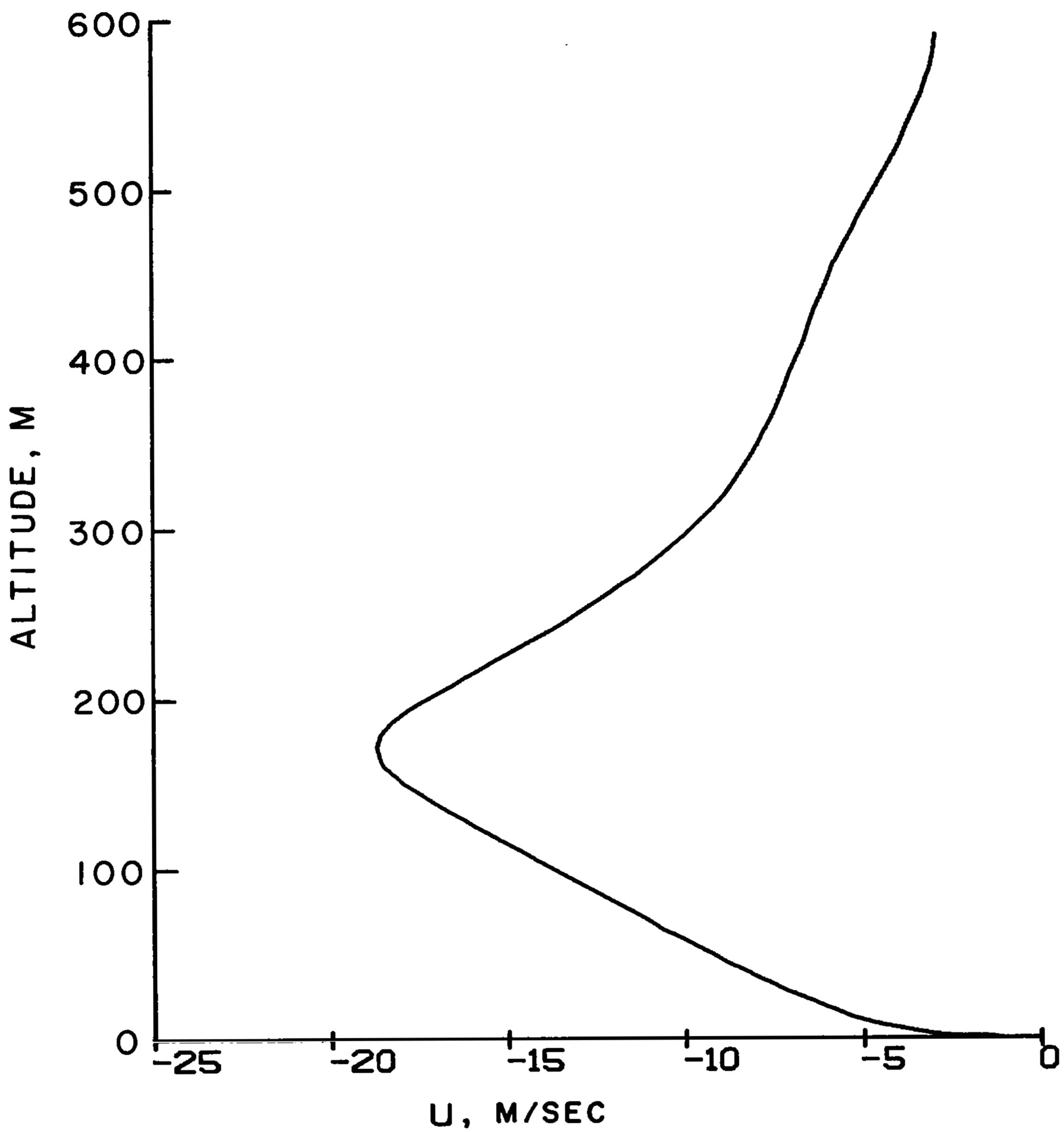


Figure 15. Profile of mean wind (u) at 2000z as predicted by the model with the pressure gradient set to simulate a storm overhead; z_o = 0.5 m (Run 6)

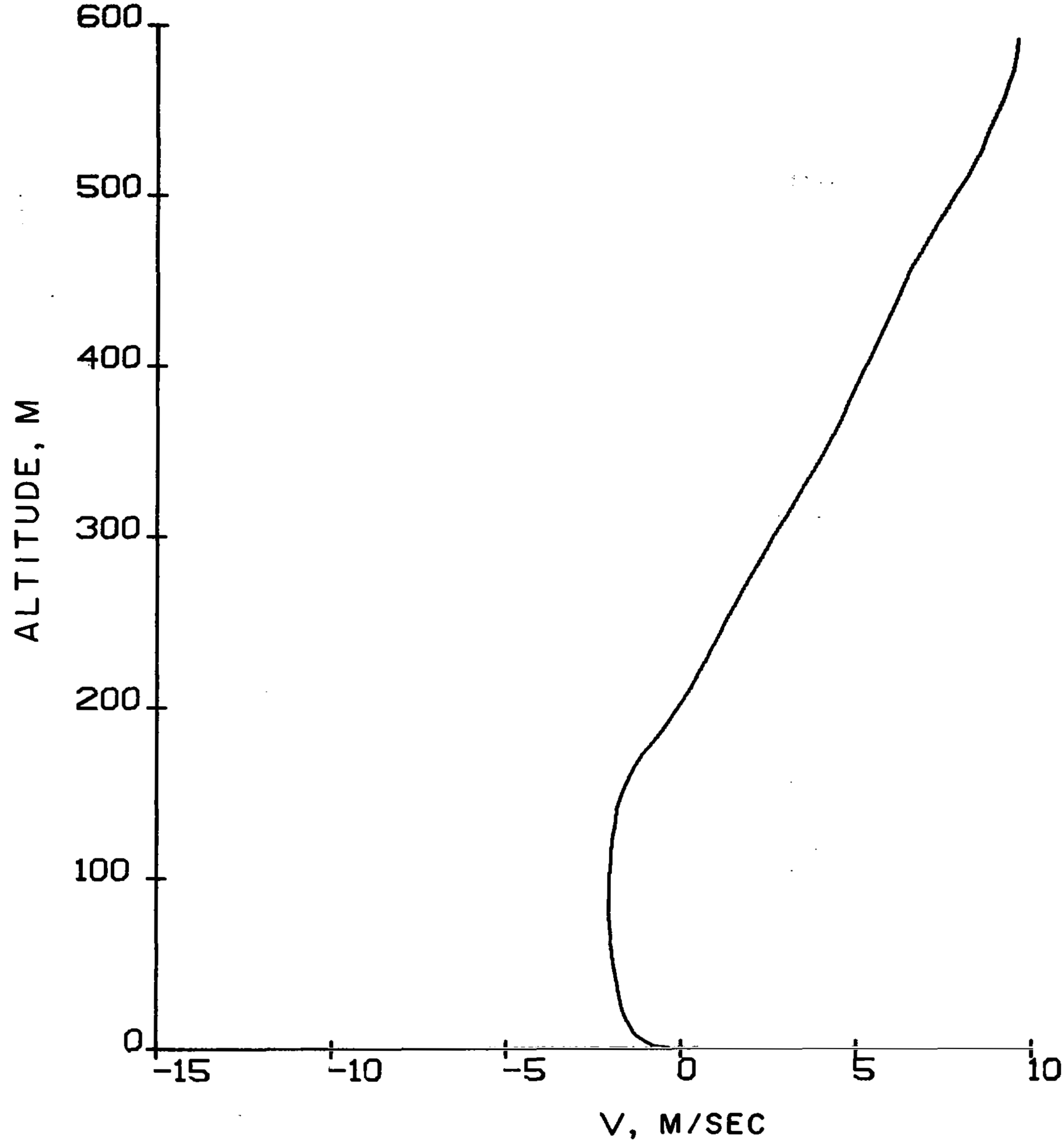


Figure 16. Profile of mean wind (v) at 2000z as predicted by the model with the pressure gradient set to simulate a storm overhead; z_o = 0.5 m (Run 6)

The corresponding profiles for the average value of the fluctuating velocities in both the vertical direction and in the direction of the runway are shown in figure 17. It should be noted that these are average rms values of the fluctuating values. Peak gust velocities would, of course, be higher. Based on the examination of a number of records of aircraft encountering severe turbulence, Houbolt (ref. 9) estimates that the average value of the maximum gust value will be in the range of 4 to 5 times the rms value.

To simulate the fact that the storm is overhead, it is also necessary to change the upper level temperature gradient boundary condition from the previously held stable value of +0.003°C/m to an unstable value less than 0. The turbulence growth rates generated beneath the storm are sensitive to the value of this instability. The profiles of figures 15, 16, and 17 (Run 6) are run with the temperature profile initially taken from Run 3 below 570 m and a gradient of -0.001°C/m above this to simulate the instability generated by condensation. The sensitivity to thermal conditions is demonstrated by repeating this run with only the initial potential temperature distribution altered. Figures 18 through 20 (Runs 7, 8) show the results of starting with temperature constant below 1 km and then decreasing at the rate of -0.001°C/m above this altitude. The local stable temperature gradients, although existing only temporarily, are sufficient to allow stronger shear to develop in Run 6.

Sensitivity to the assumed pressure gradient is demonstrated in figures 21 through 23 (Run 9) where thermal boundary conditions are the same as in figures 15 and 16 (Run 6) but the pressure gradient simulating the downdraft has been removed. The same value of thermal wind gradient is applied below 500 m, but in the opposite direction, to give the pressure gradient variation shown in figure 14. As seen by comparison of figures 15 through 17 with figures 21 through 23, both runs produce about the same maximum u velocity but, since the latter condition causes this to occur at a lower altitude, it leads to less mean wind shear.

ESTIMATES OF CONDITIONS AT 2005z

The airspeed time history for flight 66, as obtained from the recovered flight recorder, is shown in figure 24. Two estimates of the horizontal wind profiles as supplied by NTSB (refs. 6 and 10) are shown in figure 25. The two sets of curves represent data reduction with different assumptions regarding engine power setting and the distribution between headwinds and updrafts. The solid curve assumes engine thrust of 39% down to an altitude of 40 m, followed by 58% thrust to impact. The dashed curve is the result

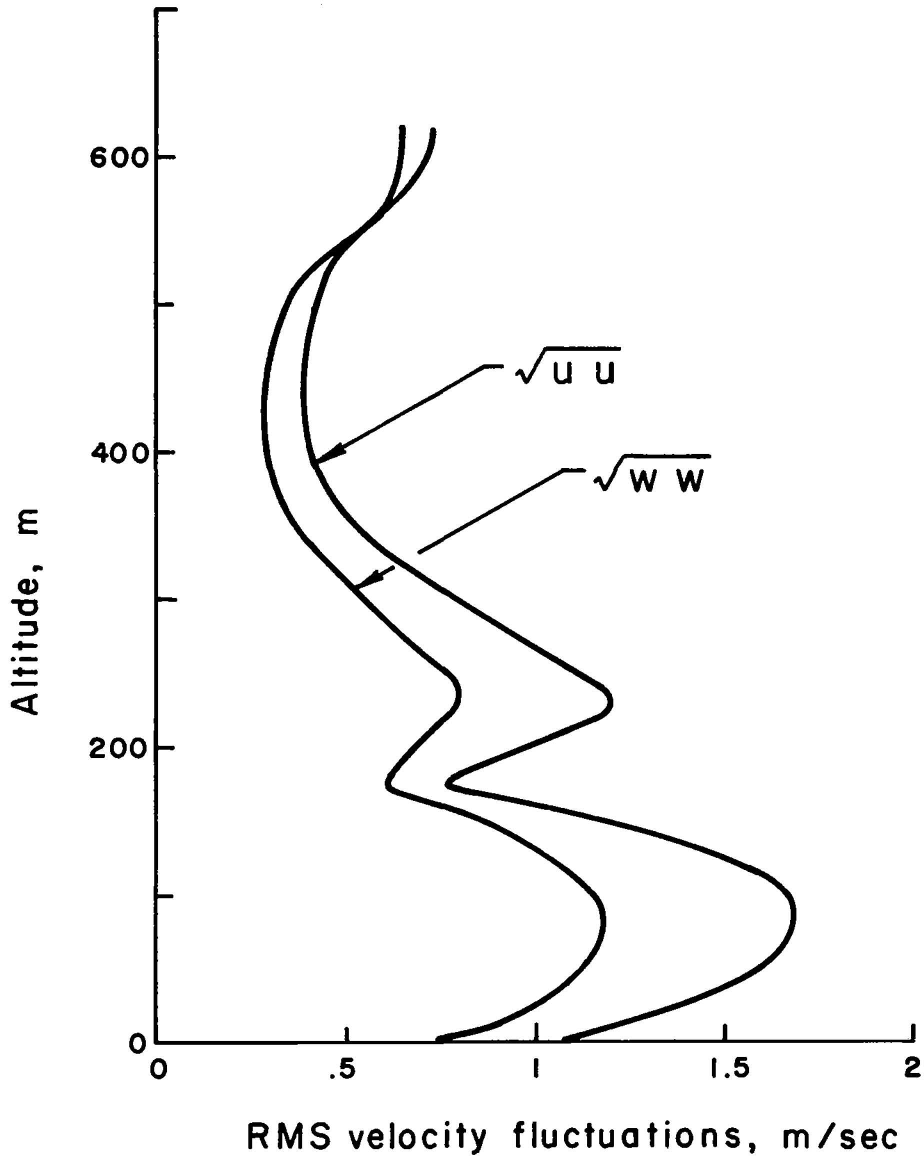


Figure 17. Profile of the rms values of the vertical and head-wind velocity fluctuations at 2000z as predicted by Run 6; z_o = 0.5 m

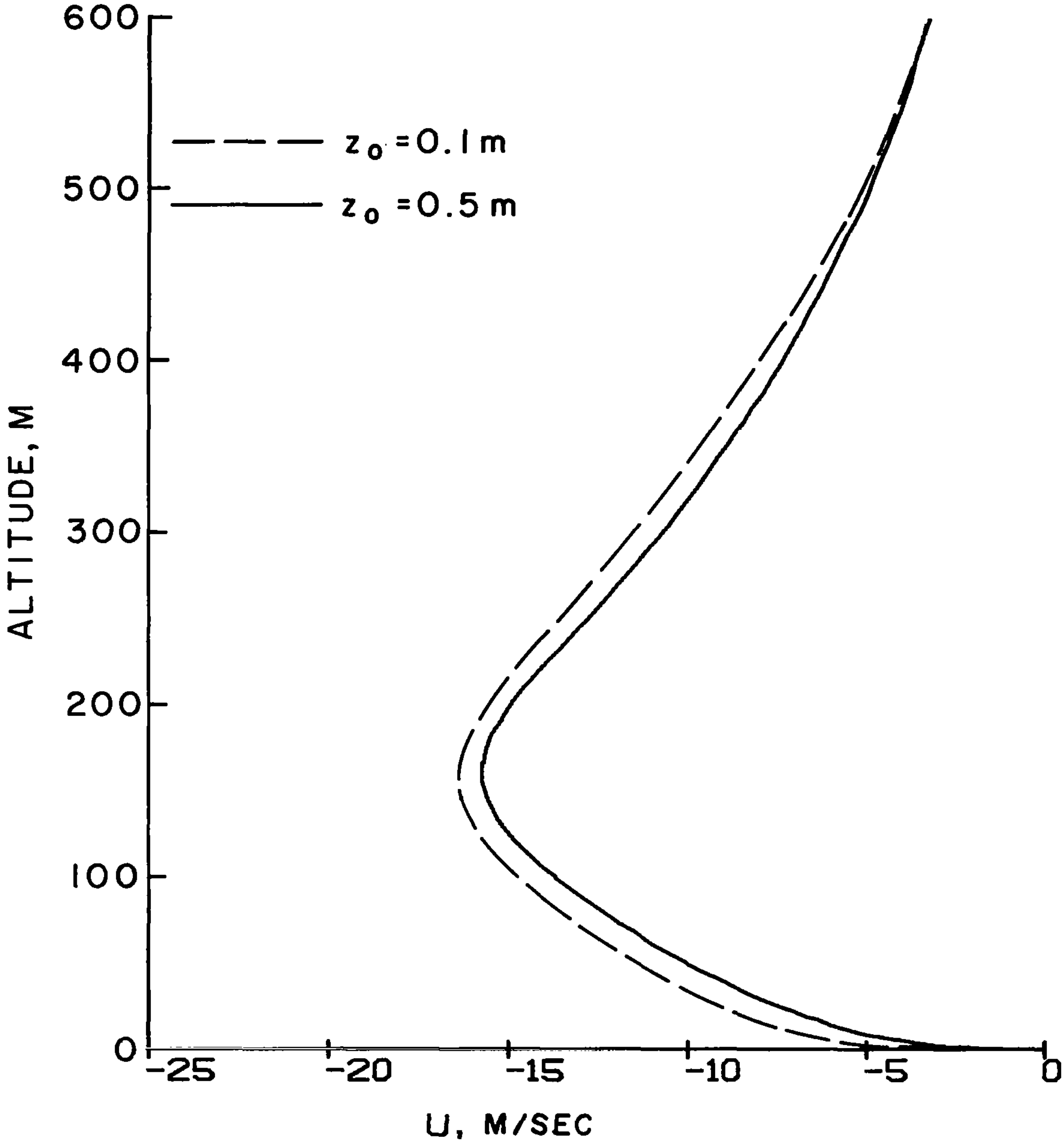


Figure 18. Profile of mean wind (u) at 2000z as predicted by Run 7 (z_o = 0.5 m) and Run 8 (z_o = 0.1 m) using the same pressure gradient as Run 6 but different stability conditions

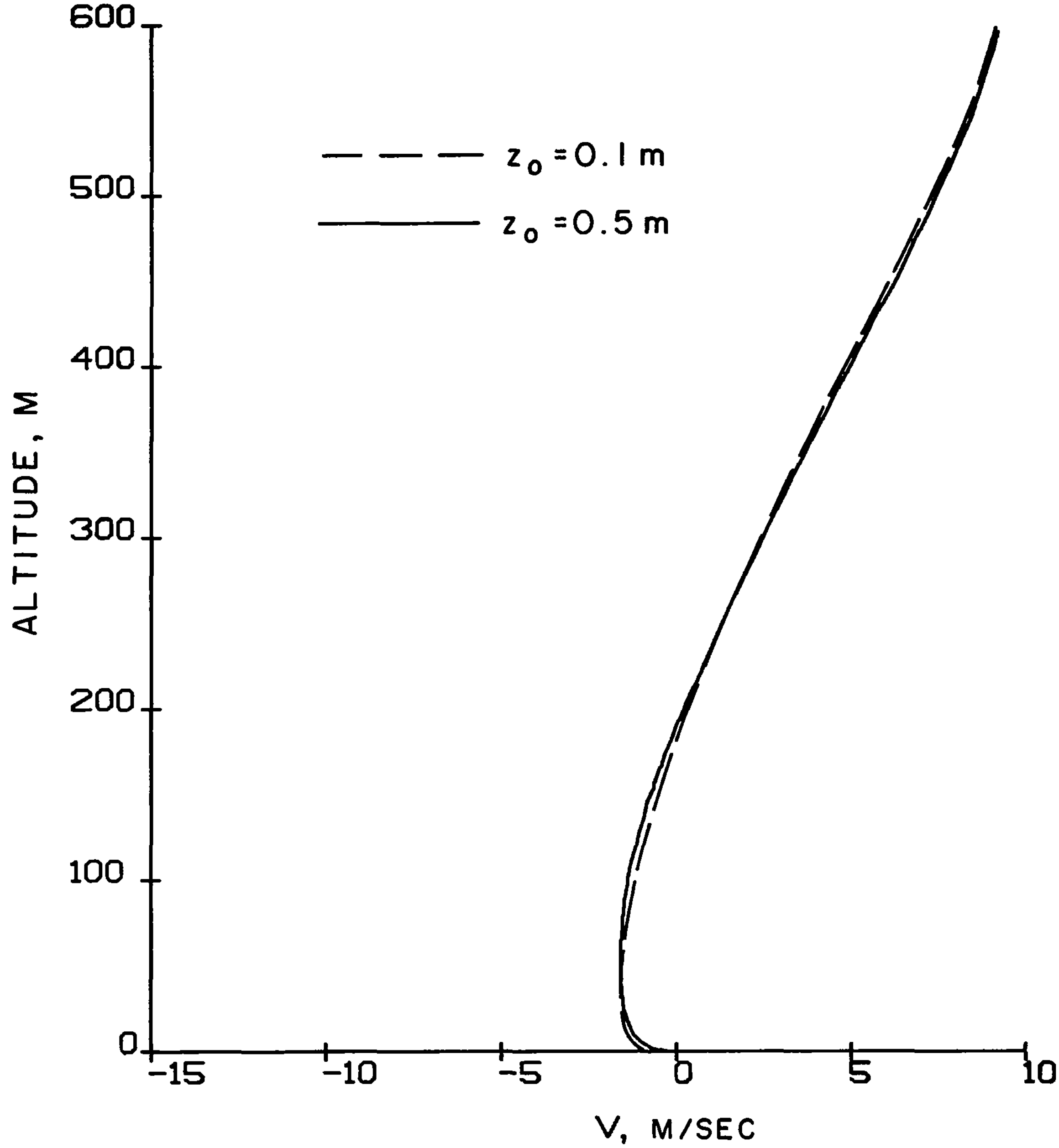


Figure 19. Profile of mean wind (v) at 2000z as predicted by Run 7 (z_o = 0.5 m) and Run 8 (z_o = 0.1 m) using the same pressure gradient as Run 6 but different stability conditions

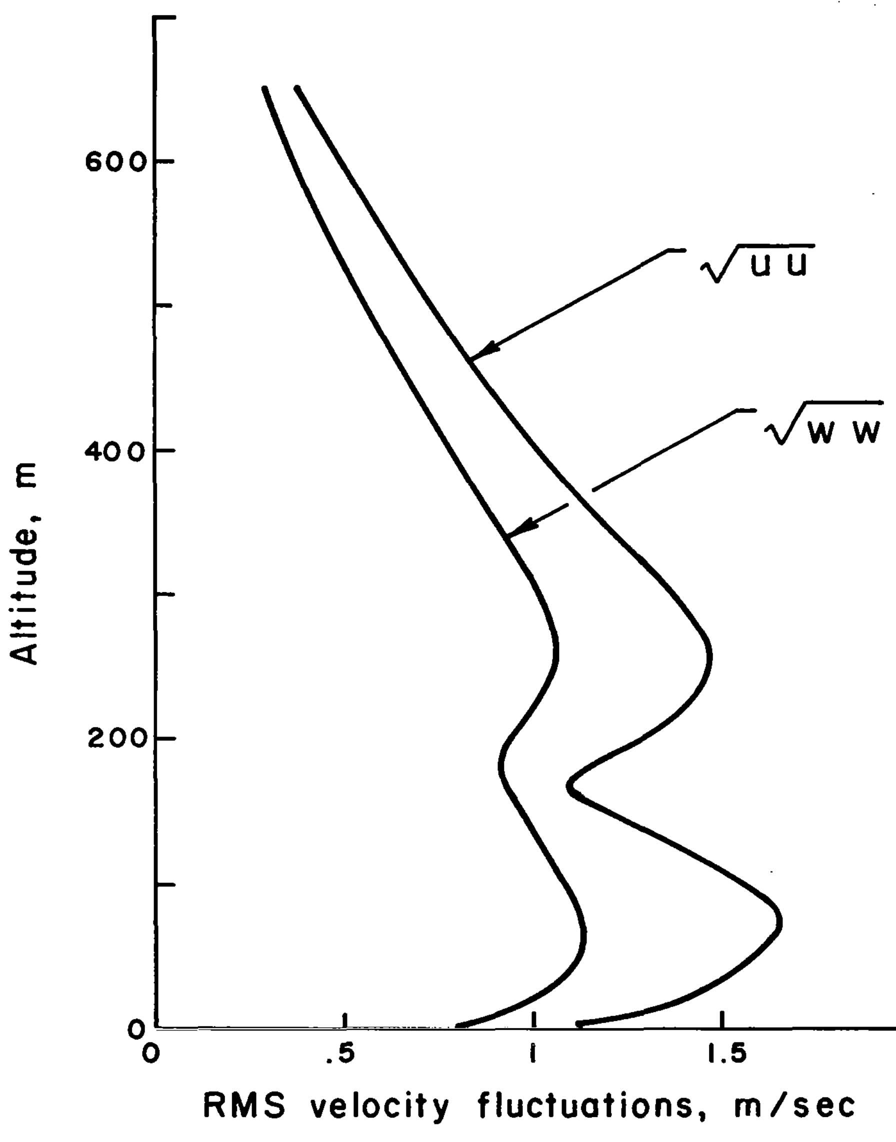


Figure 20. Profile of the rms values of the vertical and headwind velocity fluctuations at 2000z as predicted by Run 7

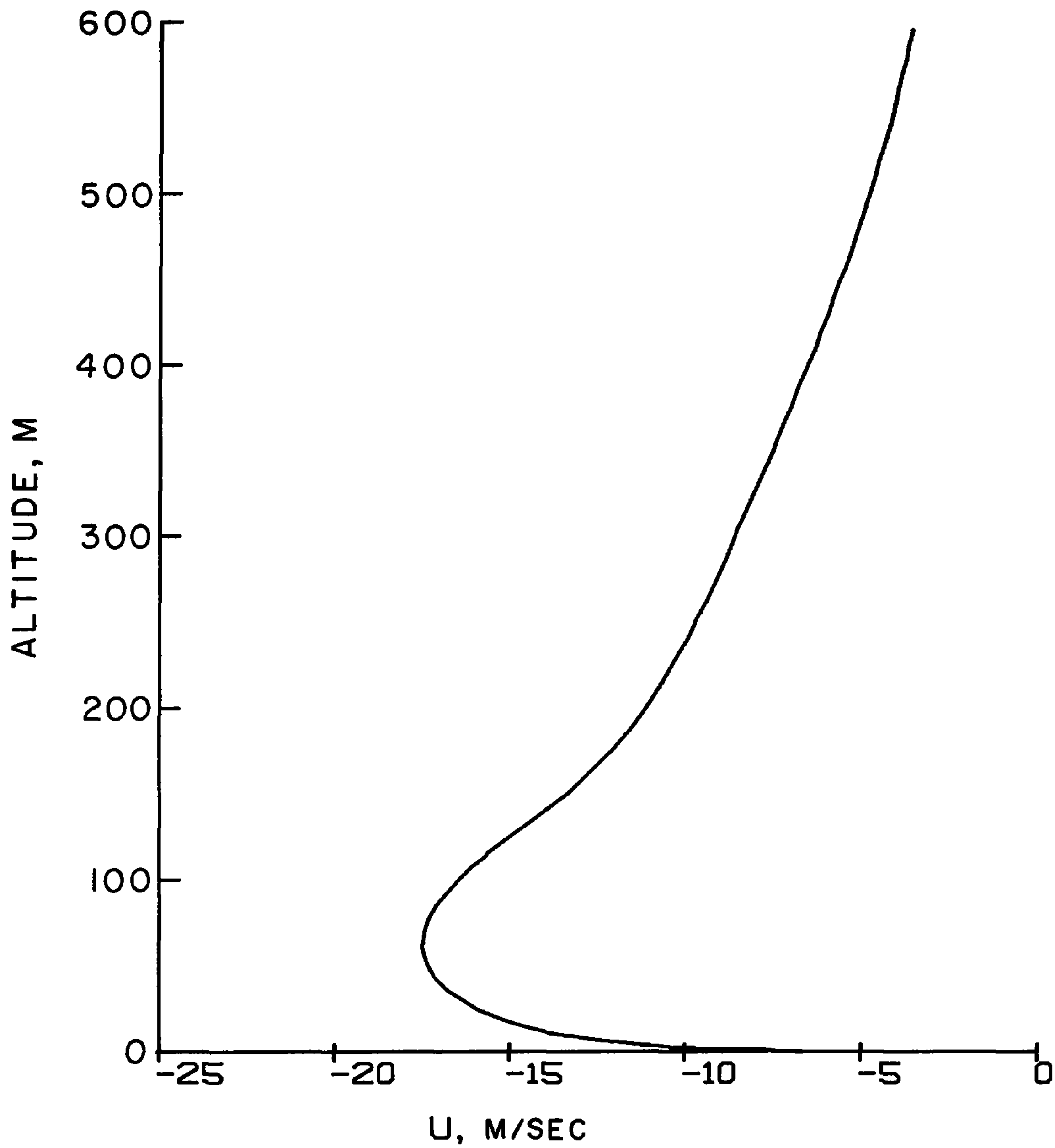


Figure 21. Profile of mean wind (u) at 2000z as predicted by Run 9 using the dashed pressure gradient in figure 14 and the same stability conditions as Run 6

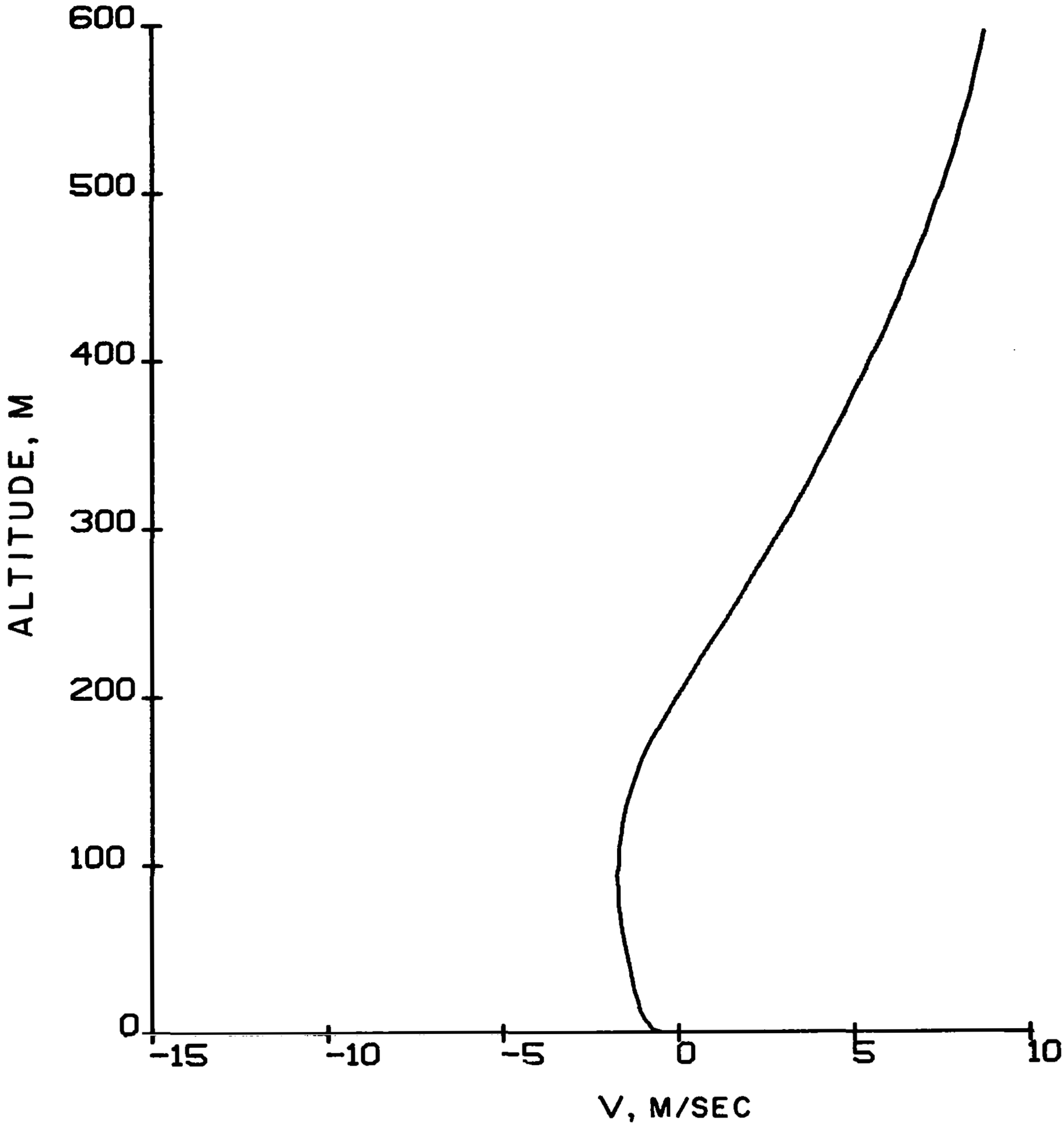


Figure 22. Profile of mean wind (v) at 2000z as predicted by Run 9 using the dashed pressure gradient in figure 14 and the same stability conditions as Run 6

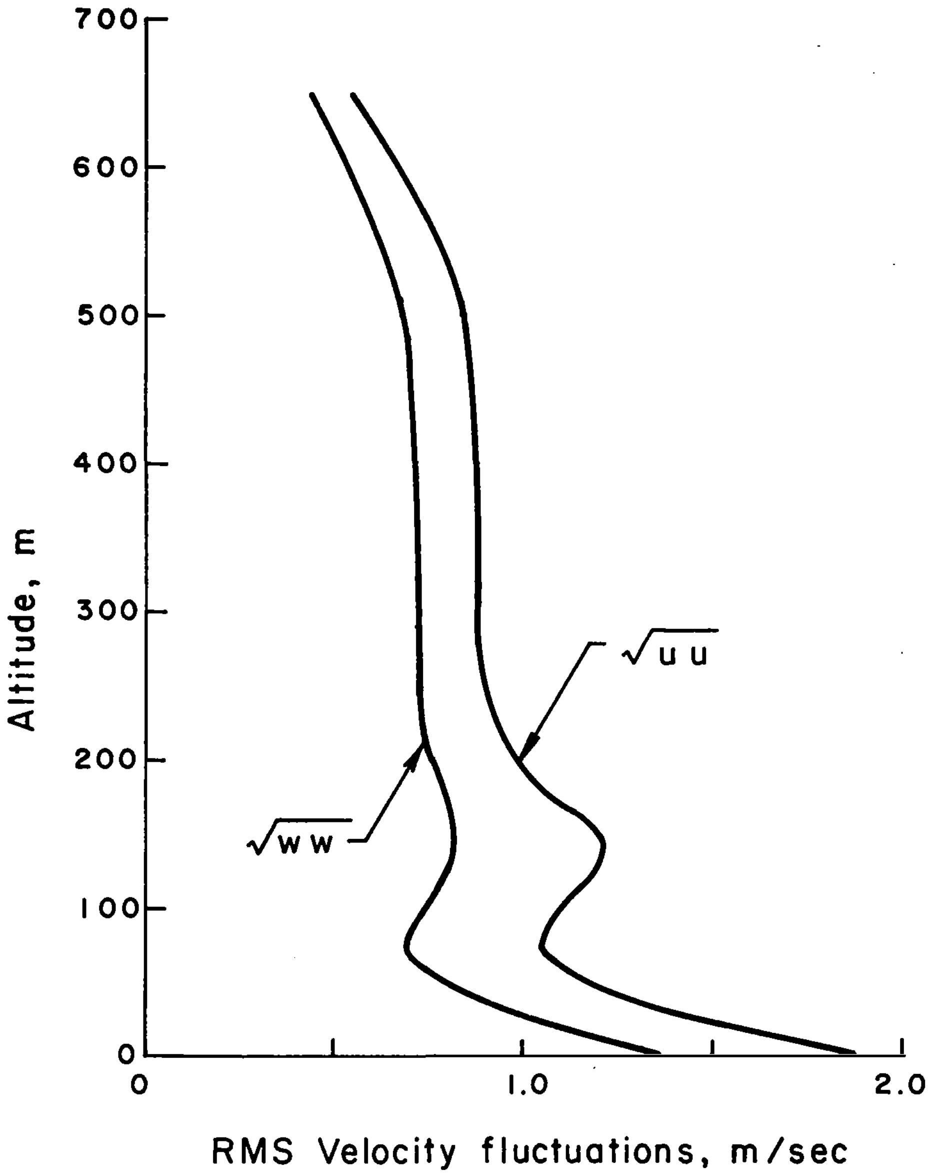


Figure 23. Profile of the rms values of the vertical $(\overline{w'w'})^{1/2}$ and headwind $(\overline{u'u'})^{1/2}$ velocity fluctuations at 2000z as predicted by Run 9

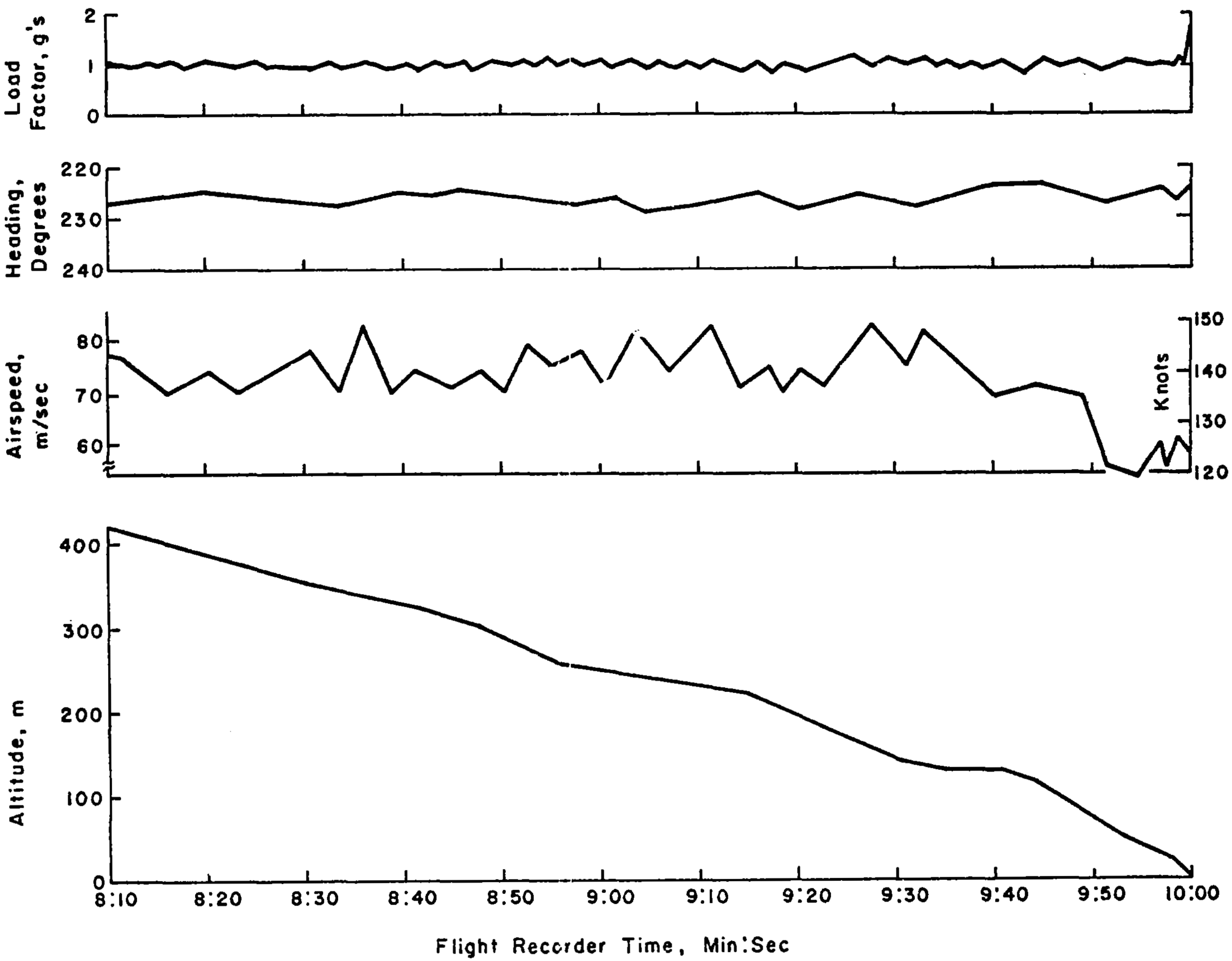


Figure 24. Flight recorder data as obtained from reference 6

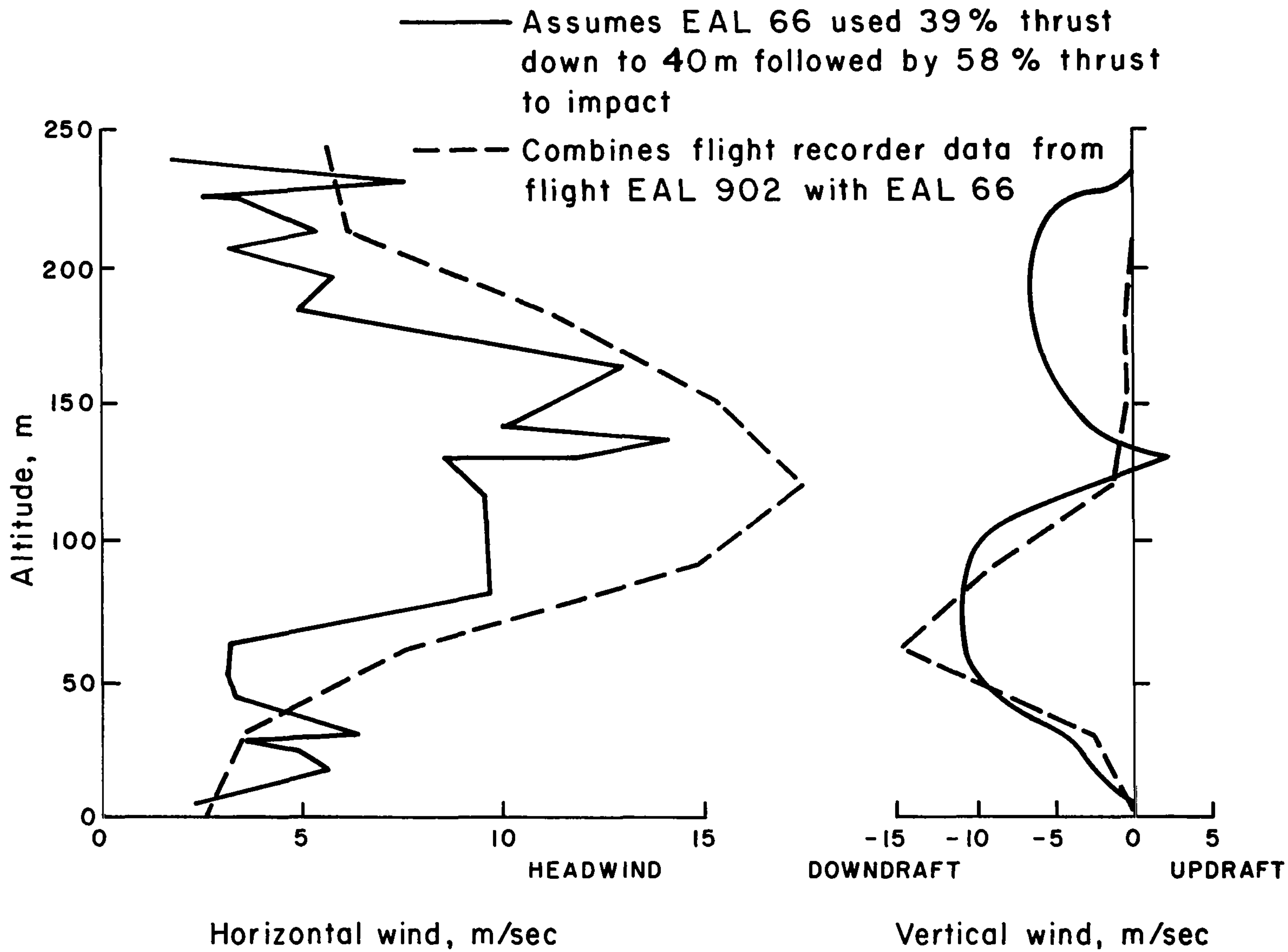


Figure 25. Estimates of horizontal and vertical wind profiles from Boeing analysis of flight recorder data (refs. 6 and 10)

of combining EAL 66 data with that of EAL 902 which had tried to land just prior to the crash. This latter set of data has been used in the simulator studies of the accident and is probably a better estimate of the conditions encountered along the flight path. The vertical wind profiles consistent with these assumptions are also shown. These combinations are not unique since other profiles are possible which satisfy all the known conditions from the flight recorder.

The velocity profiles obtained from Run 6 (figs. 15-17) appear to be the most consistent with the flight recorder data. Noting that fluctuations of as much as 4 times the rms values of figure 17 may be added to the mean wind profile of figure 15, the maximum horizontal wind shear apparently encountered, as seen in figure 25, is well within the values predicted. The turbulence macroscale (Λ) predicted for the same conditions (Run 6) as those of figures 15 through 17 are shown in figure 26. This scale is proportional to the integral scale but may be most precisely defined as 0.35 times (turbulent kinetic energy)$^{3/2}$/(dissipation rate of turbulent kinetic energy). Unfortunately, our one-dimensional unsteady program can give no information on the average downdraft profile; only vertical fluctuations may be predicted.

In order to show how the downdraft may alter the distribution, we have made one run with our new two-dimensional, unsteady program which is now under development for the Navy. For purposes of this calculation, the initial conditions on the wind and turbulence fields are taken as the output on the one-dimensional, unsteady program for 1945z of Run 3. The upper wind boundary condition at 1 km is held fixed at the assumed geostrophic conditions of 10 m/sec from 285°. A neutral temperature distribution is assumed for this run. This is a somewhat uncertain condition since the stability conditions may be expected to change rapidly with the development of the storm. The inflow boundary conditions are held fixed in time, while a pressure distribution simulating a downdraft is imposed upon the boundary layer as a function x, z, and t. The pressure distribution with altitude is proportional to that used in Run 6 (fig. 14), while the x distribution simulates a downdraft approximately 1 km wide. The time variation is such as to allow the full pressure gradient to build as a quarter sine wave over 5 minutes simulated time. The resulting mean wind contours in a plane parallel to the runway are shown in figure 27. It should be noted that in certain regions of the flow the horizontal gradients in u are of the same order as the vertical gradients. An aircraft passing through this on the 3° glide slope indicated by the dashed line would experience the horizontal and vertical velocity profiles shown on figures 28 and 29. In these figures, the bars represent the average root-mean-square fluctuations about the mean distribution. The most significant change from figures 15 and 17 is the reduction in altitude of the peak headwind. This is directly attributable to the downdraft.

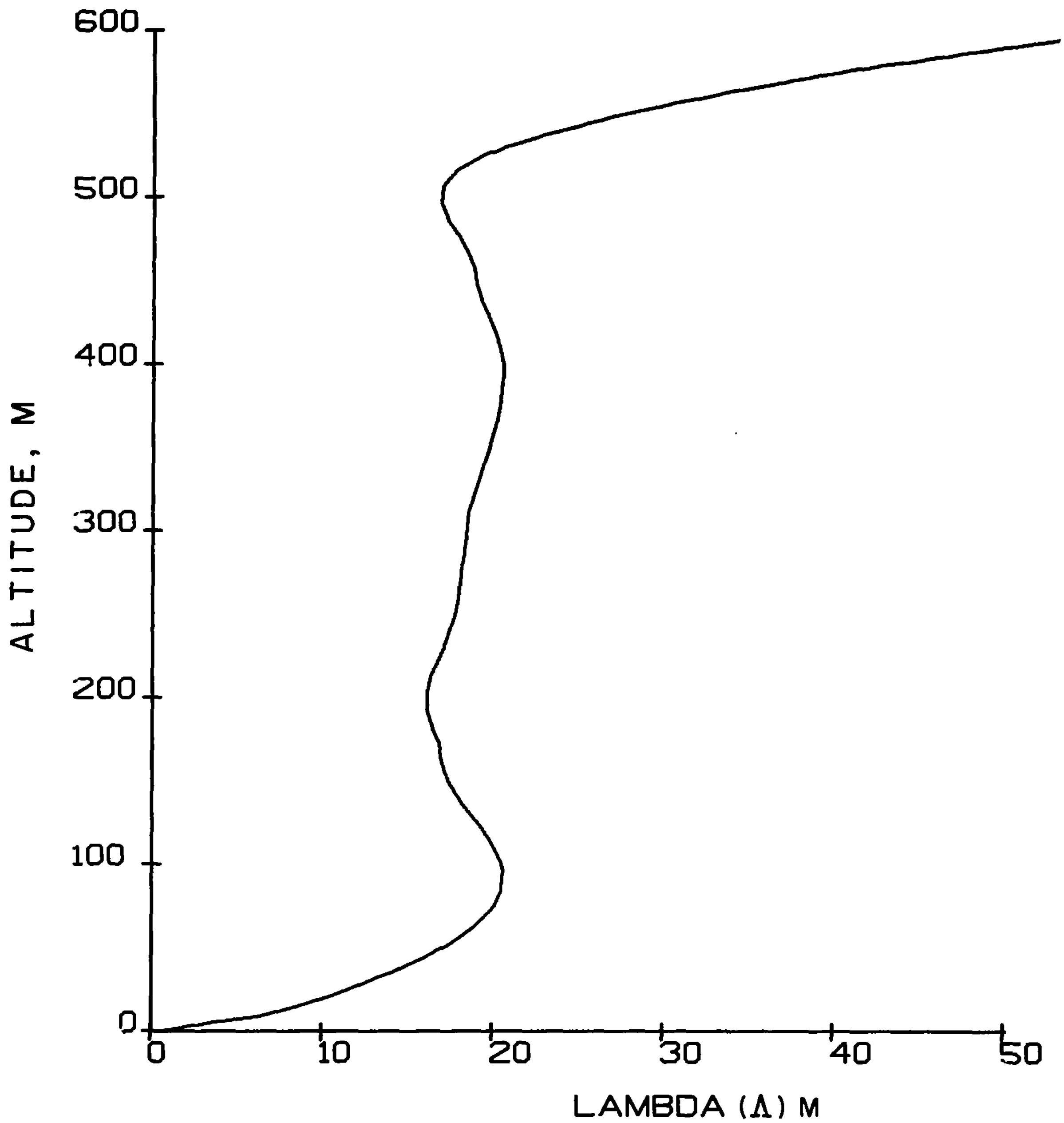


Figure 26. Profile of turbulence macroscale variation for 2000z predicted by Run 6

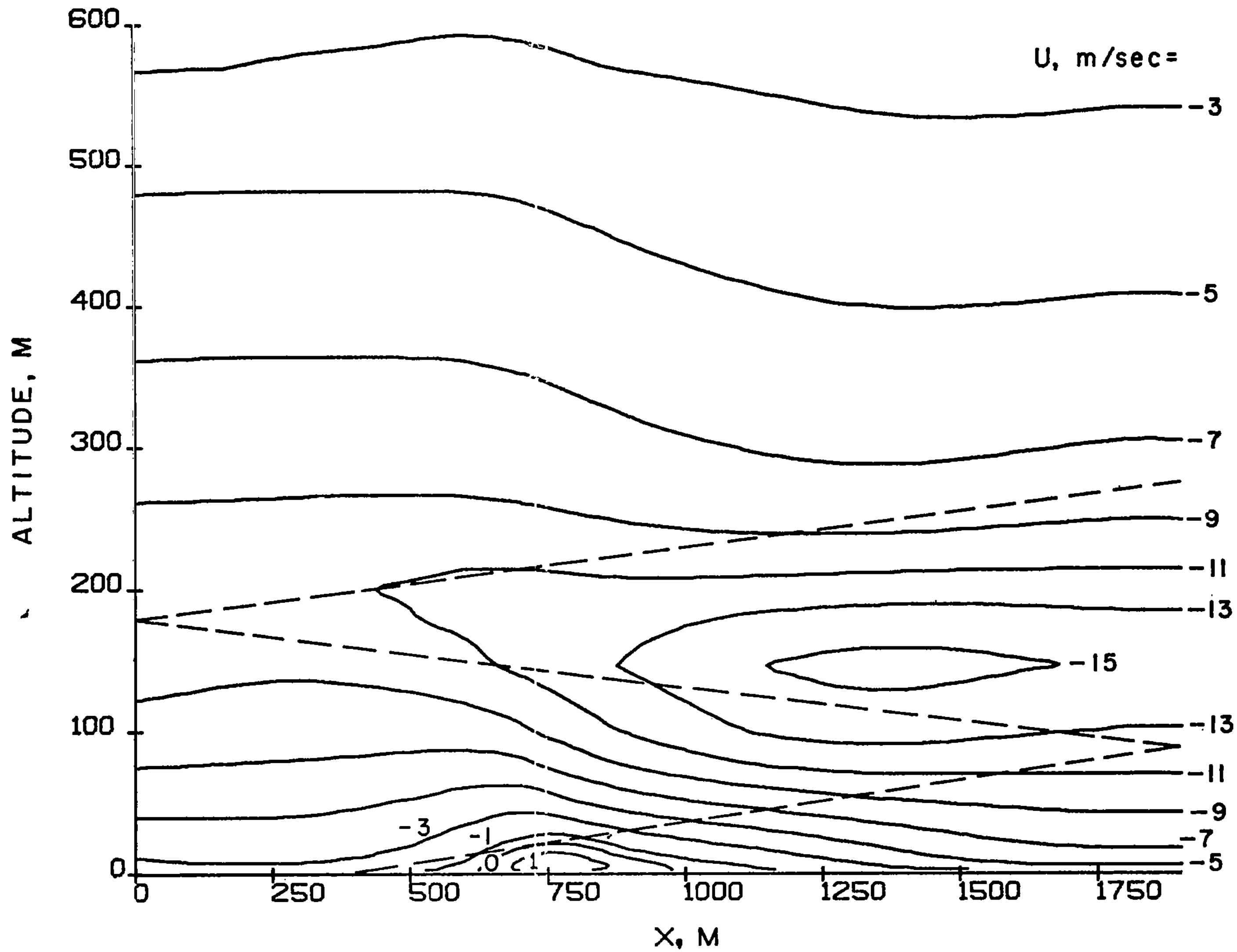


Figure 27. Contours of constant values of the mean wind component u as predicted (Run 10) by a two-dimensional unsteady simulation of a downdraft imposed upon the boundary layer (dashed line indicates a possible 3° flight path through the field)

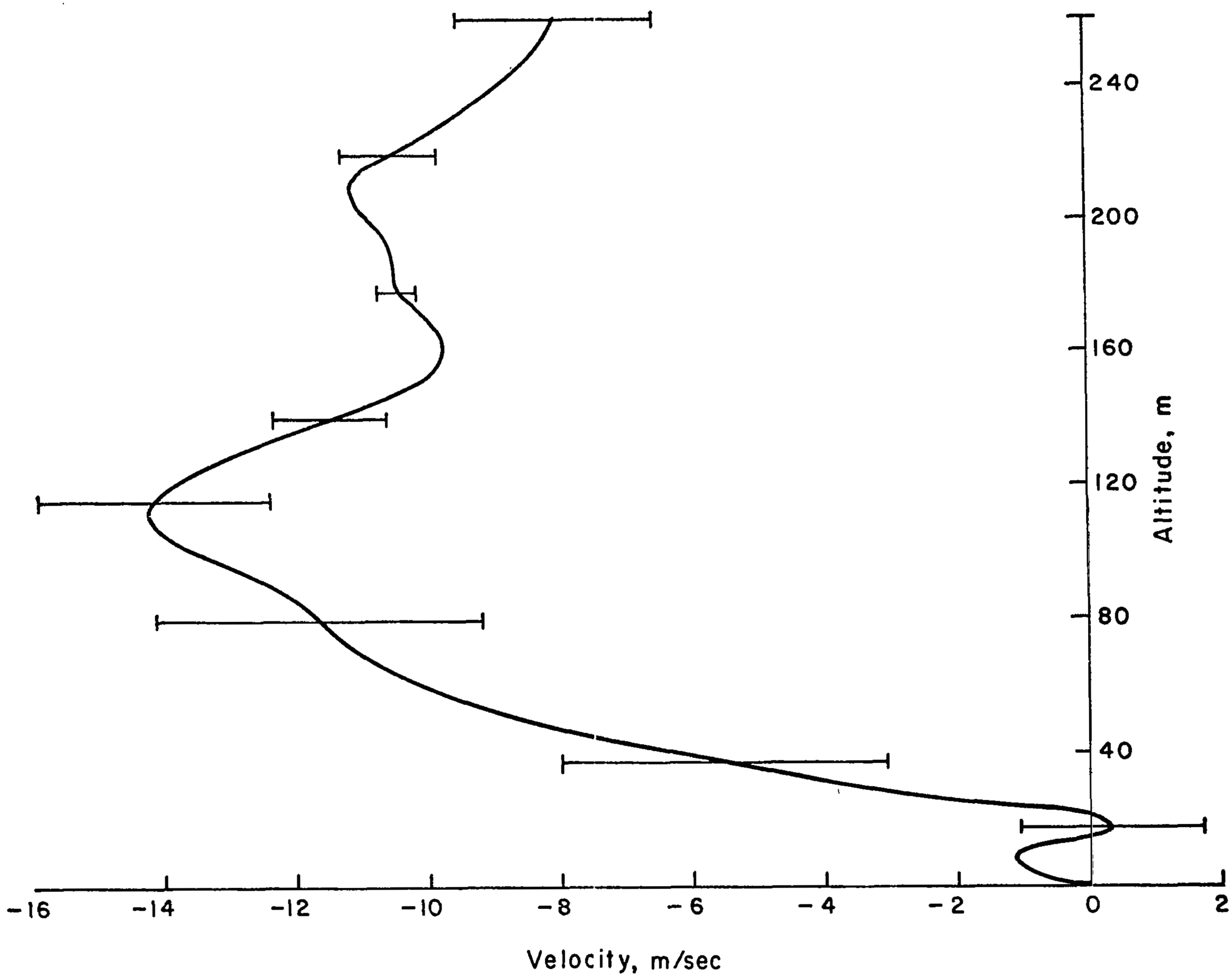


Figure 28. Possible u components of the wind encountered along flight trajectory (shown on fig. 27) with the bars denoting rms values of fluctuations about the mean value

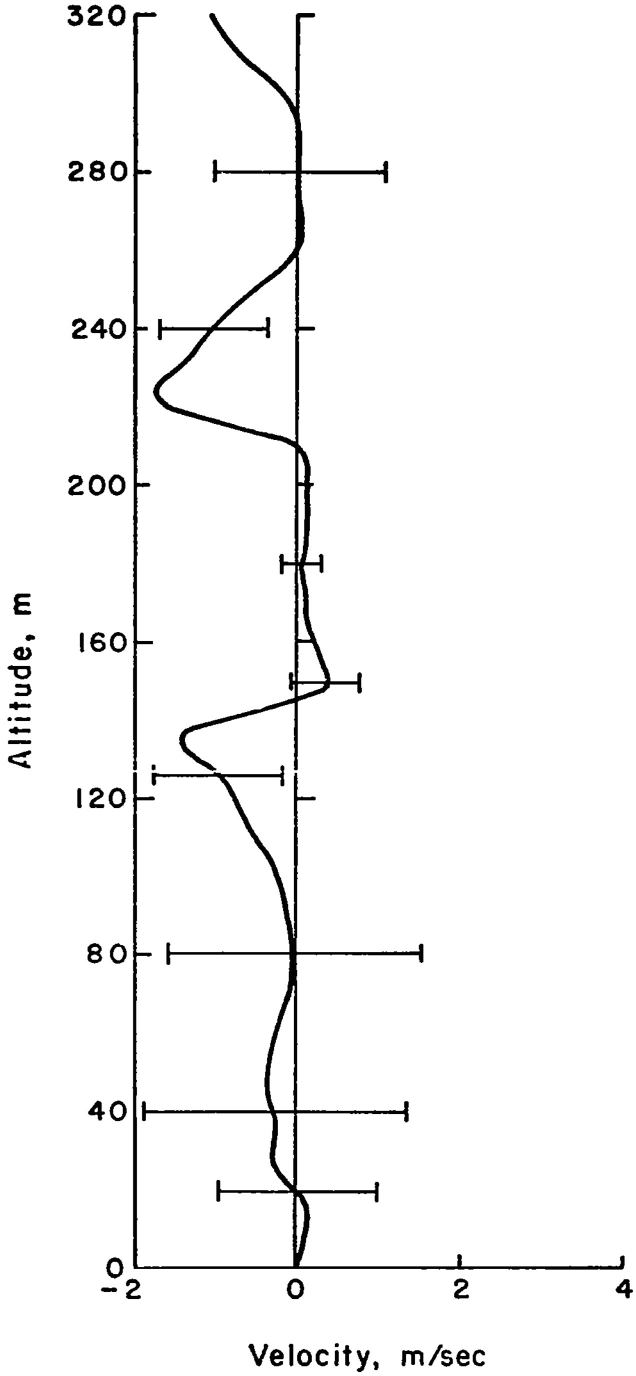


Figure 29. Possible vertical component of the wind encountered along flight trajectory (shown on fig.27) with the bars denoting rms values of fluctuations about the mean value

The horizontal wind shear predicted in this figure is of the same order as that in figure 25, while the strength of the downdraft is less. The present stage of development of our two-dimensional, unsteady, planetary boundary layer program does not permit accurate calculations when the mean vertical velocity becomes as large as the mean horizontal velocity. This has prevented us from attempting to simulate stronger downdrafts which may have occurred. Also it must be remembered that the program predicts average values of the fluctuation, while the aircraft observes instantaneous values which may be as much as 4 times higher than the rms values predicted in figures 28 and 29.

CONCLUDING REMARKS

We have shown the types of velocity distributions which are compatible with the known meteorological conditions in the vicinity of Kennedy International Airport on 24 June 1975. Table II summarizes the input conditions for the different runs made and provides a key to the figures illustrating the resulting predicted velocity profiles. The velocities are seen to be sensitive to both horizontal and vertical temperature gradients while not strongly affected by surface roughness. Run 6 represents the one-dimensional, unsteady run which we believe is closest to the conditions at the time of the crash. The two-dimensional, unsteady run demonstrates the influence a downdraft would have on reducing the altitude at which peak velocities occur.

The model results show that a wind shear of the order of 15 m/sec (30 knots) over a 100 m (300 ft) altitude change is quite consistent with the known meteorological conditions at the time of the crash.

REFERENCES

1. Lewellen, W.S.; Teske; M.E.; Contiliano, Ross M.; Hilst, Glenn R.; and Donaldson, Coleman duP.: Invariant Modeling of Turbulent Diffusion in the Planetary Boundary Layer. Report No. 225 (EPA Report EPA-650/4-74-035), Aeronautical Research Associates of Princeton, Inc., 1974.

2. Lewellen, W.S.; and Teske, M.E.: Turbulence Modeling and Its Application to Atmospheric Diffusion. Part I: Recent Program Development, Verification, and Application. Part II: Critical Review of the Use of Invariant Modeling. Report No. 254, I and II (EPA Report EPA-600/4-75-016a and b), Aeronautical Research Associates of Princeton, Inc., 1975.

TABLE II

SUMMARY OF INPUT CONDITIONS FOR COMPUTER RUNS AND KEY TO FIGURES

Run	z_o, m	Thermal wind / Pressure gradient	Initial Condition	Upper Level Temperature Gradient, °C/m	Surface Temperature	Results Plotted for:
1	0.5	0	Arbitrary at 0400z, 24 June 1975	+0.003	As reported by airport observer	1400z Figures 3, 4 1800z Figures 5, 6
2	0.1	0	Arbitrary at 040Cz, 24 June 1975	+0.003	" "	1400z Figures 3, 4 1800z Figures 5, 6
3	0.5	Sea breeze $\partial T/\partial z = 1 \times 10^{-4}$ °C/m for $z \leq 500$ m from 120°	1400z conditions of Run 1	+0.003	" "	1800z Figures 7, 8 2000z Figures 9, 10
4	0.1	Sea breeze $\partial T/\partial z = 1 \times 10^{-4}$ °C/m for $z \leq 500$ m from 120°	1400z conditions of Run 2	+0.003	" "	1800z Figures 7, 8 2000z Figures 9, 10
5	0.5	Storm passing to the north $\partial T/\partial z = 5 \times 10^{-4}$ °C/m ($z \leq 1$ km) from 30°	1915z conditions of Run 3	+0.003	" "	2000z Figures 11, 12
6	0.5	Storm overhead; pressure gradient shown in fig.14	1945z conditions of Run 3	-0.001	Same as at 1 km	2000z Figures 15, 16, 17, 26
7	0.5	Storm overhead; pressure gradient shown in fig.14	1945z conditions of Run 3	-0.001	Same as at 1 km (Initial temperature distribution modified to be constant up to 1 km)	2000z Figures 18, 19, 20
8	0.1	Storm overhead; pressure gradient shown in fig.14	1945z conditions of Run 3	-0.001	" " " "	2000z Figures 18, 19, 20
9	0.5	Storm overhead; pressure gradient shown in fig.14	1945z conditions of Run 3	-0.001	Same as at 1 km	2000z Figures 21, 22, 23
10	0.5	2-D unsteady with pressure gradient to induce downdraft	1945z conditions of Run 3		Zero temperature variation	5 min after initialization Figures 27, 28 29

3. Donaldson, Coleman duP.: Calculation of Turbulent Shear Flows for Atmospheric and Vortex Motions. AIAA Journal, vol. 10, no. 1, Jan. 1972, pp. 4-12.

4. Donaldson, Coleman duP.: Construction of a Dynamic Model of the Production of Atmospheric Turbulence and the Dispersal of Atmospheric Pollutants, in Workshop on Micrometeorology (D.A. Haugen, ed.), American Meteorological Society (Boston), 1973, pp. 313-392.

5. Lewellen, W.S.; and Williamson, Guy G.: Wind Shear and Turbulence Around Airports. Part 1: Parametric Analysis of Typical Profiles in the Planetary Boundary Layer. Part 2: Selection of an Ensemble of Aircraft Accidents for which Wind Shear or Turbulence Appeared to be a Contributing Factor. Report No. 267, 1 and 2, Aeronautical Research Associates of Princeton, Inc., 1976.

6. private communication from A. Brunstein, NTSB

7. Brown, R.A.: Analytical Methods in Planetary Boundary-Layer Modeling. Halsted Press, 1974.

8. Battan, L.J.: Radar Observations of the Atmosphere. University of Chicago Press, 1973.

9. Houbolt, John C.: Atmospheric Turbulence. AIAA Journal, vol. 11, no. 4, April 1973, pp. 421-437.

10. private communication from W.G. Laynor, NTSB

NASA-Langley, 1976