NASA

National Aeronautics and Space Administration

NASA CP-2028

PROCEEDINGS: FIRST ANNUAL WORKSHOP ON METEOROLOGICAL INPUTS TO AVIATION SYSTEMS

MARCH 8-10, 1977

UNIVERSITY OF TENNESSEE SPACE INSTITUTE

EDITORS: DENNIS W. CAMP
WALTER FROST

TECHNICAL EDITOR: WILSON J. BOAZ

FAA-RD-77-173

NOTICE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CP 2028 FAA-RD-77-173		

4. Title and Subtitle	5. Report Date
Proceedings of the First Annual Meteorological and Environmental Inputs to Aviation Systems Workshop	March 1977
	6. Performing Organization Code
7. Author's)	8. Performing Organization Report No.
Editedby Dennis W. Camp and Walter Frost	
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
University of Tennessee Space Institute Tullahoma, Tennessee	11. Contract or Gran? No. NAS8-29584
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
NASA/Marshall Space Flight Center, Alabama DOT/Federal Aviation Admin., Washington, DC DOC/National Oceanic & Atmos. Administration,	Workshop Proceedings
	14. Sponsoring Agency Code

Space Institute (NAS8-29584)

16. Abstract The proceedings of a workshop on Meteorological and Environmental Inputs to Aviation Systems held at the University of Tennessee Space Institute, Tullahoma, Tennessee, on March 8-10, 1977, are reported. The workshop, jointly sponsored by NASA, NOAA, and FAA, brought together many disciplines of the aviation communities in round table discussions. The objective of the discussions was to define areas where: (1) environmental data are currently available and useable for engineering and operation applications, (2) environmental data are available but not useful in the existing format and (3) environmental data are unavailable and should be determined. The general topic areas addressed were general services, aircraft design, simulation, and general aviation. The unique aspects of the workshop were the diversity of the participants and the achievement of communication across the interface of the boundaries between pilots, meteorologists, airplane designers, safety investigators, and researchers as well as between military, civil, general aviation and commercial interests. Twenty-seven representatives were in attendance from Government, Airlines, Private Agencies, Aircraft Manufacturers, Department of Defense, Industries, and Research Industries.

Full-length papers from invited speakers which addressed certain topics and overviews of a number of ongoing programs related to knowledge of atmospheric processes are contained in the proceedings. Also, committee chairman's reports on the results and conclusions of the committee meeting are given.

17. Key Words	18. Distribution Statement
Aviation Safety Meteorology Aircraft Design Wind Shear Flight Simulation General Aviation Aviation Weather Research and Services	Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161. Star Category 47

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	336	

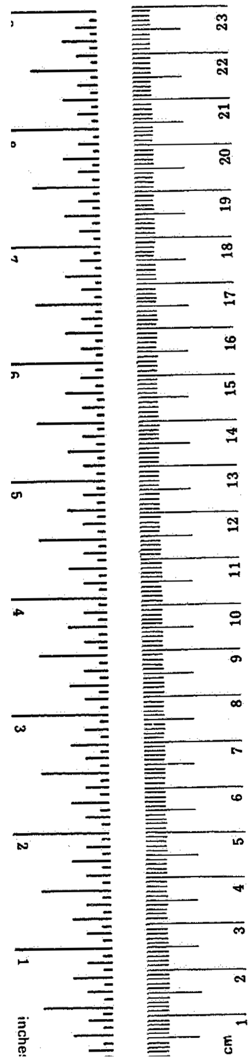
Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

METRIC CONVERSION FACTORS

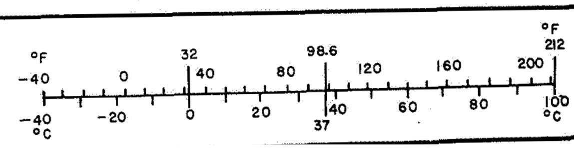
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Symbol	W	S
mm		
cm		
m		
m		
km		
cm^2		
m^2		
km^2		
ha		
g		
kg		
t		
ml		
l		
l		
l		
m^3		
m^3		
°C		



APPROVAL

PROCEEDINGS OF THE FIRST ANNUAL METEOROLOGICAL AND ENVIRONMENTAL INPUTS TO AVIATION SYSTEMS WORKSHOP

Edited by Dennis W. Camp and Walter Frost

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

Charles A. Lundquist

CHARLES A. LUNDQUIST
Director
Space Sciences Laboratory
NASA, Marshall Space Flight Center

Proceedings of
the First Annual Meteorological and Environmental
Inputs to Aviation Systems Workshop

March 8-10, 1977
University of Tennessee Space Institute

Organization Committee and Sponsoring Agencies

Dennis W. Camp
NASA Marshall Space Flight Center
Huntsville, Alabama

John W. Connolly
U.S. Department of Commerce/NOAA
Rockville, Maryland

Walter Frost
Director, Atmospheric Science Division
University of Tennessee Space Institute
Tullahoma, Tennessee

William A. McGowan
Aviation Safety Technology
NASA HQ
Washington, D.C.

Joseph F. Sowar
Chief, Aviation Weather Systems Branch
Systems Research and Development Service
FAA
Washington, D.C.

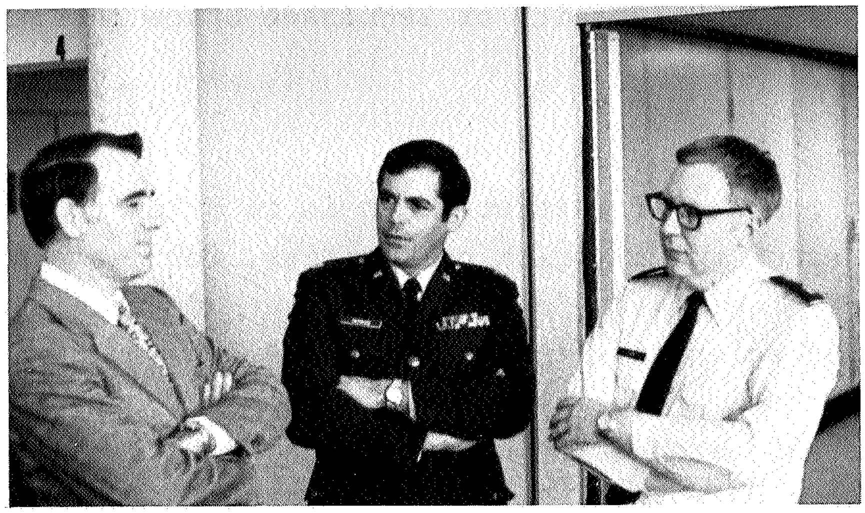
Technical Editor:

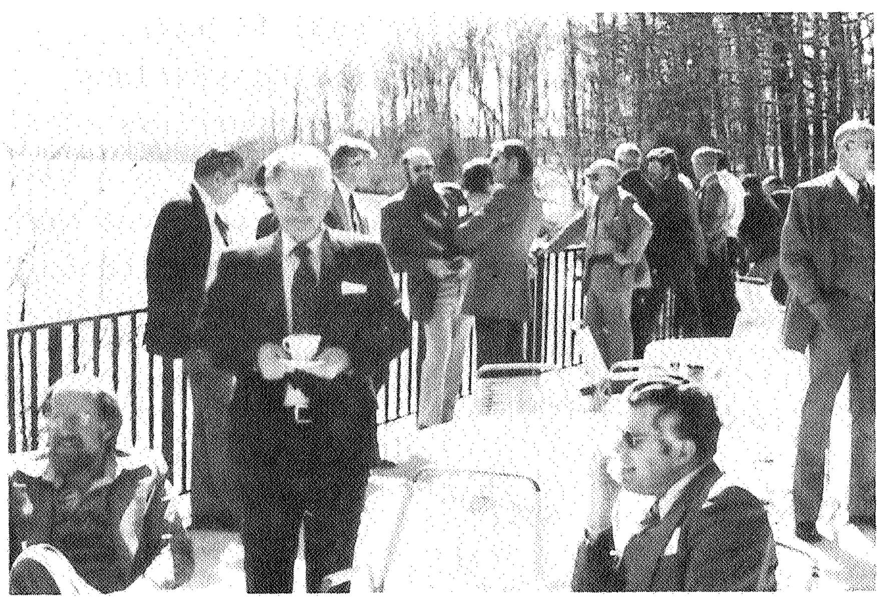
Wilson J. Boaz
University of Tennessee Space Institute
Tullahoma, Tennessee

Table of Contents

SECTION I

INTRODUCTION AND WELCOME





METEOROLOGICAL AND ENVIRONMENTAL

INPUTS TO AVIATION SYSTEMS

March 8-10, 1977

Opening Remarks

Walter Frost, Director
Atmospheric Science Division
The University of Tennessee Space Institute

Description of Workshop

The purpose of this workshop is to bring together disciplines of the aviation communities, for example, designers, pilots and general service personnel with meteorologists and atmospheric scientists in round table discussions which will establish those areas where environmental data is currently available and useable for engineer and operational applications; where data is available but not useful in the existing format; and where data is unavailable and should be determined. Suggested priorities on the required research will be established. Additionally, attempts to define consistent terminology between the aviation and environmental communities will be made.

The workshop is organized such that morning sessions consist of invited presentations which provide overviews of the general areas selected for round table discussion. Round table discussions will take place during the afternoon sessions where four fixed committees will meet separately with four floating committees. The make up and organization of the committees are as follows.

Committees and Working Sessions Format.

Committees consisting of a chairman and approximately four members will be assembled to cover the areas of (1) Aircraft Design, (2) General Services, (3) Simulation; and (4) General Aviation. Each committee will address a list of questions pertaining to their topic area and any additional questions generated during the discussion. The personnel making up each committee have expertise in the general topic area. Four additional floating committees consisting of four to five people having expertise in meteorology, environmental factors, flying, accident investigation, navigation, etc. have been organized.

Working sessions where each of the floating committees meet individually with each of the specific or fixed committees are conducted according to the schedule given in Table 1. A suggested list of questions for the individual committees is given in Table 2. These questions are simply to generate discussion and the committee may address all, some, or none of the proposed questions as they deem necessary and appropriate.

Each committee chairman has written a summary of the proceedings pertaining to his topic area for the final documentation of the workshop. These summaries are given in Section III of the proceedings. The third day session consisted of each chairman presenting a summary of their intended write-ups stemming from the discussions conducted throughout the preceeding days. General comments and recommendations from the entire group were called for at this time and these were incorporated by the respective chairmen into their committee reports.

The invited papers presented in the morning sessions are included in the proceedings in Section II. The schedule of activities and committee make up are given in Tables 3 and 4, respectively.

The organization of the workshop was carried out by the persons listed in Table 5.

Section I of the proceedings gives the welcoming addresses by Robert L. Young of UTSI, and William W. Vaughan of NASA/MSFC, as well as the banquet address by Mr. Newton A. Lieurance and his bibliography.

Table 1. SCHEDULE OF COMMITTEE MEETINGS

	Aircraft Dynamics	Simulation	General Service	General Aviation
Committee A	Tues 12:30-2:40 Room #1	Tues. 2:55-5:00 Room #2	Wed. 12:30-2:40 Room #3	Wed. 2:55-5:00 Room #4
Committee B	Tues. 2:55-5:00 Room #1	Wed. 12:30=2:40 Room #2	Wed. 2:55-5:00 Room #3	Tues. 12:30-2:40 Room #4
Committee C	Wed. 12:30-2:40 Room #1	Wed. 2:55-5:00 Room #2	Tues. 12:30-2:40 Room #3	Tues. 2:55-5:00 Room #4
Committee D	Wed. 2:55-5:00 Room #1	Tues. 12:30-2:40 Room #2	Tues. 2:55-5:00 Room #3	Wed. 12:30-2:40 Room #4

Table 2

Suggested Questions for Discussion

A) LIST OF SUGGESTED QUESTIONS FOR GENERAL SERVICE COMMITTEE

1. How accurate does a 0–30 minute forecast have to be? Should we be bothered with a 0–30 minute forecast?
2. How accurate do Slant Visual Range measurements need to be and do we need SVR systems?
3. What are the problems with the acoustic radar system, and is it reliable; for example, during thunderstorms?
4. Is it worth the cost to maintain a mesonet?
5. What influence will lighter than air vehicles have on meteorological inputs?
6. What is the status of lightning protection and what are the gaps in our knowledge of the lightning phenomenon?
7. Is snow removal a problem and are meteorological inputs needed in this area?
8. Is the trailing vortex problem strongly dependent on meteorological conditions, 1) temperature gradient, and 2) wind conditions?
9. What are some of the meteorological problems that are peculiar to off-shore airports?
10. How accurate can a temperature forecast be made?
11. How much effort should be devoted to forecasting rare events?
12. Would vertical visibility measurement be acceptable over ceiling? If so, over what area should the vertical visibility be quoted, ie., over the runway, over the approach, etc.?
13. Who should take the lead in doing the research for developing aviation weather service?

Table 2 (Cont.)

B) LIST OF SUGGESTED QUESTIONS FOR THE AIRCRAFT DESIGN COMMITTEE

1. Are current procedures for designing structural components with respect to turbulence forcing functions adequate at this time and if not, in what areas is improvement needed? For example, (1) are engineering procedures adequate, (2) is sufficient turbulence data available to do adequate modelling?
2. Are spectral models an improvement over discrete gust models?
3. Under what conditions of aircraft design are'turbulence simulations necessary and are these turbulence simulation procedures appropriate or is more meteorological data needed to develop appropriate simulation techniques?
4. What meteorological data is needed to provide more clear cut certification requirements or mil Specs?
5. Is wind shear a consideration in the structural design of aircraft?
6. Is wind shear a consideration in the design of aircraft control systems?
7. Is lightning prevention a consideration in the design of aircraft and if so, is sufficient data available to carry out an adequate design? For example, lightning effects on digital systems, lightning effects on composites, etc.
8. To what degree in the design of aircraft is meteorological data needed relative to (a) temperature, (b) rain and hail conditions, (c) icing conditions, (d) pressure and density conditions, (e) corrosive, abrasive, and other harmful consitutents in the atmosphere?
9. How well can the important parameters in question 8 above be forecast or predicted for design purposes?

a

Table 2 (Cont.)

C) LIST OF SUGGESTED QUESTIONS FOR SIMULATION COMMITTEE

1. In general, are the turbulence models used in current simulators adequate?
2. Are more accurate turbulence simulations models available which have not been incorporated into the simulator program?
3. If more complete turbulence simulation techniques were available, would they be used?
4. Do current simulation schemes give a proper impression of real turbulence?
5. If current turbulence simulation models are not adequate, what data is required for the meteorologists to develop more reliable simulation schemes?
6. What knowledge of the environment is required to conduct appropriate inflight simulations?
7. What information about atmospheric wind speed profiles is required to conduct appropriate simulation for (a) flight crew training, (b) avionics development, (c) aircraft design?
8. Is there any correlation between the wind field turbulence model and conditions of precipitation, fog, etc. that are needed for realistic flight simulation?
9. Is it necessary to simulate the effects of icing, temperature variations, humidity variations, etc., and if so, is there sufficient meteorological data available to carry out a realistic simulation?

D) LIST OF SUGGESTED QUESTIONS FOR GENERAL AVIATION COMMITTEE

1. What education programs are needed for General Aviation pilots?
2. What are some of the meteorology inputs required for General Aviation?
3. How do you envision weather briefings in the future?
4. What are some of the weaknesses of the present briefing system?
5. Should visibility and/or ceiling be the criteria for determining approach minimums?

Table 2 (Cont.)

6. Why not employ airborne sensors rather than ground based sensors?
7. Why must we orient toward ground based sensors?
8. What airborne information is required for the General Aviation pilot to know he's breaking the rule (for example, that he is 2000 ft. from clouds, etc.).
9. Where does aviation weather stop and weather start?
10. Are you satisfied with current methods of mass dissemination and if not what are the problems with them?
11. What is involved in quality controls on aviation weather and are they adequate?

Table 3. SCHEDULE

Tuesday, March 8, 1977

8:30-8:35	Introduction--Walter Frost, UTSI
8:35-8:50	WELCOME--Robert L. Young, Associate Dean, UTSI
8:50-9:05	WELCOME--William W. Vaughan, Atmospheric Science Division Head, NASA/MSFC
9:05-9:25	Overview of NASA Marshall Space Flight Center's Program on Knowledge of Atmospheric Processes: Dennis W. Camp, NASA
10:05-10:10	Coffee
10:10-10:50	Topic Area AIRCRAFT DESIGN, John C. Houbolt, NASA
10:50-11:30	Topic Area GENERAL AVIATION, James C. Pope, FAA
11:30-12:30	Lunch--UTSI Industry Student Center
12:30-5:00	Committee Sessions
6:00-7:00	Get Acquainted Social Hour, AEDC Officers Club
7:15	Banquet, Speaker--Newton A. Lieurance, Alden Associates

Wednesday, March 9, 1977

8:30-8:50	Progress and Outlook for FAA's Aviation Weather; Research, Engineering and Development, Joseph F. Sowar, FAA
8:50-9:10	LTTSI Atmospheric Science Program, Walter Frost, UTSI
9:10-9:50	Topic Area General Services, Frank Coons, FAA.
9:50-10:10	Coffee
10:10-10:50	Topic Area SIMULATION, Dwight R. Schaeffer, Boeing Co.
10:50-11:30	Topic Area PILOT'S VIEWPOINT, William W. Melvin, ALPA
11:30-12:30	Lunch--UTSI Industry Student Center
12:30-5:00	Committee Sessions
5:30	Visit to Staggerwing Museum, Tullahoma, Tennessee

Thursday, March 10, 1977

8:30-8:50	Overview of OAST Safety Program, George H. Fichtl, NASA
8:50-9:30	Summary of Aircraft Design Committee, Robert J. Woodcock
9:30-10:10	Summary of General Services Committee, John H. Enders
10:00-10:30	Coffee
10:30-11:10	Summary of Simulation Committee, Richard K. Kurkowski
11:10-11:50	Summary of General Aviation Committee, Wallace C. Goodrich
11:50-12:00	Closing Remarks
1:00	AEDC TOUR

Table 4. COMMITTEES

Committee A	Committee B	Committee C
Frank Coons Federal Aviation Admin. 2100 2nd Street, N.W. Washington, D.C. 20590	James T. Green Weather Service American Airlines Flight Academy Greater Southwest Int'l. Airport Ft. Worth, Texas 76125	Edward M. Gross Domestic Aviation Weather Service National Weather Service 8060-13 St. Silver Spring, MD 20910
George H. Fichtl Environmental Dynamics Branch NASA/Marshall Space Flight Center Mail Code ES43 Marshall Space Flight Center, Alabama 35812	Donald H. Lenschow National Center for Atmospheric Research Boulder, Colorado 80302	William Horn, Jr. Air Space/Air Traffic Control Suite 401 NBAA 425-13 St. N.W. Washington, D.C 20006
Charles A. Fluet Bureau of Technology/TE60 NTSB Washington, D.C. 20594	J. Anderson Plumer Manager Environmental Electro-Magnetic Unit General Electric Company 100 Woodlawn Avenue Pittsfield, Mass. 01201	Jean T. Lee NSSL/NOAA Norman, Oklahoma 730[illegible]
Charles H. Sprinkle W116 National Weather Service 8060-13 St. Silver Spring, MD 20910	Charles L. Pocock AFISC/SEF Norton Air Force Base, CA 92409	Hubert McCaleb TE 30 Bureau of Technology NTSB Washington, D.C. 20594
Andrew D. Yates, Jr. Air Line Pilots Association Washington Office Address 1625 Massachussets Ave., N.W. Washington, D.C.	Rance Skidmore Air Weather Service Scott AFB, IL. 62225	J. Van Ramsdell Pacific Northwest Laboratories Battelle Blvd. Richland, Washington 99352
William L. Olsen FAA 800 Independence Ave. Washington, D.C. 20591		Joseph W. Stickle Flight Research Division NASA/Langley Research Center Hampton, VA 23665

Table [illegible] (Continued)

Committee D

John H. Bliss
2740-Graysby Avenue
San Pedro, CA 90732

C.L. Chandler
Delta-Flt Control
Atlanta, GA 30320

R. Craig Goff
ANS-430
NAFEC
FAA, Department of Transportation
Atlantic City, N.J. 08405

William W. Melvin
Airworthiness & Performance Comm.
Air Line Pilots Association
1101 W. Morton
Dennison, TX 85020

William R. Durrett
Kennedy Space Center
Florida, 32899

Aircraft Design Committee

Robert J. Woodcock (Chairman)
Air Force Flight Dynamics Lab/FGC
Wright Patterson AFB, Ohio 45433

Jack Hinkleman
SRDS, ARD-451
Federal Aviation Administration
2100 2nd Street, N.W.
Washington, D.C. 20591

Arthur E. Kressly
Stability and Control Aerodynamics
36-81
Douglas Aircraft Co.
3855 Lakewood Blvd.
Longbeach, CA 90801

John C. Houbolt
Chief Aeronautical Scientist
NASA/Langley Research Center
Hampton, VA 23665

Douglas E. Guilbert
AFAL/WE
Wright Patterson AFB, OH [illegible]

General Services Committee

John H. Enders (Chairman)
Office of Aviation Safety
ASF-30
FAA Headquarters
Washington, D.C. 20591

General Services (continued)

Robert Curry
Headquarters Air Weather Service/DNP
Scott AFB, IL. 62225

Rodger Flynn
Air Transport Association of America
1709 New York Ave., N.W.
Washington, D.C. 20006

William W. Vaughan
NASA/MSFC
ES-81
Huntsville, AL 35812

Newton A. Lieurance
Alden Electronics and Impulse
Recording Equipment Co.
Westboro, Mass.

Simulation Committee

Richard L. Kurkowski (Chairman)
Simulation Office
NASA/Ames Research Office
Moffett Field, CA 94035

Charles R. Chalk
Calspan Corporation
P.O. Box 235
Buffalo, N.Y. 14221

James K. Luers
University of Dayton Research
Institute
[illegible]

Table 4. (Continued)

Simulation (Continued)	General Aviation (continued)	
Dwight R. Schaeffer Boeing Commerical Airline Company P.O. Box 3707 Seattle, Washington 98124 Paul L. Jernigan Douglas Aircraft Company 11245 Leffingwell Rd. Norwalk, CA 90650 General Aviation Committee Wallace C. Goodrich (Chairman) AOPA 7315 Wisconsin Ave. Bethesda, MD 20014	James C. Pope Industry and Government Liaison Div. AGA 200 Office of General Aviation FAA Washington, D.C. Bertha M. Ryan Naval Weapons Center P.O. Box 1982 Ridgecrest, CA 93555	

Table 5. ORGANIZATION COMMITTEE

Dennis W. Camp
Aerospace Engineer
ES43
NASA/Marshall Space Flight Center
Huntsville, Alabama 35812

John W. Connolly
U.S. Dept. of Commerce
NOAA
Rockville, MD 20852

Walter Frost
Director
Atmospheric Science Division
University of Tennessee
Space Institute
Tullahoma, TN 37388

William A. McGowan
Aviation Safety Technology
Branch ROO
NASA Headquarters
Washington, D.C. 20546

Joseph F. Sowar
Chief, Aviation Weather
Systems Branch, SRDS
2nd and V St., N.W.
Transport Building
Washington, D.C. 20591

WELCOME: REMARKS

Robert L. Young
Associate Dean
The University of Tennessee Space Institute

On behalf of The University of Tennessee and The University of Tennessee Space Institute, I welcome you to this workshop on Meteorological and Environmental Inputs to Aviation Systems. We are grateful to the NASA/George C. Marshall Space Flight Center, the National Oceanographic and Atmospheric Administration and the Federal Aviation Administration for their assistance in the organization of the workshop. With Dr. Walter Frost, Director of our Atmospheric Sciences Division, representatives of these agencies have arranged for invited lectures by a distinguished group of lecturers and for committee participants skilled and experienced in the many facets of aviation systems. Through their efforts, a format has been arranged which will lead to a maximum exchange of information and a mechanism for identifying key areas of investigation vital to progress in aviation systems.

We are honored that you chose to hold this workshop at the Space Institute and we believe it to be a most appropriate location. Aerospace in its broadest sense is our business in this academic-research environment. We believe that progress is best assured by interdisciplinary approaches such as you are taking in this workshop. The flexibility of our graduate programs, the variety of continuing education experiences we offer and our mission-oriented, interdisciplinary divisional structure provide evidence of our belief in this approach. Hence, it is our pleasure to host this workshop with its interdisciplinary considerations of meteorology, environment and aviation systems.

WELCOME REMARKS

William W. Vaughan
Atmospheric Sciences Division
NASA/Marshall Space Flight Center

On behalf of the Marshall Space Flight Center I would like to formally welcome each of you to this workshop. For several years we have been discussing and planning such a workshop with our colleagues in NASA Headquarters and the FAA. Our atmospheric sciences group at the Marshall Space Flight Center has enjoyed a rather unique role and interface association with people working in research, design, development, mission planning and operations. Throughout the Saturn-Apollo and now in the Space Shuttle program, we have been an integral part of the programs through specification of natural environment design criteria, interpretation of the criteria in design studies, conduct of environment related studies and the evaluation of test and operational flight results relative to environment influences. As a result, we have gained considerable appreciation for the necessity of frequent exchanges of views with the variety of talents involved in a program. By bringing together at this workshop the mix of talents you represent, I believe a major step has been made in the area of aeronautics relative to meteorological interface activities.

Although for a number of years our atmospheric interests have been primarily devoted to problems associated with space vehicles, a significant number of our group have spent considerable time in the field of aviation meteorology. As our association with Bill McGowan and Jack Enders, recently of the NASA Aviation Safety Technology Office, and our friends in the FAA has grown during the past decade or more, we have applied a portion of our research talents to aviation problems. In addition, we have also endeavored to pursue basic aeronautics related atmospheric processes research which can benefit by the conduct of laboratory type experiments in the orbiting Spacelab of the Space Shuttle. The areas of cloud physics and atmospheric fluid dynamics are currently represented by viable flight experiment projects. To reflect this increasing role, a couple of years ago our group was transferred to the Space Sciences Laboratory at MSFC.

In closing, I want to express my personal conviction that this interdisciplinary workshop will provide the basis for what can be a major step forward in the area of aeronautical meteorology relative to the needs of all interests. Each of you has an opportunity to convey to others an understanding of his particular area of concern and better understand the concerns of others. Therefore, the success of the workshop and its influence on the future emphasis of aviation meteorology, is in your hands--individually and collectively.

AVIATION WEATHER SERVICE REQUIREMENTS
1980 - 1990

Newton A. Lieurance
Director, Government Affairs
Alden Electronic and Impulse Recording Equipment Co.

Mr. N. A. Lieurance, Director of Government Affairs for Alden Electronics with headquarters in Washington, D.C., retired as Director of Aviation Affairs for the Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) in 1972 and served for many years in the area of aviation and weather service operations and published extensively in trade magazines and technical journals. He has also served with Trans-World Airlines, Inc., the U.S. Navy and the Army, in various positions and was a meteorological advisor to the Federal Aviation Administration for a number of years. Mr. Lieurance, as a member of many U.S. Delegations, has represented the United States at international conferences involving the International Civil Aviation Organization (ICAO), the World Meteorological Organization (WMO), and the North Atlantic Treaty Organization (NATO). He was, for many years, the U.S. Member of the WMO Technical Commission for Aeronautical Meteorology and its President from 1967 to 1972, and has been active in the affairs of the American Meteorological Society (AMS) since 1936. He is also a member of the American Institute for Aeronautics and Astronautics (AIAA); a graduate of the University of Kansas (BS-Civil Eng.); and, the U.S. Naval Academy Post Graduate School (MA-Meteorology).

There is a whole spectrum of meteorological problems associated with aircraft operations including air traffic control in the years ahead. These must be solved in order to continue the excellent safety record of aeronautics. With the advent of higher-speed aircraft, expanded use of aircraft in pleasure and business flying, the jumbo jets with up to 1,000 passengers aboard, and the V/STOL aircraft, everything we do today must be done better tomorrow. The lead time is short.

Aircraft operations in the decade of the 1980's will be global in nature rather than regional or local as in the past. The National Meteorological System is important to the safe and efficient operation of all classes of aircraft. It is through this system that the dynamic state of the atmosphere (temperature, wind and pressure) is determined, and this basic information is vital in the prediction of specific weather elements (cloud height, visibility, precipitation, turbulence, winds, and temperature) important to aviation.

The National Meteorological System produces vital information concerning the atmosphere. This must be considered an important adjunct to the air transportation system, including air traffic control. Since the National Meteorological System and the Air Traffic Control System are autonomous and since both have a mutual weather responsibility, there must be an effective means of communication between them to apply, distribute, display and present the operationally significant weather information on a timely basis for the controllers, pilots, and operational planners. Such communication does not presently exist. If this system gap is eliminated, noticeable and immediate improvements in the orderly and safe flow of traffic can be realized.

In the post-1980 period, the National Meteorological System should have greatly improved capability with weather radar, weather satellites, and the analysis and prediction of the state of the atmosphere up to 30 km, utilizing high-speed computers. Weather radar will detect severe weather and produce conflict displays for air traffic control. Poor visibility as a result of fog will be improved by weather modification techniques so that adequate visibility for visual landings and take-off can be maintained under most conditions.

However, technical gaps must be eliminated for future improvements, especially in the light of increased traffic. For the purpose of the following discussion, the terminal area is defined as the air volume within a cylinder of about 160 km diameter extending up to about 10 km. This area is the most critical from the viewpoint of planning, dispatch, operations and air traffic control, and the elements of most serious concern are visibility, turbulence, and icing. Accurate observations and forecasts of these elements are imperative in the years ahead. The inability of the weather system to provide this service by producing observations and forecasts with the accuracy and detail required in the future is a serious technical gap demanding prompt attention by the research community.

The following represent the highest priority weather requirements in the terminal area:

1. Terminal area visibility for approach, landing, and take-off for slant ranges of 5000 meters or less, with special emphasis on the very low horizontal visibility of less than 1500 meters.
2. Turbulence in the free atmosphere in the terminal area and over the runway, regardless of the cause, with special consideration given to thunderstorms and squall lines, including areas of hail.
3. Freezing rain and areas of moderate and heavy icing in clouds for the terminal area.

Deficiencies exist in the following terminal area weather observations and forecast services:

1. Wind shear and temperature profile with special emphasis on the wind shear in the lowest 60 meters on the final approach path.
2. Slant range visibility in the final approach with specific emphasis on the runway horizontal

visibility. This involved new methods of measuring and techniques for predicting the very low ranges, i.e., 800 meters and below.

3. Airport and, more specifically, runway wind measurements which would provide a more precise index of gustiness.

4. Precisely locating, identifiying intensity, and tracking of areas of turbulence, icing and hail.

Much more effort needs to be en route operations up to 30 Km in the following areas:

1. Turbulence of all classes perhaps is the most elusive parameter for the meteorologists to observe, analyze and predict. This is particularly true of clear air turbulence as a result of wind shear in the free atmosphere. Very little is known about the magnitude of this turbulence above 12 km, but there is sufficient evidence to know that Clear Air Turbulence (CAT) does occur in the region between 12 km and 30 km. Thunderstorms have been observed to extend above 20 km, particularly in tropical latitudes. The extent to which turbulence exists in these convective storms above 13 km is relatively unknown. Here, again, there is sufficient evidence by isolated experiences to indicate severe turbulence can occur at these altitudes in and above thunderstorm clouds. Mountain waves above and down wind of the major mountain ranges of the world can produce severe turbulence in the stratosphere. This is evidenced by actual flight experience at altitudes of 20 km over the Rocky Mountain range. More explaratory effort, research and development work is needed in this area to provide sufficient

techniques to predict and identify areas of severe turbulence, particularly as it is related to the super sonic transport (SST) operation.

2. The presence of suspended ice and water particles at the very high altitudes is somewhat an unknown quantity, although it is known that they can and do exist. The presence of hail in the tops of thunderstorms at very high altitudes is also unknown, but again some evidence exists that it can occur at these altitudes. More effort is needed in this area through actual flight and meteorological research.

3. The transition of the SST to supersonic speeds (between 10 and 15 km) is in the area of the tropopause where maximum changes in temperature and winds occur vertically as well as horizontally. This will be very critical to the SST operations during the transition from subsonic to supersonic. It is at these altitudes and during this phase of flight that the maximum effort is demanded of the power plant which is very sensitive to high temperatures or variable temperatures.

4. Solar radiation and ozone are perhaps design problems. However, the magnitude of these phenomena is not too well known over the globe at all latitudes. If these are limiting factors, then more should be learned about their nature, extent and predictability. Of particular concern will be the intensity of the cosmic rays as a result of solar storms for flight planning purposes.

5. Sonic boom is alleged to be one of the most critical problems facing the SST program, It is not unreasonable to expect that the meteorological

services may be required to provide a prediction of a "least-noise" track for both the en route operations over populated areas and for the climb-out corridors. This is a serious problem and research work is needed to specifically identify the meteorology of the sonic boom.

Much more scientific knowledge of the atmosphere is required before any revolutionary breakthroughs can be expected in forecasting. This is the scientific limitation. Its removal will be achieved only through fundamental research at a gradual pace over a long period of time. This is a problem common to all meteorological services. Adequate effort must be expended by the meteorological service to eliminate these technical gaps.

In many areas improvements can be brought about if more funds could be made available. This is particularly true in the areas of observations at airports, briefing facilities, communications in the broad sense, and items of this nature. The problem here is one of justification based on a reasonable return for the investment in terms of better operations and/or improved safety. This poses a difficult problem since the operational weather requirements for expanded services are not very well defined and there is not unanimity within government or the industry as to the relative importance of the various services, i.e., more weather radar vs. more communications, etc. There are also different priorities for service to the air carriers as opposed to general aviation. Here, again, the requirements for general aviation are ill-defined. The operational requirements for all spectrums of aviation operations should be quantitized and placed in a priority list for the guidance of the meteorological services.

Conclusions

1. Weather information is one of the essential tools for management of the air space and conducting aircraft operations in a safe and efficient manner. Aviation weather services must be considered an integral part of the air traffic system providing detailed and up-to-the-minute information in a form that will precisely define the environment as it is and as it will be.
2. Meteorological elements having the greatest direct impact on the safety of aircraft operations for the foreseeable future are as follows:
   (a) restricted visibilities at terminals, particularly as a result of fog, heavy rain and snow;
   (b) turbulence in the free atmosphere as a result of thunderstorms, mountain waves, and wind shear; and
   (c) heavy rains, snow and freezing rain affecting runway surfaces.
3. The meteorological elements indirectly affecting safety of flight are:
   (a) low-level wind shears in the approach zone;
   (b) unusually high surface and en route temperatures;
   (c) strong winds en route;
   (d) restricted visibilities in the air hampering VFR flight; and
   (e) strong and gusty surface winds.
4. The special meteorological elements affecting the operations of supersonic aircraft operations are:
   (a) cosmic radiation levels at cruise altitude;
   (b) precise temperature information for transition and cruise altitude;

a

(c) precise information on the existence of rain, hail, and turbulence for transition and cruise altitudes; and

(d) absolute tops of clouds along the route.

5. If airport noise and sonic boom problems cannot be solved by design, the operators, the air traffic control system, and the pilot will have to consider these problems on a day-to-day basis, using meteorological information in the decision process.

For V/STOL operations (short-haul urban transportation) there appear to be no unique weather problems that are identified. However, the same information will be needed for more airports (heliports) and quicker. These factors will be important because of the handling of these aircraft by air traffic control in a mixed environment and the need to maintain a dependable and continuous scheduled operation. An automatic terminal weather observational package with weather radar to detect and track severe storms over the major metropolitan areas is a "must" in the years ahead.

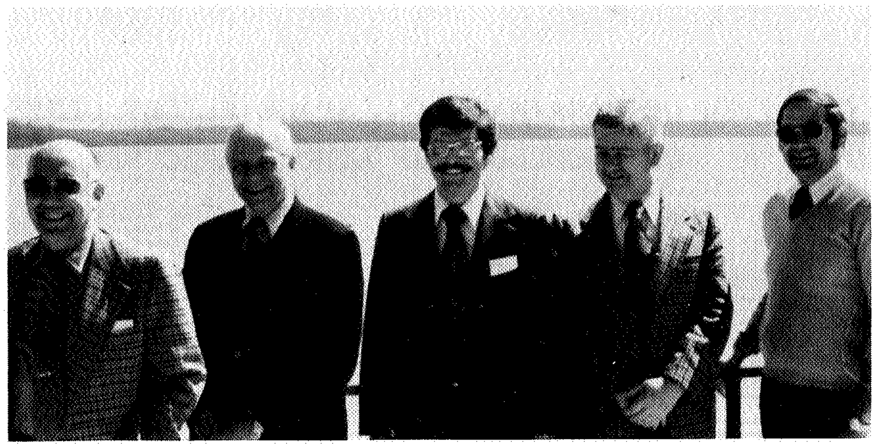
Recommendations

(1) Support the funding requirements to improve the overall National Meteorological System on a continuing basis.

(2) Eliminate the systems gap by establishing an effective and dedicated communications link between the weather system, the pilot, the operator, and air traffic control.

(3) Bridge the technical gap by stimulating scientific interest in and encouraging support of mission oriented research concerned with airport observations and forecasting of visibility, turbulence and icing in the en route and terminal areas.

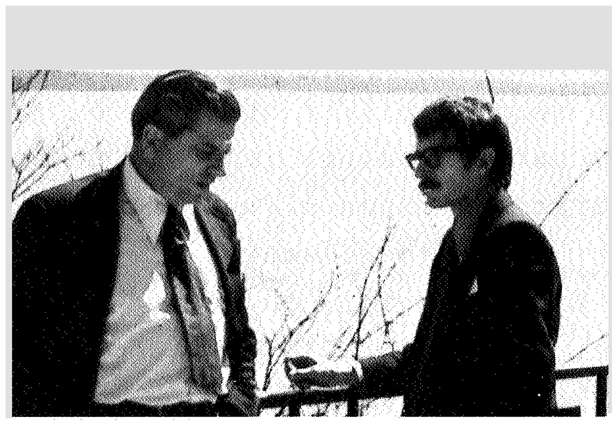
(4) **Precisely determine aviation's impact on the environment due to pollutants of gases and noise, aloft and around the terminal.**



SECTION II

TOPIC AREA

PRESENTATIONS



OVERVIEW OF NASA/MARSHALL SPACE FLIGHT CENTER'S PROGRAM ON KNOWLEDGE OF ATMOSPHERIC PROCESSES

by

Dennis W. Camp
Atmospheric Sciences Division
Space Sciences Laboratory
Marshall Space Flight Center

I. Introduction

The Marshall Space Flight Center (MSFC) is charged with the responsibility of contributing to advances in aviation safety through improved understanding of various atmospheric phenomena. To meet this responsibility, a four part specific objective has been defined and is being pursued by MSFC. This objective is the definition, modeling, and simulation of steady-state wind and turbulence environments for (1) aiding aircraft accident investigations; (2) assessing aircraft operating hazards; *(3)* advancing fundamental knowledge of the effects of buildings and the landscape on low level atmospheric winds; and *(4)* enhancing the natural environment design criteria relative to aeronautical system design. To accomplish the objective, four basic tasks have been defined. The first of these tasks is to determine and define the turbulence and steady-state wind environments induced by buildings, towers, hills, trees, etc., over and around airports. The information developed as a result of this task could be very beneficial for other locations also. The second task is to identify, develop, and apply natural environment technology for the reconstruction and/or simulation of the natural environment for aircraft accident investigation and hazard identification. Task three is to develop basic

a

information about free atmosphere perturbations. The fourth task is to develop and apply fog modification mathematical models to assess candidate fog modification schemes and to develop appropriate instrumentation to acquire basic data about fogs.

To accomplish these four tasks, MSFC has developed a well-rounded program involving field data acquisition, wind tunnel studies, theoretical studies, data analysis, and flight simulation studies. In the following sections, a brief discussion will be presented concerning the tasks and work being accomplished by MSFC both inhouse and under contract relative to these tasks.

11. Definition of Induced Wind Environments

As seen in Figure 1, this task has a twofold objective; namely that of the determination and definition of turbulence and steady-state environments induced by obstructions such as buildings, towers, hills, trees, etc., and to apply the first part of the objective to defining aircraft operating hazards. The immediate goal for the task objective is first to determine capability and reliability of mathematical and experimentally derived models. A second goal is the comparison of full scale and wind tunnel results.

The first goal is being performed as a combined effort by NASA/Marshall Space Flight Center and University of Tennessee Space Institute (UTSI) personnel. Many articles on results of this work have been reported in various publications (Refs. 1-6).
MSFC personnel are responsible for the data collection and initial data reduction and are assisting UTSI personnel with the data analysis. Two items are of prime importance from the effort with UTSI. These are the wind environment definition and a computer simulation of aircraft dynamics

DEFINITION OF INDUCED WIND ENVIRONMENTS

TASK OBJECTIVES

- DETERMINE AND DEFINE TURBULENCE AND STEADY-STATE ENVIRONMENTS AS INDUCED BY OBSTRUCTIONS (BUILDINGS, TOWERS, HILLS, TREES, ETC.)
- APPLY ABOVE OBJECTIVE TO DEFINING AIRCRAFT OPERATING HAZARDS AND AIRPORT DESIGN

GOALS

- DETERMINE CAPABILITY AND RELIABILITY OF MATHEMATICAL AND EXPERIMENTALLY DERIVED MODELS
- COMPARISON OF FULL-SCALE AND WIND TUNNEL RESULTS

EFFORTS

- FULL-SCALE FIELD MEASUREMENT PROGRAM
- WIND TUNNEL INVESTIGATION
- ANALYSIS OF DATA FROM FIELD PROGRAM AND WIND TUNNEL INVESTIGATION

RELATED EFFORT

- NATURAL WIND ENVIRONMENT CRITERIA FOR DESIGN OF WIND MACHINE

Figure 1

in variable wind fields. Since, as indicated above, many articles have been published on these efforts, no indepth discussion will be made. However, a few remarks are in order concerning the work. The full-scale field measurement program is being conducted at MSFC's eight-tower facility. Figure 2 is a pictorial illustration of this facility. From this figure, it can be seen that the terrain is quite flat, less than one (1) meter variations from the low to the high level, and has few natural obstructions which could influence the flow.

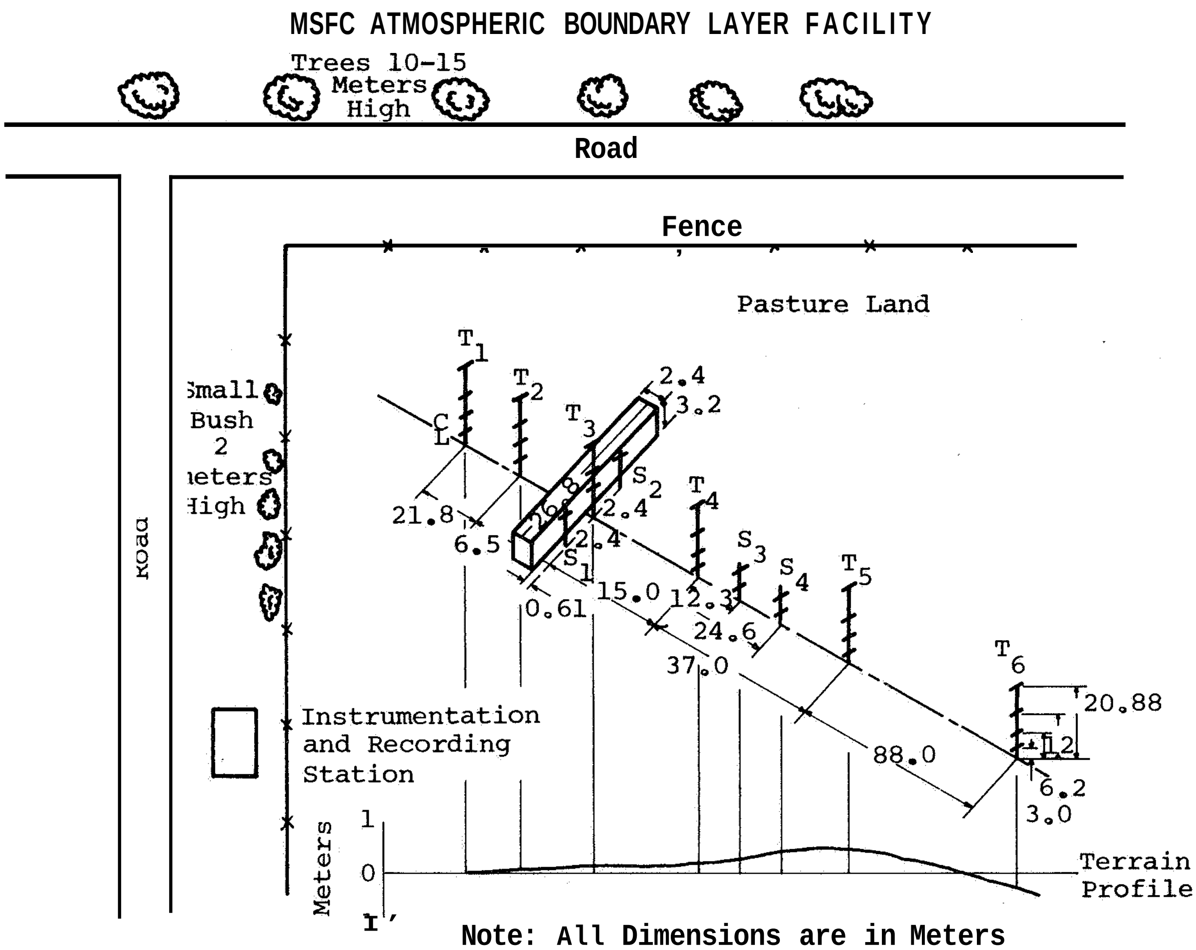


Figure 2

The wind tunnel effort accomplished so far has been done by the Colorado State University. A discussion of this effort is given in Reference 4. The wind tunnel effort so far has been primarily concerned with modeling the full scale (eight-tower) facility, conducting wind tunnel tests on the model, and making a flow visualization study.

The wind tunnel effort accomplished so far has been done by the Colorado State University. A discussion of this effort is given in Reference 4. The wind tunnel effort so far has been primarily concerned with modeling the full scale (eight-tower) facility, conducting wind tunnel tests on the model, and making a flow visualization study. This wind tunnel effort is to be continued at the Arizona State University with the prime emphasis being to make a comparison study of the wind tunnel results to the full scale results. Arizona State University is to seek the answer to the question, "Can wind tunnel modeling be used to qualitatively and/or quantitatively model wakes from buildings and natural obstacles?"

111. Natural Environment Reconstruction for Accident and Operating Hazard Investigation

Figure 3 presents an overview of this specific task. However, a few comments are in order with regard to the present status of the effort, who is accomplishing the work, and what are the future plans. The two objectives of this task are (1) the determination of those aspects of the natural environment which result in aircraft incidents, and (2) the examination of natural environment conditions to determine those conditions which pose hazards to aircraft operations. As seen in Figure 3, there are three goals for this task. Namely, the development of a nonhomogeneous turbulence simulation model, the reconstruction of natural wind environment for a selected set of aircraft accidents, and the identification of needed atmospheric technology development.

In order to accomplish the goals there are at present three efforts being performed under contract. The Pennsylvania State University is conducting an investigation of the nighttime stable boundary layer. This effort will result in the development of a mathematical model for the nighttime stable boundary layer.

NATURAL ENVIRONMENT RECONSTRUCTION FOR ACCIDENT AND OPERATING HAZARD INVESTIGATION

TASK OBJECTIVES

- DETERMINATION OF THOSE ASPECTS OF THE NATURAL ENVIRONMENT WHICH RESULTS IN AIRCRAFT INCIDENTS
- EXAMINATION OF NATURAL ENVIRONMENT CONDITIONS TO DETERMINE THOSE CONDITIONS WHICH POSE HAZARDS TO AIRCRAFT OPERATIONS

GOALS

- DEVELOPMENT OF NONHOMOGENEOUS TURBULENCE SIMULATION MODEL
- RECONSTRUCTION OF NATURAL WIND ENVIRONMENT FOR A SELECTED SET OF AIRCRAFT ACCIDENTS
- IDENTIFICATION OF NEEDED ATMOSPHERIC TECHNOLOGY DEVELOPMENT

EFFORTS

- INVESTIGATION OF THE NIGHTTIME STABLE BOUNDARY LAYER
- AIRCRAFT ACCIDENT RECONSTRUCTION
- AIRCRAFT ICING INVESTIGATION

RELATED EFFORT

- PROGRAM TO PROVIDE WIND SHEAR PROFILES FOR HAZARD DEFINITION

Figure 3

The second effort is being performed by the Aeronautical Research Associates of Princeton, Inc. Specifically, this effort has as its purpose to perform an analysis of wind shear and turbulence present at the time of several aircraft accidents (Ref. 7). The accidents were investigated using a one-dimensional, unsteady planetary boundary layer model and/or a two-dimensional model. The results from this analysis were compared with the available recorded data from the National Transportation Safety Board (NTSB) or the National Weather Service (NWS). References 7-9 present some of the results of this effort. The next phase of this effort is to use the existing two-dimensional transport model to perform calculations for both warm fronts and the cold gust front created by the cold outflow from a thunderstorm. The goal of the calculations is to determine what boundary conditions lead to the strongest wind shear within 500 meters of the surface.

The third effort is being conducted at the University of Dayton Research Institute and is concerned with the build-up of ice and/or frost on the surface of an aircraft. Specifically, the effort is to perform a parametric analysis to assess the amount of water vapor which will sublimate onto aircraft during the roll-out, take-off, and climb-out flight phases. The analysis is to be restircted to the winds and shall be performed with dimensional techniques such that the results are applicable to a variety of aircraft and can be summarized in nondimensional form. Like the first effort, this is a new undertaking, and no results have as yet been reported.

A related effort, concerning operating hazards, is also being performed. This one is a joint effort between the MSFC and FWG Associates, Inc., and is being conducted for the Federal Aviation Administration (FAA). This effort has as a general requirement the development of a comprehensive set of wind profiles and associated wind shear characteristics which encompass the full range of wind shear environments, potentially encounterable by aircraft in the terminal area and to provide the mathematical wind shear scenario in a form for direct engineering application. The initial results of this effort have been submitted to the FAA (Ref. 10) for publication. The report presents a discussion of the various types of wind shear which cause problems to aircraft operations. In the report it is noted that the condition affecting aircraft operations is not one shear parameter but *a* combination of several; for example, horizontal shear, vertical shear, wind direction change, and height of shear above ground level.

IV. Atmospheric Perturbations

Atmospheric perturbations include such phenomena as wind gusts, wind turbulence, thunderstorms, etc. The objectives, goals, and efforts of this task are noted in Figure *4*. As seen, the objectives are, first, to develop basic information about atmospheric perturbations and turbulence in the lower 18 kilometers of the atmosphere and ,second, to analyze vertical wind velocities and their relationship to aeronautical operations. As a result of these two objectives, three goals were established. These are, first, to complete the determination of the intensity, time of occurrence, and prevailing conditions relative to the peak vertical gust; secondly, to complete Richardson number statistics and comparison of critical Richardson number exceedance probabilities with clear air turbulence occurrence statistics; and, thirdly, an analysis of dynamic response Characteristics of balloons to clear air turbulence.

The first of the goals is being accomplished inhouse, and it is expected that a report documenting this work will: be published by the fall of 1977. The data for this work were obtained from the 150 meter meteorological tower facility located at the Kennedy Space Center, Florida (Refs. 11 arid 12).

The University of Dayton Research Institute is working on the second goal under contract to the NASA/Marshall Space Flight Center. It is to be noted that parameters other than Richardson number are also being investigated. Like'the first goal, it is expected that a documented report concerning this work will be forthcoming in the latter part of 1977.

ATMOSPHERIC PERTURBATIONS (GUSTS, TURBULENCE, THUNDERSTORMS, ETC.)

TASK OBJECTIVES

- DEVELOP BASIC INFORMATION ABOUT ATMOSPHERIC PERTURBATIONS AND TURBULENCE IN THE FIRST 18 KM OF ATMOSPHERE
- ANALYZE VERTICAL WIND VELOCITIES AND THEIR RELATIONSHIP TO AERONAUTICAL OPERATIONS

GOALS

- DETERMINE INTENSITY, TIME OF OCCURRENCE, AND PREVAILING CONDITIONS RELATIVE TO PEAK VERTICAL GUST DATA
- DETERMINE INTENSITY DETERMINE STATISTICS AND COMPARISON OF VARIOUS CRITICAL ATMOSPHERIC PARAMETER EXCEEDANCE PROBABILITIES WITH TURBULENCE OCCURRENCE STATISTICS
- ANALYSIS OF DYNAMIC RESPONSE CHARACTERISTICS OF METEOROLOGICAL SENSOR TO ATMOSPHERIC PERTURBATIONS

EFFORTS

- ANALYSIS OF FLIGHT PROFILE DATA FOR AERONAUTICAL SYSTEM SAFETY
- INTEGRATING UPPER AND LOWER ATMOSPHERIC WIND PROFILES AND STATISTICS
- ANALYZE FREE ATMOSPHERIC PERTUBATION AND TURBULENCE
- LOW LEVEL WIND ANALYSIS

Figure 4

The third goal of this task was accomplished under contract to the NASA/MSFC by Science Applications, Inc. This work is documented in Reference 13. No additional work for this goal is anticipated at this time,

There are, as seen in Figure 4, four efforts for this task. These efforts are presently being worked on both inhouse and under contract by various organizations.

V. Fog Investigation and Studies

Similar to the other tasks, the one concerned with fog is being accomplished by efforts of inhouse personnel as well as under contract. From Figure 5 it can be seen there are three task objectives. These are, first, to to develop a haze nuclei counter, second, to develop a numerical fog program for parametric studies, and third, to conduct a field study on the effect of turbulence to the life cycle of fog. The objectives are being conducted by inhouse personnel, the University of Alabamain Huntsville, and the University of Tennessee Space Institute, respectively.

Since the first and third objectives are relatively new no publications have been generated as yet on them. However, an excellent paper has been written on the second objective (see Reference 14). This paper presents a discussion of a mathematical model for the formation, development, and dissipation of advection warm fog.

FOG INVESTIGATIONS AND STUDIES

TASK OBJECTIVES

- DEVELOP HAZE NUCLEI COUNTER
- DEVELOP NUMERICAL FOG MODIFICATION PROGRAM FOR PARAMETRIC STUDIES
- CONDUCT FIELD STUDY ON THE EFFECT OF TURBULENCE TO THE LIFE CYCLE OF FOG

GOALS

- INVESTIGATE THE EFFECT OF TURBULENCE TO THE LIFE CYCLE OF FOG
- DETERMINE DROP SIZE DISTRIBUTION OF FOG NUCLEI
- DEVELOPMENT OF NUCLEI COUNTER FOR USE IN FIELD STUDY
- DETERMINE NUMERICAL SIMULATION OF FOG

EFFORTS

- LABORATORY STUDIES OF NUCLEI GENERATION AND USE OF LASER TYPE TRANSMISSOMETER FOR DROP SIZE DISTRIBUTION STUDIES
- DEVELOPMENT OF HAZE NUCLEI COUNTER
- FIELD STUDY OF ADVECTION FOG LIFE CYCLE, TURBULENCE MEASUREMENTS AND TECHNIQUES
- NUMERICAL SIMULATION OF WARM FOG

RELATED EFFORT

- PROPOSED LIDAR TECHNIQUE FOR OBTAINING SLANT RANGE VISIBILITY MEASUREMENTS

Figure 5

It is expected that the third objective will be well under way by the summer of 1977. This objective will be conducted at the University of Tennessee Space Institute, specifically the area over and around Woods Reservoir.

A related effort, proposed by personnel of the University of Tennessee Space Institute, is to conduct a feasibility study relative to a lidar technique for obtaining slant range visibility measurements. It is expected this effort will be initiated in the summer of 1977.

REFERENCES

1. Fichtl, G.H., D.W. Camp, and W. Frost, "Sources of low-level wind shear around airports." Journal of Aircraft, Vol. 14, No. 1, January 1977, pp. 5-14.

2. Frost, W., "Review of data and prediction techniques for wind profiles around manmade surface obstructions." AGARD Conference Proceedings, No. 140 on Flight in Turbulence, Woburn Abbey, U.K., May 1973.

3. Bitte, J. and W. Frost, "Atmospheric Flow over two-dimensional bluff surface obstructions." NASA Contractor Report No. CR-2750, Marshall Space Flight Center, Alabama, October 1976.

4. Woo, H.G.C., J.A. Peterka, and J.E. Cermak, "Wind-tunnel measurements in the wakes of structures." NASA Contractor Report No. CR-2806, Marshall Space Flight Center, Alabama, March 1977.

5. Frost, W., G.H. Fichtl, J.R. Connell, and M.L. Hutto, "Mean horizontal wind profiles measured in the atmospheric boundary layer about a simulated block building." Paper presented at the Second U.S. National Conference on Wind Engineering, Colorado State University, Boulder, Colorado, June 1975.

6. Frost, W., and A.M. Shahabi, "A field study of wind over a simulated block building." NASA Contractor Report CR-2804, Marshall Space Flight Center, Alabama, March 1977.

7. Williamson, G.G., W.S. Lewellen, and M.E Teske, "Model prediction of wind and turbulence profiles associated with an ensemble of aircraft accidents." To be published as a NASA Contractor Report, Marshall Space Flight Center, Alabama, 1977.

8. Lewellen, W.S., G.G. Williamson, and M.E. Teske, "Estimates of the low-level wind shear and turbulence in the vicinity of Kennedy International Airport on June 24, 1975." NASA Contractor Report No. CR-2751, Marshall Space Flight Center, Alabama, October 1976.

9. Lewellen, W.S., and G.G. Williamson, "Wind shear and turbulence around airports." NASA Contractor Report No. CR-2752, Marshall Space Flight Center, Alabama, October 1976.

10. Frost, W., and D.W. Camp, "Wind shear modeling for aircraft hazard definition." Interim report submitted to Federal Aviation Administration, Inter-Agency Agreement No. DOT-FA76WA1-620, March 1977.

11. Kaufman, J.W. and L.F. Keene, "NASA's 150-meter meteorological tower located at Kennedy Space Center, Florida." NASA TMX-53699, January 1968.

12. Tarver, W.B., T.E. Owen, and D.W. Camp, "An automatic data acquisition system for the 150-meter ground winds tower facility, Kennedy Space Center." NASA TMX-64708, September, 1972.

13. Tatom, F.B. and R.L. King, "Determination of constant-volume balloon capabilities for aeronautical research." To be published as a NASA Contractor Report for NASA Contract No. NAS8-31173.

14. Hung, R.J. and O.H. Vaughan, "Numerical simulation of life cycles of advection warm fog." AIAA Paper No. 77-130, American Institute of Aeronautics and Astronautics, 1977.

AN OVERVIEW OF AVIATION WEATHER SERVICES

John W. Connolly
National Oceanic and Atmospheric
Administration (NOAA)

I appreciate this opportunity to be with you today, and talk, not necessarily about meteorology as the agenda states, but about aviation weather services. I will present a brief overview of where we are and where it appears we are going in aviation weather.

To set the stage for my remarks, I would like to indicate the magnitude of the problem we face in our National Weather Service, a problem incidentally which we share with the Federal Aviation Administration (FAA). Weather is the most frequently cited causal factor in fatal, general aviation accidents and has been for several decades. From 1964 through 1972, over 2,000 fatal, weather-involved accidents killed 4,700 persons. These weather-involved accidents represent 36.0 percent of the total fatal, general aviation accidents for this period. Extrapolating these figures through 1975 shows no significant improvement.

Since 1967, the trend of fatal, weather-involved, general aviation accidents has been increasing steadily, while the trend of the accident rate for all fatal accidents has been downward generally. I do not have similar figures for the air carrier industry but I am told by the National Transportation Safety Board (NTSB) that, if I were to plot the accident figures for the air carriers, the slopes of the two sets of curves would be quite similar and the 36 percent figure for the total weather-involved fatal accidents would also be nearly correct.

It is clear from these statistics, which were prepared by the NTSB, that weather is a contributing factor in a significant number of aircraft accidents and incidents. I am sure that this comes as no surprise to this audience. However, the magnitude of the involvement may be noteworthy to some.

Although safety of flight is the first concern of the aviation weather service, the economics of air transportation is a second area of major interest. Weather is a significant causal factor impacting on the efficienty of air transportation. Over a five-year period from 1970-1975 the percentage of weather-caused delays in commercial air transportation varied from 65-90 percent, with the total number of delays averaging more than 30,000 per year; 1975 was a 90 percent year.

As you might expect, the supply of aviation weather service has not kept up with the demand. In recent years, however, the gap has widened due in large measure to the increasing demands of an ever-growing general aviation community. In spite of the gap, aviation weather is big business, with the Department of Defense providing more than 55 percent of the manpawer and perhaps as much as 70 percent of the dollars involved. FAA is the second largest contributor of resources since, in accordance with a formal FAA/NOAA Memorandum of Agreement, FAA is responsible for dissemination of aviation weather service to the pilot and the controller, as well as providing weather observations used solely for aviation. Although a junior partner in terms of resources, the National Weather Service (NWS) is a major provider in terms of aviation weather services. Aviation forecasts are prepared by 52 Weather Service Forecast Offices (WSFOs). These WSFOs prepare and distribute three-times-a-day, a total of 466 forecasts for specific airports in the 50 states and the Caribbean. They also prepare the route forecasts and synopses for the conterminous U.S. used in transcribed weather broadcasts (TWEB), The Pilots Automatic Telephone Weather Answering Servive (PATWAS), and for briefing purposes. Twelve WSFOs also prepare area forecasts for aviation, covering designated geographical areas, and issue in-flight advisories called SIGNETS and AIRMETS to warn pilots of potentially hazardous weather. Briefings are handled bv telephone, face-to-face, or by mass dissemination methods. Pilots may call Weather Service Field Offices as well as FAA Flight Service Stations (FSS) for preflight briefing information. Forecast texts are prepared and furnished to FAA for pilot weather briefing, and for dissemination via the PATWAS and the TWEB programs.

In recent discussions between the Director of the National Weather Service (NWS) and the Administrator of the FAA, agreement was reached on a number of high-priority weather-related programs to which both agencies must give increased emphasis during the coming years in an attempt to improve the service and thereby decrease the number of weather-involved accidents. Identified as the number one priority item is the dissemination of aviation weather information to the pilot and to the air traffic controller. A close second on the priority list is pilot weather knowledge. Both agencies are working to improve the existing dissemination system to insure that the pilot and the air traffic control system possess the timely weather information available within the system. There is much we can do to improve the responsiveness of the current system and we are currently working to that end. But in the longer run, we are aware that automation will play a major role in significantly improving timely availability of hazardous weather information. Both FAA and NOAA have programs underway which will produce automated dissemination systems.

The National Weather Service has established the **AFOS** program (Automation of Field Operations and Services), to help meet the ever-increasing need for more and better forecast and warning services. We are in the **AFOS** program because we can no longer keep up with the increasing need for people in labor-intensive programs, and because we believe that faster response will ultimately save lives. The FAA has a development underway, similar to the NWS AFOS program, which will be incorporated into the modernized Flight Service Station System. Both systems, AFOS and the FAA System, are being coordinated throughout their development phases so that when the systems are operational they will be able to talk to each other.

But we need to take advantage of these and other strides in automation of the weather system. To handle the projected future pilot briefing workload, there is an urgent need for updated mass dissemination systems. Needed is a nationwide PATWAS System containing multiple line entry and guaranteeing no busy signals and the latest weather forecasts. The NWS and the FAA are cooperating in testing a prototype system in the New York area. A nationwide TWEB System fed directly by computer is also needed.

To round out this system of the future, we must take advantage of programs like the recent Public Broadcast System "Aviation Weather" TV program. Cable television offers a medium which would allow a pilot to get a local flight briefing at any hour right in his own home. There is even the futuristic capability of using a touch-tone telephone to talk directly to a computer and see the result on TV. I do not think it is too much of a blue sky philosophy to believe that we are on the threshold of some dramatic improvements in providing aviation weather services. The first NWS Field Stations to be equipped with the AFOS System are scheduled to be in operation by the beginning of 1978, with the entire system equipped by the end of 1980. FAA is currently testing one prototype of its FSS Automation System in Atlanta - and a second prototype version in Leesburg, Virginia. Voice response systems are already in being, although their adaptation to aviation weather dissemination is possibly further down the line.

So it would appear that there is remarkable progress being made in disseminating aviation weather information. And there are, of course, great advancements in aviation technology--improved aircraft, NAVAIDS, and traffic control. Flight Advisory Service to pilots on the ground and in the air is manifold better with respect to quantity and quality than in the past. In fact, improvements are coming so rapidly that the novice can easily get the impression that he does not have to think anymore--just push a button and some electronic gadget will make sure that the flight will be made safe and pleasant.

I do not wish to detract from the advances that are being made in all areas of technology--they are excellent and essential to flight planning and for safe and efficient flight execution. This must continue and even be accelerated. New and even better advances in aircraft, navigational aids, traffic control and weather services will be forthcoming. We are in an era of technological explosion and we can expect better things to come. But as good as this news is, I can see nothing in the future that will replace the need for better pilot knowledge and judgement. And that's the second high priority item that I want to talk about.

Over the past few years I have participated in meetings with various aviation groups, where we discussed flight weather problems and aviation weather services. The one thing that emerges loud and clear from these discussions is the great need for pilot education in weather. There is a need to know more about the weather and its possible effects on safe flight, as well as how to cope with hazardous weather while in flight.

The aviation weather service is excellent, but imperfect. It will continue to be short of perfection for a long time to come. As you well know, an airport observation only represents the state of the weather at the surface of the earth at a particular location for an instant in time. It is made from a fixed location on the ground. It does not necessarily represent the state of the weather at the surface five miles away, nor the condition observed by the pilot in the air in the immediate vicinity of the airport. In order to have good "weather sense," the pilot must know what the observation does and does not represent. He must appreciate the fact that the weather between two stations can be quite different from that reported at the terminal points. It is not unusual for the terminals to be clear and the weather between to be below VFR minimums. Even if there were a perfect observational system which described the weather exactly as it is everywhere all the time, forecasts still would not be completely accurate because of lack of a complete understanding of what makes weather and how it moves. An aviation weather forecast is the best judgement of a professional meteorologist based on the facts at hand. It is always subject to revision and updating. The pilot must also recognize these limitations in terminal-and enroute-forecasts and warnings. The pilot needs knowledge not only about the limitations of observations and forecasts, but also about weather itself. He has to know about the danger inherent in thunderstorms with the associated turbulence, hail and lightning. He has to know the difference between an isolated or scattered thunderstorm and a squall line. He needs to know almost as much about weather as the weatherman himself.

As I said in the beginning, there were over 2,000 fatal general aviation accidents from 1964-1972 killing over 4,700 people and 36 percent of these accidents were considered to be weather involved. The statistics do not explicitly show it, but we can assume with some certainty that in many of these accidents the pilot and passengers died unnecessarily. Many times the pilot did not have sufficient knowledge about weather, or else he disregarded the available information, or he proceeded into a situation he was unable to cope with. I am convinced that significant reductions in fatalities and property damage can be made through better weather knowledge. The current expansion in general aviation makes this a "must." I would like to close by putting my comments into context, lest I be misunderstood.

Obviously the Aviation Weather System has its limitations, but it would be derelict to leave the impression that we have not made significant progress over the years in the science of meteorology and in the application of technological advancements to observing, forecasting, and to some extent, disseminating weather information for aviation. The weather satellite program is one of the more exciting advancements. Satellite pictures of clouds over the entire earth, taken from many miles above, have added a new dimension to watching the weather. Weather radar has increased our ability to detect and track thunderstorms, line squalls and tornadoes. Much is being learned about the turbulence, hail and lightning that are associated with these storms, which pose constraints on aviation operations. Computer technology now permits the production of large-scale analyses and forecasts including entire hemispheres and these are produced many times faster and as accurate as those produced manually. Further strides in the application of numerical weather prediction to forecasting smaller-scale phenomena, such as wintertime storms and perhaps hurricanes and tornadoes, are in the offing. We are seeing the application of acoustic sounding techniques to wind-shear and wake-vortex observations, and various forms of lasers are being used to observe and sound the atmosphere. Digital communications are on the way and will, to a large extent, replace the 100 word-per-minute teletypewriter in the NWS before this decade is finished.

As I said earlier, I believe we are indeed on the threshold of some dramatic improvements in providing aviation weather services. However, I don't want to oversell the role of automation in the system, since the science of meteorology will continue to require the human intervention of the meteorologist for at least as far as I can see into the future. Finally, I do not want to leave the impression that I believe aviation is unsafe. Air safety today stands as a monumental record of man's ability to cope with the multi-sciences required to create the conditions we call flight. All of us who are interested in making the airplane an efficient vehicle for the average citizen should be concerned about the utility of the airplane in business, industry and pleasure. However, as long as there continues to be a significant number of fatalities which might be avoided by some effort on our part, we must continue to improve that safety record.

THE AUTOMATION OF FIELD OPERATIONS AND SERVICES *(AFOS)* WITHIN THE NWS AND ITS IMPACT ON AVIATION METEOROLOGY

Edward M. Gross
Domestic Aviation Program Leader
National Weather Service

I would like to begin by presenting some details about our future program efforts in AFOS which, once again, stands for the Automation of Field Operations and Services within the National Weather Service, and then discuss aviation forecast products now available and our plans for future aviation products.

Within the National Weather Service (NWS), we have to begin dealing more realistically with the serious problem of expanding and improving our services (adding people is no longer feasible). We must also ensure that we can improve the response time of warnings that we issue within the national airspace system. The solution that we see internally at NWS is AFOS. The AFOS concept involves extensive use of mini-computers, video display, and rapid communications to aid our field personnel in their daily activities. By 1981 we hope to have completed the implementation of a National Distribution Circuit (NDC) connecting all our Weather Service Forecast Offices (WSFO's) and National Centers: The National Meteorological Center (NMC), National Severe Storms Forecast Center (NSSFC), National Hurricane Center (NHC), and the National Climatic Center (NCC), plus State Distribution Centers, (SDC) connecting all lower level stations with their parent WSFO's along the interfacing with the future FAA modernization program. Mini-computers at 200 stations will handle all communications, maintain the station data base, service the forecasters' data requests, and drive cathode ray tube (CRT) display units. In a typical forecast work station, forecasters will be able to call up weather maps (within a few seconds) and compose messages on a console. Other combinations of graphic and alpha numeric consoles (including about 70 serviced by remote computer) are planned to meet the needs of individual NWS offices.

Some of the predominant characteristics of AFOS are:

.....communications will be consolidated and streamlined

.....the system is modular in structure

.....is not subject to catastrophic failure

.....can be implemented in phases adaptable to changing conditions and requirements

Now, I would like to present some more details on the NDC and SDC. The NDC (Figure 1) will replace existing facsimile (FAX) and teletypewriter circuits within the NWS by an 11,620 mile communication circuit connecting 47 **WSFO's**, three national centers, and a Systems Monitoring and Coordination Center (SMCC) in a closed loop. The NCC in Asheville, North Carolina, and forecast offices in Alaska, Hawaii, and Puerto Rico will be connected by spur nodes on the NDC. The NDC will consist of independent, leased, voice quality, station to station linkages, each operating at 2400 bits per second, full duplex. Circuit protocol will be simple stores and forward with full error checking on data in entry and receipt. All NDC communications will be computer to computer with each NDC link consisting of dual dedicated lines. In the event of failure of both leased lines, the stations involved will reestablish communications automatically via commercial telephone networks. When one of the leased lines comes back into operation, the telephone connections will be terminated. Data can be entered on the NDC at any of the stations and once on the circuit, will move from station to station in both directions

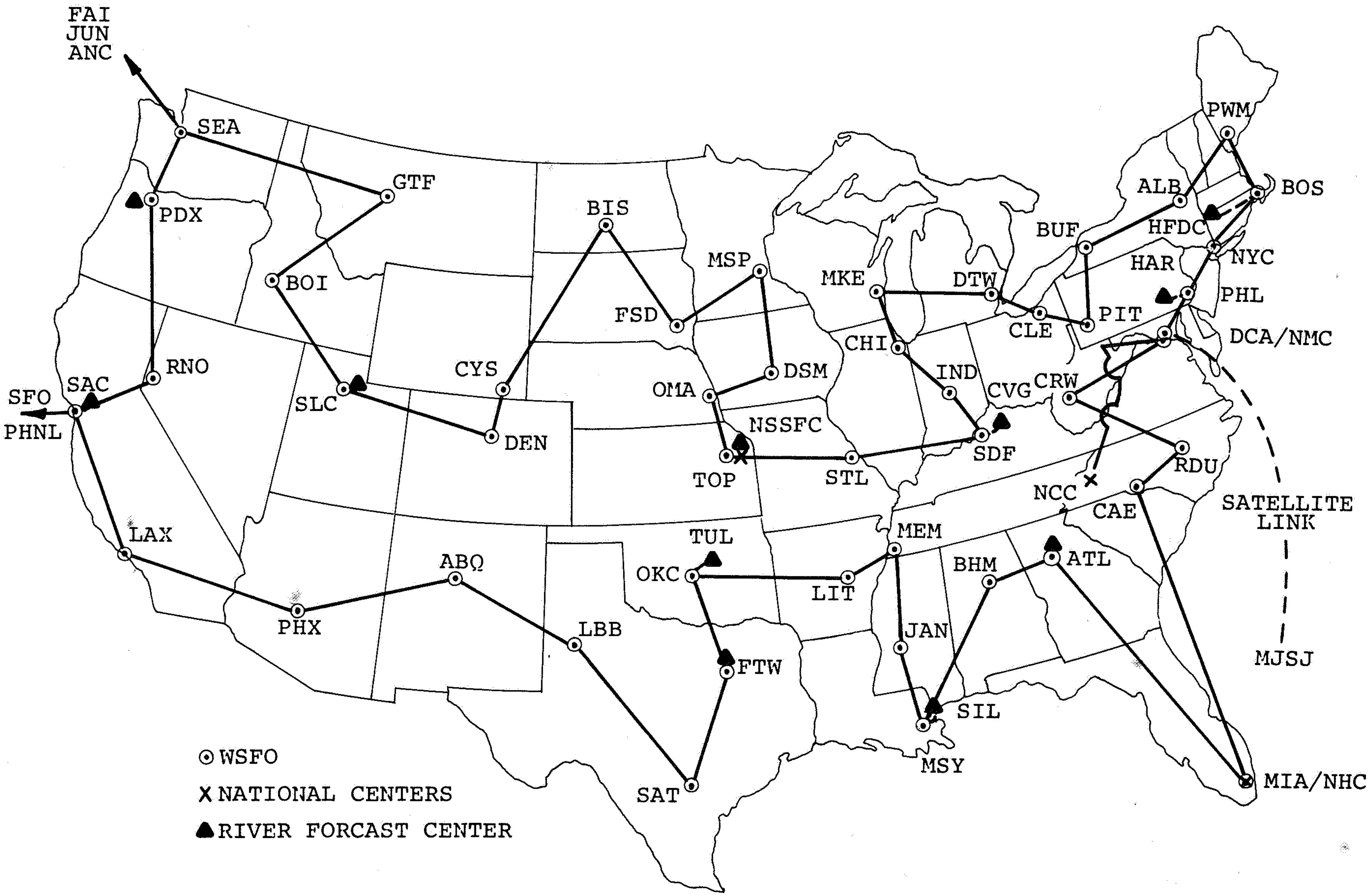


Figure 1 -- AFOS National Distribution Circuit

from the originator. In less than a minute the messages will be received in duplicate by a station on the opposite side of the NDC, whereupon it will be automatically removed from the circuit.

The state distribution circuit (SDC) is our second level of the **AFOS** communications system (Figure 2). It will connect from one to nine weather service offices (WSO's) and river forecast centers (RFC's) within each forecast area to the parent WSFO in a star configuration. This will allow each WSFO to exchange messages with the local level. Since the SDC's will be operated at *2400* bits per second, half duplex, many of the software and equipment modules will be common with those required for operation on the NDC. All data collected from meteorological observations (surface, upper air, radar, etc.) within a forecast area will follow local distribution circuits into the WSO and back along its SDC to the WSFO for distribution circuits into the WSO and back along its SDC to the WSFO for distribution on the NDC.

On January 30, 1976, the Department of Commerce signed the contract with Aeronautronic Ford Corporation to develop and install 213 AFOS automated weather stations over a 5-year period. The latest agreement calls for installation of about six field sites per month beginning with Pittsburgh, Pennsylvania, in January 1978 and ending with Hilo, Hawaii, in November 1980, at a total cost of about $35 million. Each WSFO will have two mini-computers, one for communications and storage, the other for on-station data processing and control. The **WSO's** and RFC's will have one mini-computer each, with storage of 128,000 bytes, equivalent to 64,000 words (16 bits each).
AFOS will help the NWS eliminate the following tasks:

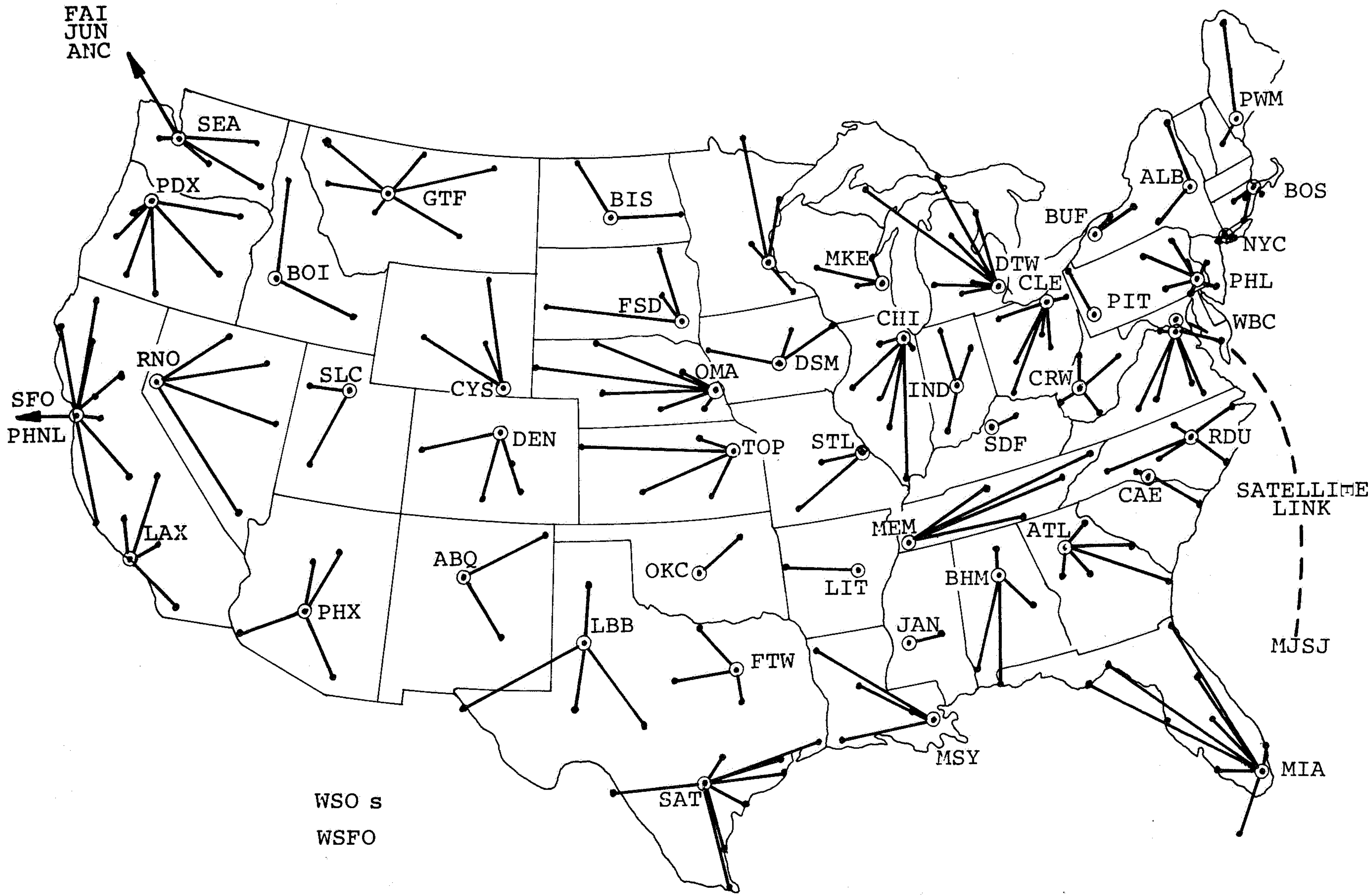


Figure 2 -- State Distribution Circuits (SDC)

tearing teletypewriter paper
posting facsimile charts
plotting local maps
cutting teletype tapes
relaying telephone messages
and telephoning long warning lists

Along with those items, we will be able to prepare more timely warnings. Once a message is prepared, AFOS will automatically transmit it to appropriate users, saving valuable time now lost in dissemination. And, of course, we are working to ensure that AFOS interfaces efficiently with the FAA modernization program. The Observational Program will also be assisted by AFOS's ability to collect observations more rapidly and more frequently, and monitoring the message content automatically for quality and accuracy. Video display systems will be utilized for text editing and message composition by the forecaster. By providing better tools to the forecaster, we will be able to produce more terminal forecasts for airports, river forecasts for more points on the river, more complete agricultural forecasts, more detail in forecasts, more efficient meteorological watches, and more frequent updating of forecasts, watches, and warnings.

To take advantage of AFOS capabilities, the NWS is working toward standardization of all our forecast product formats. One of the first programs we have developed for AFOS, which we feel will aid the aviation community, will be a program we call "Terminal Alert Procedures" (TAP), (See Figure 3). Establishing fixed formats for hourly observations and terminal forecasts will enable the computer to continuously monitor terminal. forecasts for validity and alert the forecaster when the forecast needs amending, along with producing objective categorical forecasts as guidance.

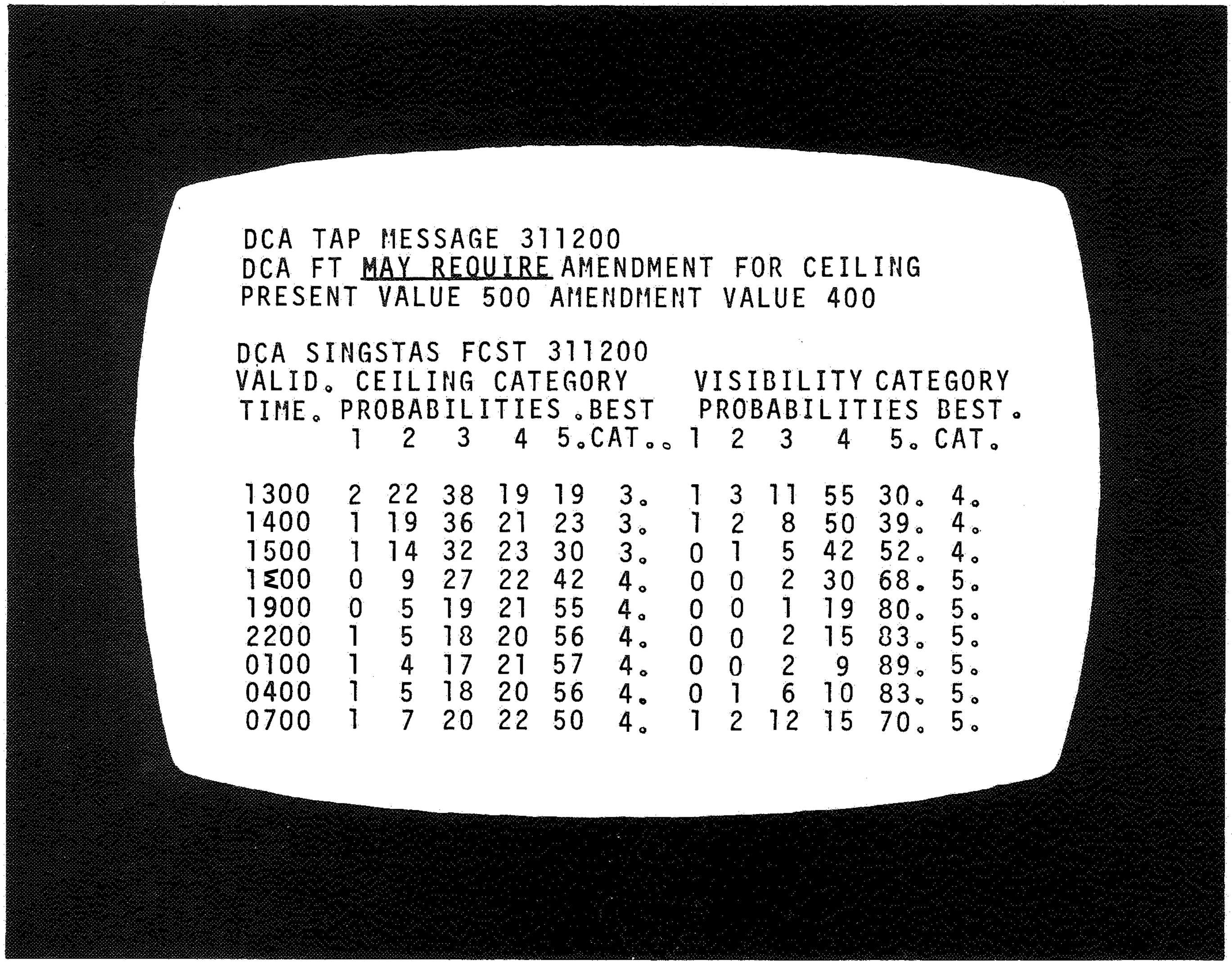


Figure 3 A TAP (Terminal Alerting Procedure) Message will be Automatically Received when the Present Value of a Meteorological Variable Approaches or Reaches the Amendment Value. Hourly Guidance Forecasts of Ceiling and Visibility for the First Four Hours Followed by Three-Hourly Forecasts will be Included.

After many years of hard work, we have developed a fixed format for pilot reports in the United States. Through a cooperative effort of the FAA, NWS, Department of Defense, and the airlines, we will now be able to sort pilot reports by type (icing, turbulence, sky condition, wind, and temperature) by location and altitude, and use these pilot reports more efficiently in monitoring our en-route forecasts and in-flight advisories. Right now, the NWS is producing a whole series of computer-derived aviation guidance products, using our model output statistics (MOS) approach, in which statistical relationships are determined between the forecast output of numerical weather prediction models (predictors) and observed occurrences of a particular weather element (predictand). Among the products are six category ceiling and visibility forecasts for 233 terminals with projections out to 48 hours from model runs of 00 and 1200 GMT, along with objective cloud cover amounts, in four categories for opaque sky cover in tenths. (See Table 1)

Table 1 Definition of the Categories Used for the Development of Prediction Equations for Ceiling, Visibility, and Cloud Amount

Category	Ceiling (ft.)	Visibility (mi.)	Cloud Amount (Opaque sky cover in tenths)
1	<200	<1/2	0-1
2	200-400	1/2-7/8	2-5
3	500-900	1-2 1/2	6-9
4	1000-2500	3-4	10
5	3000-7500	5-6	
6	>750	≥7	

Objective freezing level, surface wind, precipitation, and temperature forecasts are also available in projections out to 48 hours. We are testing new satellite-derived products for use in aviation forecasting and briefing, along with more detailed radar charts. Future products being considered are automated route forecasts for any two points in the country, along with wind and temperature aloft forecasts for any location. A whole new series of aviation graphic products, time cross-sections, and work on voice response systems will help improve increasing mass dissemination requirements.

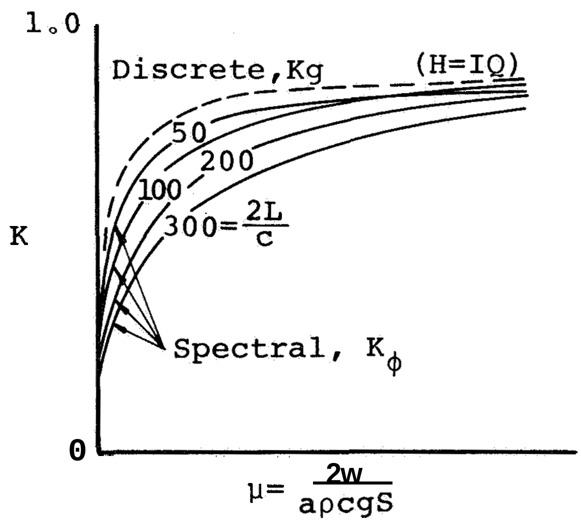
As can be seen, the NWS is working toward the implementation of new hardware to make our internal operation more efficient, along with improved guidance for our forecasters which should lead to more tailored and improved forecasts to aid the aviation community in getting from Point A to Point B more efficiently and safely.

AIRPLANE DESIGN FOR GUSTS

John C. Houbolt
National Aeronautics and Space Administration

I. Structural Design for Gusts

Two basic approaches are generally used for the structural design of aircraft due to gust encounter. One is a discrete gust approach, the other is based on power spectral techniques. Both of these approaches are explained quite thoroughly in References 1 and 2, and thus only a brier coverage is given here. Figure 1 gives the essentials of the discrete gust approach. The incremental load factor An is computed by the equation shown, where K is found from the K_g curve shown on the left. A representative design level for the gust velocity U is 50 fps (equivalent air speed) for altitudes below 20,000 ft. and for cruise airplane speed. The An is added to the 1-g load factor to give the gust load design factor, or n = 1 + An; for design this load factor n



Discrete

$$An = \frac{a\rho SV}{2W} KU$$

Spectral

$$\sigma \Delta n = \frac{a\rho SV}{2W} K\sigma_w$$

$$= A\sigma_w$$

$$An = A\eta\sigma_w$$

Figure 1 Gust Loads

is treated as though produced by a steady state maneuver load, and is considered to be associated with limit load conditions.

The essentials of the power spectral approach are shown in Figures 2 and 3, and in Figure 1. In reference to

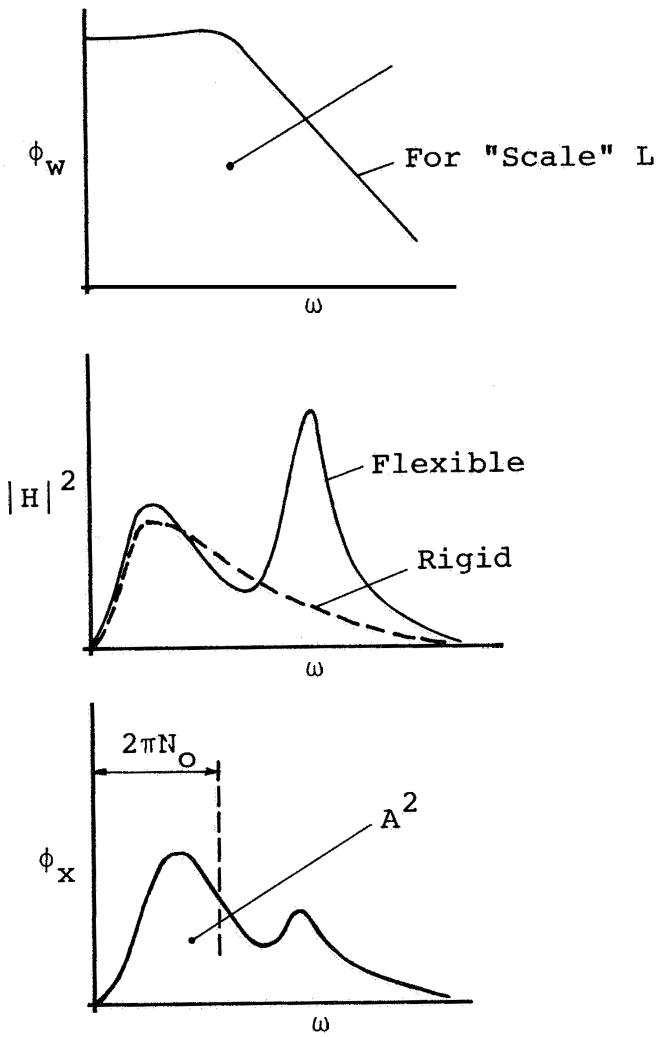


Figure 2 Elements of Power-Spectral Approach

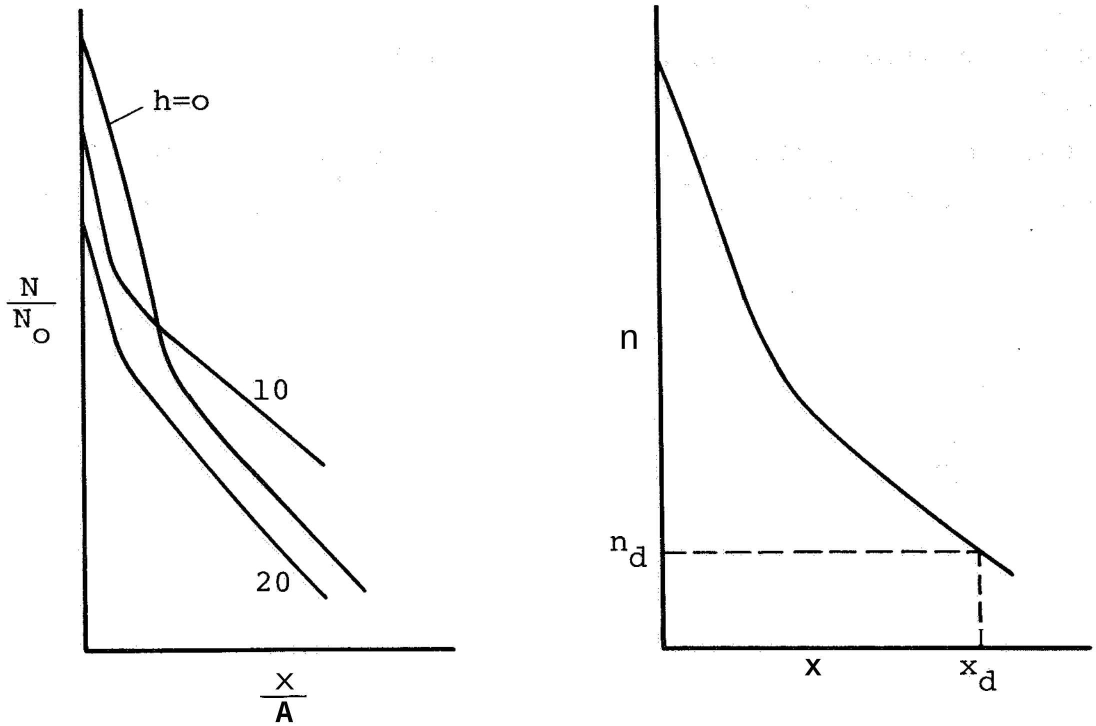


Figure 3 Exceedance Curves for Gust Loads

Figure 2, the input spectrum, as associated with the atmospheric turbulence encountered, is multiplied by the airplane transfer function $|H|^2$ to yield the output response spectrum Φ_x. Two basic parameters are deduced from the output spectrum; one is A which relates σ_x to σ_w according to the relation

$$\sigma_x = A\sigma_w$$

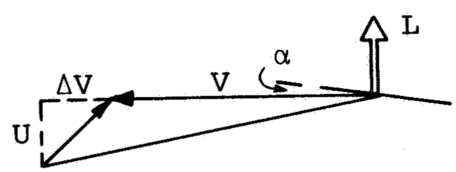
and the other is N_o. Specifically, the area under the spectrum is A^2, while the radius of gyration of this area about the vertical axis establishes N_o. Design can proceed in two ways. One procedure is analogous to the discrete gust design approach. The spectral equation for An shown in Figure 1 is used, where A is found using the solid K curves on the left. The value of the product $\eta\sigma_w$ is taken in the neighborhood of 60-80 fps. Note, Figure 1 applies to a rigid airplane with the degree of freedom of vertical motion only. For this case the type of evaluation shown in Figure 2 can be performed in generalized form, leading to the results given in Figure 1; for this procedure N_o is not used.

The second power spectral approach is shown in Figure 3. A mission profile for the aircraft is specified. Values of A and N_o for each segment of the mission are then evaluated. These values are then used in conjunction with the generalized load exceedance curves shown on the left to establish an expected load exceedance curve as shown on the right. Design is made such that the number of exceedances, n_d, in a specific "lifetime" does not exceed a certain value at the design limit load value x_d. The load exceedance curve established has a second significant use since it represents the expected structural fatigue loading on the airplane due to turbulence encounter.

II. Influence of Horizontal Gusts

Tacit to the discrete and power spectral approaches is the assumption that loading on the airplane arises primarily from vertical gusts. In the study of atmospheric turbulence, measurements have been made of not only the vertical component, but of the longitudinal and transverse gusts components as well. Very little has been done, however, to establish how the gust loads are influenced by the horizontal components; particularly the longitudinal or head-wind component. An analysis was therefore made to establish the loads that develop when explicit consideration is given to both the vertical and head-wind component. A summary of the results of this study is given in this section. (Note, in the measurement of vertical acceleration during gust encounter, some of the vertical loading may be due to the horizontal gusts; subsequent reduction of results to deduce vertical gust velocities assume, however, that only vertical gusts are acting.)

The following evaluation serves to give an indication of the relative influence of the vertical and head-on gusts. Consider an airplane flying at a speed V encountering an inclined gust which has a vertical component U and a horizontal component ΔV, as depicted in the following sketch:



If quasi-steady flow is assumed, the lift is given by

$$L = \frac{a}{2}\rho S(V + \Delta V)^2\left(\alpha + \frac{U}{V + \Delta V}\right)$$

Before the gust encounter the lift was equal to weight, or

$$W = \frac{a}{2}\rho S V^2 \alpha \ .$$

Division of these two equations yields

$$\frac{L}{W} = 1 + \left(2 + \frac{1}{\alpha}\frac{U}{V} + \frac{\Delta V}{V}\right)\frac{\Delta V}{V} + \frac{1}{\alpha}\frac{U}{V}$$

The first term on the right is associated with the 1-g level flight condition. The last term is the increment due to the vertical gust; its value may be in the order of 3. The middle term, which generally has not been considered, represents the magnitude of the loading that is due to the horizontal component, If $\frac{1}{\bar{\alpha}} \frac{U}{V}$ is 3, and for $\frac{\Delta V}{V}$ - 0.2 this term evaluates to *1.04;* thus, the horizontal component of a gust may develop a vertical load on the airplane of the same order of magnitude as the airplane weight.

This rough analysis shows that in establishing structural loads, the inclusion of horizontal gusts appears significant. To gain further insight, a more refined analysis was made, wherein nonsteady lift effects and gust penetration effects due to both vertical and horizontal gusts were included. The analysis yielded two primary results, described in schematic form by the aid of Figure *4.* One result, curve B, gives the combinations of U and V at which aerodynamic stall of the airplane occurs; the stall region is above the curve. The second result, curve **A**, gives the combinations of U and V which could develop structural loads of sufficient magnitude to cause structural breakup; the failure side is above. Consideration of both curves, then, defines a failure region, as shown by the shaded region on the figure. The lower edge of this region

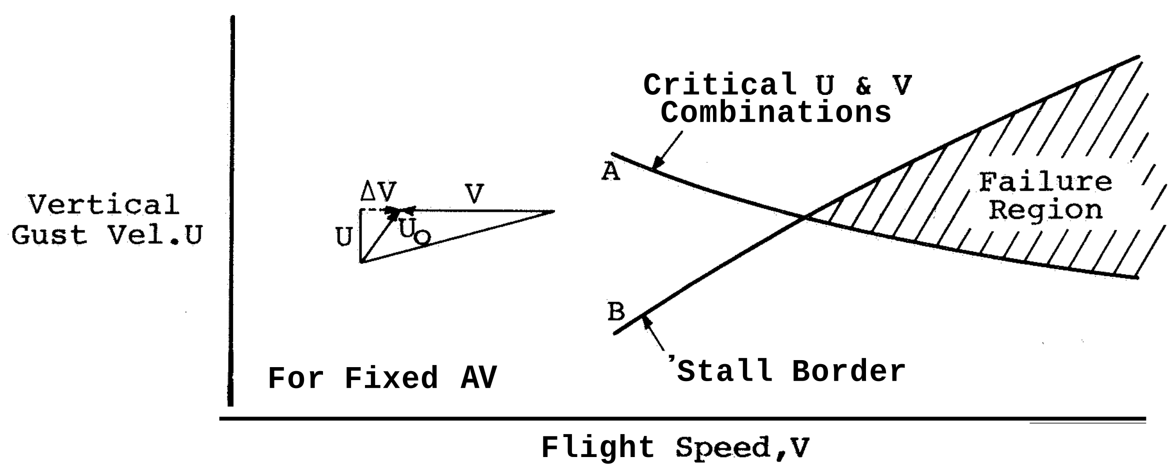


Figure 4

is of prime concern since, for a given V, it indicates the lowest value of U which can cause structural failure, but still not cause stall conditions for the airplane. Note, to the left of the crossing point, failure cannot occur because stall is encountered with increasing U, again for a fixed V, before a failing type load can be reached.. Note also, the results are for a specific choice of AV.

The applications of the analysis to a specific large airplane configuration yielded the results shown in Figure 5. The results apply to the outboard wing section. Part (a), for AV = 0, shows the sensitivity of the results to two parameters of the problem, the slope of the lift curve a, and the effective quasi-steady flight load on the airplane. It must be recognized that in flight through severe turbulence, the pilot is struggling to maintain control of the airplane; in this effort, an effective load factor greater

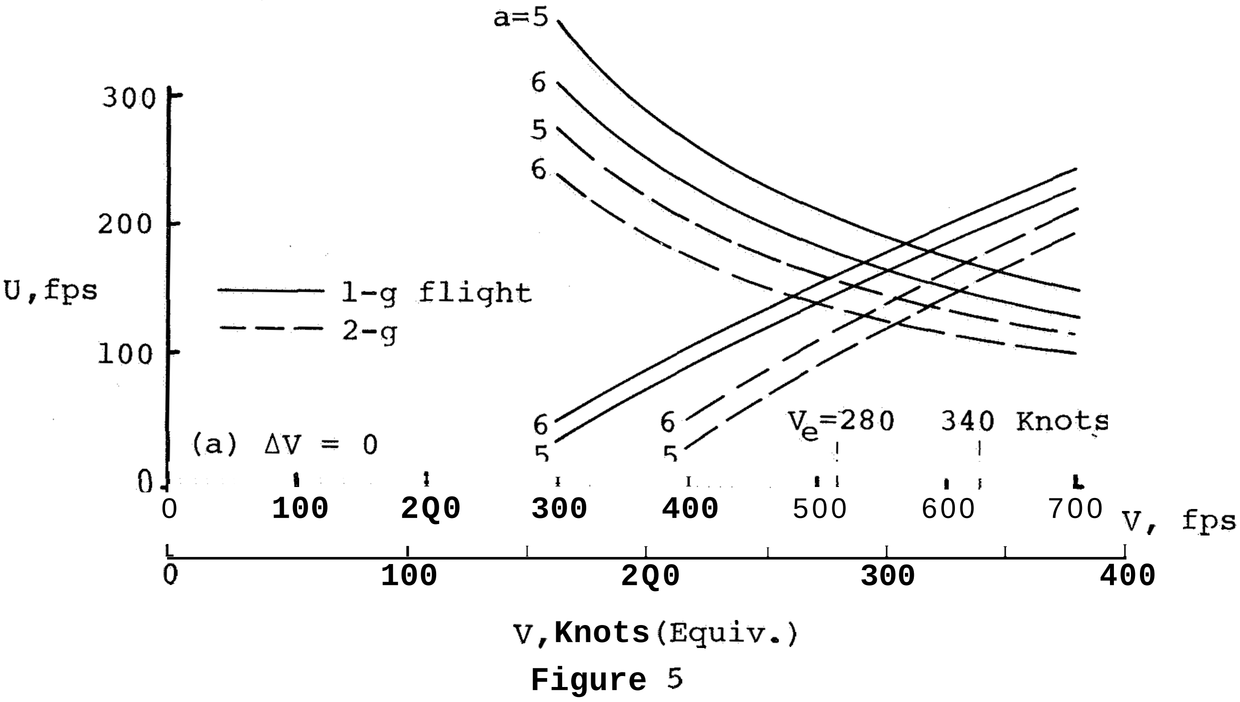


Figure 5

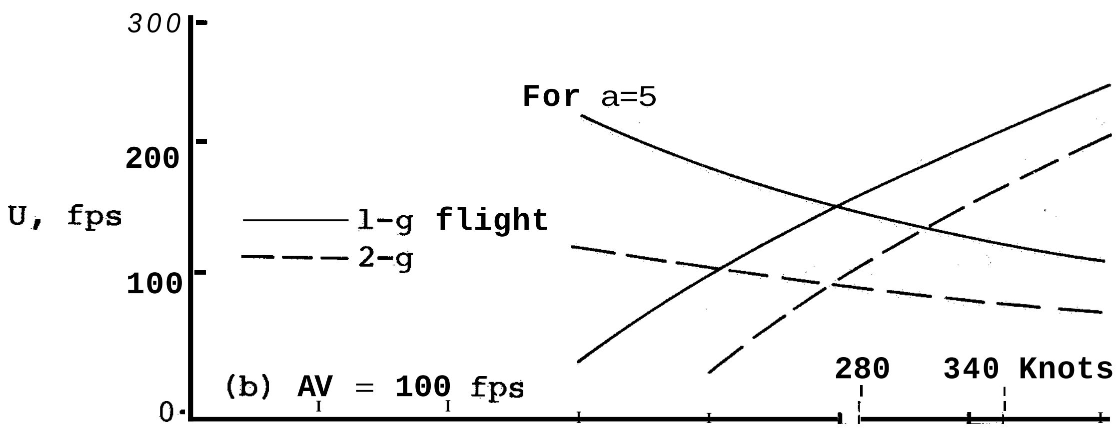


Figure 5, (Cont.)

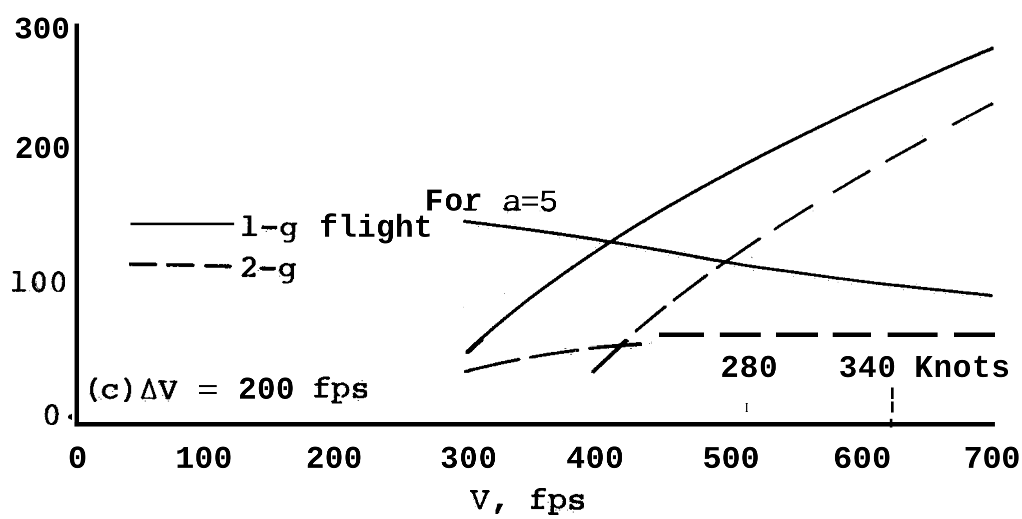


Figure 5, (Cont,)

than the level flight 1-g condition may be induced at a given wing station either by a pullup type maneuver or by a rolling motion on the airplane. Both the lift curve slope and the effective maneuver factor are seen to have a very significant influence on the critical combinations U and V. By contrast with Figure 5(a), results for AV of 100 and 200 fps are shown in parts (b) and (c), but only for a = 5. (The vertical ticks at 280 and 340 knots define an estimated range in speed for the particular airplane under consideration at the time of turbulence encounter.) The primary result brought out by Figure 5 is that the inclusion of the horizontal gust component AV can have a very significant effect on the combinations of U and V which can produce failure type loading conditions.

A cross plot of the results shown in Figure 5 is shown in Figure 6. This plot emphasizes the importance of knowing various flight conditions in inferring what gust velocities are needed to lead to failure type structural loads. As an example, if we consider the airplane in 1-g flight and travelling at 600 fps, and take AV = 0, then we see that a U of around 180 fps is necessary to cause failure. If U and AV are taken about equal, which is more likely, then the U causing failing loads is about 130 fps. If the wing is experiencing a 2-g loading, then U and AV need only be around 100 fps to produce failure type loading; this observation is seen to apply even for a flight speed of 500 fps. It should be remarked that the results shown in Figures 5 and 6 are conservative in a sense, since certain load aggravating effects were not included. The analysis is based on a rigid airplane encountering a single discrete gust that is uniform in the spanwise direction. The following three load amplifying effects are thus not taken into account: (1) the continuous nature of turbulence or the possibility that a

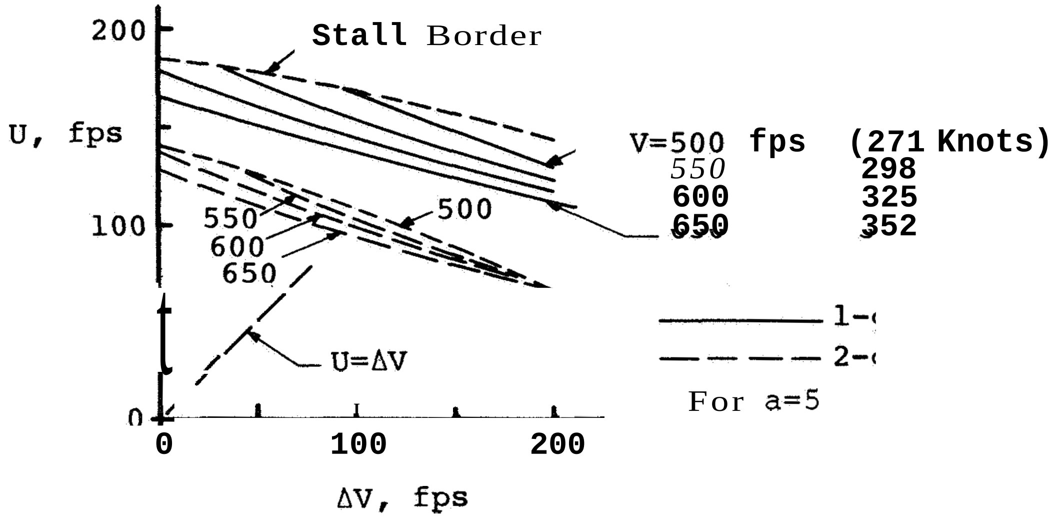


Figure 6

down gust may follow an up gust, (2) dynamic amplification effects due to aircraft flexibility, and (3) the nonuniformity of the turbulence in the spanwise direction. The inclusion of these effects would probably indicate smaller values of U and **AV** to produce failure.

A few comments on the measurement of turbulence are made to end this section. Systematic measurement of the U and **AV** components have been made in clear air turbulence and in cumulus clouds, and some probing has been done near thunderstorms. Unfortunately, systematic measurements in or near thunderstorms of the more severe or extreme combinations of U and **AV** have not been made, The reason is, of course, understandable because any attempt to make such measurements with the type aircraft probes normally used would cause destruction of the aircraft. Systematic measurements of the various components of turbulence in the vicinity of thunderstorms with "rigid" fighter type aircraft are very much in need.

With respect to the use of radar to interpret turbulence severity near or in thunderstorms, much has been done to correlate the various signature patterns with broad levels of turbulence severities. Identification of localized areas of extreme combinations of U and **AV** does not, however, appear possible from the signatures obtained with present equipment. Airplane flight in or near thunderstorms should in general be avoided. But if such flights are to be made for some reason, then for safe flight we need reliable ways to interpret radar signatures, or other measurements, to pinpoint areas of severe combinations of U and AV, so that these areas can be avoided.

III. Gust Effects During Landing Approach

Some brief comments of a general nature are made in this section on gust effects during landing. The previous sections dealt mainly with gust loads as influencing aircraft strength. Gust loading is also of concern, however, during takeoff and in the landing approach of an airplane. The concern in these stages of flight is mainly with respect to maintaining control of the attitude, altitude, and power setting of the airplane. During approach, in particular, we need to know not only the variation in turbulence along the flight path, but we need to know its spatial distribution about the airplane. The gusts acting, for example, on the left wing, the right wing, and the vertical tail may all be different, see Figure 7. For approach simulation studies, we need to know these quantities better, not only to be able to apply more realistic values of forces on the airplane, but also to apply realistic values of pitching, yawing, and rolling moments.

For Approach Simulation

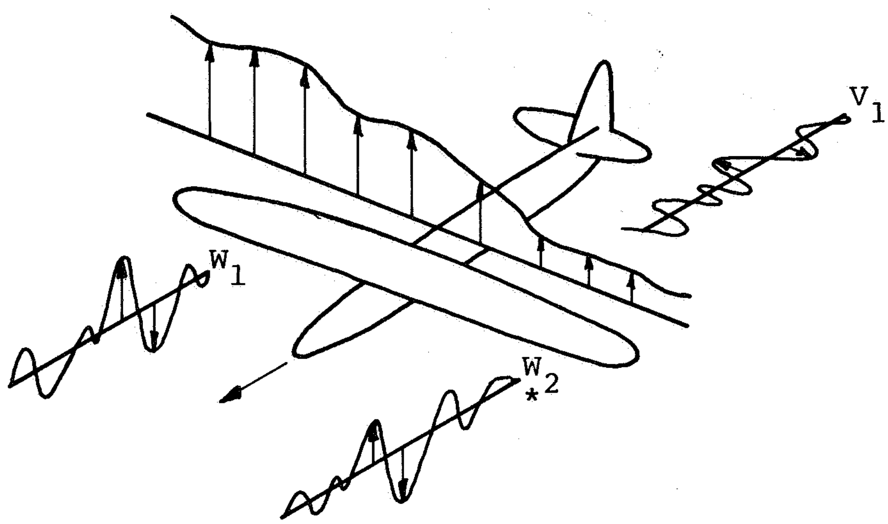


Figure 7

An ideal facility to measure these turbulence velocities would be a track centered along the approach path to a runway, with a cart that could measure the u, v, and w components of turbulence at various spatial points, see Figure 8. The feasibility of constructing such a facility is, of course, not very good; the main point to be made, however, is that measurements of the type that could be made with such a facility are needed.

The Ideal Facility for Approach Turbulence Studies

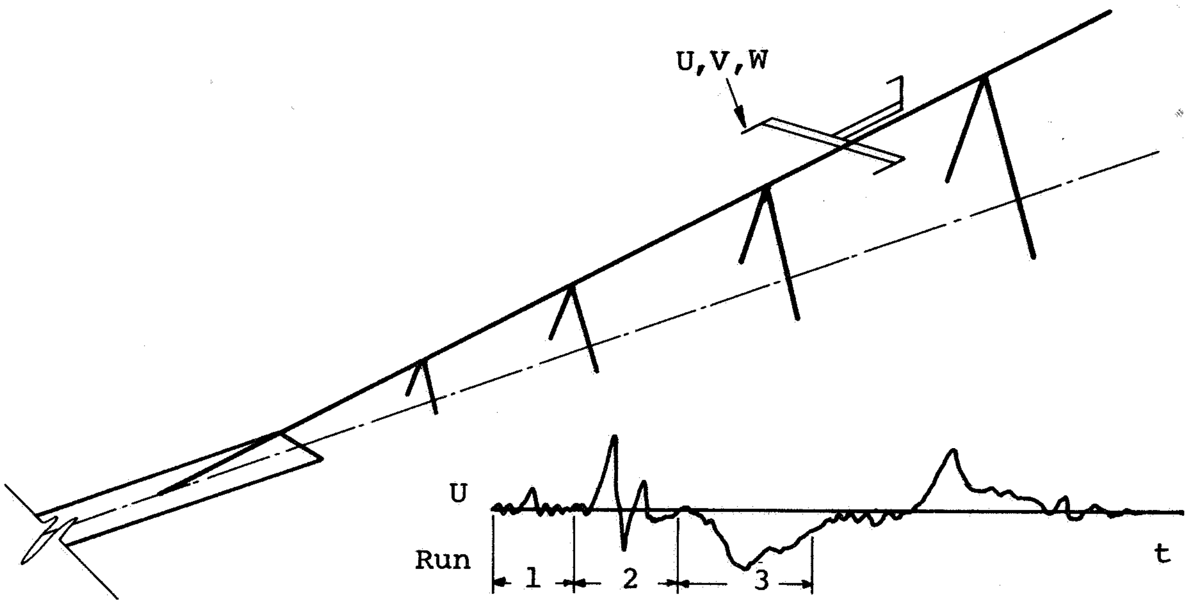


Figure 8

With respect to the wind shear problem, more information on the wind profiles that are encountered during approach is needed. Possibly we need to establish a stable of the types of wind profiles that are encountered, Figure 9. It may be that, out of this stable of profiles, there may be a distinct type that could serve as critical wind shear profile for landing approach studies, just as the discrete-gust profile has been used for years for strength design. Most urgently needed in the wind shear problem is the means €or predicting when a non-negotiable profile may exist.

Need "Stable" of Wind Profiles

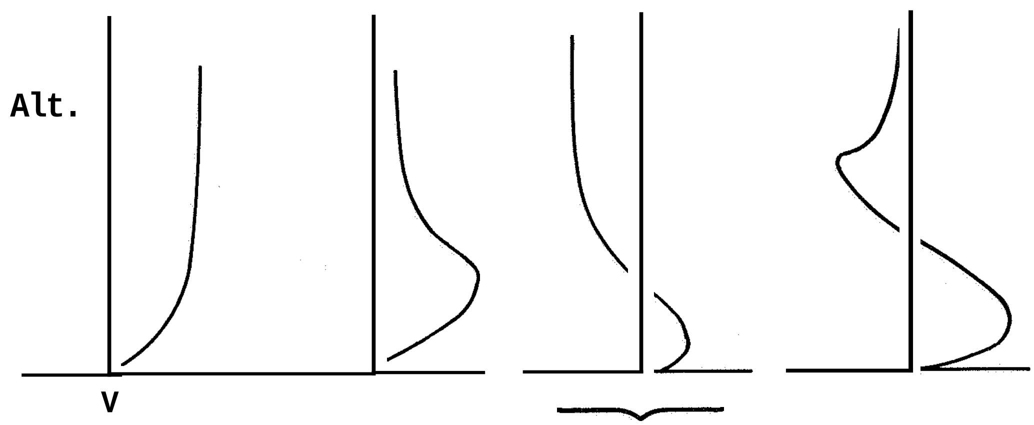


Figure 9

References

1. Houbolt, John C. "Dynamic Response of Airplanes to Atmospheric Turbulence Including Flight Data on Input and Response." NASA TR R-199, June 1964.

2. Houbolt, John C. "Design Manual for Vertical Gusts Based on Power Spectral Techniques." AFFDL-TR-70-106, December 1970.

A SYNOPSIS OF THE WEATHER PROBLEMS FACING TODAY'S GENERAL AVIATION PILOTS

James C. Pope
Chief, Industry/Government Liaison Division
Office of General Aviation, Federal Aviation Administration

Flying is frequently defined as "Hours and hours of utter boredom punctuated by moments of stark terror." It is probably realistic to assume that a high percentage of that punctuation is generated by weather involvement.

A review of the National Transportation Safety Board statistics on fatal general aviation accidents for the past ten years reveals a very interesting pattern. The number of fatal accidents from year to year is reasonably constant. Moreover, weather-related accidents comprise an almost consistent 36 percent of each year's total. Initially, it would appear that we aren't making much progress in either accident prevention or weather education. The facts are that we are constantly improving both, but with the ever-increasing numbers of airplane owners and pilots, as the safety ratio increases, the actual numbers and fatalities remain rather constant, thus camouflaging the progress we have been achieving.

John H. Shaffer, former FAA Administrator, is quoted as saying that "We need more pilots with good judgement." When asked how we develop this good judgement, he answered, "Through experience." In answer to the obvious final question of how do we gain this experience, Mr. Shaffer retorted, "Through bad judgement, of course!" The

a

challenge obviously is to achieve good judgement through the media of education and information. On the subject of education, many forces are at work. Excellent safety programs and government flight clinics, and aviation seminars are a wonderful way of life for thousands of pilots ambitious to develop better judgement. Unfortunately, there are other untapped thousands who are lacking in both ambition and education, and therein lies one of our major challenges.

Once a pilot has education and a reasonable amount of good judgement, he then begins to seek more information--and usually, this sought-after information is in the field of aviation weather. Are pilots satisfied with our aviation weather dissemination system? Are we satisfied with the system? Answers to both these questions are perhaps admirably addressed by a synopsis titled "Weather and Air Safety," authored by the National advisory Committee on Oceans and Atmosphere, in their "A Report to the President and Congress." The following "essential findings" take on particular significance.

> "Aviation weather service seems to be deteriorating."
>
> "Weather information dissemination seems to be largely routine."
>
> "Pilot education and certification for general aviation pilots, as related to weather, do not seem adapted to practical needs..."

Further, the report recommends that:

> The Federal Aviation Administration put greater emphasis on the early recognition of deteriorating weather situations in civilian pilot training and on the requirement for weather knowledge in pilot certification;
>
> The National Weather Service improve the quality of air weather information by computer checks on

observations, by post-mortems on forecasts, and by training in format and enunciation for voice communicators;

Aviation weather expertise be put back into the traffic control environment and, especially, that the Kansas City test (integrating controllers and professional weather personnel) be extended and developed throughout the nation (for controlled flights) and the Enroute Flight Advisory Service (largely for general aviation) also be extended throughout the nation;

The agreements between, and the directives to, the the National Weather Service and the Federal Aviation Administration, splitting the responsibility for aviation weather service, be reviewed and updated and the requirements for aviation weather service be reviewed in the light of technological advance on a broad front.

If acronyms could provide the answer to weather dissemination, we wouldn't have any problems: witness ATIS, PATWAS, FSS, EFAS, SIGMETS, PSBT, PIMPS, TWEB, ETV, AFOS, CATV, AWANS, MAPS, just to name a few. Each of these programs, however, contributes to our total goal of weather information availability. In addition, the prototype Flight Service Station at Leesburg, Virginia, is the first of its kind to involve a consolidation of several satellite Flight Service Stations with co-location at an Air Route Traffic Control Center (ARTCC). This effort has the support of many general aviation organizations and is the first major effort of its kind to evaluate a myriad of concepts and technology in an effort to reduce manpower requirements while concurrently improving many pilot services, particularly weather information dissemination.

We have been concentrating to date primarly on weather at the points of observation. True, there have been efforts to obtain and disseminate en route weather through pilot reports (PIREPS), but the efforts have been comparatively meager. We need now to concentrate our cooperative efforts on the application of technology to the acquisition and dissemination of this vital en route weather data- for those pilots in the air as well as those who are flight planning on the ground.

Visualize a comprehensive, three-dimensional computer storage system (3DWX) that receives weather information from all aircraft on IFR flight plans and stores this information by altitude and geographical coordinates. We have today the technology in the form of computers and read out CRT displays to provide a total view of FSS personnel and pilots of all en route weather. Work has already begun on improving the format of PIREPS, a good first step in the right direction. En route pilot weather reporting has left much to be desired, primarily because the information is not effectively utilized. This new 3DWX program would have the potential to not only improve safety, but to greatly increase operational reliability and aircraft utilization--both IFR and VFR. But let's take such a program one more step forward and develop combination airborne weather sensors and transmitters that will automatically read out weather conditions in flight and send this data to the 3DWX computers. Such a program could be initiated tomorrow. Shall we begin now, or will we procrastinate as we continue to quote the Latin expression: "El Evictus es Manifesto Su Flexiatus", which, when translated, means "Indecision is the keynote to Flexibility'!

PROGRESS AND OUTLOOK FOR THE FEDERAL AVIATION ADMINISTRATION'S AVIATION WEATHER RESEARCH, ENGINEERING AND DEVELOPMENT

Joseph F. Sowar
Chief, Aviation Weather Systems Branch
Systems Research and Development Service
Federal Aviation Administration

I have been asked to report on the Federal Aviation Administration's Research, Engineering and Development Aviation Weather Program, from the aspect of past, present, and future, and I welcome the opportunity to do so. I do not intend to dwell on the past; suffice it to say, let the record speak for itself. Some will say that it's good and others that it's bad; however, I think all will agree that, compared to say 1955, we are measuring more weather elements more accurately and more often. There are also more specialized aviation weather forecasts produced and transmitted to more locations and in shorter time. There are other advances too numerous to list, but even more important than our advances in hardware, software, and communications, has been our increased knowledge of the weather and the impact that it can and does have on flight operations. However, and this is one of the reasons why we are here, we can also all agree we haven't come far enough.

We should take advantage of the past to get direction for the future. Since one of the principal objectives of our Aviation Weather Program is to reduce weather involved accidents let's review some statistics. Starting with general aviation weather involved fatal accidents, we see in Figure 1 that between 1964 and 1972 the rate of such accidents per 100,000 aircraft hours slightly decreased, but we also see that percentage-wise the record didn't improve, actually there was a slight rise to where in 1972, over 30 percent of all general aviation fatal accidents were weather involved. A comparison which is somewhat shocking is that between 1964 and 1970 the number of fatalities in weather involved general aviation accidents was nearly three times as many as the number caused by hurricanes and tornadoes. Such statistics should be considered when we set priorities for assignment of resources in weather work. Weather involved aircraft accidents are not limited to general aviation. Looking at wind shear related accidents between 1971 and 1976 five out of the six were air carrier aircraft.

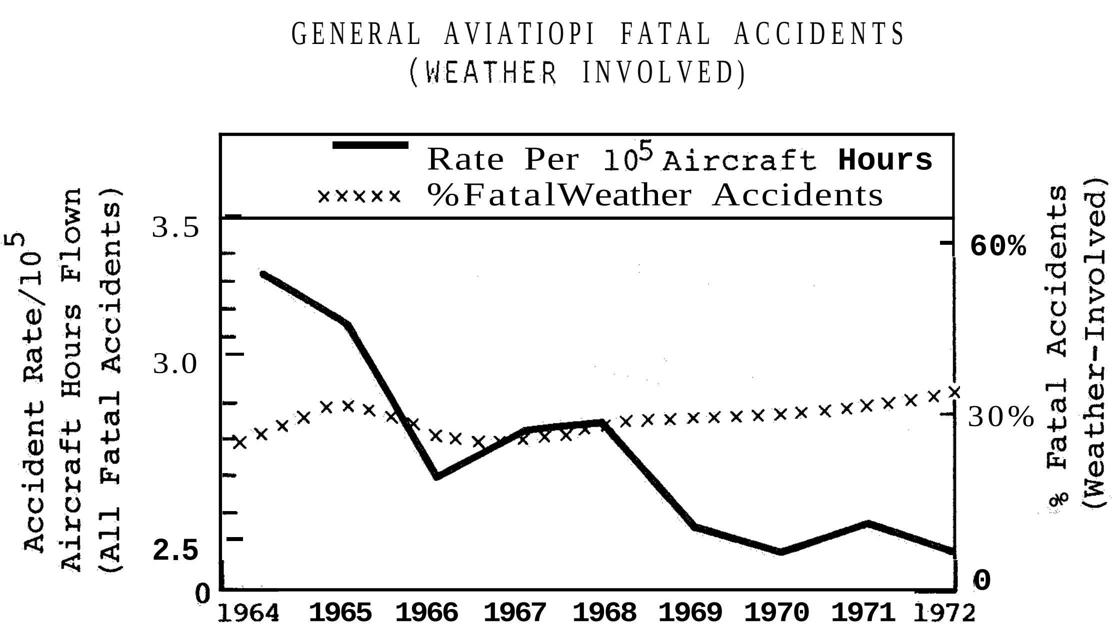
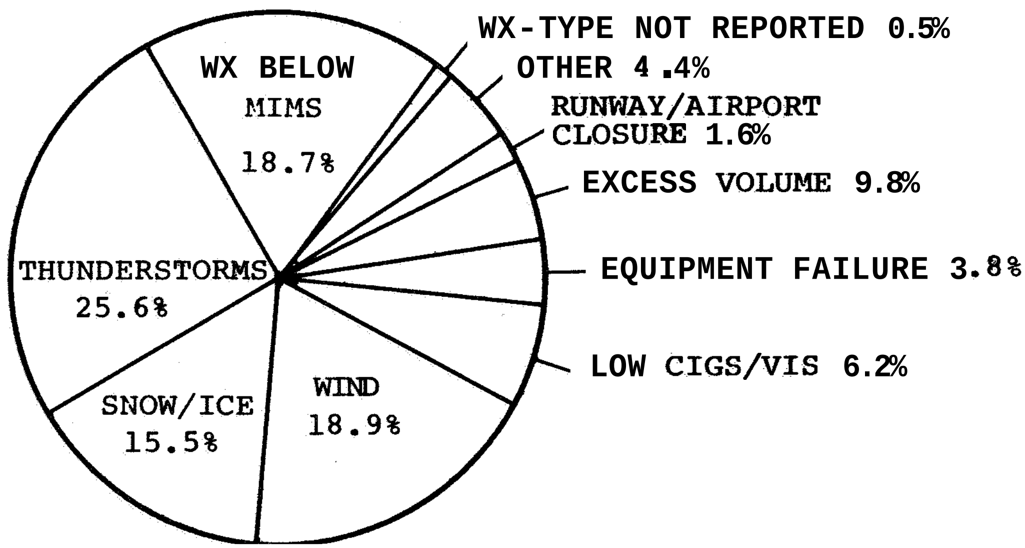


Figure 1

We can look at another statistic, not as critical as fatal accidents since lives are not lost, but still an important and costly item to commercial aviation. It's the cause for air traffic delays of thirty minutes or longer, (Figure 2). We see that nearly 80 percent of these are caused by some type of weather. Even knowing that realistically we won't ever zero out accidents and delays caused by weather, it seems almost certain that improved aviation weather information in the hands of the pilots and air traffic controllers can reduce them.

CAUSE FOR AIR TRAFFIC DELAYS-1975
(30 minutes or longer)



WX RELATED-27,047
NON WX-4,625
TOTAL DELAYS-31,672

Figure 2

Today there is a gap between the demand for aviation weather service and the fulfillment of this demand, (Figure 3). This gap was very wide in the 1940's because of the introduction of large numbers of aircraft during and shortly after World War II. The gap closed in the late 1950's, but with the introduction of jet aircraft into the commercial fleet and the unprecedented growth of general aviation through the 1960's, the gap today is again open, even though there are enormous resources in manpower and dollars allocated to aviation weather. We estimate that the Federal Aviation Administration allocates more than 4,500 man years and 58 million dollars annually on this problem. If we add in the Department of Commerce, Department of Defense, Airlines and others we come up with a total allocation of over 14,500 man years and 222 million dollars allocated in this area.

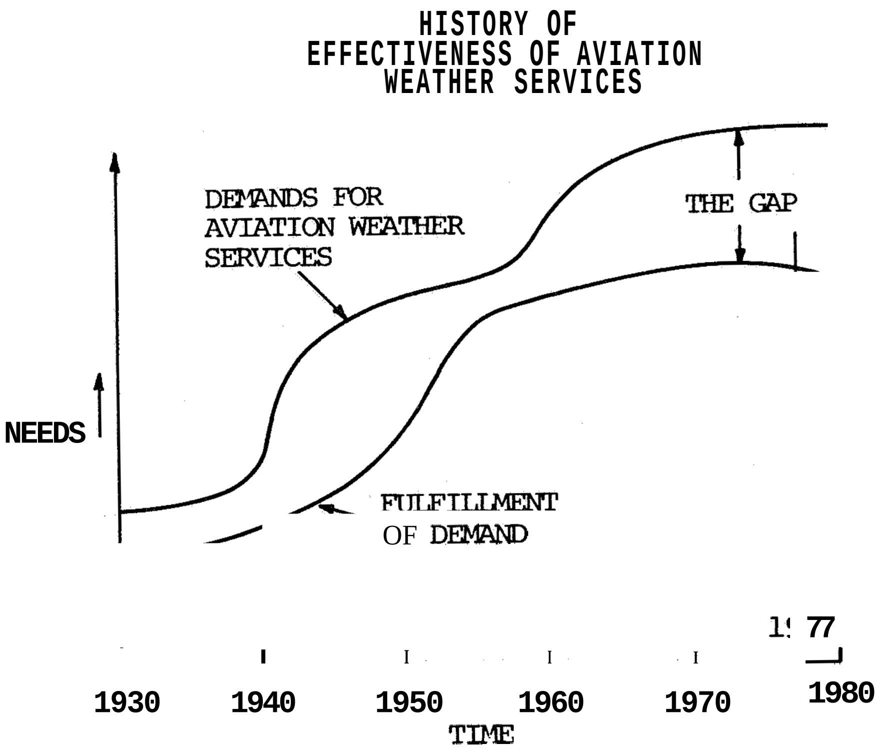


Figure 3

Our Aviation Weather Program is geared to improving on past statistics with respect to the costly effects, in both lives and dollars, of weather on aircraft operations. To accomplish this the specific objectives of the program are to:

1. Reduce the need for manual aviation weather observations at towers and Flight Service Stations.
2. Improve the measurement of aviation weather parameters.
3. Provide real-time severe weather information in the National Airspace System.
4. Improve the forecasting of visibility, ceiling, wind shear, clear air turbulence and severe weather.

There are many elements that make up the Aviation Weather Program, (Figure 4), and its interfaces with other programs, such as, the Flight Service Station Program, and the Wake Vortex Program.

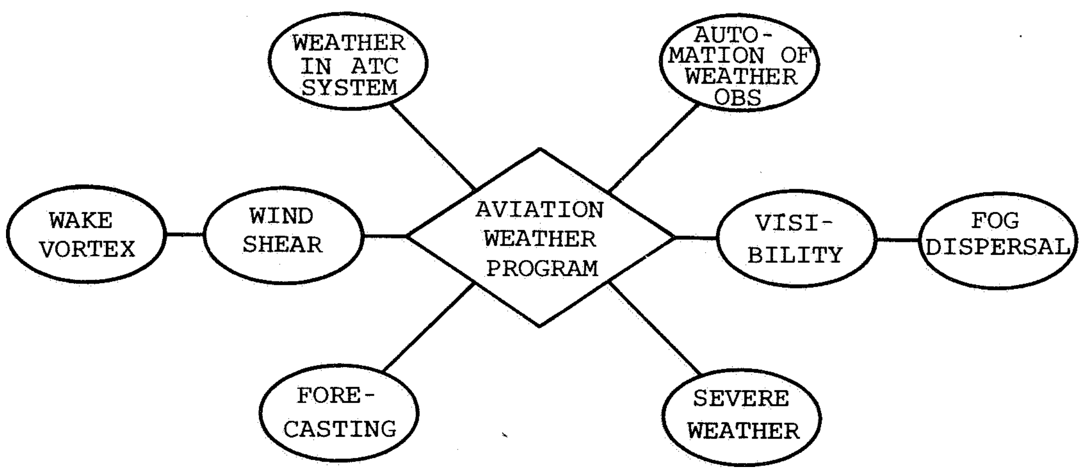


Figure 4

Let's look at some of the things that we are trying to accomplish. Today we measure horizontal visibility with our Runway Visual Range (RVR) system. An additional operationally useful measurement for very low visibility approaches would be one that gives the pilot the distance that he will see when he is at his decision height. We call this Slant Visual Range (SVR). A system that has promise of meeting this requirement is under test at the Federal Aviation Administration's test facility at Atlantic City, New Jersey.

There are about one thousand locations in the conterminous United States where aviation weather observations are being taken. Automation of the aviation weather observation is designed to free specialists from doing this task at those locations where it will be cost effective. We have under development an automatic observation system called AV-AWOS, which is designed to provide an aviation weather observation, including automating ceiling, sky cover, and visibility for those airports where Flight Service Station (FSS) specialists now provide this service.

Only a few of our FSS's have near real time radar information available. Such information is particularly valuable in pinpointing thunderstorms. F M, in cooperation with the National Severe Storms Laboratory and Bendix Avionics, has developed a digital radar relay system which can be used on both weather and air traffic control radars. The system permits transmission of Plan Position Indicator presentations over telephone lines and gives excellent detail at the receiver end.

I have mentioned several items from our Aviation Weather Program that will help FSS specialists. There is a major FSS Program underway to make the FSS system less labor intensive through automated data handling and dissemination. The AWANS system now operating at the Atlanta

FSS is a first step in this direction. In future systems it is planned that pilots will interface directly with the data base in about 70 percent of briefing situations.

Wind shear has been identified as a hazardous weather phenomena that has caused aircraft accidents, some quite recently. The FAA's wind shear program is well funded and addresses the problem on a broad front. It includes efforts to: (1) characterize wind shears, (2) to define "the wind shear'' hazard, (3) to develop both airborne and ground based equipment which will give warning of the hazard, (4) to establish a wind shear data base and to test techniques for forecasting the onset and intensity of wind shear. A ground based wind shear measuring system has been installed and is being tested at Dulles International airport as part of this program.

What does the future hold? First, and foremost is the successful completion of on-going programs, but beyond that we think we see an integrated aviation weather support system for the National Airspace System. A system which will take advantage of modern technology to insure that fresh tailored weather information is in the hands of the pilot, air traffic controller, or Flight Service Station specialist when he needs it. We have a concept and plan for developing such a system and we are ready to move toward a detailed design.

NASA'S AVIATION SAFETY RESEARCH AND TECHNOLOGY PROGRAM

George H. Fichtl
Environmental Dynamics Branch
NASA/Marshall Space Flight Center

NASA's Aviation Safety Research and Technology Program is a broad-based multidisciplinary effort aimed at solving those operational problems where new knowledge or understanding is required.

The field of aviation safety and operating problems provides a continuing challenge to raise the levels of our knowledge and understanding of the aircraft operating environment. As aircraft design, operational boundaries, human roles, and social and economic constraints change, so do the nature and relative importance of operating problems. What may have been an economic nuisance yesterday, may well become a safety problem today or tomorrow. The task of the research planner in not only responding to identified problems, but also in trying to anticipate where the next serious problem area will be, is difficult and formidable. Funding for solutions to tomorrow's problems is difficult to justify, and public impatience for rapid solutions to difficult problems involving highly complex disciplinary and system interactions is often unreasonable. Nevertheless, safety research and technology is an exciting area, carrying with it the satisfaction of achieving in part perhaps the most important goal of all reduction of suffering, misery, and loss.

INTRODUCTION

Safety is difficult to define, but can be thought of as the absence or control of factors which can cause injury, loss of life, or loss of property. Aviation safety is challenged by the practical necessity of comprising inherent factors of design, environment, and operation. If accidents are to be avoided, these factors must be controlled to a degree not often required by other transport modes. The operational problems which challenge safety seem to occur most often in the interfaces within and between the design, the enviornment, and operations, where mismatches occur due to ignorance or lack of sufficient understanding of these interactions.

Aircraft operating problems accompanies the first success of flight, and have been aviation's constant companions ever since. As aviation's role in public transportation has become firmly establsihed, more and more attention has been devoted to ensuring the reliability, and therefore the safety, of flight. The travelling public has come to expect a very low risk associated with air travel. A recent issue of Flight International (Ref. 1) places the chances of a passenger being killed before arriving at his destination at three in a million. One might quibble somewhat with the data used in arriving at this figure, but the essential point is well made ; air transportation is safe indeed. Why then, pursue improved levels of safety? Surely because survival and expansion of air travel demands the lowest operational risk commensurate with the economic well-being of the air transport system. It is in the best interests of the aviation consumer and the aviation engineer and operations communities to ensure the lowest practical risk.

The Nature of Operating Problems:

Operating problems arise most frequently when a new aircraft design is put into service, when a new air or ground operating environment is entered, or when operating procedures are changed. By far, the majority of these types of operational problems can be solved by straightforward engineering methods, calling upon established bases of knowledge, or by modifications in operating techniques or procedures. Examples of this class of problems include such things as hydraulic system malfunctions, abnormally high material deterioration rates, localized vibratory stress failures, avionics malfunctions, terminal area procedural problems, flight crew task loading, etc.

There is another class of operating problems, however, that is characterized by an elusiveness of cause or by a lack of sufficient understanding of how the airplane and its equipment will be operated and of the requirement placed upon the airplane and its equipment as it interacts with the environment. Solutions to these problems have generally required an expansion of knowledge or understanding of not only the nature of the problem, but also of the effects of employing different solution options with a view towards avoiding the creation of another problem. Research serves this purpose well by laying down the basis for development of new materials, system's processes, operating techniques, and design practices which establish a satisfactory safety margin or risk level. Very often an old problem which has been "solved" through research reappears, due to a change in aircraft type or change in operating environment. The new situation has uncovered a subtlety which necessitates a "finer scale" view of the earlier understanding. Additionally, there are situations where an improvement in design, materials, or procedure undertaken for efficiency improvement or environmental benefit subtly introduces a new vulnerability to hazard, affecting the safety margins previously established. Examples of this class of operating problems include, for instance, gust loading and wind shear, wake vortex interaction with encountering aircraft, engine performance degradation, composite structures integrity, flight crew workload, aircraft crashworthiness and fire-worthiness, and lightning hazard effects.

NASA Aviation Safety Research:

NASA's Aviation Safety Research and Technology efforts address the latter class of operational problems, where solutions require a new level of knowledge or understanding of the hazard and its enabling factors. The output of these programs is directed at providing an upgraded technology base upon which manufacturers and operators may draw to reduce risk through design and operation. Better understanding of problems and solutions can also strengthen the rationality of standards setting and regulatory activity aimed at maintaining low risk levels. Public confidence in transportation systems grows as reliability and dependability increase and as risk decreases. Coupled with reasonable fares, high reliability, dependability and safety of operation will increase patronage with obvious benefits to the industry and the public alike.

One can always identify more research needs than there is funding to support. Prioritization is difficult because of the "reactive" nature of operational problems research. The "probable cause" of accidents frequently provides clues to research needs. Incidents, if recognized early and as significant, can cause remedial action that can hopefully prevent a catastrophe. Accidents often impart an urgency for a solution which is inimical to thorough, necessary research; therefore, compromises must frequently be arrived at in planning the safety research program.

Inputs to NASA's research program planning come from formal and ad hoc adivsory panels and communities, from requests and recommendations from other government agencies, and from the industry. These are considered along with NASA staff recommendations in view of resources, manpower, expertise, and facility availabilities in finalizing program plans. Presently, the NASA Office of Aeronautics and Space Technology Aviation program comprises research in meteorological hazards to aircraft operation, wake vortex research, engine rotor fragment containment research, fire research, crashworthiness investigations, aircraft ground operations research, and investigations of the man-vehicle interface. The program is coordinated as broadly as possible, both domestically and internationally.

A comprehensive status report on all elements of the Aviation Safety and Operating Problems Research programs in NASA is clearly beyond the scope of this survey paper, but a report of significant recent progress in several of these areas will be offered as representative of NASA's current program. References are cited throughout and at the end of the paper as sources for more complete information on these topics. However, Reference 2 provides an indepth review.

HAZARDS AND OPERATING PROBLEMS IN THE NATURAL ENVIRONMENT

NASA and its predecessor, the NACA, have for many years studied aircraft operational problems associated with the variability of natural atmospheric parameters. Most of this effort has been targeted on achieving a better understanding of atmospheric processes or to describe them in functional terms of use of the designer, operator, and forecaster. While we share this research responsibility with the FAA, the military services, and the National Oceanographic and Atmospheric Administration (NOAA), our efforts generally derive from an identified operating problem or hazard which affects the design or operation of the flight vehicle. NASA's Office of Applications supports a major effort in Atmospheric Science, but the emphasis of our aviation-oriented meteorology research lies in civil aircraft operating problems associated with turbulence and wind shear, lightning hazards, fog, and radiation hazards.

Clear Air Turbulence Characeterization and Prediction:

Turbulence research addresses problems of operation both in the atmospheric boundary layer and at higher altitudes. Representative of this work are efforts to characterize Clear Air Turbulence, or CAT, for use in reliably forecasting its occurrence and to guide development of CAT detection instrumentation. Obtaining accurate, reliable correlations between CAT occurrence and synoptic conditions is fundamental to further understanding of CAT.

A goal of a recent research task was the development of discriminant functions, with synoptic-scale parameters as variables, capable of predicting the areas and altitudes of stratospheric CAT. Also, predictive methods indicating the intensity of the expected turbulence were investigated. The data used in the program were obtained from turbulence experienced with the XB-70 and YF-12A aircraft and 69 synoptic-scale parameters determined from rawinsonde data. A full description of the discriminant function analysis used as the primary analysis tool is contained in Reference 3. The results of this research indicate that there is, indeed, a relationship between selected combinations of synoptic scaleparameters of the upper troposphere and lower stratosphere and stratospheric CAT. The relationship is verified only for occurrence, not intensities. Nevertheless, the results are encouraging in offering promise of more reliable forecasting of CAT which should, in turn, enhance safety by providing warning and avoidance information.

CAT Detection:

Several years ago, as part of the U.S. Federal Coordinator's Program for Meteorological Research, NASA undertook an investigation of laser technology as applied to the program of CAT detection and warning. The goal was to examine the feasibility of developing an airborne laser-Doppler system (LDS) for operational use, and to determine whether CAT could be measured far enough ahead of an airplane sufficiently well to be considered practical. Theoretical studies to determine feasibility and to define preliminary design requirements were conducted in 1968-69. The results of these studies led to the design and development of a breadboard pulsed CO_2 laser Doppler system during 1970 to 1972. This breadboard system was flight tested in 1972 and 1973 aboard NASA's CV990. A special forward looking fairing was desinged and built for the portside emergency door of the aircraft, which permitted the laser beam to be transmitted forward along the heading of the aircraft. Receiving backscatter light from micron-sized aerosol particles in the atmosphere, the system measures this signal, comparing it with the transmitted beam, processes the information, and relays it to the displays and recorders. Since the CAT warning must extend over many miles, the laser beam must be higly stable and have large coherence lengths. **Two** series of successful flight tests were conducted. Some modifications were made to the hardware between the two tests that increased the signal-to-noise performance of the system by about 15 dB.

The feasibility of the **LDS** as a CAT detector was demonstrated, and some clouds not shown on the aircraft weather radar were detected by the **LDS.** While turbulence detection ranges were disappointingly short (5 to 6 n. mi. vs 16-20 n. mi.), it is believed that system sensitivities and signal-to-noise (S/N) ratios can be improved to achieve near-theoretical performance. In the coming year we plan to conduct a series of ground based tests with the system incorporating hardware improvements made since the flight test series. These ground tests will lead to a flight test data of mid-1977 for further onboard evaluations.

MAT Program:

Another effort, begun about five years ago, is the Measurement of Atmospheric Turbulence (MAT) program employing a B-57B aircraft with a nose boom incorporating low inertia flow vanes (α & β) and Statoscope (P). The objective of this program is to obtain detailed measurements of the time histories of the components of atmospheric tubulence of all kinds (e.g., jet stream, low altitude, clear air, mountain wave, storm, etc.) using the same aircraft instrumentation and data reduction procedures for all measurements. This program has yielded homogeneous turbulence data which is required in order to determine the adequacy of the von Karman model at lower frequencies, and to determine a value for the integral scale, L, associated with this model.

Data samplings have been completed between sea level and 50,000 feet (15.2 km) altitude. A total of 60 data runs were taken in 46 flights (30 in eastern U.S., 16 in western U.S.). Instrumentation is being removed from the B-57B preparatory to its installation in a B-57F airplane for sampling between 50,000 and 65,000 feet (15.2 km and 19.8 km) during January-June 1977. Early preliminary results of data analysis indicate that the von Karman description of atmospheric turbulence power spectra is good for. the vertical component, but that for the horizontal component, a second power rise is evident at very long wavelengths. Finally, the results of a recently completed study are providing new knowledge concerning the degree of "rounding" of the knee of the von Karman model introduced by nonhomogeneity.

Lightning:

Lightning strike hazards to safe aircraft operation have been the object of NASA study for nearly two decades. In the 1960's attention was focused on prevention of fuel vapor ignition by lightning, and on the behavior of stainless steel and titanium "wet wing" structural panels when struck by lightning. Out of this work evolved design principles which avoided the hazards presented to the fuel tank by "hot spots" and metal spalling behavior. Present design practices in lightning protection center primarily about the avoidance of direct effects of burning, blasting, and physical deformation of skins and structural elements. Both the military services (Ref. 4) and the FAA (Kef.5) have published specifications which provide guidance to the designer for avoiding direct hazards.

There is currently increasing evidence of troublesome electromagnetic effects due to lightning, involving both permanent damage and temporary malfunction of equipment.

While lightning-induced effects are suspect in some causes of lost aircraft, they are more certain to have caused curtailment of operations or reductions in safety margins. Earlier vacuum tube electronics were relatively immune to lightning-induced transient voltage surges; however, the newer generations of modern, solid-state microcircuitry are increasingly vulnerable to upset or damage from the indirect effects of lightning seen as electromagnetically induced surges. As modern aircraft become more and more dependent upon reliable operation of critical electronic systems, it becomes evident that new knowledge and understanding of lightning indirect effects is essential to safe operation.

NASA, through contractural efforts with General Electric, developed a simulated lightning test and measurement system known as Transient Analysis. This system permits the investigation of specific electromagnetic effects of lightning without hazard to the aircraft being tested. The Transient Analysis technique is fully described in Reference 6.

NASA's Dryden Flight Research Center has developed and demonstrated a digital fly-by-wire flight control system in an F-8 aircraft. Industry is moving toward incorporating even more digital computer and control electronics in new aircraft designs. The indirect effects of lightning very clearly have the potential of presenting a hazard to the safety of flight, and this hazard may be particularly acute for digital systems. While most practical digital fly-by-wire systems would include multiple redundant control circuits, there may be situations wherein the high level electromagnetic interference produced by lightning could interfere with all of the channels of a fly-by-wire system at once, yielding what is in fact no redundancy at all.

Thunderstorm Gust Fronts:

The thunderstorm is one of the most destructive natural phenomena, producing intense rain showers, hailstones, and tornadoes. Another, but often unrecognized, destructive product of the thunderstorm is the sudden, intense wind surge or gust front that develops at the surface. These gust fronts, or "straight line winds" can be a major hazard to aircraft flying at low levels or on approach to landing. The danger of these gust fronts is the sudden onslaught of high winds as far as 20 Km ahead of' the parent storm cell. During frontal passage, wind speeds may increase from a relative calm to 60 knots in five minutes or so, and then decrease just as suddently. Such gust front occurrences can constitute a major hazard to low-flying aircraft, especially on approach to a landing.

A challenge for aviation meteorologists is to be able to predict the occurrence, intensity, and position of these gust fronts using readily available rawinsonde, satellite, radar, and surface observations. Currently, most observations are obtained on time and spece scales much larger than the gust front itself, the cold outflow of which is usually about 10 Km long, 2 Km deep, having a lifetime of up to about an hour. Several past efforts in predicting gust fronts involved relating large scale parameters to small scale events, but the results were inconclusive and disappointing, demonstrating the lack of a sufficiently complete understanding of the complex mechanisms of the gust front. Knowledge of the gust front structure is therefore of prime importance to achieving confident prediction. Only a high density surface observation network can resolve the surface features of a gust front, Data on its vertical structure is lacking. Tower measurements have the drawback of limited height and fixed position. Aircraft measurements are costly. Radar and other remote sensing concepts may offer promise, but have not been applied to this problem to any great extent.

NASA has tried therefore, to overcome some of these limitations by employing numerical modelling to obtain more information on the structure and mechanism of the gust front phenomenon. Our model is a non-hydrostatic high resolution, two-dimensional primitive equation model, described fully in Reference 7. The model includes sound waves, but they are strongly damped by a high frequency filter, leaving the gravity waves virtually untouched. A fine resolution grid was used to resolve small scale features. The model is very stable computationally. The chief limitation was the short time step necessitated by the non-hydrostatic degree of freedom. The effect of evaporative cooling in producing a vigorous downdraft was parameterized by an arbitrary local cooling function. This function was applied to produce a steady downdraft of cold dense air to drive the cold outflow and assoicated gust front. The result is a good simulation of the gust front with the capability to examine its structure in some detail for predictive purposes, and NASA and other meteorological research agencies are now using the model as an effective tool to determine the behavior of gust fronts.

AIRCRAFT GROUND OPERATING PROBLEMS

For many years, NASA has conducted research on problems associated with improving the control of aircraft during takeoff roll and landing touchdown and rollout operational phases. This research has included attention to runway pavement design, tire tread design, landing gear loads, and the tire/surface interface under all weather conditions.

Additionally, NASA has explored ways of reliably measuring runway slipperiness in functional terms useful to a reliable prediction of stopping distance.

Representative special facilities and equipment supporting this research and the Landing Dynamics Facility at Langley Research Center, the Research Runway at Wallops Flight Center, the Powered Ground Test Vehicle, and various slipperiness-measurement vehicles, including the Diagonal Braked Vehicle.

Major programs currentlyunder way include investigations of air cushion landing systems concepts, determination of mechanical and frictional properties of tires, continued investigation of runway slipperiness, antiskid control research, takeoff/landing simulator development, and tire materials research.

AIRCRAFT FIRE TECHNOLOGY

Modern jet transport aircraft operating at weights double that and more of older piston engine airplanes provide an increased likelihood of crash-impact survival for their occupants. Modern structural designs, including stronger floor and improved seat retention, subjected to decelerative loads of a landings crash or aborted takeoff, absorb much of the impact that the occupant would otherwise sustain. However, the large amounts of onboard fuel and its potential for being spilled and involved with a multitude of ignition sources make post-crash fire a continuing potential threat to occupant survival in a crash. The large amount of organic materials aboard the modern aircraft consitute another potentially ignitable "fuel" which can produce toxic gas and smoke during pyrolysis. While three catastrophic inflight fires have occurred in jet transports within recent years, most in-flight fires are of small magnitude, are detectable early, and can usually be controlled. Nevertheless, the potential for catastrophe remains, and further attention to preventing, detecting and quenching is essential. Ramp fires are a relatively recent problem, where aircraft with ground power connected may be left unattended for periods of time awaiting scheduling turn-arounds. If they are connected by passenger corridors to the ground terminal, the potential for further fire spread is broadened.

Opportunities to improve fire safety are easily identified with the use of "logic trees" framework, and NASA is sponsoring research in close coordination with FAA, the military services, and the aircraft industry to effect an improved fire safety level. Overall fire safety and survivability for both military and civilian aircraft can be increased by preventing ignition of combustible substances. This is a major factor in considering survivability and vulnerability of close support military combat aircraft. Survivability has been achieved in some instances by ignition suppression of the ballistic incendiary threat and by protection of the fuel system with low densityfoams and composites, preventing the fuel from coming into contact with the ignition source. NASA research in these areas was described by Parker during the AGARD Propulsion and Energetics Panel Meeting on Aircraft Fire Safety in Rome in April 1975.

NASA's program of fire research and technology is deeply entwined with activity in other agencies and departments. Industry involvement is high, and cooperation between all parties in attacking the fire problem is unusually good. NASA and FAA have entered into an Interagency Agreement which specifies respective roles of the two agencies in fire research. NASA's research takes cognizance of the various factors contributing to aircraft fire and survivability.

Our goals are to improve the understanding of fire dynamics in ramp, postcrash, and in-flight situations; to support the development of improved test methodology; to provide materials technology that will yield properties which cooperate to resist ignition, to insulate, and to exhibit low outgassing levels of smoke and toxic by-products; to explore means of reducing ignition and fire build-up rate; and to provide basic research and technology support to other agencies. This basic program is augmented by a 5-year program called FIREMEN (Fire Resistant Materials Engineering) which is aimed at evaluating new materials concepts in real aircraft applications, improving test methods, and expoloring processing and fabrication problems in order to accelerate the application of fireworthy technology.

CRASHWORTHINESS RESEARCH

Crashworthiness Design Technology:

A joint NASA-FAA program was begun three years ago to develop an upgraded reliable technology upon which crashworthiness design of aircraft can be based. This program has three objectives:

- Development of analytical methods,
- Definition of a survivable crash envelope,
- Improved seat and restraint systems.

The organization of this program divides the respective responsibilities of the two agencies, and NASA's portion of the joint program has three program elements;

- Full-scale crash simulation testing,
- Nan-linear crash impact analysis,
- Crashworthy design concepts.

The full-scale crash simulation testing is being conducted at the Langley Research Center's Impact Dynamics Facility, the former Lunar Landing Research Facility. It has been modified for free-flight crash testing of full-scale aircraft structures and structural components under controlled test conditions (Ref. 8). The test vehicles are suspended pendulum fashion from beneath the bridge of the facility, swung and released just prior to impact to simulate free-flight crash conditions at impact.

The objective of the analytical effort is to develop the capability to predict the non-linear geometric and material behavior of sheet stringer aircraft structures subject to large deformations and to demonstrate this capability by determining the plastic buckling and collapse response of these structures to impulsive loadings. Two specific finite-element computer programs are being developed with attention focused on modeling concepts applicable to large plastic deformations of realistic aircraft structures:

- Plastic and Large Defelction Analysis of Nonlinear Structures (PLANS): This computer program for static finite-element analysis is capable of treating problmes which include bending and membrane stresses, thick and thin axisymmetric bodies, and laminated composites (Ref. 9).

- Analysis of Crash Transients in Inelastic Or Non-linear Range (ACTION): A non-linear dynamic finite-element computer program is being extended at Langley to more realistic aircraft sheet stringer structures. Membrane elements have been added to the initial truss and frame simulation capability to predict the transient response of frames with and without sheet coverings.

These programs are currently being evaluated in comparison with experimental results on some simplified structures.

The development of structural concepts that improve the energy absorption characteristics of a structure is key to improving occupant survivabiltiy in a crash. Langley is investigating effects of modification of structural assemblies, changing the geometry of its elements, or adding specific energy absorption devices to help dissipate kinetic energy.

AIRCRAFT WAKE VORTEX HAZARD RESEARCH

Aircraft wake vortices have been recognized for many years as a major operating problem to contend with as traffic densities in the terminal area have increased to the extent that aircraft separations are limited by vortex upset considerations. There is ample documentatin of the hazards associated with vortex encounters which have resulted in upset of the following aircraft at close distances.

The potential hazard of vortices was recognized well over a decade ago, but not until 1972 was a substantial joint program mounted between the FAA and the NASA to investigate means of reducing the operational restrictions imposed by vortex presence. NASA's research in wake vortex alleviation and support to FAA in developing ground-based vortex warning concepts is broad-based.

AVIATION SAFETY REPORTING SYSTEM

The Federal Aviation Administration implemented an Aviation Safety Reporting Program in May 1975, for the purpose of identifying discrepancies and deficiencies in the national air transportation system. The program permits anyone using and working in the system to report, in a convenient manner, problems or other situations critical to system safety. FAA recognized the need for a "third party" to receive, process, and analyze safety reports in order to insure anonymity to the person or persons providing the information. It has been generally hoped that this procedure would encourage voluntary, timely reporting of potential safety problems by reducing the risks of potential organization or peer-group harassment of the reporting individual. The FAA requested NASA's participation as the "third party" in the process, based upon the success of a NASA Human Factors research effort begun in 1974 (Ref. 10). NASA subsequently designed the present Aviation Safety Reporting System (ASRS) and has been operating it since it went "on line."

Reference 11, NASA Release 76-52, contains a complete description of the ASRS, its background, management, staffing, and procedures for reporting.

The ASRS is designed to act as an early warning system. Its purpose is to collect reports which may provide valuable safety information, to extract the safety-related data, and to inform those who can act positively on the information hopefully before an accident occurs. As a so-called "clearing house" for the collection and dissemination of data, the ASRS is organized to detect longer term trends of events which individually may not appear significant, but which collectively may suggest unsafe tendencies.

While the ASRS is being operated by NASA for the FAA's use in maintaining air transportation system safety, it will also function as a part of NASA's ongoing research in aviation safety. Thus the ASRS will gather descriptive data while NASA's Aviation Safety Program will continue to perform analytical and experimental studies of problems in the operational environment.

ACKNOWLEDGEMENT

The author is indebted to Mr. John Enders, Chief Aviation Safety Technology Branch, NASA Office of Aeronautics and Space Technology for providing extensive material without which this paper would not have been possible.

REFERENCES

1. Flight International, w/e April 10, 1976, p. 892.
2. Enders, John H., and Joseph W. Stickle, "Aviation Safety and Operating Problems Research and Technology."
3. Scoggins, J.R., Clark, T.L., and Possiel, N.C., "Relationships between Stratospheric Clear Air Turbulence and Synoptic Meteorological Parameters over the Western United States between 12-20 Km Altitude," NASA CR-143837, December 1975.
4. Mil Spec MIL-B-5087B (Bonding, Electrical, and Lightning Protection for Aerospace Systems).
5. FAA Advisory Circular No. AC 25-3A (Protection of Transport Aircraft Fuel Systems Against Lightning).
6. Walko, L.C., "A Test Technique for Measuring Lightning Induced Voltages in Aircraft Electrical Circuits," NASA CR-2348, February 1974.
7. Mitchell, Kenneth E., "A Numerical Investigation of Severe Thunderstorm Gust Fronts," NASA CR-2635, December, 1975.
8. Hayduk, R.J., and Thomson, R.G., "Simulation of Aircraft Crash and its Validation," AIAA Paper 75-271, AIAA 11th Annual Meeting and Technical Display, Washington, DC, February 24-26, 1975.
9. Arment, H., Jr. Pifko, A., and Levine, H., "Finite Element Analysis of Structures in the Plastic Range," NASA CR-1649.
10. Barnhart, W.C., Billings, C., Cooper, G., et al, "A Method for the Study of Human Factors in Aircraft Operation," NASA Ames Research Center, NASA TMX 62472.
11. NASA Fact Sheet, Release No. 76-52, "Aviation Safety Reporting System," NASA Headquarters, Washington, DC, 1976.

UTSI ATMOSPHERIC SCIENCE PROGRAM

Walter Frost
Director of Atmospheric Science
University of Tennessee Space Institute

Two areas of research are being carried out in the Tullahoma area which is of interest to a group concerned with meteorological and environmental inputs to aviation systems. One effort deals with the investigation of wind fields about bluff geometries typical of buildings or other man-made obstructions to the surface wind and the behavior of aircraft flying through these disturbed wind fields. The second effort is the definition and mathematical models of atmospheric wind shear associated with thunderstorms, stable boundary layers and synoptic fronts. These mathematical models can be utilized in flight simulators to train pilots and flight crews and to develop instrumentation for landing in adverse wind shear conditions.

The objective of the first project is to enhance the safety of aircraft operations under adverse wind conditions with special emphasis on wind fields around a surface obstruction. The project consists of two parts: (1) definition of the wind environment and (2) computer simulation of aircraft dynamics in variable wind fields. The scope of the wind environment definition portion of the program is presently to (1) survey and define the problem (2) analytically model winds about bluff building-like geometries, (3) conduct experimental field studies of winds over simulated block buildings, (4) develop turbulence simulation techniques and (5) conduct analytical studies of the secondary wave structure in the planetary boundary layer.

a

The work conducted to date in the wind environment definition is listed in Tables 1 through 4. References to detailed reports on the research are also listed in the tables.

The scope of the computer simulation of aircraft dynamics in variable wind fields includes computer simulation of flight paths through the wind fields which are computed under the wind environment definition portion of the study. The two-dimensional equations of motion with variable wind inputs are utilized with both fixed control and digital automatic control simulation. Some work on the influence of variable winds on aerodynamic coefficients is also being carried out. Table 5 lists the areas of completed work and reference reports of the research conducted to date. A brief description of this aspect of the work is given in the following.

Operations of V/STOL aircraft in the vicinity of buildings may became hazardous due to the complex flow fields created by surface winds passing over the buildings [1]. The research investigates the behavior of winds about block geometries characteristic of building shapes and of the flight performance of an airplane passing through the wind fields. For illustrative purposes an aircraft having the characteristics of a DHC-6 or DC-8 is utilized. The two-dimensional equations of motion for the aircraft are written to include variable winds and wind shear components. The influence of those terms in the, equations of motion which explicitly contain effects due to wind shear have been assessed as part of the research effort.

Two characteristic building geometries considered to date are a long, low two-dimensional building which is simulated as a forward facing step and a long, rectangular cross section block geometry. Both geometries are illustrated in Figure 1.

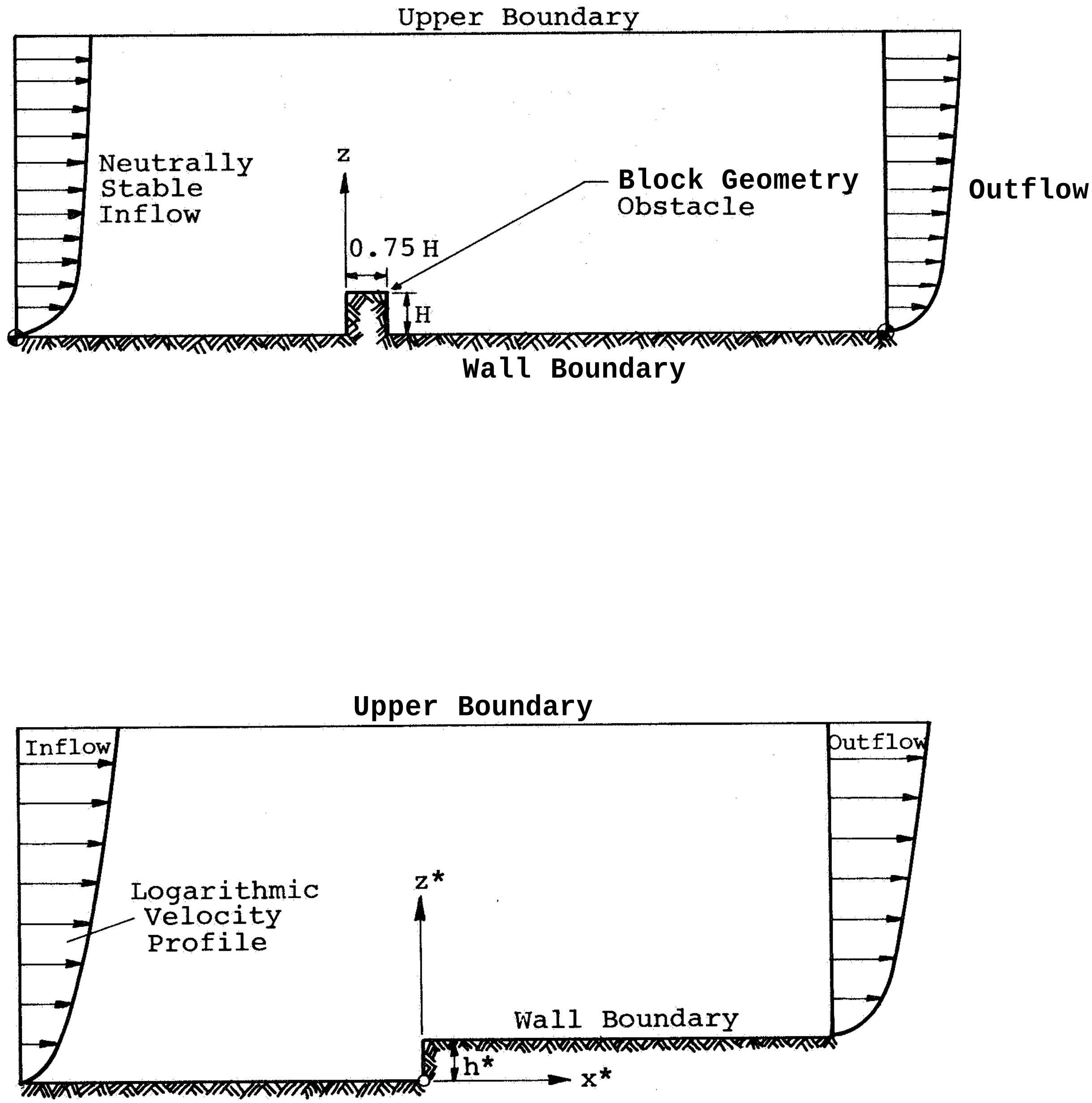


Figure 1. Illustrates typical bluff geometries considered to simulate buildings.

Wind fields about bluff geometries. Wind fields about the bluff geometries illustrated in Figure 1 have been computed by solving the two-dimensional incompressible Navier-Stokes equations. Turbulence was modelled in the solution with the two equation model that includes a transport equation for the turbulence kinetic energy and a transport equation for the turbulence length scale. Details of these solutions are given in Bitte and Frost [2] and Shieh, Frost and Bitte [3] . Figure 2 shows typical wind fields over the forward facing step and over the block geometry, respectively.

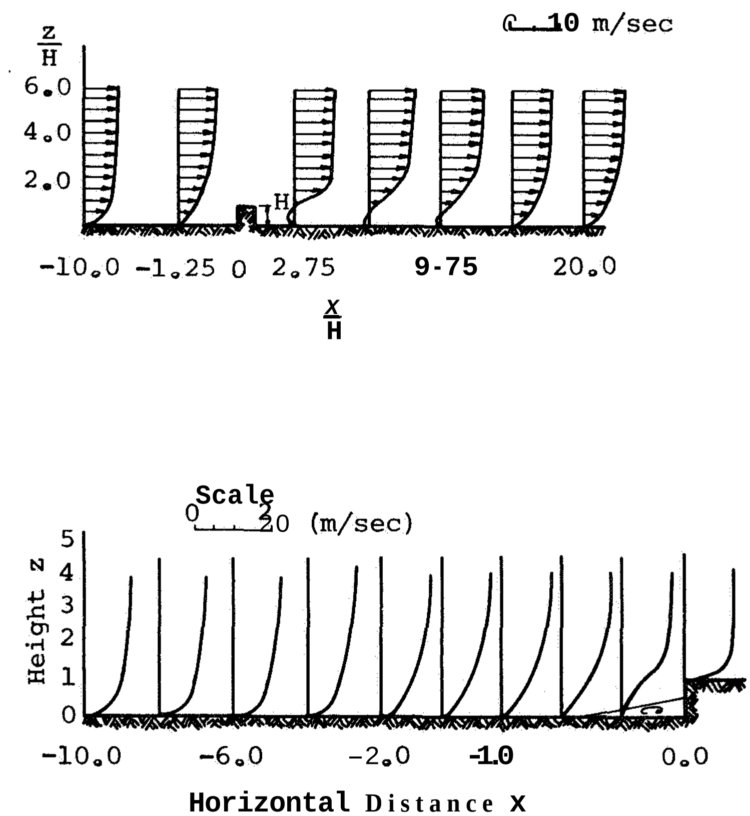


Figure 2 Typical Wind Fields About Simulated Buildings.

The influence of these wind fields on a STOL aircraft passing over the building or landing upon the top of the building are investigated by solving the two-dimensional equations of motion for the aircraft with the computed wind fields as inputs.

Governing equations of motion. The aircraft is modelled as a point mass and a force balance perpendicular and parallel to the ground speed velocity vector, Figure 3, is employed to derive the following equations:

$$V = -D_1 \; (C_D \cos \delta + C_L \sin 6) \; V_a^2 - D_2 \sin \gamma$$
$$+ \; D_6 F_T \cos \; (\delta_T + \alpha) \qquad (1)$$

$$\dot{\gamma} = \; (D_1 V_a^2 \; (C_L \cos \delta = C_D \sin \delta) - D_2 \cos \gamma$$
$$+ \; D_6 F_T \sin \; (\delta_T + \alpha))/V \qquad (2)$$

where Figure 3 defines the nomenclature. A momentum balance gives:

$$q = D_7 F_T + D_5 V_a^2 C_m \qquad (3)$$

with the remaining equations making up the complete set being:

$$V_a = [(is - W_x)^2 + (\dot{z} - W_z)^2] \qquad (4)$$

$$V = W_x \cos \delta - W_z \sin \gamma + ((W_z \sin \gamma - W_x \cos \gamma)^2$$
$$+ \; V_a^2 - (W_x^2 + W_z^2))^{1/2} \qquad (5)$$

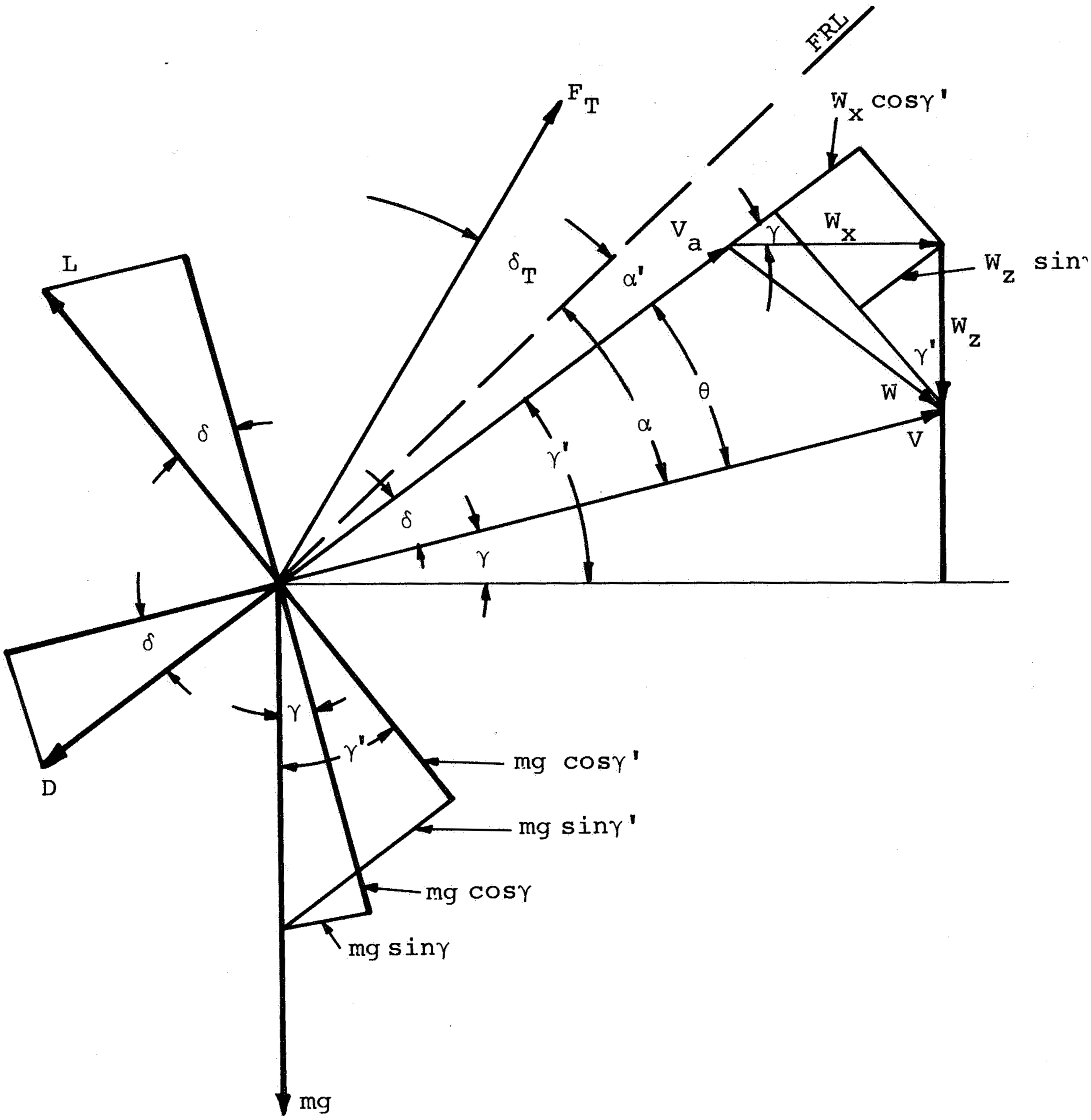


Figure 3 Point Mass Aircraft Model and Nomenclature.

$$\sin \delta = (W_x \sin \gamma + W_z \cos \gamma)/V_a \tag{6}$$

$$\dot{\alpha}' = q - D_1 C_L V_a - (D_2 \cos \gamma' + D_6 F_T \sin (\delta_T + \alpha')$$

$$+ (\dot{W}_x \sin \gamma' + \dot{W}_z \cos \gamma'))/V \tag{7}$$

$$W_x = \frac{\partial W_x}{\partial t} + V \left[\frac{\partial W_x}{\partial x} \cos \gamma - \frac{\partial W_x}{\partial z} \sin \gamma \right] \tag{8}$$

$$W_z = \frac{\partial W_z}{\partial t} + V \left[\frac{\partial W_z}{\partial x} \cos \gamma - \frac{\partial W_z}{\partial x} \sin \gamma \right] \tag{9}$$

Inspection of the equations show that wind shear enters explicitly only in Equation (7). The term $\dot{W}_x \sin \gamma' + \dot{W}_z \cos \gamma'$ in this equation demonstrates that passing through a varying wind field results in a contribution to the rate of change in angle of attack. Of course, variation in wind enters Equations (1) and (2) indirectly through V_a and δ, see Equations (4) and (6). Characteristic aerodynamic coefficients C_L, C_D and C_M are used in the analysis as pertain to the aircraft of interest.

If the equations of motion are written in terms of airspeed V_a and pitch angle relative to the direction of V_a for a coordinate system with x aligned along V_a, one obtains:

$$V_a = - D_1 V_a^2 C_D - D_2 \sin \gamma' + D_6 \cos (\delta_T + \alpha')$$

$$- W_x \cos \gamma' - W_z \sin \gamma') \tag{10}$$

$$\dot{\gamma}' = - D_1 V_a^2 C_D - D_2 \sin \gamma' + D_6 \cos (\delta_T + \alpha')$$

$$- (W_x \cos \gamma' - W_z \sin \gamma') \tag{11}$$

In these equations wind shear appears explicitly when W_x and W_z are introduced through Equations (8) and (9).

Discussion of the equations of motion. It is frequently reported that the influence of wind shear will have particularly strong effects on STOL aircraft due to their slow landing speed and steep flight paths. To investigate the significance of this statement, the various terms which explicitly contain wind effects in the equation of motion are examined for the conventional take-off and landing aircraft (CTOL) and for the short take-off and landing aircraft (STOL). Aerodynamic coefficients characteristic of a **DC-8** and of a DHC-6 are used in the investigation. Examination of Equations (10) and **(11)** indicate that there is a contribution to the acceleration of relative air speed of the aircraft and of pitch rate due to the direct entrance of wind shear into the last term on the right-hand side of the equations.

One can isolate these terms and compare their relative magnitudes for different types of airplanes under different glide slopes and landing speeds. The contribution to $\dot{V}_a$ and γ' of the wind shear terms thus isolated are given in Equations (12) and **(13)** below:

$$\Delta V_a = - \frac{\partial W_x}{\partial z} V_a \left| \frac{V}{V_a} \sin\gamma \left| \frac{V}{V_a} \cdot \cos\gamma - \frac{W_x}{V_a} \right| \right| \qquad (12)$$

$$\Delta \dot{\gamma}' = \frac{\partial W_x}{\partial z} \left[\frac{V}{V_a} \right]^2 \sin 2\gamma \qquad (13)$$

Equation (12) shows the contribution to the acceleration of relative velocity resulting in Equation (10) from the wind shear contribution. Figure *4* illustrates the variation of this contribution to the acceleration as a function of altitude. The wind shear considered in Figure *4* is taken as a conventional logarithmic wind profile having a friction velocity $u^* = 1$ m/s and a surface roughness $z_o = 10^{-3}$ meters.

$$W_x = \frac{u^*}{\kappa} \ln \frac{z + z_o}{z_o} \qquad (14)$$

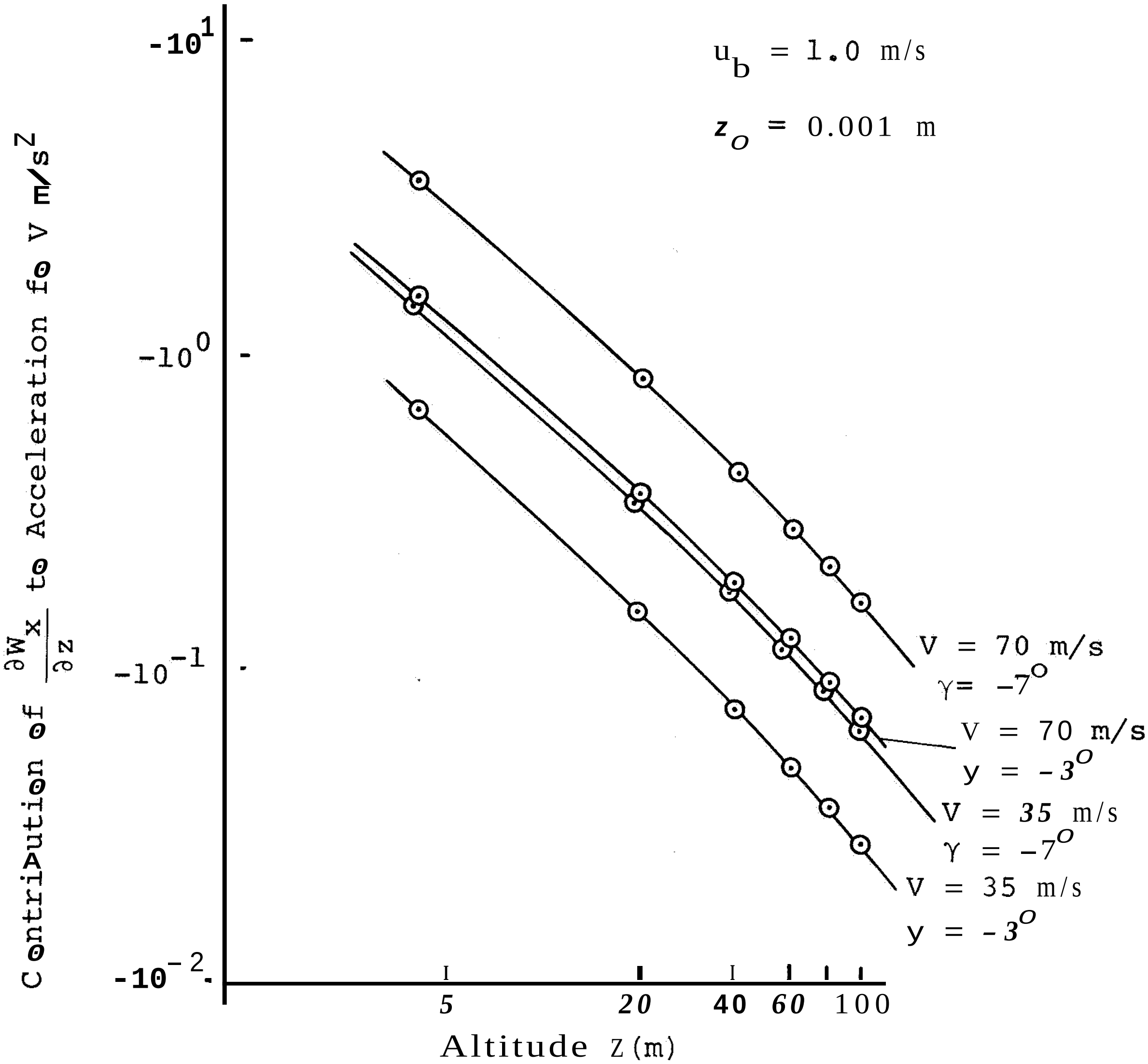


Figure 4 Contribution of Wind Shear Term to the Relative Acceleration

It is interesting to observe that the curves for the landing speed of 70 m/s at an angle of 3" lies almost on top of the curve for a slower landing speed of 35 m/s and a steeper glide path of 7". The former values are typical of the landing speed and glide path of a CTOL aircraft whereas the latter values are typical of those of a STOL aircraft. The figure illustrates that the strong influence of wind shear suspected to occur on STOL aircraft is no worse than the CTOL due to the compensating effects of the steeper glide path. The reason is that even though the STOL has a slower landing speed it "cuts" through velocity gradients at an equal rate to that of the CTOL aircraft because of the steeper glide slope.

Figure 5 shows the contribution to the change of pitch angle caused by wind shear. Again one sees that the compensating effects of higher landing speed coupled with smaller glide slope and slower landing speed coupled with steeper glide slope tends to bring the curves for the rate of change of pitch rate closer to one another.

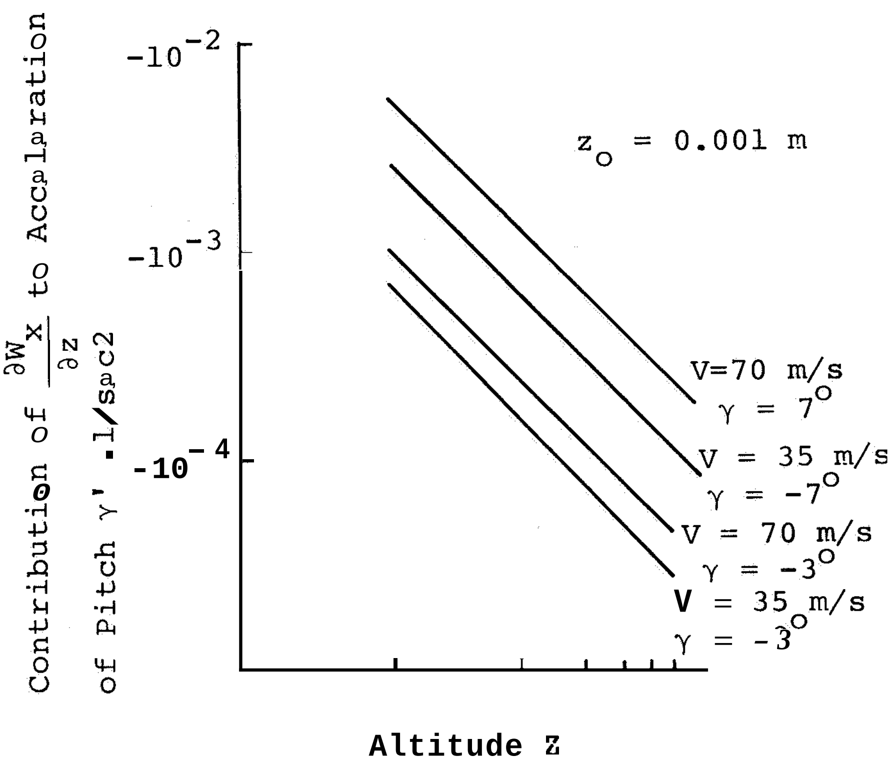


Figure 5 Contribution of Wind Shear to Change in γ'.

It is also interesting to compare the contribution to the change of relative velocity caused by wind shear to that caused by drag. Taking the ratio of those two terms appearing in Equation (8) andcomputingtheir effects for an atmospheric boundary layer, one obtains the results shown in Figure *6*. Once again, due to the variation in landing speed and glide slope, this ratio remains almost identical for the two different aircraft. Thus one is led to believe that the suspected influence of wind shear on the STOL aircraft will not be as pronounced as originally suggested [4,5]. Similar conclusions regarding the influence of wind shear on **STOL** aircraft are reported by Ramsdell[6]. Further examination of the various terms and their comparison with terms contributed due to wind shear are being investigated under the current contract effort.

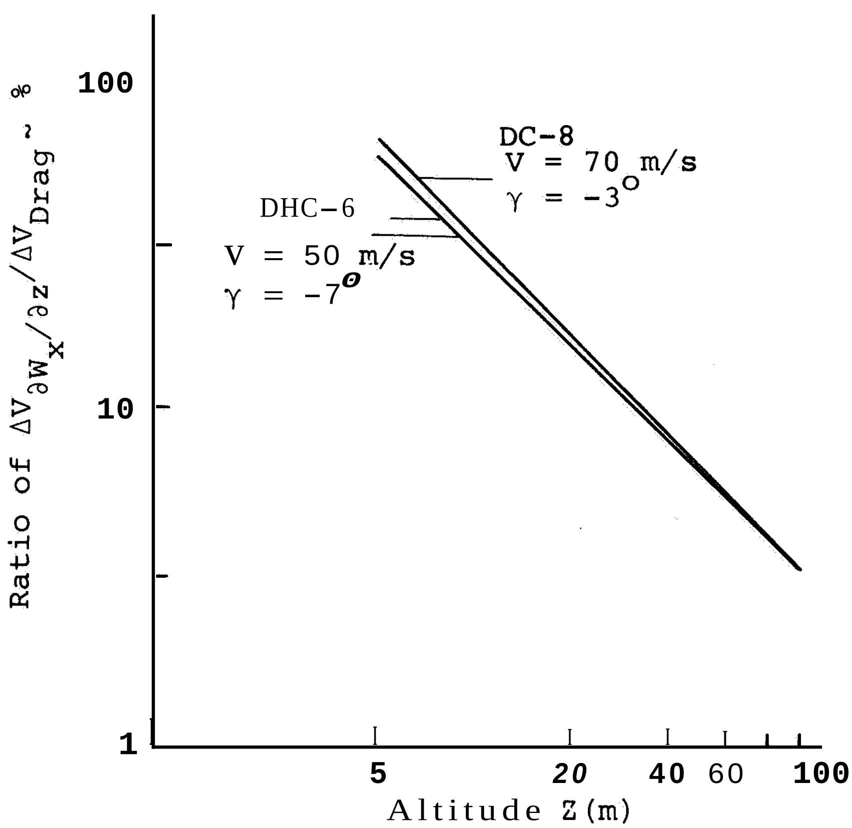


Figure 6 Ratio of Change in V_a due to Wind Shear to that due to Drag

Flight through building; disturbed winds. Having introduced the effects of wind shear into the governing equations of motion for the airplane, the performance of aircraft in the wind fields created by atmospheric flow over simulated buildings is investigated. Figure (7) shows the flight path of an aircraft taking off and landing into the wind flowing over a two-dimensional bluff type body similar to a long building. Figures (8) and (9) show typical wind fields that would be encountered by the aircraft if it remained on the prescribed flight path. One observes for landing into a flow over a building a sudden drop in longitudinal wind speed just as the aircraft passes over the building and a sudden increase in vertical updraft. Figure (9) shows the wind encountered by an airplane on the fixed take-off path. Again one observes a rather severe increase in head-wind as the airplane passes over the building. These wind fields

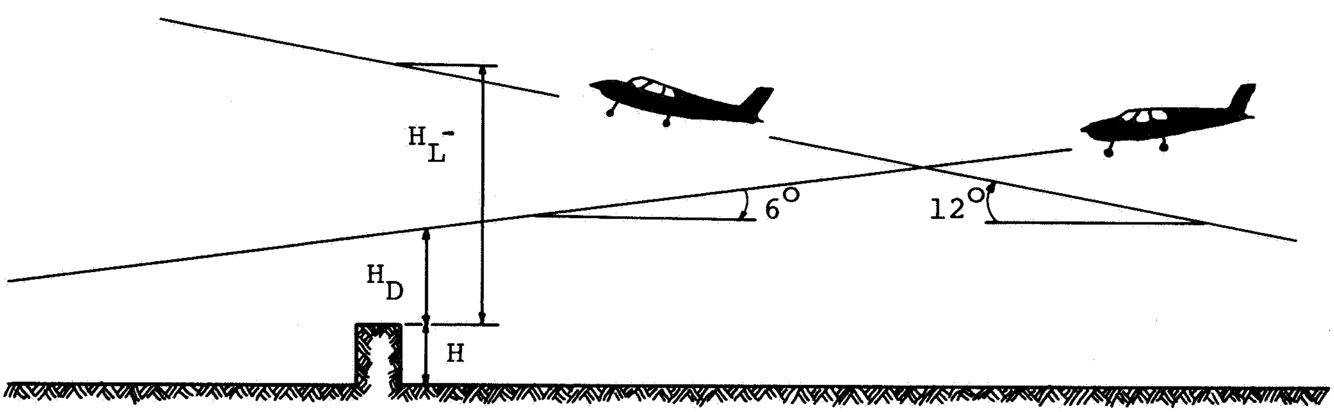
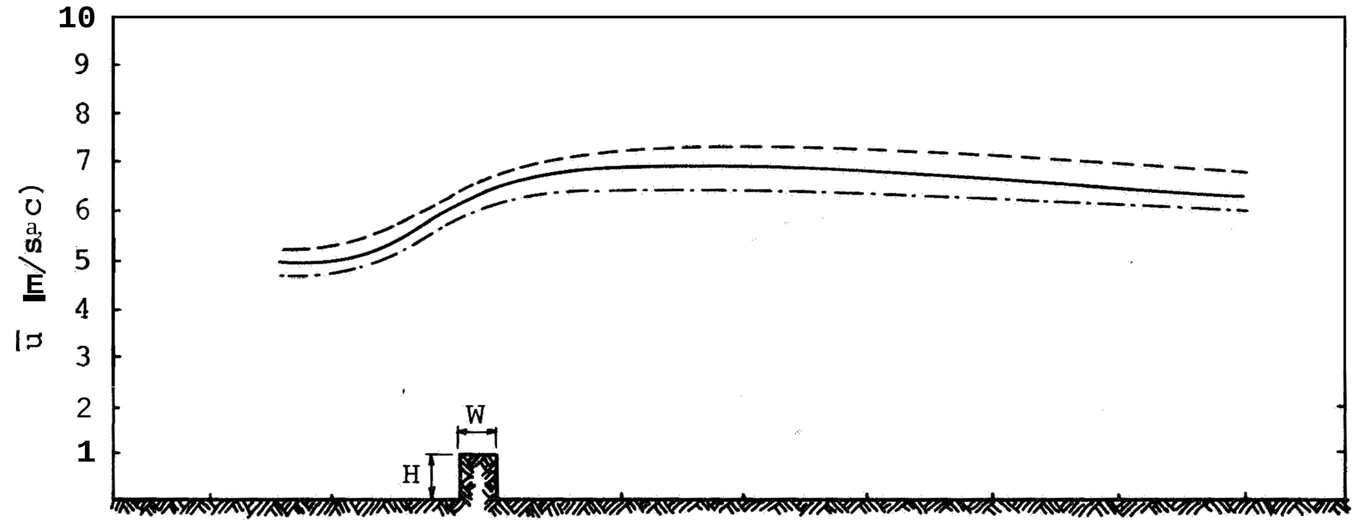
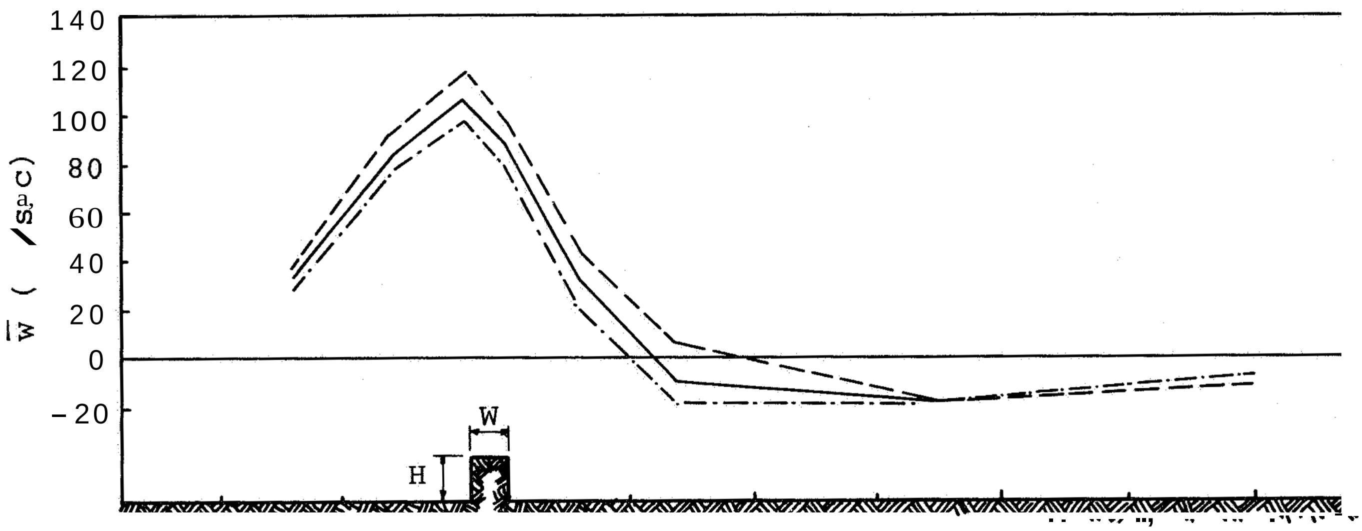


Figure 7 Illustrates Flight Path of Aircraft over Building



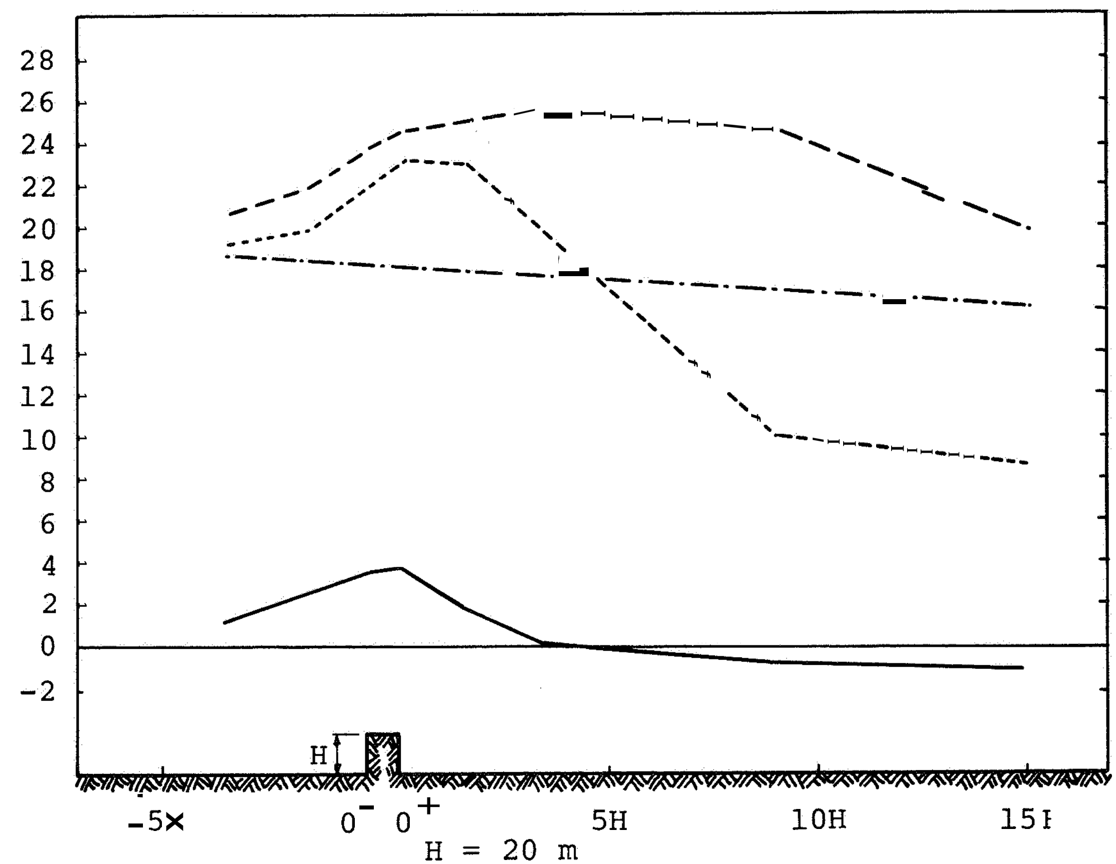
z_o = 0.7 cm; u_* = 31.0 cm/sec — z_o = 3.5 cm; U_{6H} = 6.1 m/sec; H = 3.2 m — z_o = 7.0 cm; W = 2.4 m



z_o — z_o — z_o

U_* = 31.0 cm/sec U_{6H} = 6.15 m/sec H = 3.2 m W = 2.4 m

Figure 8 Wind "Seen" by Aircraft Landing over Block Building.



u-component velocity distribution along 6° take-off path.
(no building presence).
u-component velocity distribution along 9° take-off path.
(building presence).
u-component velocity distribution along 12° take-off path.
(building presence).
v-component velocity distribution along 9° take-off path.
(building presence).

Figure 9 Wind Speed 'Seen' by Aircraft Taking off over Block Building.

are being introduced into the equations of motion and results describing the computed flight paths of the airplane through the wind fields with both fixed and automatic controls will be provided.

Figures 10 and 11 show the flight path of a STOL aircraft landing with fixed controls over a long, very wide, low building. Additionally, the flight path and the aircraft trajectory if landing in an atmospheric boundary layer undisturbed by the presence of the building are illustrated. The sudden decrease in headwind encountered just at the leading edge of the building causes the airplane with fixed controls to land short. With a 10 m/s wind the airplane lands approximately 30 m short of the glide path touchdown point and with a 50 m/sec wind and the aircraft lands approximately 70 m short. Thus under strong wind conditions, the aircraft encountering a strong shear caused by the edge of the building, is drawn in toward the building. This illustrates the potential hazard of the presence of large bluff objects which create complex wind patterns in approach paths.

Many other flight paths with both fixed and automatic controls and the control inputs required to remain on the glide slope will be investigated during the study. Results of the program will provide an envelope of wind speeds and building geometries for parametric variations in surface roughness of the surroundings which create hazardous landing conditions for STOL type aircraft operating in the vicinity of buildings.

Flight through Wind Shear. The second phase of the work has the objectives of studying and analyzing available wind shear information for synthesizing wind shear models for aircraft hazard definition. From this information a comprehensive set of wind profiles and associated wind shear characteristics which incompass the full range wind shear environment potentially encounterable by an aircraft in the terminal area will be developed. The mathematical wind shear scenario will be provided in format for direct engineering applications.

A supplementary effort to this program is to develop the necessary two-dimensional computer code for aircraft motion which will allow analysis of the flight through the thunderstorm wind shear profiles to be carried out.

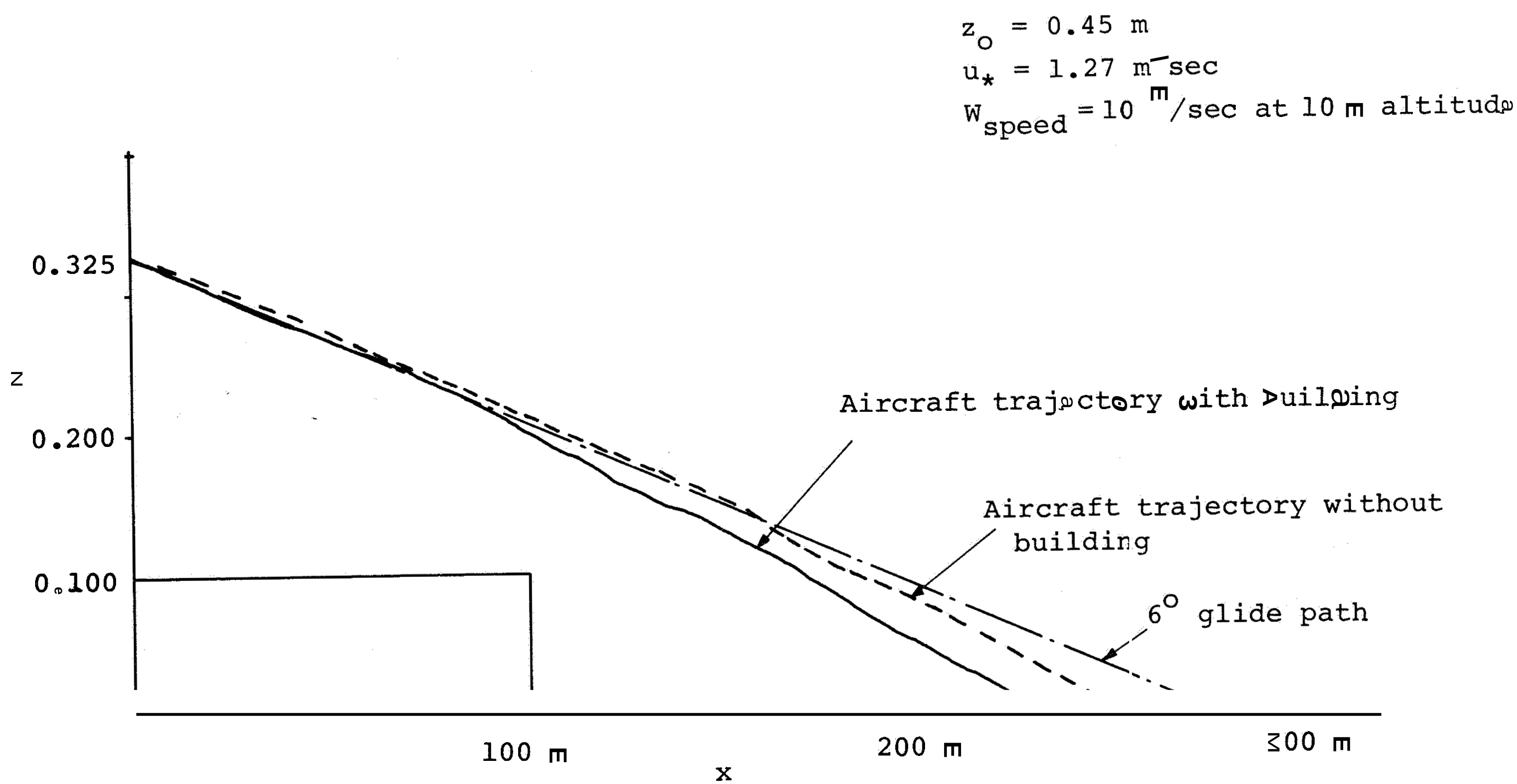


Figure 10 Landing Flight Path over Long, Very Wide, Low Building in a 10 m/s Headwind.

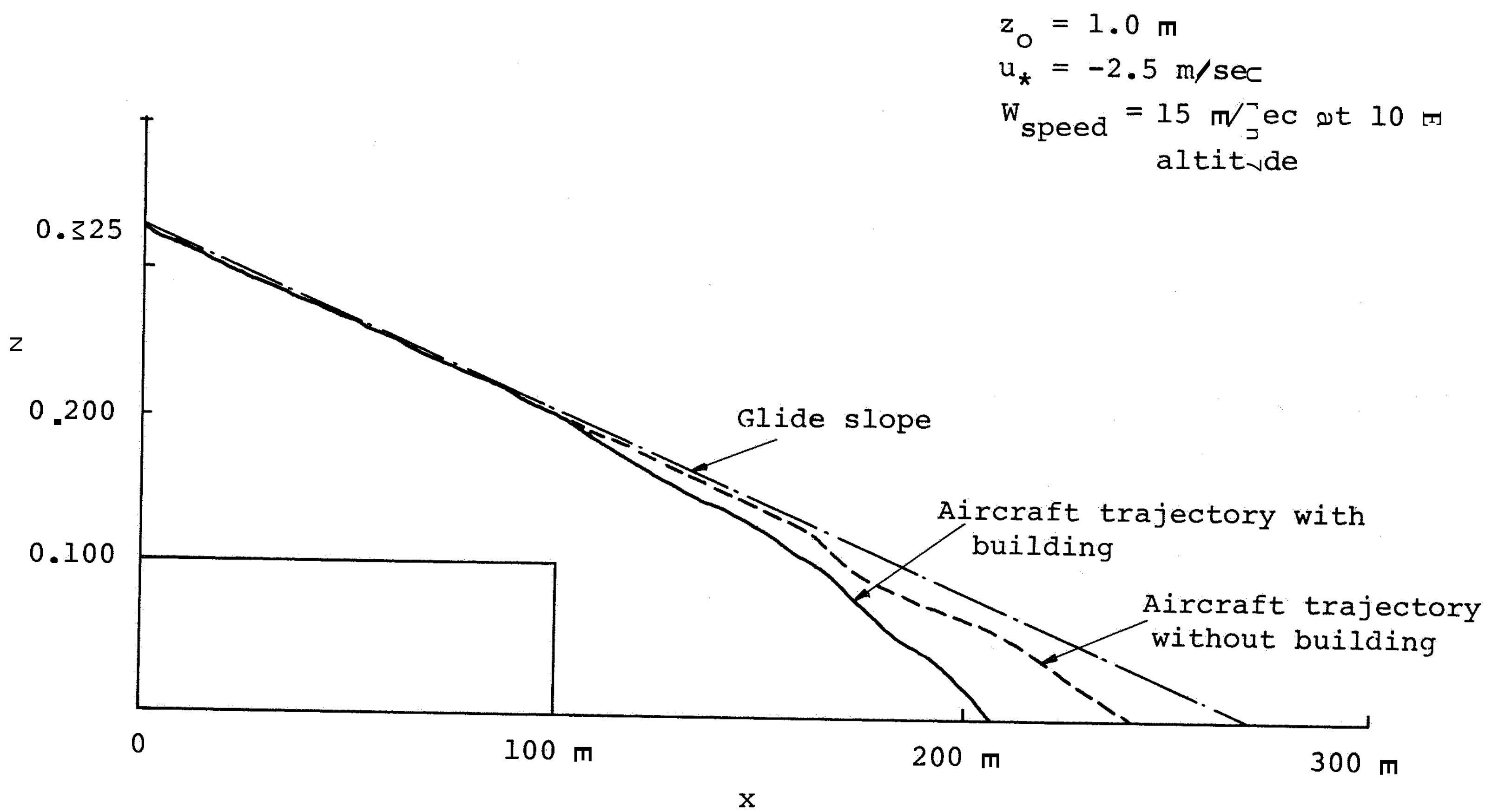


Figure 11 Landing Flight Path over a Long, Very Wide, Low Building in a 15 m/s Headwind

The wind shear profiles considered are the stable and neutral boundary layer, thunderstorms and frontal winds. The wind shear models developed will be briefly summarized and then a more detailed discussion of the flight paths through the thunderstorms will be given in view of the fact that this is probably of more interest to this particular group.

Mathematical models of the neutral and stable boundary layers consist of a table look up computer code based on the experimental data from Clarke and Hess [7] . These authors measured hourly wind profiles over flat homogeneous terrain for forty days. They expressed their data in terms of contour maps of dimensionless height versus dimensionless stability criteria. These data have been tabulated in a computer program look up routine developed which will permit the wind profile in the vertical direction for both the longitudinal and lateral wind fields to be computed for any given stability condition within the range of $\mu > -200 < -300$. A discussion of the program is given in Reference 1. The mathematical models for the thunderstorm gust fronts also utilize a table look up computer code based on the data of Goff from the National Severe Storms Laboratory [8]. Goff [8] has measured the wind profile's variation with height and with horizontal spatial coordinate based on Taylor's hypothesis for some twenty thunderstorms. These data were measured with a 500 meter tower over varying periods of time. Typical streamline patterns developed by Goff [8] were shown in Figure 12. Corresponding velocity contour maps for the longitudinal, lateral and vertical components of the wind have been given in this reference. All these data have been tabulated on cards and a prescribed grid format with computer table look up routine developed which allows these data to be extrapolated for any position in the x and z coordinates,

Data for major frontal velocity profiles is still being developed.

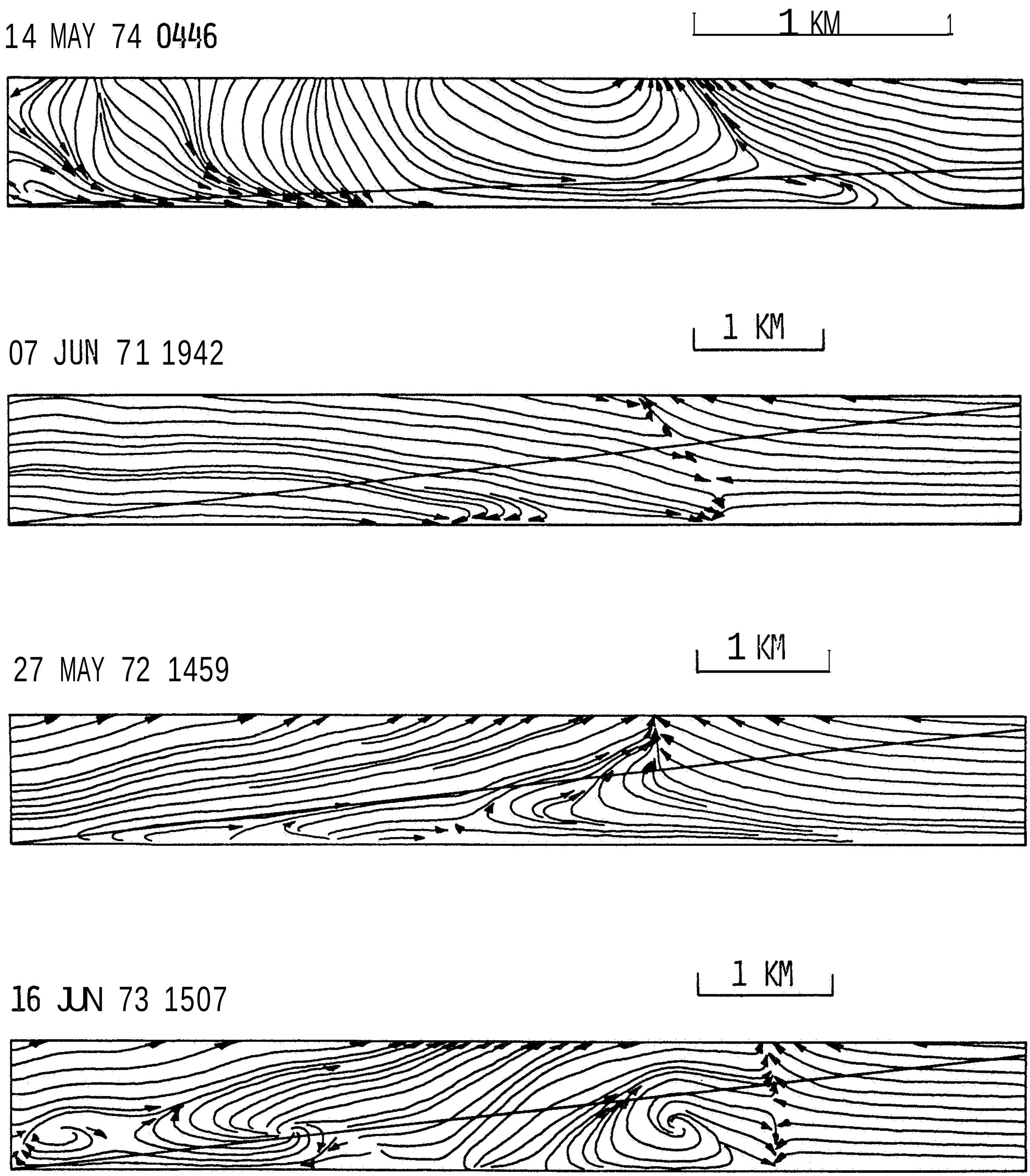


Figure 12 Typical Gust Front Streamline Patterns by Goff [8]

a

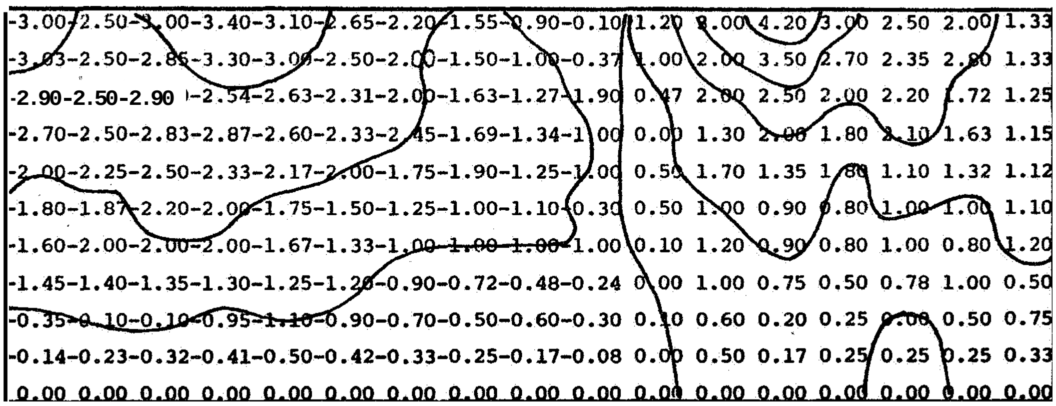
Attention is now directed to the behavior of aircraft passing through the thunderstorm gust fronts developed as described in the preceding paragraph.

Wind shear associated with thunderstorm gust fronts is a serious hazard to aircraft operations in the terminal areas. Accidents in which wind shear has been identified as a contributing factor have occurred at Kennedy International Airport, Eastern Airlines [9] , at Stapleton Airport, Continental Airlines [10], at Logan International Airport, Iberian Airlines [11] , to mention only a few recent events.

One phase of the research investigates computer simulated flight characteristics of a large jet commercial type airliner landing through 11 separate mathematical models of wind fields associated with thunderstorm outflows. The influence of the wind field and of the separate wind components individually on the aircraft flight path, pitch, ground speed and other aerodynamic parameters is investigated. The analysis is carried out first, with the aircraft controls fixed in the trimmed condition at entry into the flow field and, second, with individual parameters such as ground speed, pitch and relative airspeed held constant throughout the approach. The parameters held constant are those being investigated as the most suitable visual displays for pilot monitoring during landing in severe wind shear in the FAA wind shear manned flight simulation program currently in progress. The results of the study will isolate and identify the influence of individual wind components and of individual control input on landing through wind shears characteristic of thunderstorm outflows.

<u>Wind Shear</u>. Eleven thunderstorm outflows measured with the 500 m tower at the National Severe Storms Laboratory in Norman, Oklahoma [8], as previously described provide two-dimensional wind field where z designates the vertical dimension and x the horizontal dimension. These are tabulated on a grid system as illustrated in Figure 13. The data are punched on computer

cards and a computer look up subroutine is programmed. The subroutine when called with the position (x,z) return the horizontal wind speed, W_x, the vertical wind speed, W_z, and the spatial wind gradients W_{xx}, W_{xz}, W_{zx} and W_{zz} at that position. The programmed wind fields combined with the two-dimensional equations of motion governing aircraft flight allows the aircraft behavior in severe wind shear to be evaluated. The governing equations of motion have been described previously.



-3.00	-2.50	-3.00	-3.40	-3.10	-2.65	-2.20	-1.55	-0.90	-0.10	1.20	3.00	4.20	3.00	2.50	2.00	1.33
-3.03	-2.50	-2.85	-3.30	-3.00	-2.50	-2.00	-1.50	-1.00	-0.37	1.00	2.00	3.50	2.70	2.35	2.80	1.33
-2.90	-2.50	-2.90	-2.54	-2.63	-2.31	-2.00	-1.63	-1.27	-1.90	0.47	2.80	2.50	2.00	2.20	1.72	1.25
-2.70	-2.50	-2.83	-2.87	-2.60	-2.33	-2.45	-1.69	-1.34	-1.00	0.00	1.30	2.00	1.80	2.10	1.63	1.15
-2.00	-2.25	-2.50	-2.33	-2.17	-2.00	-1.75	-1.90	-1.25	-1.00	0.50	1.70	1.35	1.80	1.10	1.32	1.12
-1.80	-1.87	-2.20	-2.00	-1.75	-1.50	-1.25	-1.00	-1.10	-0.30	0.50	1.00	0.90	0.80	1.00	1.00	1.10
-1.60	-2.00	-2.00	-2.00	-1.67	-1.33	-1.00	-1.00	-1.00	-1.00	0.10	1.20	0.90	0.80	1.00	0.80	1.20
-1.45	-1.40	-1.35	-1.30	-1.25	-1.20	-0.90	-0.72	-0.48	-0.24	0.00	1.00	0.75	0.50	0.78	1.00	0.50
-0.35	-0.10	-0.10	-0.95	-1.10	-0.90	-0.70	-0.50	-0.60	-0.30	0.10	0.60	0.20	0.25	0.00	0.50	0.75
-0.14	-0.23	-0.32	-0.41	-0.50	-0.42	-0.33	-0.25	-0.17	-0.08	0.00	0.50	0.17	0.25	0.25	0.25	0.33
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 13 Vertical Velocity Contour Given by Goff [4] Compared with Tabulated Values for Computer Look-up Grid System

The governing equations are solved with a variable step size, multiple equation Runge-Kutta numerical integration scheme. The initial conditions for all analyses are trimmed conditions at the point at which the aircraft is assumed to enter the wind field. Typically the point of entry is either at z=91 m (300 ft) or at z = 305 m (1000 ft) and at the right-hand side of the wind field. This results in the aircraft being normally trimmed for a light tail wind and updraft with subsequent flight into strong headwinds and fluctuating up and downdrafts.

Typical Results. Figure 14 shows the flight path of an aircraft characteristic of a DC-8 with fixed thrust and elevator setting through four representative gust front wind fields. Three of the wind fields excite the phugoid mode of the aircraft causing severe overshooting of the touch down point. Note the approximate phugoid period for the assumed landing speed of 150 mph given by $T = \sqrt{2}\pi V_a/g$ is 32 sec. giving a horizontal wave length $\lambda = TV$ of 1907 m (6256 ft). The non-dimensional $\hat{\lambda} = \lambda/h_a$ is 20 corresponding closely to the typical wave length observed in Figure 14.

For Case #9, the ground speed and pitch angle during approach are shown in Figure 15. The ground speed twice reaches a low of 91 kts at a pitch angle of zero degrees. This ground speed is below the stall speed and represents a very hazardous situation.

In Case #11 wind field, the aircraft does not depart substantially from the 2.7 glide slope for which it is initially trimmed. Inspection of the wind speeds actually "seen" by the aircraft (Figure 16) during landing for Case #9 and Case #11 wind fields reveals that for Case #11 headwinds increase at approximately the same rate as for Case #9, but updrafts were not as severe. In Case #11 a strong downdraft was encountered at the end of the horizontal shear whereas for Case #9, a strong updraft was encountered which forced the aircraft through a second oscillation. To separate the influence of

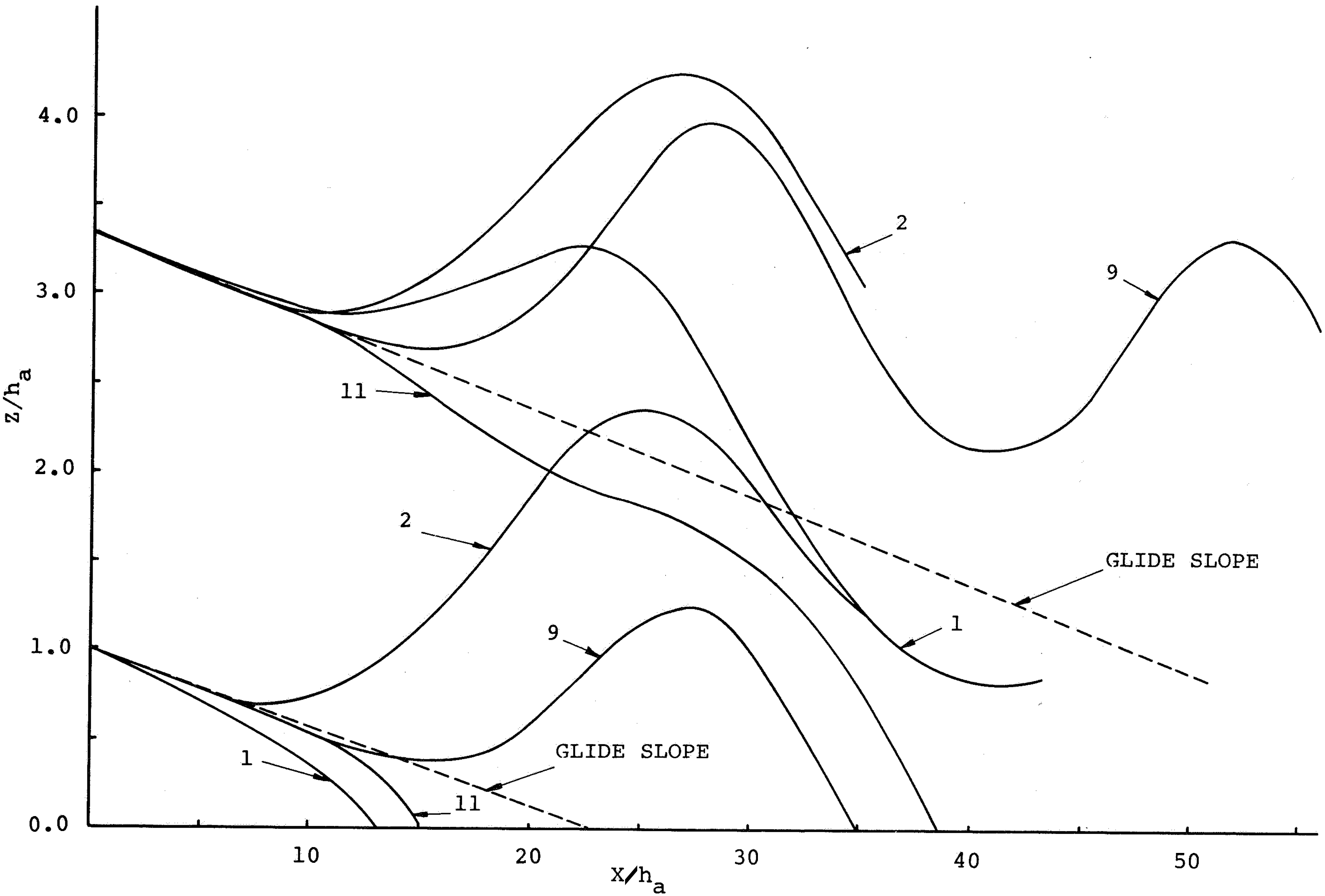


Figure 14 Flight Path of an Aircraft Having Characteristics of a DC-8 Landing with Fixed Controls through Four Different Thunderstorms

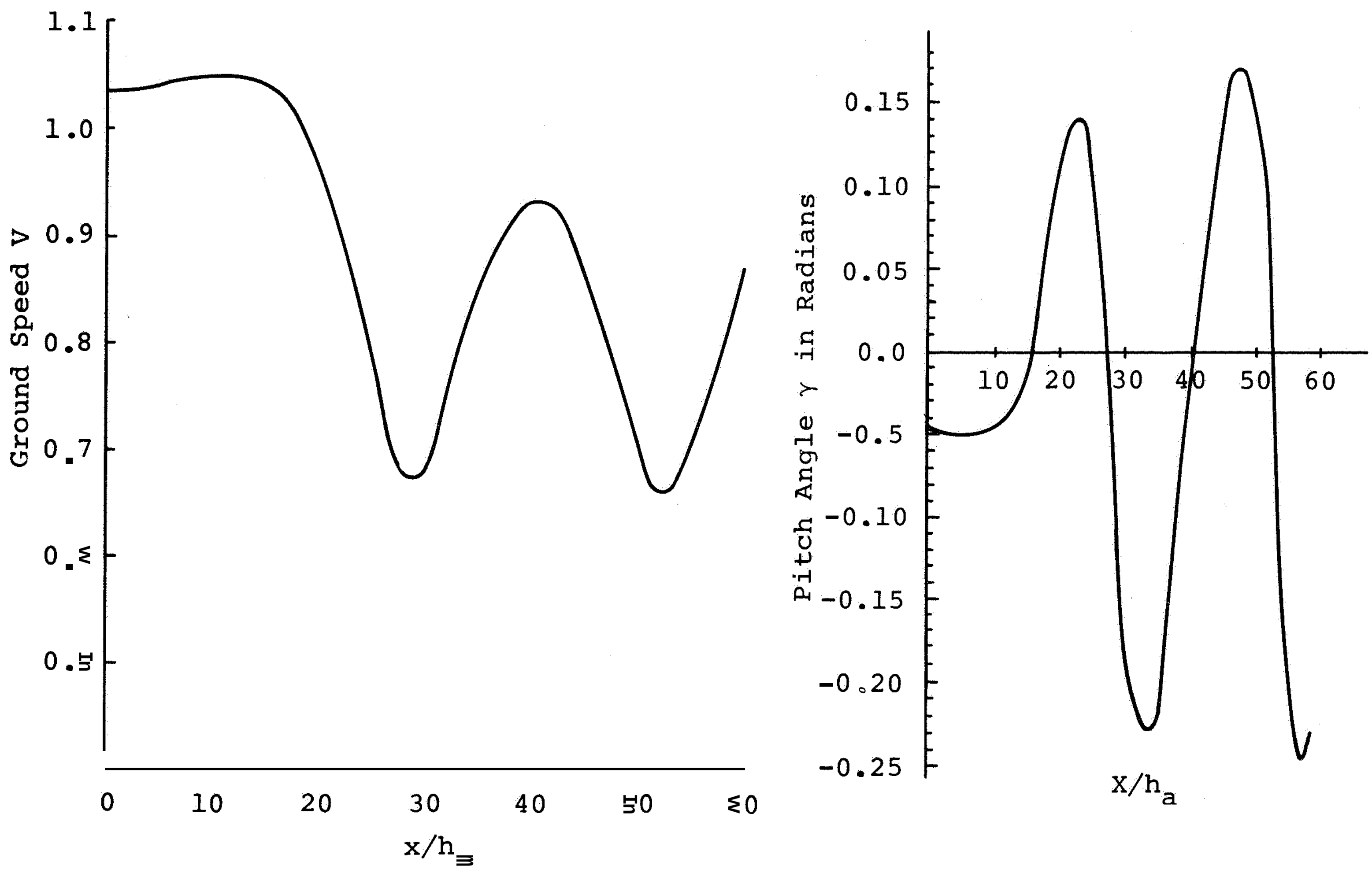


Figure 15 Ground Speed and Pitch Angle During Approach through Thunderstorm
Case 9

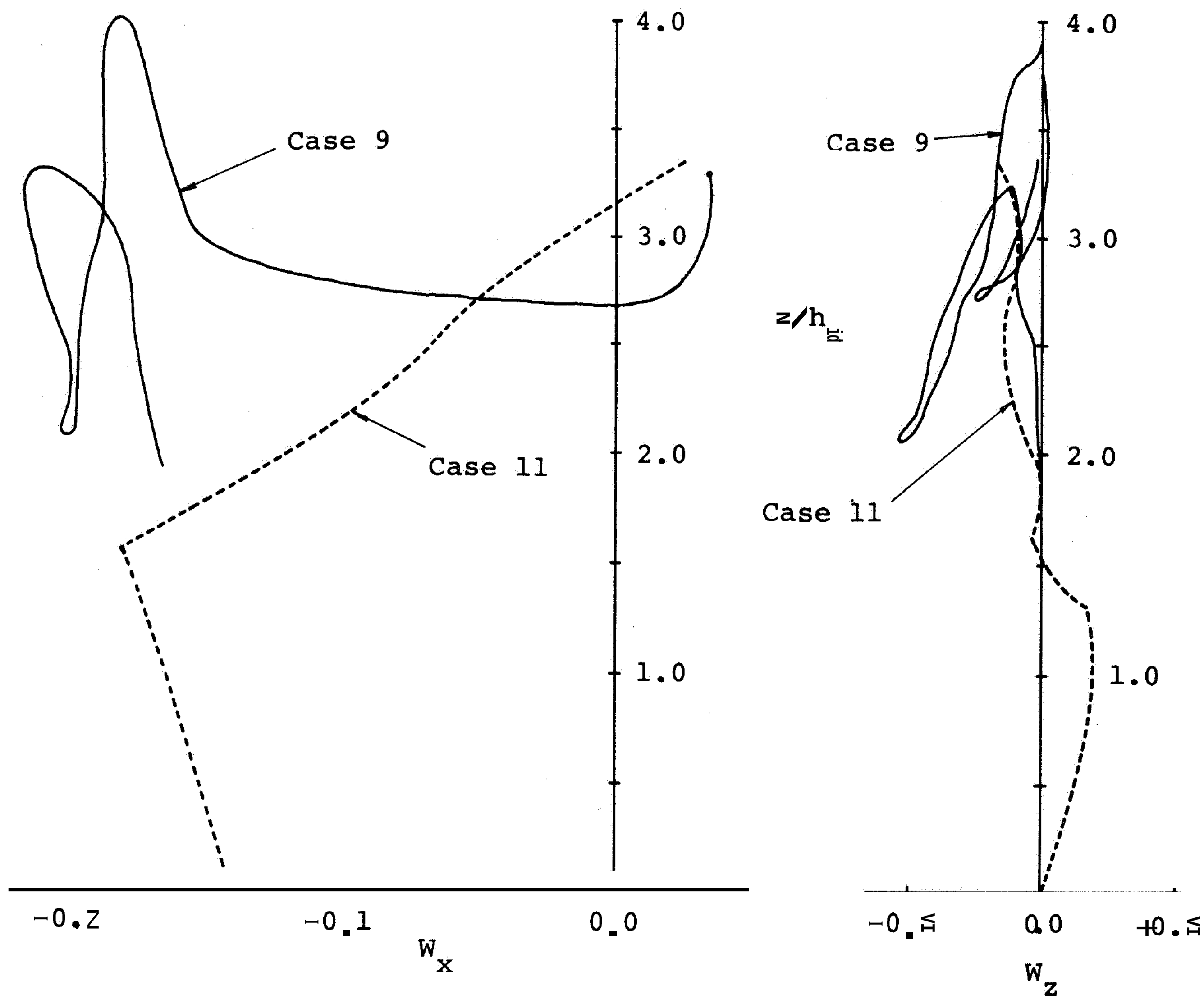


Figure 16 Wind Field "Seen" by Aircraft During Landing through a Thunderstorm Gust Front

variation in up and downdrafts from the influence of variations in horizontal wind speed, the solution for Case #9 was repeated first with $W_z = 0$ and second with $W_x = 0$. The resulting flight paths are shown in Figure 17, respectively.

Figure 17 illustrates that the phugoid mode is excited by the horizontal wind shear from $15 < x/h_a < 40$ but is considerably less strongly influenced by the horizontal wind when the vertical component is absent as in the region of $x/h_a > 40$. Recall, however, from Figure 14 that the wind shear in the horizontal direction is essentially gone when the airplane is beyond $x/h_a > 40$. The curve for the case $W_z = 0$ has only a very small excitation of the phugoid mode and, although causing an over-riding of the glide slope and a long landing, does not cause the extreme oscillations with associated loss of ground speed and severe pitch angles found for Case #9. This observation tends to support the conclusion of McCarthy and Blick [12] that the characteristic wind speed wavelength of thunderstorms can cause instability in the phugoid mode. The results, on the other hand, do not support the conclusions of Fujita [13] who attributes the strong downbursts associated with thunderstorms as being the positive factor in accidents related to flight through thunderstorms. The continuing research will draw further conclusion in this regard and will discuss this aspect of flight in thunderstorms in much greater detail for all 11 thunderstorm cases investigated in further reports.

The preceeding discussion relates to the case where the airplane's controls are fixed at trim condition at the point of entry into the thunderstorm wind field and are then held constant while the airplane makes the approach. Thus, these flight paths represent the one extreme of no control inputs. The opposite of this extreme would be the case where the airplane remains on the 2.7° glide slope and the control inputs required to maintain trimmed conditon all the way along the flight path computed. This case is referred to as the quasi-equilibrium case and has also been computed. Figure 18 shows the thrust requirement of

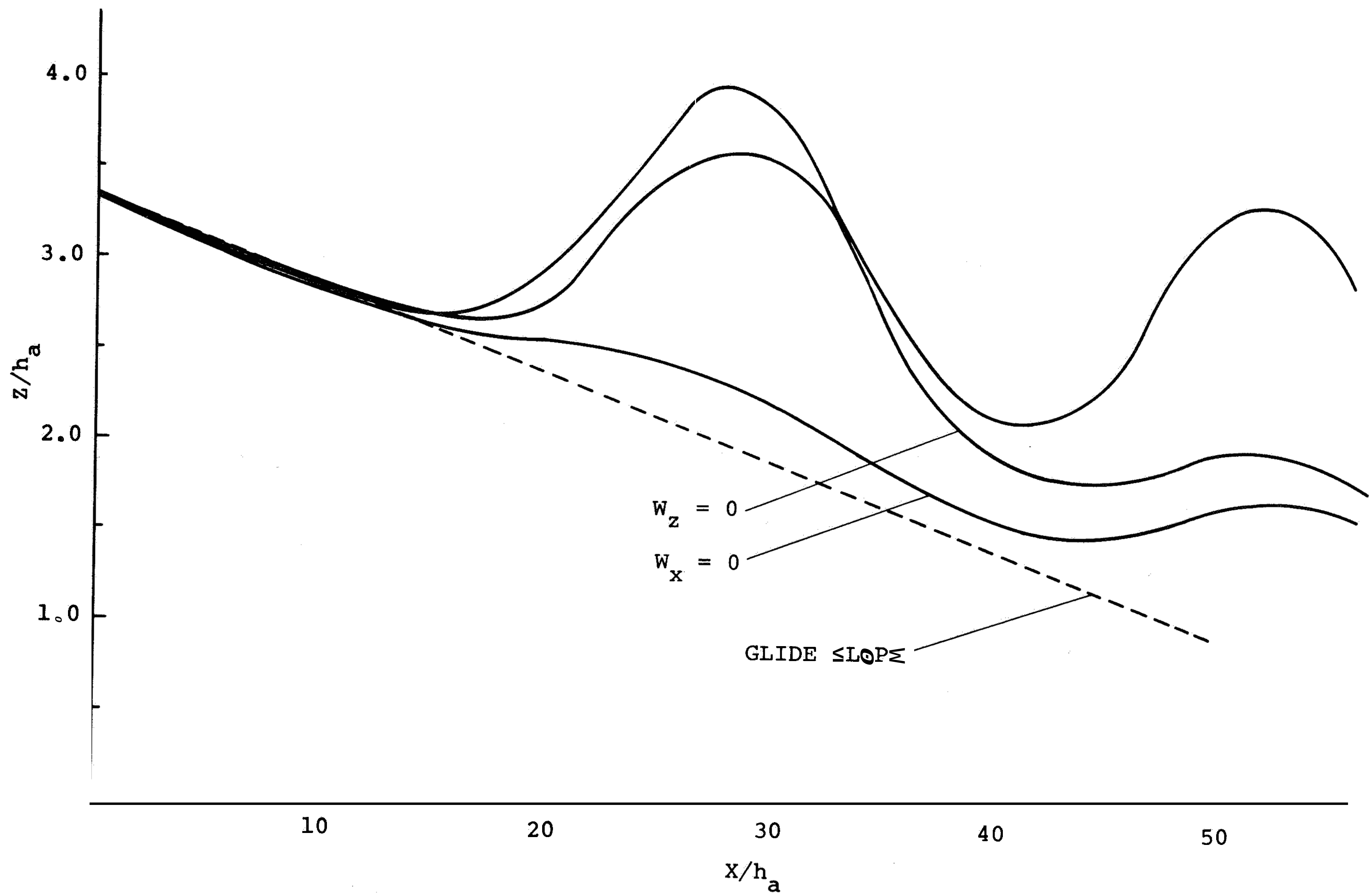


Figure 17 Comparison of Flight Paths through Thunderstorm Case #9 with both Wind Speed Components and with Individual Wind Speed Components: with Neither W_x nor W_z Equal Zero: with W_z Equal Zero: and with W_x Equal Zero

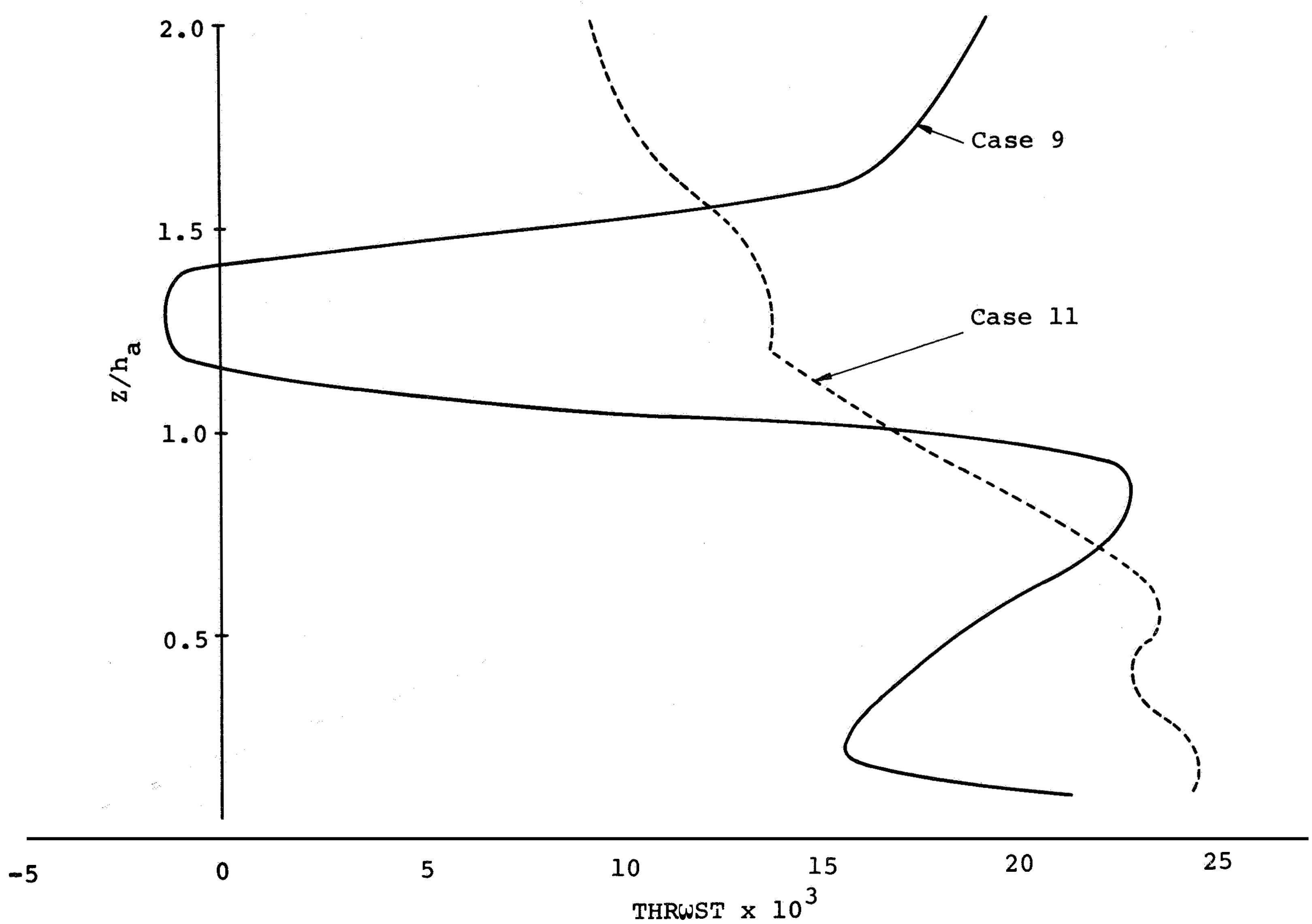


Figure 18 Thrust Required to Maintain Trimmed Conditions along a 2.7° Glide Slope through Thunderstorm Case 9

the airplane with DC-8 characteristics if it is to remain on a glide path during an approach through the Case #9 and Case #11 thunderstorms. In Case #9 maintaining constant relative air speed, one sees that the pilot must draw the thrust control well back and in this extreme ase even negative thrust results. As the horizontal shear diminishes the pilot must quickly restore the thrust if he is to remain on the glide slope. The approximate time required to reduce the thrust to practically zero and return to approximately the original value is on the order of 22 seconds. This is less than the spool up time of most jet engines and thus illustrates that it is essentially impossible to maintain glide slope through thunderstorms as intense as thunderstorm Case #9. For Case #11 where the phugoid mode is not excited, the pilot slowly increases thrust and maintains the glide slope without any extreme variation in thrust taking place.

The nature of the thunderstorm is thus observed to be an important factor in the behavior of the aircraft entering a thunderstorm gust front. The research will investigate the intensity of storms which create hazardous situations such as illustrated for Case #9. Examination of the response of the aircraft in all 11 thunderstorms gives insight into the possibility of aircraft encountering hazardous situations when flying through thunderstorms.

Other results from the study will include landings through the same wind fields with constant ground speed, with constant relative velocity and with constant pitch angle, respectively. The controlled variable which provides for the most stable flight through the strong wind shears will be delineated.

Acknowledgement. This work is being carried out under NASA Contracts NAS8-29584 and NAS8-31718 sponsored by the NASA Marshall Space Flight Center, Atmospheric Science Division. The author is greatful for the assistance of Dennis W. Camp and George H. Fichtl. Also, the financial support of Kenneth Hodge and William Gowan, Office of Aviation Safety Technology, NASA Headquarters, Washington, D.C., are most appreciated.

REFERENCES

1. "Sources of Low-Level Wind Shear Around Airports," George H. Fichtl, Dennis W. Camp, NASA Marshall Space Flight Center, Huntsville, Ala., and Walter Frost, University of Tennessee Space Institute, Tullahoma, TN; J. Aircraft, Vol. 14, No. 1, January 1977.

2. "Atmospheric Flow over Two-Dimensional Bluff Surface Obstructions," Juergen Bitte and Walter Frost, NASA CR-2750, October, 1976.

3. "Neutrally Stable Atmospheric Flow Over a Two-Dimensional Rectangular Block," Chih Fang Shieh, Walter Frost and Juergen Bitte, Contract report prepared under Contract No. NAS8-29584, Atmospheric Science Division, The University of Tennessee Space Institute, Tullahoma, TN 37388.

4. "STOL Technology," NASA SP-320, a conference held at Ames Research Center, Moffett Field, California, October 17-19, 1972.

5. "Flight in Turbulence," AGARD-CP-140. Symposium of the 42nd meeting of the Flight Mechanics Panel of AGARD held at Woburn Abbey, Bedfordshire, England, on 14-17, May 1973.

6. "Wind Shear Fluctuations at a Typical Urban V/STOL Port Site," J.V. Ramsdell, Pacific Northwest Laboratories, Richland, Wash., Sixth Conference on Aerospace and Aeronautical Meteorology of the American Meteorological Society, November 12-15, 1974, El Paso, Texas.

7. Clarke, R.H., and G.D. Hess, "Geostrophic Departure and the Function A and B of the Rossby-Number Similarity Theory," Boundary Layer Meteorology 1, 1974.

8. Goff, R. Craig, "Thunderstorm Outflow Kinematics and Dynamics," NOAA Technical Memorandum ERL NSSL-75, National Severe Storms Laboratory, Norman, Oklahoma, December, 1975.

9. Eastern Air Lines, Inc., Boeing 727-225, N8845E, John F. Kennedy International Airport, Jamica, hew York, June 24, 1975. Aircraft Accident. Report Number: NTSB-AAR-76-8., National Transportation Safety Board.

J

10. Continental Air Lines, Inc., Boeing 727-224, N88777, Stapleton International Airport, Denver, Colorado, August 7, 1975. Aircraft Accident. Report Number: NTSB-AAR-76-14, National Transportation Safety Board.

11. Iberia Lineas Aereas de Espana (Iberian Airlines), McDonnell Douglas DC-10-30, EC CBN, Logan International Airport, Boston, Massachusetts, December 17, 1973. Aircraft Accident. Report Number: NTSB-AAR-74-14, National Transportation Safety Board.

12. McCarthy, John and Edward F. Blick, "Aircraft Response to Boundary Layer Turbulence and Wind Shear Associated with Cold-Air-Outflow from a Severe Thunderstorm." Seventh Conference on Aerospace and Aeronautical Meteorology and Symposium on Remote Sensing from Satellites, American Meteorological Society, November 16-19, 1976, Melbourne, Fla.

13. Fujita, T. Theodore and Fernando Caracena, "An Analysis of Three Weather Related Aircraft Accidents," Research conducted at the Department of the Geophysical Sciences, The University of Chicago, Chicago, Illinois.

NOMENCLATURE

$\dot{q}$	time derivative of the pitching rate (q)
L_T	effective moment arm of the thrust vector
M	pitching moment
I_{YY}	moment of inertia about the symmetry plane of the aircraft
$\dot{( )}$	refers to the derivative with respect to time
g	magnitude of the acceleration of gravity
V	dimensionless magnitude of the velocity relative to the earth
γ	angle between $\vec{V}$ and x-axis (the flight path angle)
m	aircraft mass
δ_T	angle between the thrust vector and the fuselage reference line (FRL)
a	angle of attack
6	angle between $\vec{V}_a$ and $\vec{V}$
$\vec{F}_T$	thrust of the engines
$\vec{L}$	lift
$\vec{D}$	drag
$\vec{m}g$	gravitational forces
$\vec{V}$	dimensionless velocity vector relative to the earth
$\vec{V}_a$	dimensionless velocity vector relative to the air mass
FRL	fuselage reference line
x	dimensionless distance parallel to the surface of the earth
z	dimensionless distance perpendicular to the surface of the earth (positive downward)
D_i	(i = 1, 2, 3, 4, 5, 6, 7) dimensionless constants
Z_o	surface roughness
u_b	friction velocity
W_x	wind speed horizontal to ground
W_z	wind speed vertical to ground

a

TABLE 1.

WIND ENVIRONMENT DEFINITION

'SURVEY OF FLOW FIELDS AROUND IRREGULAR TERRAIN FEATURES

•QUALITATIVE INTERPRETATION RELATIVE TO AIRCRAFT SAFETY

REPORTED IN

"Review of Data and Prediction Techniques for Wind Profiles Around Manmade Surface Obstructions," presented at the 42nd Flight Mechanics Panel Meeting Symposium, on "Flight in Turbulence." Woburn Abbey, UK, May, 1973, published in Proceedings AGARD-CP-140 (1973), by Walter Frost.

"Sources of Low Level Wind Shear Around Airports," Proceedings of the Society of Air Safety Investigators, Fifth International Seminar, September 1974, Washington, D.C., G. H. Fichtl and Walter Frost.

"Sources of Low Level Wind Shear Around Airports," Journal of Aircraft, Vol. 14, No. 1, January 1977, G. H. Fichtl, D. W. Camp and Walter Frost.

TABLE 2.

WIND ENVIRONMENT DEFINITION

ANALYTICAL MODELLING

- BOUNDARY-LAYER ANALYSIS
  - SEMI-ELLIPTICAL GEOMETRY
  - FENCE GEOMETRY
- TRANSIENT BLOCK GEOMETRY
  - TWO-DIMENSIONAL CONSTANT VISCOSITY
  - SMAC
- TWO-DIMENSIONAL NAVIER-STOKES EQUATIONS
  - FORWARD FACING STEP
  - REARWARD FACING STEP
  - BLOCK GEOMETRY

TABLE 3.

WIND ENVIRONMENT DEFINITION

BOUNDARY LAYER ANALYSIS

REPORTED IN

"A Boundary Layer Approach to the Analysis of Atmospheric Motion over a Surface Obstruction," NASA CR 2182 (1973) by Walter Frost, J. R. Maus, W. R. Simpson.

"A Boundary Layer Analysis of Atmospheric Motion over Semi-Elliptical Surface Obstruction," Boundary-Layer Meteorology, 7 (1974), pp. 165-184, by Walter Frost with R. M. Maus and G. H. Fichtl.

"Analysis of Atmospheric Flow over a Surface Protrusion Using the Turbulence Kinetic Energy Equation," Boundary Layer Meteorology, 8 (1975), pp. 401-418, by Walter Frost with W. L. Harper and G. H. Fichtl.

"Analysis of Atmospheric Flow over a Surface Protrusion Using the Turbulence Kinetic Energy Equation with Reference to Aeronautical Operating Systems," NASA CR-2630 (1975), by Walter Frost and W. L. Harper.

"Development of SMAC Computer Code for Atmospheric Science Application," M.S. thesis, The University of Tennessee Space Institute, Tullahoma, Tennessee 37388.

"A Simple Analysis of Vortex Formation on Buildings," accepted for publication in the Journal of Industrial Aerodynamics, by Walter Frost with E. E. Hutto and G. H. Fichtl.

TABLE 4.

WIND ENVIRONMENT DEFINITION

FIELD STUDY OF BLUFF BODY IN THE NATURAL WIND

- EIGHT-TOWER ARRAY
- INSTRUMENTATION
  - HORIZONTAL WIND SPEED CUP-ANEMOMETERS
  - DIRECTION VANE ANEMOMETERS
  - VERTICAL WIND SPEED PROPELLOR ANEMOMETERS
- RESULTS
  - MEAN VELOCITY PROFILES
  - TURBULENCE INTENSITIES
  - REYNOLDS STRESSES
  - CORRELATIONS
    - AUTO-CORRELATIONS
    - CROSS-CORRELATIONS
    - COHERENCE FUNCTIONS

REPORTED IN:

"A Field Study of the Wind over a Simulated Block Building," report contract number NSF GK-42942 (1976), by Walter Frost and A. M. Shahabi.

"Mean Horizontal Wind Profiles Measured in the Atmospheric Boundary Layer About a Simulated Block Building," Proceedings Second U.S. National Conference on Wind Engineering Research, June 1975, Colorado State University, Fort Collins, Colorado, by Walter Frost, G. H. Fichtl, J. R. Connell, and M. L. Hutto.

"Mean Horizontal Wind Profiles Measured in the Atmospheric Boundary Layer About a Simulated Block Building," Boundary Layer Meteorology, 1 (1977), by Walter Frost, G. H. Fichtl, J. R. Connell, and M. L. Hutto.

a

TABLE 5.

WIND ENVIRONMENT DEFINITIONS

'TURBULENCE SIMULATION WITH COHERENCE MATCHING

REPORTED IN

"Three Velocity Component, Nonhomogeneous Atmospheric Boundary Layer Turbulence Modelling, AIAA Paper No. 76-413, AIAA 9th Fluid and Plasma Dynamics Conference, San Diego, California (1976), by Morris Perlmutter, Walter Frost and G. H. Fichtl.

"Three Velocity Component Atmospheric Boundary Layer Turbulence, Contract No. NAS8-29548 Report, University of Tennessee Space Institute, Tullahoma, Tennessee 37388 (1976), by Walter Frost and Morris Perlmutter.

TABLE 6.

AIRCRAFT DYNAMICS

- TWO-DIMENSIONAL EQUATIONS OF MOTION WITH VARIABLE WIND
  - MEAN WIND
  - WIND SHEAR
  - TURBULENCE
- CONTROL SIMULATION
  - FIXED CONTROLS
  - DIGITAL AUTOMATIC CONTROLS
- SOLUTION FOR FLIGHT PATHS THROUGH COMPUTED WIND FIELDS
- AERODYNAMIC COEFFICIENTS IN VARIABLE WINDS

REPORTED IN:

"The Influence of Wind Shear on Aerodynamic Coefficients," Proceedings of the 6th Conference on Aerospace and Aeronautical Meteorology, El Paso, Texas, November 1974, by Walter Frost and Enice Hutto.

"Helicopter Response in Gusty Winds About a Building," Proceedings of the 7th Conference on Aerospace and Aeronautical Meteorology, Melburne, Florida, November 1976, by Walter Frost, K. R. Reddy and D. W. Camp.

THE MULTI-DIMENSIONAL NATURE OF WIND SHEAR INVESTIGATIONS

William J. Cox
Federal Aviation Administration
(Presented by Mr. Frank Coons, FAA)

I. Introduction

You may ask, "What's new about wind shear? Hasn't it been with us for a long time?" Yes, it has been around a while and it has always been something less useful than a pilot's best friend. It certainly is difficult to imagine there is anything really new about this rather common phenomenon. Perhaps it's a greater awareness of an old problem. Without considering other factors, wind shear is generally little more than a nuisance; an increase in the pilot's workload or an occasional firm landing announcing arrival at destination to an anxious passenger. Then why should we get so concerned about such a common atmospheric disturbance? Doesn't the system which has worked well in the past still provide for performance and control margins to accomodate disturbances or at least provide an alternative for the pilot? Yes, the margins are there and the system is reasonably good. The long term records so indicate. But recently, the records are also beginning to indicate something else.

Within the past few years, we are beginning to understand the various ways in which the wind shear nuisance can develop into a serious destructive force, especially when the approach and landing scenario includes serious pilot workload factors in combination with deceptive shears.

The influence of limited flight visibility and other localized weather phenomena, the effects of time constraints on the flight crew and terminal landing acceptance capacity, and even the runway surface condition are very important. They all have a bearing on either the performance required of the flight crew encountering a shear or the options available to cope with the ensuing situation. However, one additional factor, which is probably the most serious, is the lack of information (or lack of confidence in available information) on the existence of a low-level shear in the approach and landing area.

Not unlike many other forms of adversary encounter, the severity of a significant low-level wind shear is enhanced greatly by its element of almost total surprise. Given these considerations, the existing margins may not be sufficient to provide the options required for safe operation during shear encounters. Since 1971, there have been six air carrier accidents in which a low-level wind shear has been identified as a major factor. The impact of these accidents on the aviation community has resulted in a variety of investigations seeking to develop a better understanding of the wind shear phenomenon. The investigations often involve a multi-disciplinary effort supported by numerous government, institutional and industry organizations. Examination of a wide variety of related factors include such topics as wind shear characterization, aircraft/pilot performance in shear conditions, terminology and language development, wind shear forecasting, ground based and airborne wind shear sensor development, ground and flight wind shear displays, wind shear data collection and dissemination, and certainly not least of all, the investigations include pilot factors associated with wind shear encounters.

II. Today's Operational Scenarios

A look at today's operational scenario reveals that the introduction of the turbojet airplane into civil air carrier operations had rather broad implications to the wind shear problem. The increase in air traffic in our airport terminal areas, brought about by the wide acceptance of the jet transport, has not only increased the probability of an encounter with any particular low-level shear but it has significantly increased the workloads of the flight crew as well as the air traffic controllers. In addition, the turbojet airplane's sensitivity to wind shear appears to be greater than that of the propeller driven airplane due in part ot its slower power response and slower aircraft acceleration. There appear to be very few compensating factors to lessen the severity of this weather phenomenon that are provided by the introduction of the turbojet airplane into the system. Because of these considerations, the operational pilot must develop increased astuteness and decision making capacity to cope with the increased workloads. The pilot's decision to continue or abandon an approach often requires a comparison of the results of a subjective evaluation in a deteoriorating situation against the hard objective factors associated with a lengthy holding requirement or a diversion to alternate. His concern for justifying his decision to either himself or others may be no small factor in his decision making process. This is especially worthy of examination where erroneous cues are provided the pilot, as is possible, or even probable, in a wind shear encounter.

In its report on the June 24, 1976, John F. Kennedy International Airport (JFK) B-727 accident, the National Transportation Safety Board (Ref. 5) has stated in the analysis; "In summary, the accident involving Eastern 66 and the near-accidents involving Flying Tiger 161 and

Eastern 902 were the results of an underestimation of the significance of relatively severe and dynamic weather conditions in a high density terminal area by all parties involved in the movement of air traffic in the airspace system. The Safety Board, therefore, believes that no useful purpose would be served by dwelling critically on individual actions or judgements within the system, but that the actions and judgements required to correct and improve the system should be reviewed. All parts of the system must recognize the serious hazards that are associated with thunderstorms in terminal areas. A better means of providing pilots with more timely weather information must be designed."

III. Wind Shear Investigations

A. FAA Program Definition

As a result of the June 24, 1975 accident of Eastern Air Lines (EAL) Flight 66 at JFK and the August 7, 1975 accident of Continental Air Lines Flight 426 at Stapleton International Airport, the FAA has been investigating aircraft performance and control characteristics associated with low-level wind shears. In addition, it has begun an accelerated investigation of the various techniques available to detect hazardous shears in the approach and departure phase of flight operations.

An earlier FAA wind shear detection project has been initiated in 1972. The major objective of this effort was the development of ground-based sensors capable of measuring wind speed and direction to altitudes of 2000 feet AGL. Having been identified as a high priority effort in 1975, the FAA increased the level of activity from a single project to program level activity involving a number of projects, all of which are identifiable within the following six major task areas: Wind Shear Characterization; Hazard

Definition; Ground-Based Wind Shear Detection Systems; Airborne Wind Shear Development Efforts; Wind Shear Data Management; and, Integration of Wind Shear Systems and Data into the National Airspace System (NAS). The increased scope of the FAA wind shear program as defined by FAA report, FAA-ED-15-2, Engineering and Development Plan-Wind Shear (Ref. 1), includes an examination of all aspects and potential solutions for the hazards created by low-level wind shear.

Hazardous low-level wind shears are not adequately considered in the landing and takeoff criteria, either as a part of the Air Traffic Control system procedures or Federal Aviation Regulations or specifically addressed as part of the operating limitations requirements for the Airplane Flight Manual. Therefore, part of the wind shear investigation effort will be directed toward providing the FAA operating services with data on the capabilities of aircraft to cope with varying wind shear intensities at low altitude. This information could be used to determine the safe limits for arrival or departure conditions within the airport terminal area. It is also conceivable that some of the results may have an impact on future aircraft and system certification.

B. Assessment of Related Wind Shear Investigations

Prior to the implementation of the FAA Wind Shear Program, assessments were made of the various independently conducted investigations, observations, and experiments involving low-level wind shear. A continuous assessment is maintained, where possible, to assure the FAA efforts are maximized within the limitations of time and resources. Typical of the results of these assessments, the following limited descriptions illustrate the degree of diversification found in various independent low-level wind shear studies.

1. Accident Investigations

Accident investigative studies concerning wind shear characterization and its influence on pilot/aircraft control and performance have been greatly aided in recent years by the availability in operational aircraft of the inertial navigation system (INS) and digital flight data recorders (DFDR). Where found in combination (usually limited to wide bodied turbojet airplanes engaged in long range, over water operations), these two devices can produce sufficient data to provide reasonable approximations of the pertinent atmospheric activities and aircraft flight profiles.

While it is possible to establish the physical contributions to approach and landing accidents from the relationship of the atmospheric activity to the flight profile, an assessment of the human factors which influence the pilot behavior must also be accomplished. The dependence upon the recall of piloting experiences to provide sufficient assessment of these factors, especially during low visibility, weather-related approach and landing operations, has not always proved adequate. Further examination through highly controlled experiments has been found to provide additional insight into pilot/aircraft performance interface. For these examinations, use has been made of highly sophisticated flight simulators which combine the capability to simulate the particular atmospheric disturbance with the appropriate visual external cues. Under these conditions, it is possible to replicate the various cockpit scenarios for detailed examination.

Early results of the use of INS/DFDR data to reconstruct the atmospheric dynamics and support flight simulation investigations of wind shear can be found in the National Transportation Safety Board (NTSB) report (Ref. 3) on the December 17, 1973 Logan International Airport DC-10 accident.

Through use of a McDonnell Douglas DC-10 simulator, the NTSB has been able to simulate the approach and landing environmental conditions that existed at the time of the accident. Flight scenarios were developed and flown in the simulator by a variety of subject pilots. The results of these experiments provided a verification of the existance and contribution of influencing physiological factors during the pilot's transition from instrument to external visual reference during certain types of wind shear encounters.

The atmospheric dynamics which existed at JFK on June 24, 1975 (Ref. 5) between 1944 and 2009 GMT have also been the subject of rather extensive investigations. During this time period fourteen aircraft either landed or attempted to land on Runway 22L at JFK. Of these, EAL 66, a B-727, descended the glide slope to approximately 400 feet where it encountered heavy rain and a down draft, referred to as a "downburst" by Fujita (Ref. 2), of such magnitude that the aircraft contacted the approach lights, impacted the ground and came to rest short of the landing Runway 22L.

The reconstruction of the atmospheric dynamics representative of the EAL 66 encounter required an extensive analysis (Refs. 4 and 5) and considered data from the following flights in addition to EAL 66:

- -Flying Tiger Flight 161, a DC-8 that preceded EAL 66 on the approach by 8 minutes and 59 seconds;
- -Eastern Air Lines Flight 902, a L-1011 that preceded EAL 66 on the approach by 7 minutes and 28 seconds; and,
- -Finnair Flight 105, a DC-8 that preceded EAL 66 on the approach by 6 minutes and 45 seconds.

Based on these available data, wind models were constructed separately by The Boeing Company, the Lockheed California Company, the Douglas Aircraft Company, and the National Aeronautics and Space Administration (NASA). A selection of three of the resulting wind models were programmed into a Boeing Company B-727 engineering simulator for an examination of the dynamic effects of these reconstructed winds on the total performance of a pilot/airplane combination. The NTSB identified objectives of the simulator taks were: "(1) to examine the flight conditions which probably confronted the flight crew of EAL 66, and (2) to observe the difficulties that a pilot has in recognizing the development of an unsafe condition and in responding with appropriate corrective action." When plotted as a function of distance from the runway, several of the airspeed and altitude traces recorded during the simulated approaches closely resembled the traces on the EAL 66 flight recorder.

In addition to the NTSB manned simulation experiments described above, other simulation experiments, conducted in the past 2-3 years, have combined wind shear and reduced visibility to assess pilot performance in approach and landing maneuvers. These include a joint USAF/FAA Low Visibility Simulation Program at Wright-Patterson AFB, Flight Dynamics Laboratory (Ref. 8) and a Douglas Aircraft Company experimental simulator study program (Ref. 7). The conclusions gained from these experiments indicate that effective pilot decision-making studies on the combined influences of low-visibility and wind shear encounters could be accomplished in current state-of-the-art simulation.

2. Atmospheric Studies Associated with Flight Operations

Extensive analyses of satellite, radar and synoptic weather radar have also been performed (Ref. 2) and correlated with wind models and other data resulting from the EAL 66 accident investigation. With this information Dr. Fujita has developed a model of the spearhead' storm and downburst cells[2] associated with the EAL 66 accident. Figure 1 depicts three significant downburst cells (DBC) in relation to the time-space coordinates of the paths of arriving and departing aircraft at JFK Runway 22L. It is interesting to note the existence of a sea breeze front situated along a line nearly Perpendicular to the runway at about the glide path intercept point. The out flow from the downburst cells was distorted by the sea breeze front, resulting in strong out flow winds to the north of the front. Since most of the airport was under the influence of the sea breeze, the official wind instrument used to select the landing runway was indicating the surface wind was most nearly aligned with Runway 22L. Strong support for additional wind sensors around the perimeter of the airport, as provided in the FAA ground-based wind shear detection system development plan, can be developed from these detailed studies. The thunderstorm gust-front activity that figures in the Continental Air Lines Flight 426 accident at Stapleton International Airport also supports the need for additional wind sensors.

1. Spearhead (echo)- a radar echo with a pointed appendage exceeding toward the directions of the echo motion. (Byers and Fujita)
2. Downburst (cells)- a localized intense downdraft with vertical currents extending a downward speed of 12 fps at 300' above the surface (Byers and Fujita).

J

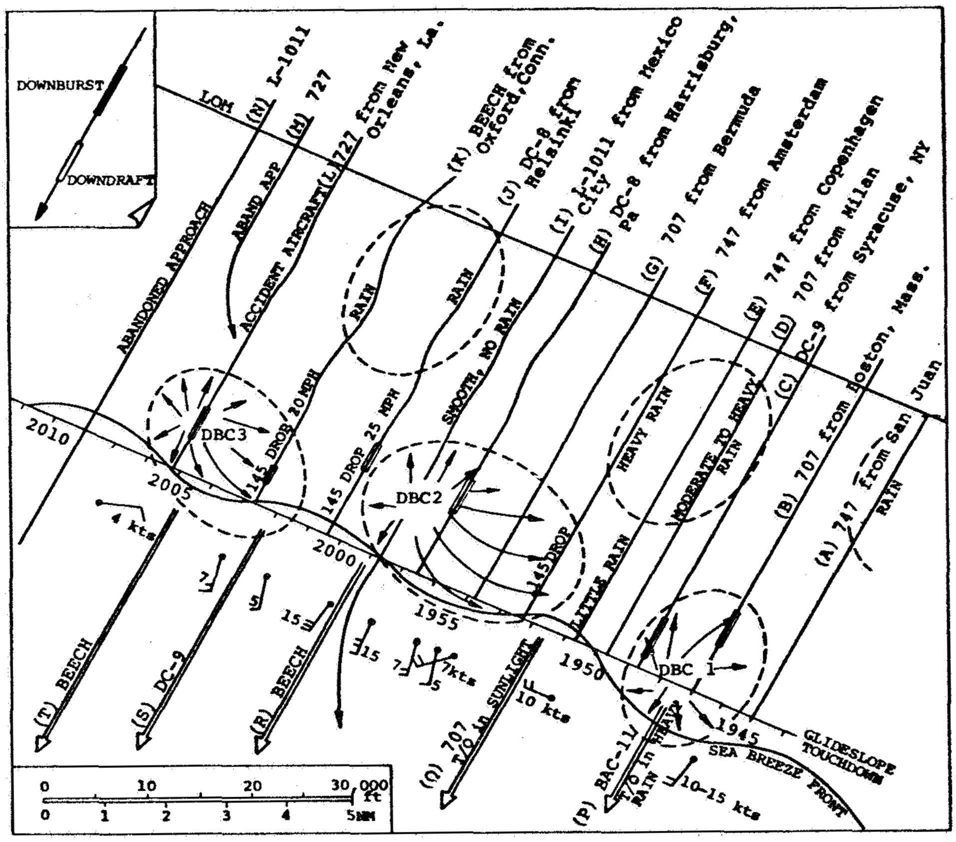


Figure 1 Three Downburst Cells (DBCs) Depicted on Time-space Coordinates, DBC 1 was on the Runway Threshold and DBC 2 Affected Seriously the Approach Effort of Aircraft "H" and "I" DBC 3 Blew Aircraft "L" Down to the Ground, 2000 ft. Short of Runway 22L (Fujita 1976)

Other atmospheric studies and assessments on low-level wind shear include a rather extensive data collection and wind shear characteristics comparison by Northwest Orient Air Lines (NWA). For several years, the NWA flight crews and meteorologists have maintained a two-way reporting system which has provided observational data on the presence of wind shear and turbulence throughout the NWA route structure. Sowa (Ref. 6) has developed the data collected during 70 cases of NWA wind shear encounters into a wind shear versus turbulence comparison. These data were plotted against two low-level wind shear forecasting parameters, speed of the front and temperature differences across the front. The resulting plot provided the basis for developing the nomogram, Figure 2, which can be used to indicate to flight crews whether wind shear will be smooth or turbulent.

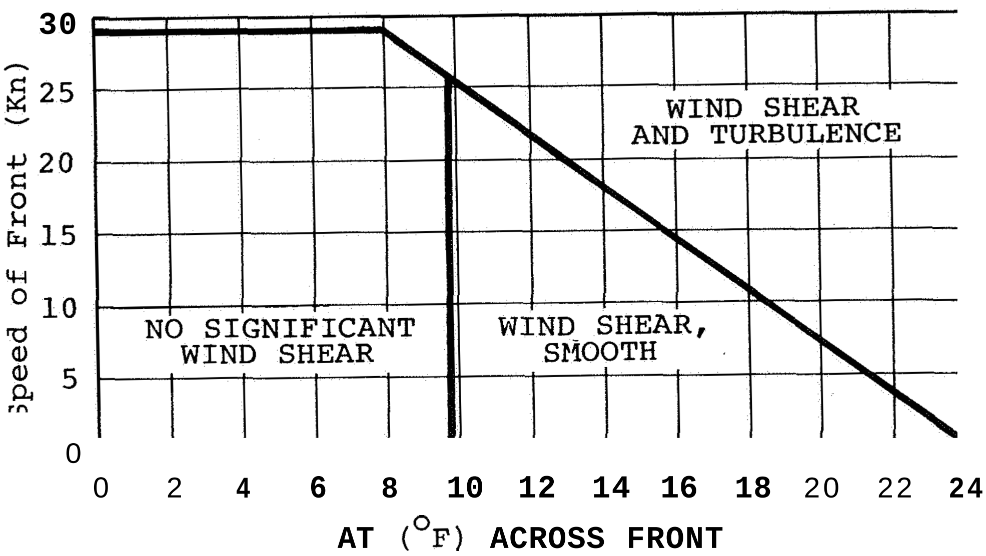


Figure 2 Wind Shear Forecast Nomogram
(COURTESY NORTHWEST ORIENT AIRLINES)

The FAA wanted to determine the validity of the nomogram to support forecasting the wind shear. It assigned the task to a joint USAF/FAA All Weather Landing Project operating a C-141 airplane into Category III weather. The task objective included, in addition to determining the validity of the forecasting technique, a requirement to determine what levels of wind shear (if any) could be found in the very low visibility (down to Category IIIB) landing condition. The results indicated that the NWA forecasting technique, based on the use of the nomogram criteria, has sufficient validity to warrant its use in an expanded forecast evaluation project. The results also provided data showing the presence of significant levels of wind shear in combination with very low visibility.

C. FAA Wind Shear Program Establishment

In establishing a wind shear research and development program within the FAA, one of the requirements was the need for an early product which could be used to provide near-term alleviation of the wind shear hazard, even if only in a limited degree. Therefore, implementation of any near term results is a priority requirement reflected in many of the following major task areas.

1. Wind Shear Characterization

Early deliverables from this task area involved the development of four wind shear profiles for use in various fast time and manned flight simulation projects identified in other task areas. The use of a common set of profiles in the various simulation efforts is providing some measure of comparability between the separate efforts. The profiles used provide a range of wind shears from mild changes in the along track wind components to shears with direction and speed changes, and one which also includes changes in the vertical wind component.
These include:

- a neutral wind shear profile, Figure 3, which represents wind conditions in a highly mixed atmospheric boundary layer when temperature stratification is consistent with adiabatic distribution (9.8°C/KM);
- an inversion wind shear profile, Figure 4, which is representative of a low-level temperature inversion overlaid by fairly strong winds immediately above the inversion;
- a frontal wind shear profile, Figure 5, which is representative of a fast moving frontal zone producing significant turning of the wind vector with altitude; and,

4

- a thunderstorm wind shear profile, Figure 6, which is representative of a thunderstorm cold air outflow pattern producing abrupt changes in both horizontal and vertical wind velocities.

The longer term objective of this task consists of research into the meteorological conditions that cause hazardous low-level shears, its life cycle manifestations and its climatological and geographical distribution. FAA-sponsored work in this area is being performed by NOAA's Wave Propogation Laboratory (WPL), NOAA's National Severe Storms Laboratory (NSSL) and the Space Sciences Laboratory of NASA's Marshall Space Flight Center (MSFC)

2. Hazard Definition

The primary objective of this task is to establish the wind shear hazard potential in terms that are meaningful and useful to pilots. It embodies a requirement to express the hazards in a standardized operational/technical language based on the hazard being defined in terms of altitude, aircraft type (or category) airspeed, configuration, gross weight, etc. The task is divided into the following sub-tasks:

a. Computer simulation of Aircraft Response to Wind Shear-In a joint effort betwen FAA and NASA Ames, a comprehensive review of aircraft response data is being made to determine the critical aerodynamic and performance characteristics of aircraft based on given atmospheric dynamics of wind shear activity. Fast time simulation of wind shear encounters will be conducted using models of generic aircraft types.

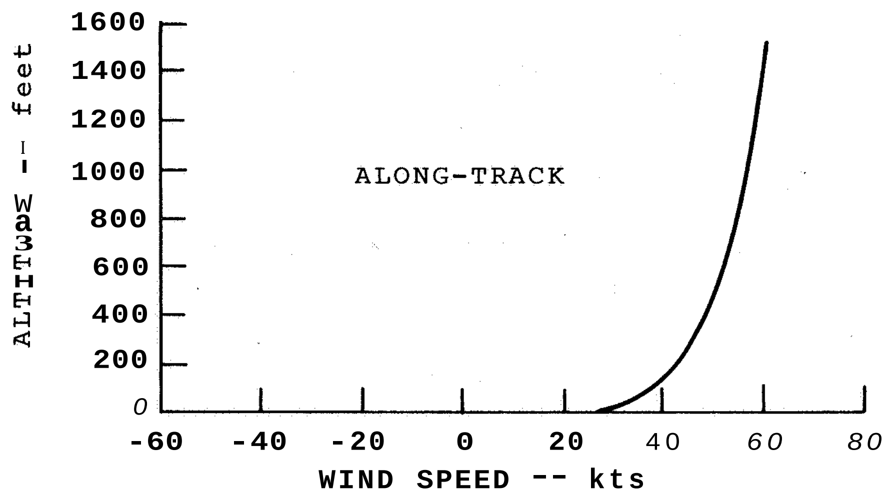


Figure 3 Neutral Wind Shear Profile

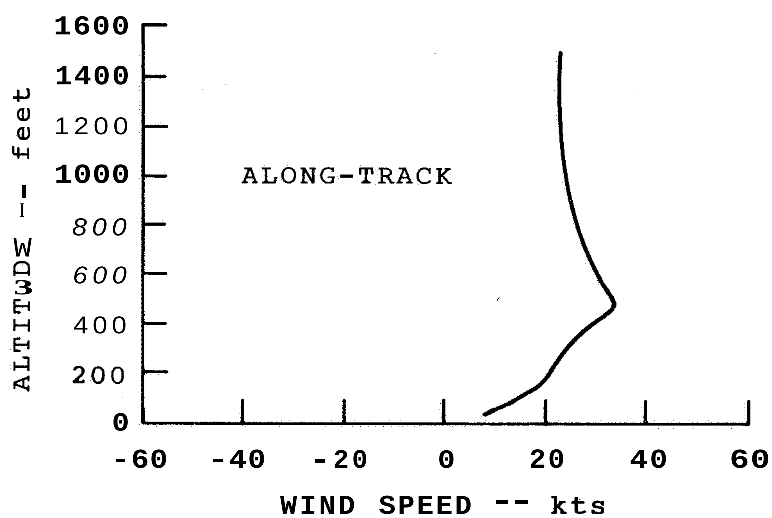


Figure 4 Inversion Wind Shear Profile

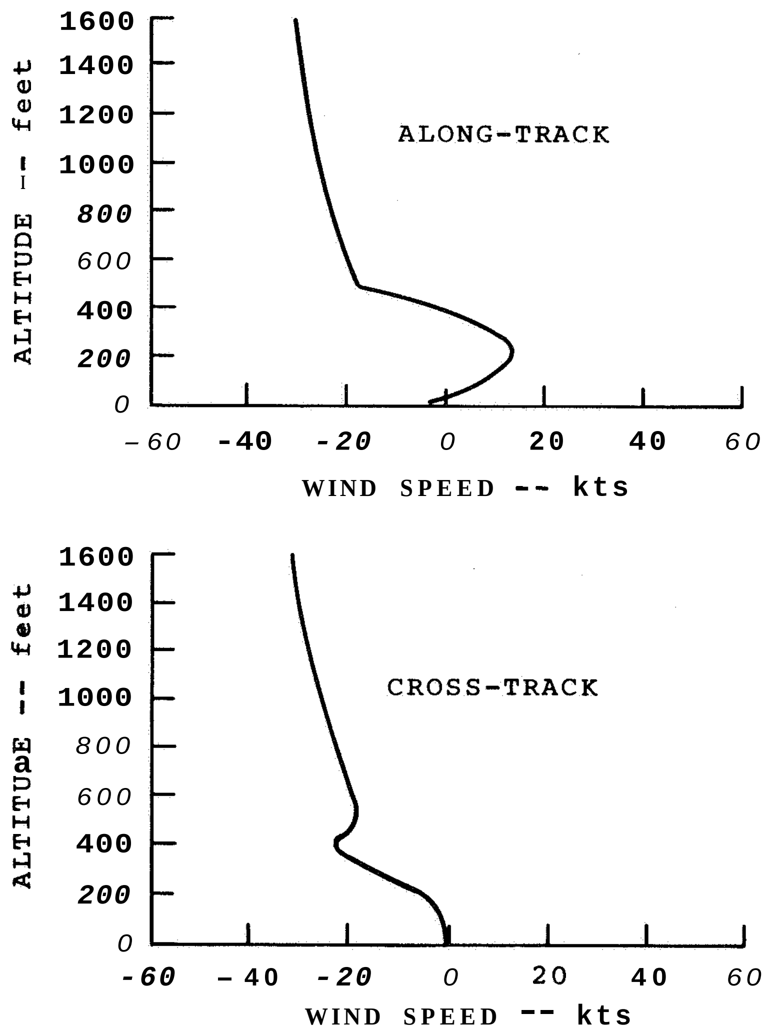


Figure 5 Frontal Wind Shear Profile

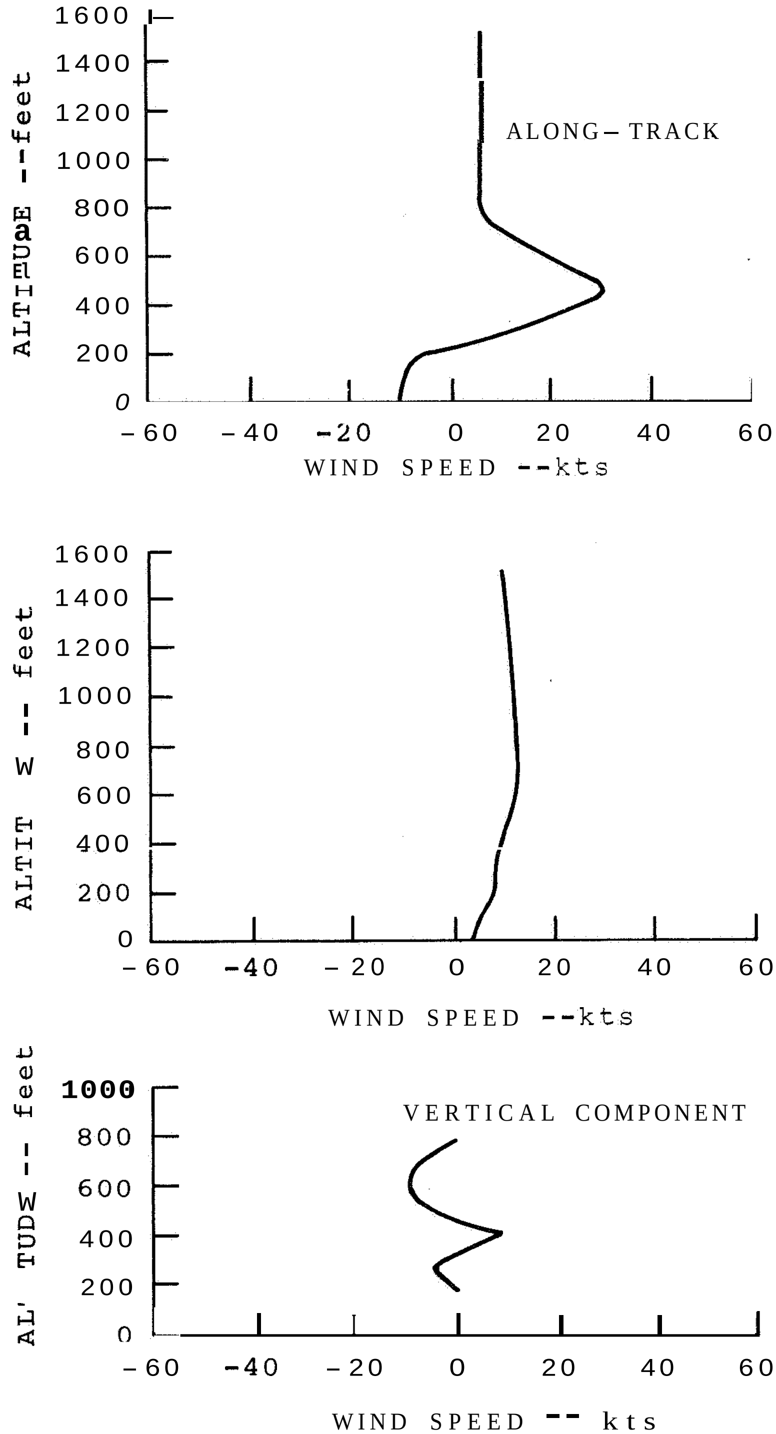


Figure 6 Thunderstorn Wind **Shear Profile**

b. Accident/Incident Analysis- The objectives of this task is to examine a broad segment of the existing aviation accident records to identify wind shear factors which may have been a contributing factor to an accident. These factors will be used to establish a wind shear hazard profile.

c. Language Development- At present, there are misinterpretations of the technical terminology used by engineers, meteorologists and pilots to describe wind shear, and there is no commonly accepted operational wind shear terminology for use by pilots and controllers. For example, in the literature some call a horizontal wind which changes as a function of altitude a "vertical" wind shear and some call it a "horizontal" wind shear. Pilots and controliers have had no common terminology for a shear which causes a decrease in the aircraft's airspeed as opposed to a shear which causes an increase in airspeed.

It is obviously desirable for a pilot who has just encountered a wind shear to report the event before a following aircraft encounters the shear (on either arrival or departure). Also, it is equally desirable that the pilot of that succeeding aircraft understand precisely the terminology of the transmitting pilot and the type of the wind shear encountered.

The objective of this task is to develop standardized terms to be used operationally to communicate the necessary information to assist pilots in avoiding or coping with a shear on approach or departure.

3. Ground-Based Wind Shear Detection Systems

Wind sensors which range in complexity from single anemometers to elaborate and complex microwave, sonic, and laser probes are being evaluated for use in ground-based shear detection systems.

a. Barometric Systems- Since 1973, four out of six wind shear related air carrier accidents have occurred when thunderstorms have been in the vicinity of the airport. Therefore, thunderstorm gust front detection has been assigned a very high priority in the FAA wind shear program.

To accomplish the gust front detection, the characteristic pressure change that precedes a surface wind or temperature change is detected with pressure-jump sensors located in arrays adjacent to the airport. The warning provided by these detectors will be used to inform arriving and departing flights of an impending or potential gust front encounter. At present, gust front warning systems (GFWS), consisting of arrays of pressure-jump sensors (PJS) have been installed at the Chicago O'Hara airport and the NSSL WKY-TV meteorological tower at Oklahoma City, Oklahoma. PJS are also being installed at Dulles International Airport (IAD).

b. Anemometers- At O'Hare and NSSL, anemometers have been installed in conjunction with **PJS** to provide additional information about the surface strength and duration of thunderstorm gust fronts.

c. Acoustic Doppler Systems- The Acoustic Doppler systems have been used primarily as research tools to vertically probe the atmosphere and provide wind speed and direction data at low altitudes. Their major operational limitation is that this vertically looking system can only provide data over one small zone above the transmitter. Because of the large areas of major airports, wind conditions reported by the acoustic sensor may be significantly different from those several miles away. Since the acoustic system is a comparatively high cost system there is some question concerning the number of sensors which could be economically employed at any one airport. Also, the system is unable to operate under heavy precipitation conditions. The use of a dual-sensor system, using a pulsed-Doppler radar during precipitation, is scheduled for testing at Dulles International Airport.

d. Laser Systems- Doppler Laser systems for low-level atmospheric measurements fall into two classes: continuous wave (CW) and pulsed. The CW Laser system has a demonstrated capability to scan vertically and report wind speed and direction from the surface to altitudes of up to 1000 feet AGL. Up to this altitude they may also offer "all weather" capability at a cost comparable to or less than acoustic Doppler system without its pulsed Doppler backup. For this reason,

a

the CW Laser's potential capabilities will be investigated for near term airport implementation.

The pulsed Laser has a much greater range than the CW Laser and therefore may be used to scan up the glide slope. This ability appears to be a most desirable method of providing wind shear data.

The pulsed Laser approach, although offering a greater range capability, can only be pursued in a longer term development program.

e. Radar Systems- The potential of microwave radars is presently being evaluated to determine their ability to make wind shear measurements under "all weather" conditions. Their radar scanning capability could provide greater volumetric sampling than overhead vertical probes such as an acoustic Doppler sounding system. This area of the program plan is also viewed as a longer term effort.

4. Airborne Wind Shear Development Efforts

Ideally an airborne system for aiding a pilot to cope with shears should be predictive in nature. This is especially true for the severe shears where aircraft performance margins have been virtually eliminated. The timeliness of wind shear information is a basic consideration. The system must be free from ambiguous interpretation and its impact on flight crew work loads must be carefully considered.

To aid in the evaluation of specific pilot aiding concepts, it is necessary to identify the various roles which an airborne wind shear detection and/or information system could fulfill.

Advisory-Alerting a pilot of an impending potential dangerous shear, if accomplished in sufficient time has been demonstrated in simulation experiments to be an effective aiding concept. It is especially helpful if the type of shear is also identified to the pilot. A word of caution- the credibility of this concept must be established and maintained. The pilot must have confidence in the information given.

Detection- To be assured of a shear detection during an encounter while using conventional instrumentation requires a very astute, attentive, pilot. If the detection concept is based on panel-mounted (head down) displays and unless it has some degree of predictive characteristic, it could adversely impact the crew workload, in which case some automation might be in order. If the shear has been encountered after the pilot has transitioned to outside visual references, some forms of head-up displayed information have been shown to have merit.

Airspeed Management- This role is of major importance since it provides the means of maintaining sufficient kinetic energy with which recovery from a severe shear can be accomplished. The airspeed management role should have predictive capability and must be based on a rationale which considers limiting flap speeds and aircraft landing performance.

Flight Path Control- This role could possibly provide the pilot with a form of improved pitch guidance following a shear encounter. However, the mechanization of flight path angle must avoid the use of terms which are affected by vertical wind components, otherwise erroneous indications can be expected.

One of the objectives of the FAA wind shear airborne equipment task has been a survey and evaluation of existing and developmental airborne systems, procedures and techniques to determine the effectiveness in reducing the wind shear hazard. While we are aware of various developmental efforts underway by the industry we have not had the opportunity to evaluate all of these because of budgetary limitations or proprietary reasons. However, there has been a number of recommendations made regarding the potential of various state-of-the-art concepts to wind shear alleviation. Many of these recommendations appeared to have sufficient merit to warrant examination in a controlled experiment.

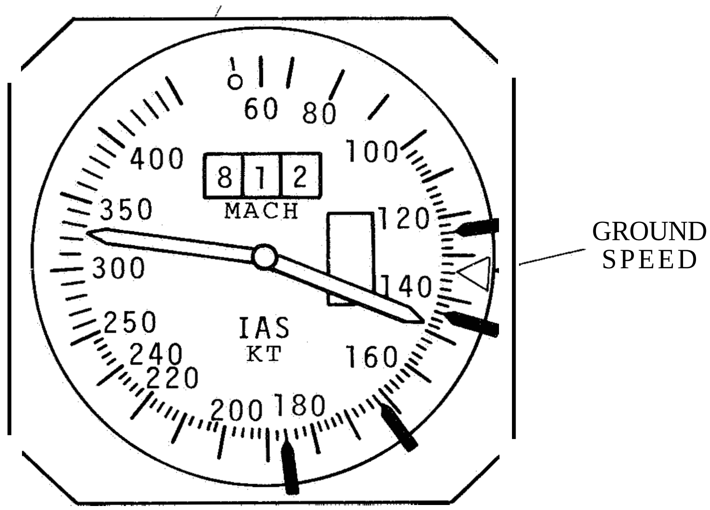
a. Manned Flight Simulation Experiments- Prior to any decision to develop new avionic equipment for wind shear detection/display, it was necessary to evaluate pilot performance and response to shear encounters while being exposed to the various aiding concepts referenced above. To accomplish this evaluation, a series of flight simulation experiments are being conducted for the FAA through a contract with Stanford Research Institute (SRI). The first simulation effort was designed to provide an early determination of the potential operational effectiveness of candidate systems and techniques that could be used to guide in-depth studies and systems refinement. These experiments were conducted in a DC-10 simulator at the Douglas Aircraft Company Flight Crew Training Center in Long Beach. The simulator was equipped with a full complement of controls and instruments for all flight crew member positions and was capable of simulating all flight guidance and control modes available on the aircraft in service use. In addition to the six degrees of freedom motion system it was equipped with a Vital III computer generated imaging system for representing the external visual scenes. The wind shears represented by the profiles in Figures 3, 4, 5, and 6, were programmed in the computer along with a moderate level of turbulence.

In Phase I of the simulation effort, pilot performance data and subjective pilot opinions were recorded on eight highly experienced pilots most of whom held DC-10 pilot qualifications. The pilots were subjected to various flight scenarios and wind shear combinations while being aided by the following concepts presented separately:

- Wind shear advisories based on ground sensor data;
- Panel display of groundspeed versus vertical speed for a 3" glide slope;
- INS wind speed and direction;
- Panel display of groundspeed integrated with conventional airspeed indicator (AV) (Figure 7);

Panel and head-up display of difference between along-track wind component at surface and aircraft altitude (ΔV_w) (Figures 8 and 11); and,

Panel and head-up display of flight path angle and potential flight path angle (Figures 9 and 10).



MACH/AS INDICATOR

Figure 7 Test Display of Ground Speed

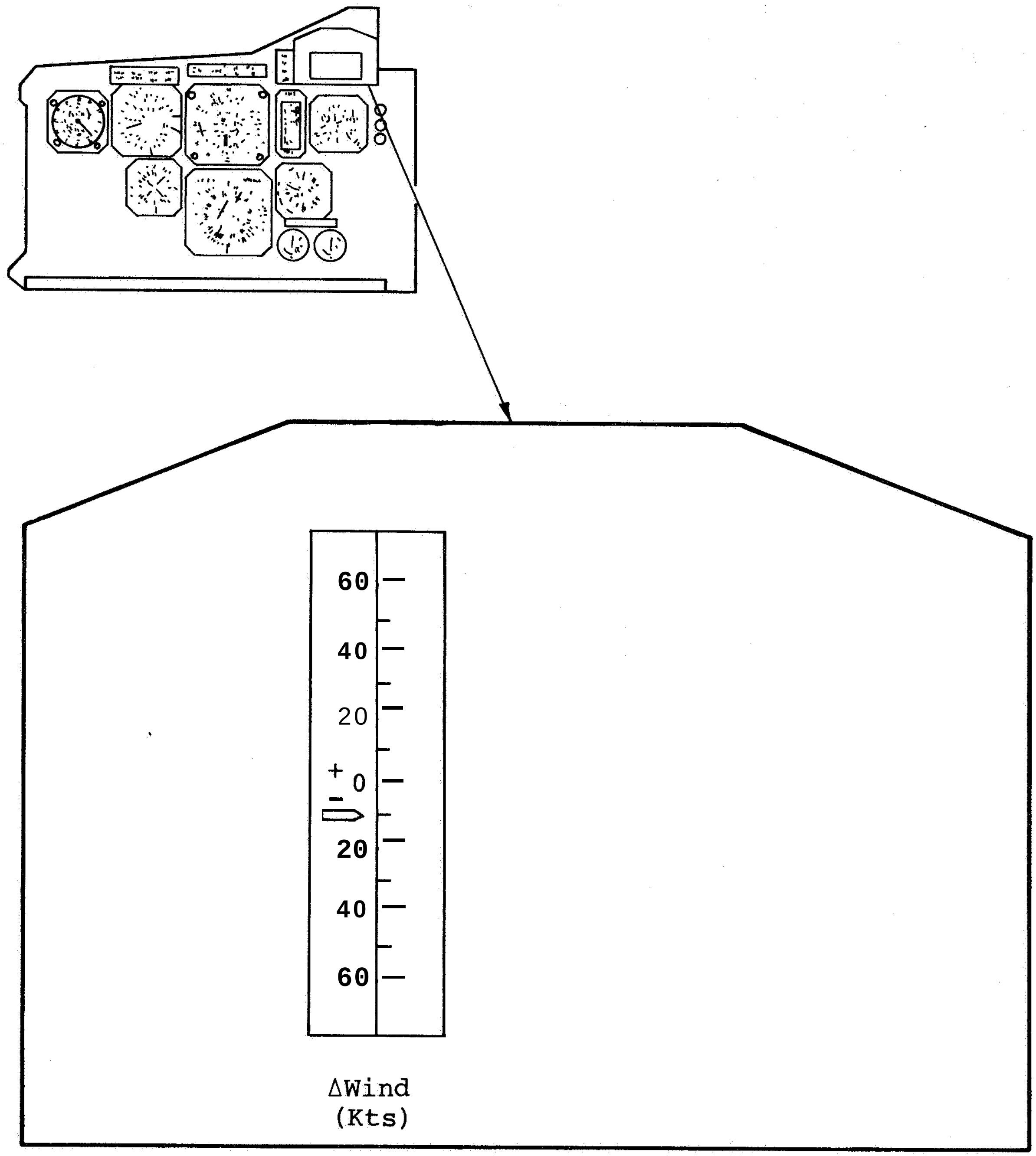


Figure 8 Test Display of the Wind Difference Indicator

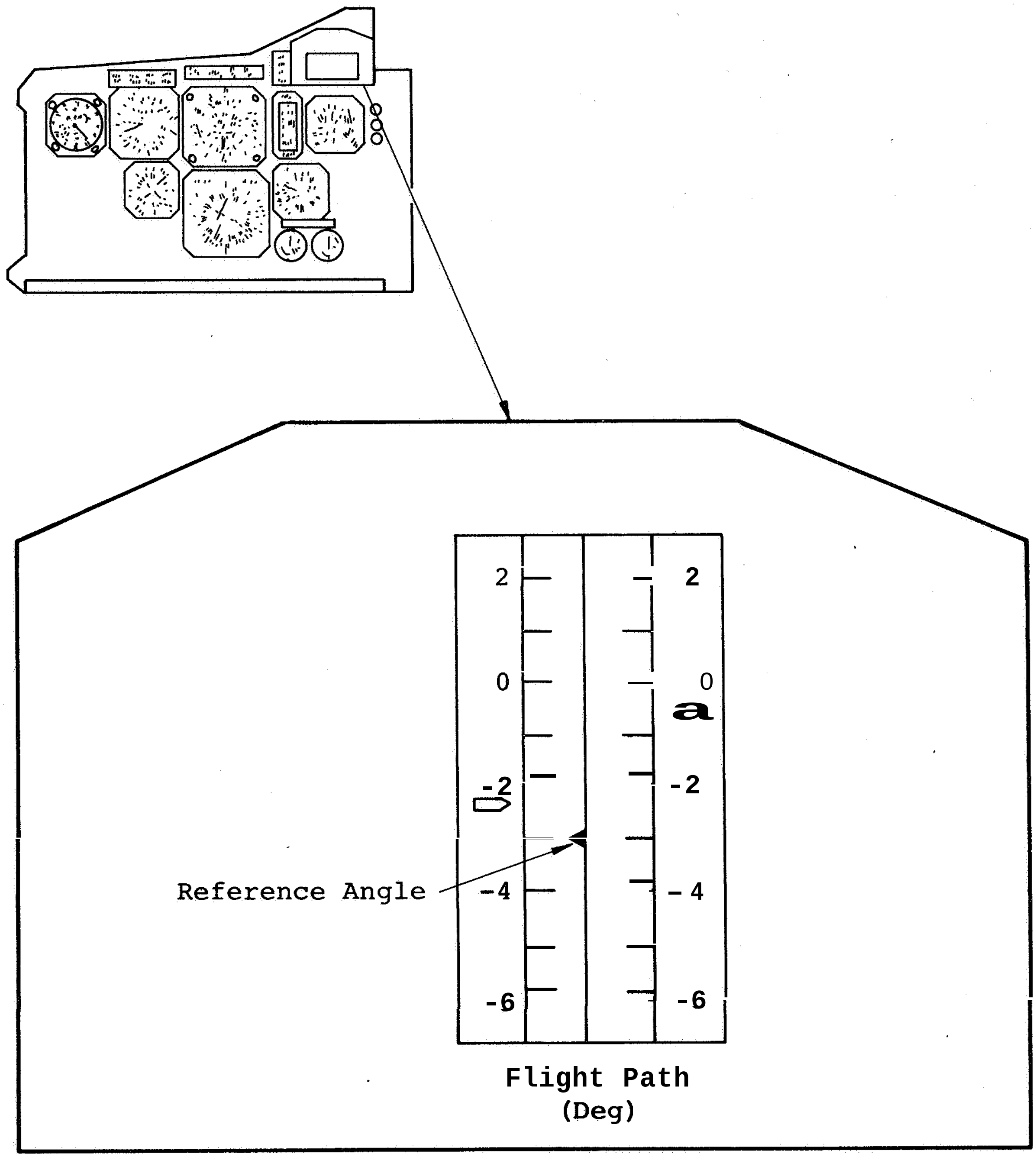


Figure 9 Panel Display of Flight Path Angle (Left) and Potential Flight Path Angle (Right)

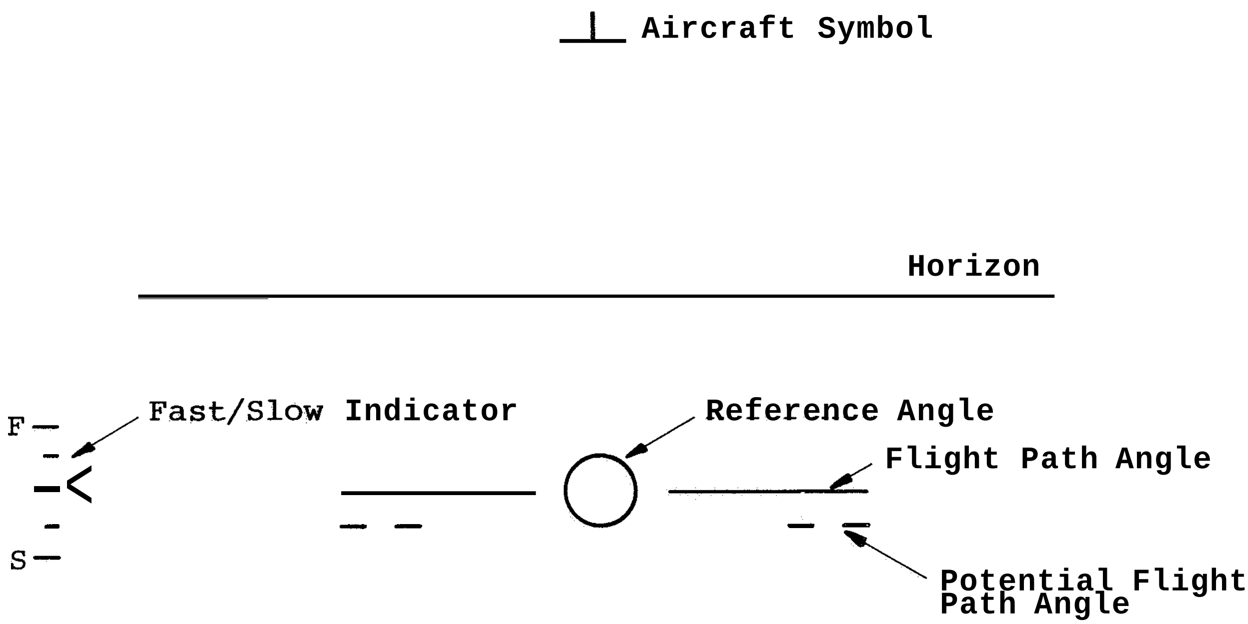


Figure10 Head-up Display Format for Phase 1 Testing

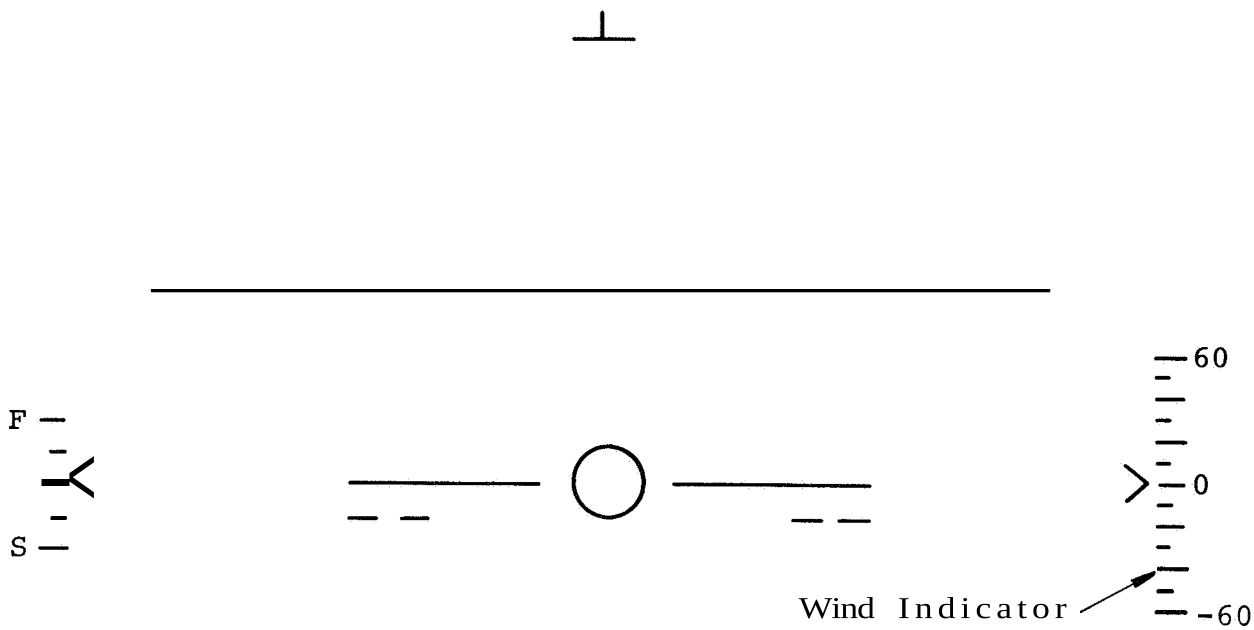


Figure 11 Head-up Display with the Wind Difference Indicator

a

b. Results of Airborne Experiments- The results of these experiments indicate the groundspeed/airspeed comparison (AV) ranked as the best aiding concept by pilot subjective opinions and by the comparison of recorded landing performance. The second ranking aiding concept was found to be the along-track wind component comparison (ΔV_w), particularly when presented in a head-up display. There is also an indication that the head-up displayed flight path angle has some merit. The role of head-up displays for wind shear detection will require additional study.

The AV and ΔV_w concepts assume the availability of accurate, timely groundspeed information in the airplane. For those aircraft so equipped, INS can provide this function. As a priority development, the FAA has efforts underway to develop a less costly method of obtaining the ground speed (closure rate) within the accuracy and time delay requirements. For the four shears examined in both manned and fast-time simulation experiments, the results indicate that a sensor lag of up to 5 seconds can be permitted on the groundspeed signal. The accuracy limits have not been established since velocity errors in addition to the 5-second delay have not yet been programmed in wind shear simulation experiments conducted by the FAA. In addition to the groundspeed input accurate wind information from the runway threshold area must also be available.

c. Operational Use of Groundspeed Augmented Wind Shear Detection Systems- The mass of the airplane precludes its inertial velocity from changing rapidly. But because of mass, the airspeed changes due to shears can occur almost instantaneously. Monitoring the relationship between the inertial velocity (groundspeed or closure rate, for all practical purposes) and airspeed provides a technique for aiding wind shear encounters.

The ΔV groundspeed information, displayed on an airspeed indicator mechanized through a controllable speed "bug" or through the use of an additional needle, is used in conjunction with a minimum groundspeed reference. The minimum groundspeed reference value is derived from approach speed TAS minus the along-track wind component at the threshold. In use, the pilot never allows either airspeed or groundspeed to drop below their respective reference approach speeds.

The ΔV_W concept uses a display (Figures 8 and 11), which indicates a value representing the surface along-track head wind component minus the flight level along-track head wind component. A negative value indicates the presence of a shear between the aircraft and the runway, characterized by a decreasing head wind (or increasing tail wind). For negative values, the pilot should increase his approach airspeed by the indicated value. For positive values no decrease below approach airspeed would be made but the pilot is informed that a shear can be expected.

The positive value indicates an excess of total aircraft energy may occur at some point during the approach. While this situation may appear to be the least critical of the two cases, it shows indications in simulation experiments of being the most critical-simply because the pilot is deceived into making excessive thrust reductions to overcome the temporary indication of excessive airspeed and/or altitude. The longer term stabilized thrust requirement following a decrease in tail wind (or increase in head wind) is for increased thrust.

d. Future Airborne Programs- Based on the results of the Phase I simulation experiments, the second phase of simulation to be conducted by SRI will be designed to accomplish the following: (1) examine improved AV and ΔV_W displays; (2) evaluate additional uses for flight path angle information, particularly where the dynamic effect of the wind shear causes misleading thrust cues to the pilot; and, (3) evaluate flight director and thrust command information made possible through acceleration augmented algorithms. A head-up display evaluation is also being pursued by the FAA, although the scope of this project goes beyond the time constraints placed on the wind shear program. The head-up display program; however, includes wind shear related considerations.

5. Wind Shear Data Management

The objective of the wind shear data management is to organize the airborne and ground-based meteorological data collected in the program for subsequent analysis and processing and to build a data base of wind shear information for use in the program. In addition to the ground-based sensors, met-towers, etc., a dedicated meteorological data collection airplane is employed to expand the sampling of various atmospheric phenomena.

6. Integration of Wind Shear Systems and Data into the National Airspace System (NAS)

There is a high priority placed on implementing the results of the wind shear investigations into the NAS. Wind shear displays, languages, advisory messages are subject to human factors analyses, testing and evaluation. Projects for these evaluations are underway.

IV. Conclusions

The solution to the wind shear hazard must depend on a variety of developments. It is quite probable that each of these developments will provide contributions to the total but none will provide all the solutions required.

The areas which show promise for short term solution are:

- Greater pilot awareness of wind shear through improved training.
- Improved forecasting for certain types of frontal shears.
- Airborne displays based on groundspeed/ airspeed comparison.
- Improved gust front warning through ground-based sensors.

References

1. Anon.: Engineering and Development Plan-Wind Shear, Federal Aviation Administration Report No. FAA-ED-15-2, March 1976.
2. Fujita, T.T.: Spearhead Echo and Downburst Near the Approach End of a John F. Kennedy Airport Runway, New York City. Satellite and Mesometeorology Research Project. Research Paper 137, Department of Geophysical Sciences, The University of Chicago, March 1976.
3. National Transportation Safety Board: Aircraft Accident Report-Iberian Airlines, McDonnell Douglas DC-10-30, EC CBN, Logan International Airport. Boston, Massachussets, December 17, 1973. Report Number NTSB-AAR-74-14, November 1974.
4. National Transportation Safety Board: Performance Group Chairman's Factual Report of Investigation (Eastern Air Lines Flight 66, John F. Kennedy International Airport) Docket No. SA 451 (William G. Laynor, Jr., Air Safety Investigator).
5. National Transportation Safety Board: Aircraft Accident Report-Eastern Air Lines, Incorporated, Boeing 727-225, N8845E, John F. Kennedy International Airport, Jamica, New York, June 24, 1975, Report Number NTSB-AAR-76-8, March 12, 1976.
6. Sowa, D.F.: Low-Level Wind Shear-Its Effects on Approach and Climbout, DC Flight Approach No. 20, June 1974, Douglas Aircraft Company.

7. Stout, C.D. and Stephens, W.A.: Results of Simulator Experimentation for Approach and Landing Safety. Preprints International Air Transport Association 20th Technical Conference, Istanbul, Turkey, Douglas Paper No. 6395A, Douglas Aircraft Company, November 10-15, 1975.

8. Warner, H.D., et al: A Preliminary Simulator Investigation of Pilot Factors in Low Visibility Approach and Landing, Phase II, Technical Memorandum AFFDL-TM-76-7-FGR, U.S. Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio, January 1976.

PROBLEMS PILOTS FACE INVOLVING WIND SHEAR

W.W. Melvin
Airline Pilots Association

Wind shear has been with us as long as there has been wind, but only recently re-discovered as a limitation to flight. Early pioneers of flight knew of some of the problems of wind shear effects upon their aircraft. In 1896, aviation pioneer Otto Lilenthal was killed in a glider probably for the same reason modern hang glider pilots are being killed, that is, lack of lateral control sufficient to handle the turbulent wind conditions close to the ground. Recognizing this problem and devising a means of lateral control was probably the Wright Brothers' most important contribution to early flight--and also the subject of a bitter patent infringement suit against Glenn Curtiss for his use of an aileron.

Early flight manuals tell about the air losing its lift, air pockets and so forth to describe wind shear phenomena, but it has generally been regarded for several decades that modern aircraft could fly through any meteorological phenomenon except possibly a tornado. Educating pilots and the aviation industry to the contrary has been our biggest problem. In Pogo terminology "we have met the enemy and he is us". Having heard about the wind shear related accidents which were caused by "pilot error", we have been ill prepared to cope with strong wind shears because we depend upon our ability and skill to manipulate aircraft and do not easily admit we could make a mistake or error which would result in a serious accident.

When I first described how an aircraft could hit short in a decreasing tailwind shear (1969), published meteorological literature at the time expressed the conclusion that the strongest probable wind shears were on the order of 10 knots per 100 feet vertical travel. Meteorologists still call this vertical wind shear which the engineer and student of fluid dynamics calls horizontal wind shear. We don't even have a common language--which brings us to the pilot's second most pressing problem--the need for a language to discuss wind shear encounters with other pilots so that the reaction of the aircraft to the wind shear encounter can be accurately described without expecting all pilots to be experts in wind shear analysis. For several years I have been suggesting the use of positive and negative shear as follows:

Positive Shear: A shear which results in the aircraft having a tendency to increase airspeed and/or overfly the glidepath.

Negative Shear: A shear which results in the aircraft having a tendency to decrease airspeed and/or underfly the glidepath.

These definitions are important, I think, because reporting a decreasing tailwind shear or a tailwind to headwind shear does not accurately describe the reaction in all cases and requires interpretation. As I have consistently pointed out, a decreasing tailwind which is always a decreasing tailwind can change from a positive effect to a negative effect if the pilot corrects for the rate of encounter and if the rate of encounter subsequently decreases, (See Figure 1). In this case if "wind shear" is simply reported, a following pilot could interpret the positive effect as the only effect and be even more unaware than if he heard no report at all. A report in this case such as "a positive shear at the outer marker with a moderate negative shear at the middle marker" would accurately describe to a following pilot what to expect. This type effect usually is encountered in the situation such as that which caused the Iberia DC-10 to crash at Boston, that is, shortly after a cold front has passed the airport so that most of the approach is done with a decreasing tailwind aloft. For positive shears which occur all the way to the ground, it is important that following pilots are aware of the type effect they are expected to deal with. Otherwise they are likely to add far too much speed to complete a successful landing.

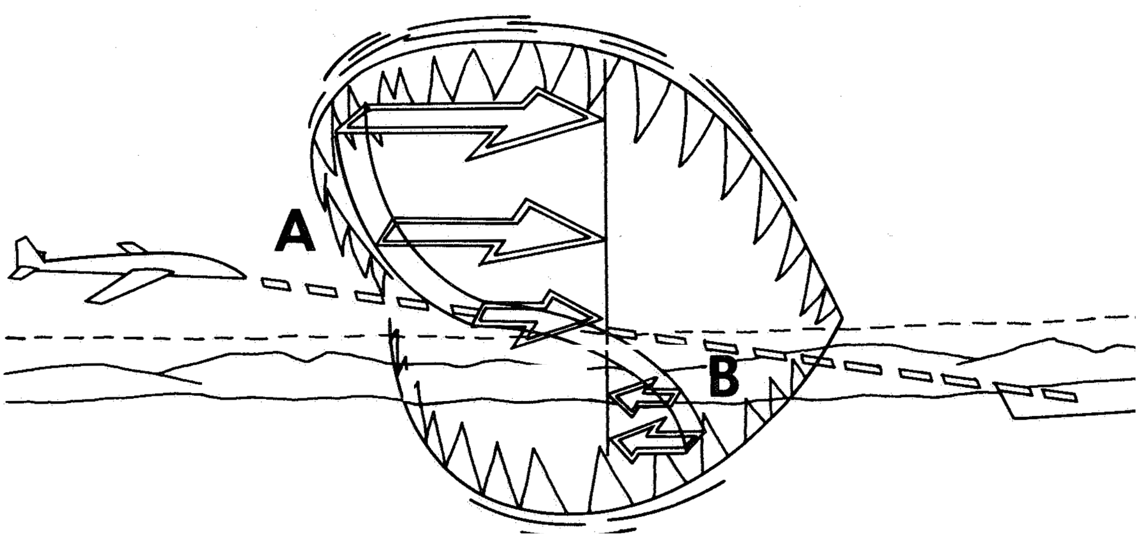


Figure 1

CAUTION! Shears associated with thunderstorm downdrafts are likely to cause pilots to report strong positive shears which will become strong negative shears as a thunderstorm downdraft moves from the far end to the approach end of the runway. Initial enounters will be only with the front side of the downdraft base area since the aircraft will be on the ground before passing through the base area (See Figure 2). All wind shears which are associated with thunderstorms should be considered as having the potential for severe negative reaction regardless of how they are reported.

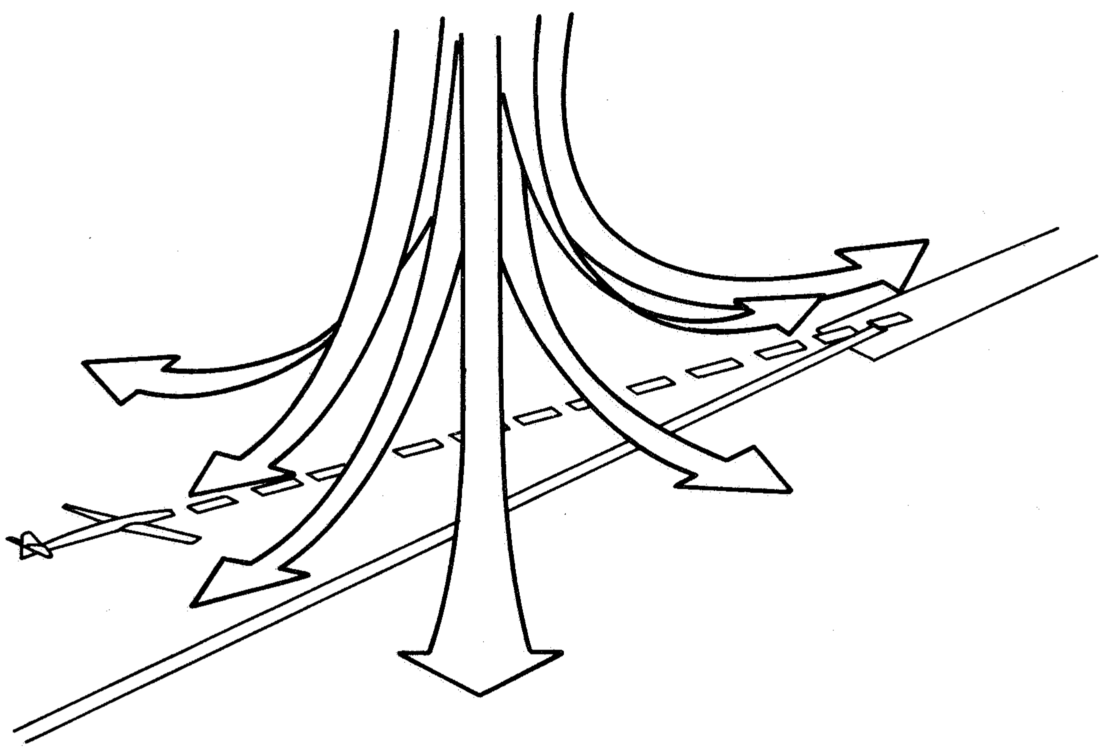


Figure 2

It appears at present that the severe downdraft or downburst, as named by Dr. Fujita, is very rare. They apparently can come from small thunderstorms as well as large ones, but in both cases the cells must have rapid development. This presents a real problem to pilots. We have all flown beneath thunderstorms with very little adverse effect. In fact, this was recommended when I went through flight training. Downbursts are rare and unpredictable, and pilots want to complete their mission. Adequate training and communication between pilots could help avoid some downburst accidents since there has usually been some evidence to preceding pilots before the accident or incident, Although a warning of severe wind shear can reduce a pilot's recognition and reaction time, only a refusal to fly though the area will guarantee safety since no commercial aircraft ,in the takeoff or landing configuration can adequately cope with an encounter of the base area of a downburst with outflowing winds on the order of 60 knots or more. Out best bet now, that is immediately attainable, is a network of anemometers along the arrival and departure routes to an airport with an automatic monitor to signal any gross deviation of wind condition to tower controllers so they can take appropriate action.

Dr. Fernando Caraceno, atmospheric physicist at NOAA, also suggests measuring pressure and temperature to determine these areas of significant deviation.

In training pilots we must make them aware of the fact that there must be inertial acceleration of the aircraft to correct for a negative shear, and that this acceleration which they feel can cause them to under react to the shear. In all cases when they detect a strong negative shear condition close to the ground they should advance full thrust and prepare for a go around if necessary.

Incidentally several instrument systems and autopilot/autothrottle systems use longitudinal accelerometers to modulate the response rate, which means that for normal conditions when the aircraft has longitudinal acceleration, the response rate is retarded. In a strong negative shear condition through where longitudinal acceleration is required and the response rate needs to be increased, it will instead be decreased for these systems. This is one reason why a well trained pilot can beat the automatic system. Also, it is the reason why a potential flight path instrument or display will not work in a wind shear.

Another problem is the flight director which gives a centered pitch command for a given angular displacement from the glide slope. What may be sufficient for normal conditions may be inadequate for strong wind shear conditions. I have objected to the use of this as pitch command since I first saw one. They should instead be called flight path command and should not center unless the aircraft is actually correcting to the flight path.

This opens the whole arena of aircraft instrumentation. Basic to our present problem is that our primary instrument, the attitude indicator, does not tell us where we are going relative to the horizon. The pilot must integrate into his thinking the descent rate and glide path position to determine where he is going. However, under good visual conditions he has instant recognition of where he is going because he sees the aircraft's trajectory, terminating at that point on the runway that doesn't move. Limitations to a pilot's recognition of a hazardous situation which are inherent to his instrument system and operational procedures may be the determining factor in many accidents. One recent aid has been the Ground

Proximity Warning System (GPWS). Even though pilots are generally annoyed at the false warnings, this warning of glide path departure may be the pilot's first clue to a deteriorating situation. The GPWS is a band aid approach though. With better instrument systems we would be aware of a deteriorating situation before the GPWS told us about it.

A special problem in pilot recognition time occurs when the auto-pilot increases the aircraft's pitch close to the ground. While the pitch is increasing, the pilot's normal cisual cue that the aircraft is goint to hit short is obscured because he does not observe the runway rise in his field of view. If he is not aware of the condition and especially if he has just transitioned from a heads down instrument approach to a heads up visual landing, he will be several seconds late in recognizing his predicament. Even though in some wind shear accidents it can be proved theoretically that the aircraft could have made a successful landing or go around, we must consider the entire system which includes the pilot. His recongnition and reaction times are often the crucial element. By training we can reduce the recognition time somewhat, but with better instrumentation displays we could cut the recognition time to a minimum.

Related to the instrument system is the method of flight control. Approach couplers utilize a method of flight control whereby pitch changes are used to correct for errors in flight path position and resultant changes in airspeed are expected to be corrected for with thrust. Flight directors command this type response. Aside form the fact that magnitudes of pitch correction which are suitable for stable wind conditions are not suitable for wind shear conditions, there is a serious conflict with aerodynamic theory--partly recongized in some late model systems which have coordinated inputs to pitch and thrust. To change the direction of an aircraft's inertial vector requires centripetal force supplied at a change in lift. An increase in lift is accompanied by an increase in induced drag which if not immediately offset by thrust means a decrease in airspeed will result. In addition, to fly a less negative flight path angle requires a definite amount of thrust increase. Thus for a known thrust deficient condition where the aircraft is going below the glide slope, thrust must be added along with a change in pitch. However, except for the brief application of centripetal force requiring a momentary increase in angle of attack, the net result of the pitch change is to maintain a constant angle of attack, while the change in thrust is the major contributor to a new flight path. The old rule "Attitude plus power equals performance" is as correct today as when I went through navy flight training.

Those who explain to themselves and others the effects of wind shear based on an assumption of instantaneous change in airspeed. Their view imposes an assumption that a change in airspeed is the first observable effect of a shear, and of course they argue for a thrust correction to rectify the situation. I certainly agree that whatever causes the pilot to first observe a thrust deficient condition should cause immediate corrective action. However, in a negative shear condition of a reasonably finite rate, an aircraft with positive longitudinal stability will of its own accord pitch over to maintain its trimmed airspeed. Only after the aircraft departs from the glide slope will the autopilot (or pilot) exert an elevator input which will cause an airspeed decrease. The deficient thrust condition should be recognized before the airspeed decrease, but again if the airspeed decrease

a

is the pilot's first observation of the condition, he should certainly respond.

A competent pilot upon sensing a thrust deficient condition will respond with thrust and pitch, but the autopilot responds only with pitch. The pilot then must interpret the autopilot response before adding thrust. This is a serious limitation of auto coupler approaches, and flight director approaches if pitch command is used as an action uncoordinated with thrust. Fortunately most pilots coordinate the two and have learned to anticipate the approach coupler, but unfortunately some have used the uncoordinated action of the approach coupler to argue a fallacious method of flight control that can only be demonstrated by uncoordinated action. The alarming fact is that they want to force beginning instrument flight students to adopt their uncoordinated method. An energy trade is a more rapid response than a thrust change so they get deeper into their problem by forcing an energy trade before a thrust response. Indeed a certain amount of energy trade will occur but a pilot content with uncoordinated action will be very late in responding with thrust in a strong wind shear. An intentional energy trade should be reserved for drastic conditions which is the reason for carrying extra airspeed. Energy not traded can be used at any time, but thrust not applied is lost forever.

Since a large part of what we think we know about wind shear effects upon aircraft has come from review of past accidents and incidents, we should be careful in reviewing the data. In most cases 4 channel flight recorders were being used which means that to determine the magnitude of a shear a thrust level must be assumed. Since the Airline Pilot Association generally believes the pilots were telling the truth, we usually come up with larger shear values than other parties who want to make assumptions of lesser thrust levels. In some cases, to come up with a modest shear or none at all, the pilots would have to have selected reverse thrust while the aircraft was several hundred feet in the air. We believe that most hard landings have been caused by wind shear and that the problem has been far greater than formerly suspected.

The most important safety hedge the pilot has had to protect himself from an adverse encounter with wind shear has been the pad of airspeed he puts on for "Mama and the Kids". I believe that many potential wind shear accidents have been avoided by pilots' good judgement in this matter. Extra airspeed is a double edged sword though--the extra energy which is so important in protecting against a strong negative shear encounter can severely limit the stopping capability with a positive shear encounter.

The effect of runway over run accidents upon approach procedures must be examined and put in their proper context. For many years the industry has not recognized a very important factor in runway over runs. In most cases the aircraft touched down long and fast, usually due to wind shear. So called safety experts have been quick to label this as pilot error. They argue that if the aircraft hadn't landed long and fast the accident wouldn't have occurred. However, in almost all cases if the stopping capability after the touchdown had been what the pilot was accustomed to having the accident also would not have occurred. The important point that has been so often overlooked is that the pilots almost invariably were aware of their long fast touchdown and believed they could stop the aircraft. Since all such previous accidents occurred from "pilot error" rather than inadequate stopping capability, pilots have been unprepared to cope with their situation.

When a pilot gets his first case of rubber tread reversion, with water ingestion into engines causing loss of reverse thrust or a number of other factors which rapidly compound, the situation can grow into one he may be incapable of handling. The point though is that instead of recognizing the serious limitations of stopping under adverse conditions, educating the pilots and correcting the runway friction problem by grooving, the simple solution has been to insist on using low approach speeds. Now I certainly don't approve of arbitrarily adding speed increments when the need doesn't exist nor do I approve of long fast touchdowns, but I am very much against the intimidation of pilots to not use the speed required for the existing condition. I hope pilots will continue to exercise good judgement and add extra speed in turbulent conditions despite intimidation by those more interested in proving their past actions have been correct than in safe operating procedures. If so, there should continue to be cases of pilots being high and fast over the threshold. However, with proper appreciation of the stopping problem, such cases should result in go arounds instead of over runs. The rule of adding one half the steady wind plus all of the gusts is inadequate for wind conditions different than observed by the tower, but some in the industry want to rigidly limit a pilot's judgement by this rule. To do so runs the risk of causing more approach accidents short of the runway. Although the rule is generally a good one it should not be used to limit pilot judgement of the actual condition which may be totally irrelevant to the ground reported wind.

Recent emphasis has centered in downbursts related wind shear, but other types should not be disregarded. Many pilots still do not know what to expect when a front lies close to an airport, and the low level or nocturnal jet stream is practically unknown.

Joe Gera of NASA Langley, in his paper (NASA TN-D-6430, 1971) describes how a strong increasing head-wind could excite the phugoid oscillation of some aircraft. It is a known fact that some jet upsets occurred while encountering strong increasing headwinds. More study needs to be devoted to this area and if a hazard exists, pilots need to be informed.

In several downdraft related wind shear accidents and incidents we have been able to produce WSR-57 radar pictures of the thunderstorm cell that caused the accident or incident, yet that vital information which was recorded at the time was unavailable to the flight crews flying beneath the cells.

If we are to have safe operations without unduly limiting them, we must better develop our information gathering and knowledge of wind shear. There is a risk of operation of anything that moves and our job is often one of risk assessment. Just as many factors come together in precise focus to cause an accident, the absence of a single one can make the difference between a fatal accident and a good story. We must not be content with single solutions as there are no panaceas. We need to unload as many chambers as quickly as possible before the hammer falls again on the proper combination.

REFERENCES

1. "Effects of Wind Shear on Approach With Associated Faults of Approach Couplers and Flight Directors," W. Melvin, AIAA Paper No. 69-796.
2. "Effects of Wind Shear on Approach," W. Melvin, Flight Safety Foundation Bulletin 70-103/105.
3. "Wind Shear on the Approach," W. Melvin, Shell Aviation News, 393-1971.
4. "Wind Shear on the Approach," W. Melvin, Flight Safety Facts and Analysis, March 1974.
5. "Effects of Wind Shear in the Base Area of Downdrafts," W. Melvin, Flight Safety Facts and Reports, September 1975.
6. "The Dynamic Effect of Wind Shear," W. Melvin, Pilot Safety Exchange Bulletin, November/December 1975.
7. "The Bastard Method of Flight Control," W. Melvin, Pilot Safety Exchange Bulletin, March/April 1976.

WIND MODELS FOR FLIGHT SIMULATOR CERTIFICATION OF LANDING AND APPROACH GUIDANCE AND CONTROL SYSTEMS

Dwight R. Schaeffer

FOREWORD

This paper is taken from Department of Transportation Report No. *FAA-RD-74-206,* December *1974,* having the same title, authored by Neal M. Barr, Dagfinn Gangsaas, and Dwight R. Schaeffer. Substantiation of information presented is provided in this report.

INTRODUCTION

This paper reports an investigation performed to provide the information for improved accuracy of low-altitude wind and turbulence models to be used for the certification by flight simulation of approach and landing guidance and control systems.

Historically, the structural designers were first to recognize the requirement for a mathematical model and initially used only the discrete 1-cosine gust for the design limit case. As airplanes became lighter and more flexible, fatigue life became more critical and the need for a more accurate description became greater. This led to the application of the statistical power spectra. Attempts to fit a mathematical model to measured data began seriously in the late 1950s and has progressed to the point of "which model do I use?"

Automatic controls were used initially to provide modest improvements of airplane stability and to provide guidance during noncritical flight phases (altitude, attitude, and heading hold). Automatic control authority tended to be low. Hence, the interaction of the control system with wind and turbulence was unimportant; it was not a concern for flight safety,

For typical flight controls analysis, such as handling qualities, ride qualities, and controllability, concern was for a qualitative, rather than quantitative, answer; that is, does a parameter variation (in the aircraft or control system) improve or degrade the particular output? A forced change in this philosophy occurred when the autoland systems began to appear in the early 1960s. The dependence upon an automatic landing system rather than the highly adaptive pilot required analytic proof that the landing would be performed with adequate safety. The problem is now quantitative rather than qualitative and a gross error in the approach wind model could be very serious; parameters of the wind model have effects comparable to parameters of the aircraft and guidance system. Certification of autoland systems is dependent upon demonstration of very low orders or risk of fatal accidents. Obtaining adequate statistical data to validate remote probabilities of fatal accidents is impractical without heavy reliance upon simulation.

The search for a low-altitude wind model, providing a better representation of low-altitude wind phenomena than provided by existing certification wind models, was principally concerned with the region from the surface to about 1000 feet. The model for this altitude region tends to be the most general and complex due to the strong dependence of wind characteristics upon altitude and surface terrain and the orientation dependence of turbulence characteristics. Additionally, the landing approach task is the most difficult and critical task for which relatively small changes of wind characteristics may result in large changes in maneuver performance. The low airspeed during approach tends to couple vertical motion with longitudinal wind components and longitudinal motion with vertical wind components, increases the nonlinearity of aircraft responses to winds, and increases the significance of the distribution of winds over the aircraft. Hence, the aerodynamic model incorporating the effects of winds tends also to be most general and complex.

The main objective of the investigation was to define a model suitable for certification. A model for design must be simplified to reduce the wind model parameters to enable evaluation of a large number of aircraft and control system design parameters.

The studies were concerned with the "average" airport, although it is recognized that the "average" airport may not exist. It is both impractical and undesirable to represent unique characteristics of any particular airport for the certification of an aircraft that will land at many different airports. "Average" airport is used in regard to possible unique operating procedures and terrain features and does not imply "average" winds at the "average" airport.

Consideration is not for the wind alone, but for aircraft responses in wind environments, so the investigation included the representation of aerodynamic forces due to winds and a brief analysis of the effects of winds on aircraft motion.

No original work on the description of low-altitude winds is intended. The wind model is a combination of the work of others. The structure of the model has been parameterized to enable incorporation of new material and updating of parts without discarding the entire model.

For virtually every aspect of low-altitude winds there are conflicting descriptions. Some descriptions are based on undocumented data collection, analysis techniques, and test conditions. Some general considerations used for selecting one among competition descriptions are:

- Weight of evidence
- Physical and intuitive reasonableness
- Substantiation
- Existing specifications, when the choice appears arbitrary
- Compatibility with the description of other parameters
- Validity of the assumptions
- Avoidance of descriptions providing unreasonable discontinuities

Analytic descriptions of wind phenomena are presented. Where possible, a deterministic description is preferred in the presumption that all physical processes have cause-and-effect relationships. When relationships are too complex to permit quantitative understanding or when deterministic descriptions are impractical, probabilistic descriptions are used, with the statistical parameters defined deterministically as much as possible.

For those parameters defying analytic description, probabilistic descriptions have been sought. Probabilistic descriptions were first sought from the literature. For those aspects not well defined by the literature, descriptions have been sought by reducing and evaluating tower data.

A brief analysis of the effects of winds on aircraft motion has been conducted to gain an appreciation of what needs to be modeled. The axes transformations required between wind and turbulence components in their inherent axis system and in the airplane's axis system are shown. Techniques of providing a random process on computers for the representation of turbulence are presented. A simulation model is presented that combines all the foregoing components.

NOMENCLATURE

b	Wing span
C_p	Specific heat at 'constant pressure
$\bar{c}$	Mean chord
d	Atmospheric boundary layer thickness
e	Exponential function
f	Coriolis parameter, $f = 2\omega_E \sin \lambda$
$f(h/\ell')$	Contribution of nonneutral atmospheric stability to the mean wind
$f(\xi), g(\xi)$	Fundamental longitudinal and transverse correlation functions for isotropic turbulence, respectively
G_u, G_v, G_w	Filters for producing u, v, and w components of turbulence
g	Acceleration due to gravity
$g(h/\ell')$	Contribution of atmospheric stability to mean wind caused by variation of shear stress
H	Heat flux, positive upward
h	Altitude
h_{REF}	Reference altitude
h_I	Altitude above which turbulence is isotropic
k	von Karman constant, $k = 0.4$
L	Longitudinal isotropic turbulence integral scale

L_H, L_V	Integral scales for horizontal and vertical turbulence components
L_P, L_N	Longitudinal and transverse integral scales for turbulence components parallel and normal to the displacement vector, respectively
L_u, L_v, L_w	Integral scales corresponding to the longitudinal, transverse, and vertical turbulence components, respectively
ℓ, ℓ'	Monin-Obukov scaling length and Monin-Obukov scaling length modified by ratio of eddy conductivity to eddy viscosity
ℓ_T	Distance from the wing-body aerodynamic center to the tail aerodynamic center along the x body axis, positive aft
$M(\omega)$	Frequency response amplitude
p	Inertial body axis roll rate
p_T	Effective roll rate of the air mass due to turbulence relative to the earth
q	Inertial body axis pitch rate
$\bar{q}$	Dynamic pressure
q_T	Effective body axis pitch rate due to turbulence with respect to the earth
R_i, $R_{i_{20}}$	Richardson's number and that at 20-foot altitude
R_{ij}	Correlation for the i and j turbulence components
r	Inertial body axis yaw rate

$\vec{r}$	Displacement vector
r_A	Yaw rate relative to the air mass
r_T	Effective body axis yaw rate due to turbulence relative to the earth
$r_W, \bar{r}_W$	Effective yaw rate due to the wind and mean wind relative to the earth
s	Laplace transform variable
T	Absolute temperature
t	Time
u	Inertial linear velocity along the x body axis
u_*, u_{*_0}	Friction velocity (shear stress/density density)$^{1/2}$ and that at the surface
u_A	Linear velocity with respect to the air mass along the x body axis
$u_{A_{TG}}$	Component of airspeed along the x turbulence generation axis
u_P, u_N	Turbulence velocity parallel and normal to the displacement vector
$u_T, u_{T_{TG}}$	Linear turbulence velocity along the x body axis and the x turbulence generation axis relative to the earth
$u_{T_{TAIL}}$	u_T at the tail
$u_W, \bar{u}_W$	Linear velocity of the wind and mean wind with respect to the earth along the x body axis

$\bar{V}_W, \bar{V}_{20}$	Mean wind speed and that at 20-foot altitude
V_A	Total air speed
v	Inertial linear velocity along the y body axis relative to the earth
v_A	Linear velocity with respect to the air mass along the y body axis
$v_T, v_{T_{TG}}$	Linear turbulence velocity along the y body axis and the y turbulence generation axis relative to the earth at the center of gravity
$v_W, \bar{v}_W$	Linear velocity of the wind and mean wind along the y body axis relative to the earth
w	Inertial linear velocity along the z body axis
w_A	Linear velocity along the z body axis relative to the air mass
w_T	Linear turbulence velocity along the z body axis relative to the earth
w_W, w_W	Linear velocity of the wind and the mean wind along the z body axis relative to the earth
z_0	Surface roughness length
a	Angle of attack
β	Sideslip angle
Y	Glide slope
e	Euler pitch angle

$\theta_{ij}(\vec{\Omega})$	Three-dimensional spectrum function for the i and j turbulence components
χ	Latitude
λ_1, λ_2	Turbulence wavelength along the x and y axis
$\vec{\xi}, \xi$	Position displacement vector and magnitude
σ_i	Standard deviation for parameter i
σ_H, σ_V	Standard deviation of horizontal and vertical turbulence
$\sigma_u, \sigma_v, \sigma_w$	Standard deviations of the u, v, and w components of turbulence
σ_{ij}^2	Covariance between the i and j turbulence components
τ	Time displacement
τ, τ_0	Shear stress and that measured at the surface
Φ_I, Φ_O	Input and output power spectra
$\Phi_i(\Omega_1)$	One-dimensional power spectrum for parameter i
$\Phi_{ij}(\Omega_1)$	One-dimensional spectrum function for the i and j turbulence components
Φ_N	Random noise power spectrum
$\Phi_{NN}(\Omega_1), \Phi_{PP}(\Omega_1)$	Isotropic one-dimensional spectrum functions for u_N and u_P
$\Phi_u(\Omega_1), \Phi_v(\Omega_1), \Phi_w(\Omega_1)$	One-dimensional power spectra for components of turbulence along the x, y, and z axis

$\Phi_{uw}(\Omega_1)$	One-dimensional cospectrum for components of turbulence along the x and z axis
$\phi(h/\ell')$	Universal function of h/ℓ' defining nondimensional wind shear: $$\frac{kh}{u_{*_0}} \frac{\partial \overline{V}_W}{\partial h} = \phi(h/\ell')$$
ϕ	Euler bank angle
$\psi_{ij}(\Omega_1,\Omega_2)$	Two-dimensional spectrum function for the i and j turbulence components
ψ	Euler heading angle
$\overline{\Psi}_W$	Heading to which the mean wind is blowing
$\vec{\Omega},\Omega$	Spacial frequency vector and spacial frequency magnitude
Ω_1	Component of spacial frequency along the x axis
ω	Temporal frequency, rad/sec
	Angular velocity of the earth

Note: Dotted terms refer to derivatives with respect to time. Overbar indicates an average. Other terms defined where used.

WIND MODELS FOR FLIGHT SIMULATOR CERTIFICATION OF
LANDING AND APPROACH GUIDANCE AND
CONTROL SYSTEMS

Wind phenomena are classed as being mean wind, turbulence, and discrete gusts. Mean wind and turbulence are statistical parameters that appear together with turbulence being a random deviation of wind velocity about the mean. Distinction between the mean wind, which eventually is variable given enough time or space, is made on a frequency basis using the Van der Hoven bimodal wind speed spectrum (Fig. 1).

Discrete gusts are deterministic phenomena caused by localized terrain or atmospheric inhomogeneities of which there are an infinite number of possibilities. So long as conditions of reasonably homogeneous terrain and atmospheric features or restrictions on the proximity to inhomogeneities are justified, consideration of discrete gusts is unnecessary.

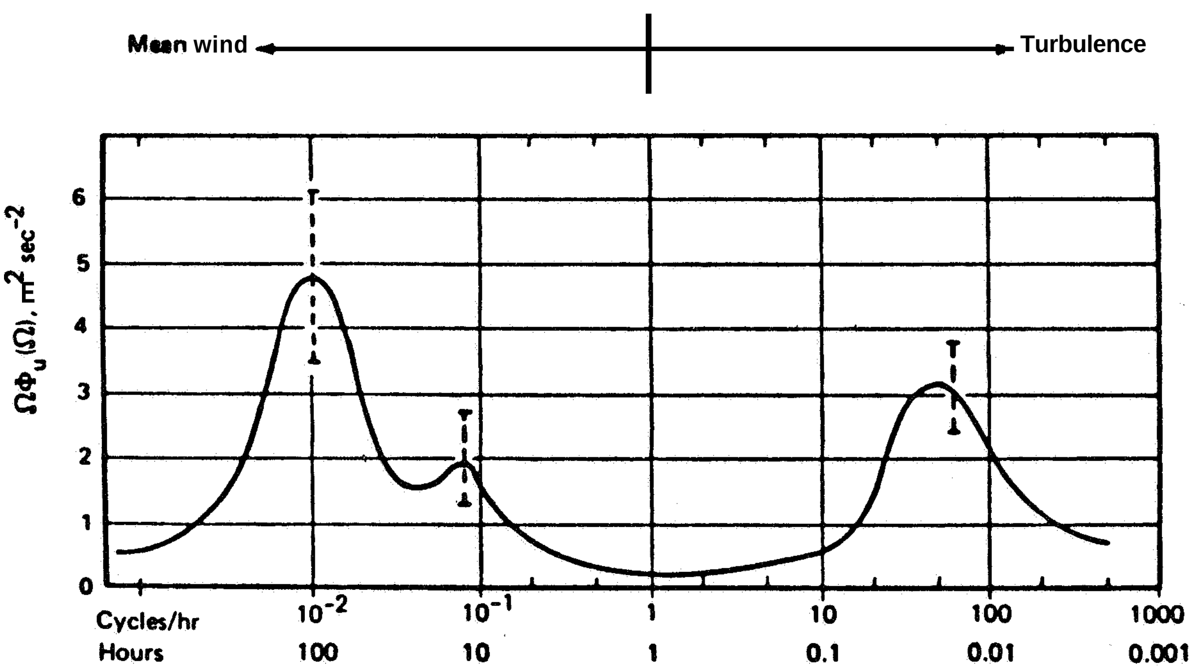


FIGURE 1 – SCHEMATICSPECTRUM OF WIND SPEED NEAR THE GROUND ESTIMATED FROM A STUDY OF VAN DER HOVEN (1957)

MEAN WIND

Analytic Description

The mean wind is characterized by:

- Zero vertical component
- Zero wind speed at the surface
- Invariant with altitude above the atmospheric boundary layer

The mean wind model having the greatest acceptance, both theoretically and empirically, is that developed from dimensional analysis. The parameters involved are:

$\frac{\partial \bar{V}_W}{\partial h}$ = mean wind shear

τ = shear stress

ρ = atmospheric density

c_p = specific heat at constant pressure

h = altitude

g = gravitational acceleration

H = heat flux

T = absolute temperature

$\frac{\partial T}{\partial h}$ = lapse rate

This inclusive list assumes:

- Pressure gradients are invariant with altitude, at least over a sufficiently constrained region.
- Viscous forces dominate pressure and Coriolis forces.
- The flow of air is fully rough so that molecular viscosity is not a significant parameter.

The parameters appear in the combinations

$$u_* = \sqrt{\frac{\tau}{\rho}} = \text{friction velocity}$$

$$\frac{kh}{u_*}\frac{\partial \overline{V}_W}{\partial h} = \text{nondimensional shear}$$

($k = 0.4$ = von Karman's constant)

$$\ell = \frac{u_*^3 C_p \rho T}{kgH}$$

Dimensional analysis then predicts

$$\frac{kh}{u_*}\frac{\partial \overline{V}_W}{\partial h} = \phi(h/\ell)$$

where $\phi(h/\ell)$ is some specific function.

It is additionally assumed that shear stress and density are invariant with altitude for a sufficiently constrained altitude region. Then

$$\overline{V}_W = \frac{u_{*_0}}{k} \int_{z_0}^{h} \frac{(h/\ell)}{h}\, dh$$

where

z_0 = the altitude at which the mean wind speed formally goes to zero

$u_{*_0} = u_*(h = 0)$

The scaling length, *2*, is difficult to measure due to the difficulty of measuring the heat flux, so an alternate scaling length, ℓ', is introduced:

$$\ell' = \frac{u_{*_0} \; T \; \dfrac{\partial \bar{V}_W}{\partial h}}{kG \left[\dfrac{\partial T}{\partial h} + \dfrac{g}{C_p} \right]}$$

This alternate scaling length is equal to the dimensional analysis scaling length multiplied by the ratio of eddy conductivity to eddy viscosity and is assumed to be a constant, implying that there is a one-to-one relationship of the wind and temperature shears independent of altitude.

The alternate scaling length can be related to a more conventional and still more easily measured parameter reflecting atmospheric stability, Richardson's number:

$$R_i = \frac{\dfrac{g}{T} \left(\dfrac{\partial T}{\partial h} + \dfrac{g}{C_p} \right)}{\left(\dfrac{\partial \bar{V}_W}{\partial h} \right)^2}$$

$$\frac{h}{\ell'} = \left[\frac{\dfrac{g}{T} \left(\dfrac{\partial T}{\partial h} + \dfrac{g}{C_p} \right)}{\left(\dfrac{\partial \bar{V}_W}{\partial h} \right)^2} \right] \left(\frac{kh}{u_{*_0}} \; \frac{\partial \bar{V}_W}{\partial h} \right) = R_i \phi(h/\ell')$$

Richardson's number is a nondimensional ratio between the mechanical wind shear that tends to displace air and the buoyancy force, which may damp or amplify this tendency.

Richardson's number thus gives rise to the notion of atmospheric stability, a dynamic concept:

$$R_i,\ h/\ell' > 0 \rightarrow \frac{\partial T}{\partial h} > \frac{-g}{C_p}\text{; stable (weak lapse or inversion)}$$

$$R_i,\ h/\ell' = 0 \rightarrow \frac{\partial T}{\partial h} = \frac{-g}{C_p} = -0.00536°R/ft\text{; neutral (adiabatic lapse)}$$

$$R_i,\ h/\ell' < 0 \rightarrow \frac{T}{h} < \frac{-g}{C_p}\text{; unstable (strong lapse)}$$

Given the nature of $\phi(h/\ell')$, the variation of R_i is known with altitude and R_i could be used in place of h/ℓ'. However, it is simpler to use h/ℓ' as it varies linearly with altitude. The greater ease involved in measuring R_i provides an indirect means of computing R.

Investigators have examined $\phi(h/\ell')$ for different regions of stability. For neutral stability $\phi(h/\ell') = 1$ and

$$\frac{\partial \bar{V}_W}{\partial h} = \frac{u_{*0}}{kh}$$

$$\bar{V}_W = \frac{u_{*0}}{k} \ln\left(\frac{h}{z_0}\right)$$

or, after an axis system shift to provide $\bar{V}_W = 0$ at $h = 0$,

$$\bar{V}_W = \frac{u_{*0}}{k} \ln\left(\frac{h + z_0}{z_0}\right)$$

a

For neutral stability, the shear is inversely proportional to altitude and the mean wind is described by the logarithmic profile. The term z_0 reflects surface roughness and is larger for greater roughness. z_0 = 0.15 foot, as provided by the British specification, and is representative for autoland applications.

If the mean wind, V_{REF}, is known at some altitude, h_{REF}, the friction velocity, u_{*_0}, may be found from the equation for the mean wind profile:

$$u_{*_0} = \frac{k\overline{V}_{REF}}{\ln\left(\frac{REF + z_0}{z_0}\right)}$$

For a given wind speed at h_{REF} an increase in roughness length, z_0, is related to an increase in friction velocity, which in turn provides an increase of the shear at every altitude, a decrease in wind speed for $h < h_{REF}$, and an increase in wind speed for $h > h_{REF}$.

For near neutral stability, $\phi(h/\ell')$ may be estimated from the first two terms of a Taylor series expansion about neutral stability:

$$\phi(h/\ell') = 1 + \alpha' h/\ell' \ , \ h/\ell' \ll 1$$

$$a' = \text{constant}$$

Thus,

$$\overline{V}_W = \frac{u_{*_0}}{k}\left[\ln\left(\frac{h + z_0}{z_0}\right) + \alpha' h/\ell'\right]$$

which is the log-linear mean wind profile. For stable conditions ($h/\ell' > 0$), the effect of stability appears to cause an increase in the mean wind speed and shear. Unstable conditions appear to cause a decrease in the shear and mean wind speed.

For the log-linear profile, friction velocity can be determined from the mean wind speed at a given altitude by

$$u_{*_0} = \frac{k\overline{V}_{REF}}{\ln\left(\frac{h + z_0}{z_0}\right) + \alpha' h_{REF}/\ell'}$$

Stable conditions result in a decrease and unstable conditions result in an increase of friction velocity.

Combining the effects of stability on friction velocity and the nondimensional wind shear gives

$$\frac{\overline{V}_W}{h} = \frac{\overline{V}_{REF}}{h}\left[\frac{1 + \alpha' h/\ell'}{\ln\left(\frac{h_{REF} + z_0}{z_0}\right) + \alpha' h_{REF}/\ell'}\right]$$

Stable conditions cause the shear to be greater than for neutral conditions above some altitude, but less than the neutral stability shear below that altitude. The reverse is true for unstable conditions.

For near neutral stability, the constant ℓ' can be determined by knowing Richardson's number at some altitude, h_{REF}:

$$h/\ell' = R_i \phi(h/\ell') = R_i(1 + \alpha' h/\ell'), h/\ell' << 1$$

$$1/\ell' = \frac{R_{i_{REF}}}{h_{REF}(1 - R_{i_{REF}})} \cong \frac{R_{i_{REF}}}{h_{REF}}$$

The general form of the mean wind profile may be reformulated to represent the contribution of neutral conditions plus the increment due to nonneutral conditions:

$$\bar{V}_W = \frac{u_{*0}}{k}\left[\ln\left(\frac{h + z_0}{z_0}\right) + f(h/\ell')\right]$$

where

$$f(h/\ell') = \int_0^h \frac{0(\xi) - 1}{\xi}\, d\xi$$

Different investigators have developed expressions for the mean wind shear for various regions of stability. For unstable conditions:

$$\phi(h/\ell') = \frac{1}{1 - \beta' R_i^{1/2}} \quad \text{, small negative } R_i$$

$$6' \quad = \text{constant}$$

$$\frac{\partial \bar{V}_W}{\partial h} \sim h^{-4/3} \quad \text{, strong instability}$$

A form that matches the logarithmic, log-linear, and the above two expressions is the KEYPS equation:

$$\phi(h/\ell') = \frac{1}{(1 - \gamma' R_i)^{1/4}} \quad R_i \le 0$$

$$\gamma' \quad = 2\beta' = 4\alpha' = \text{constant}$$

This form has been adopted along with $\gamma' = 18$, which implies *a' = 4.5*, values in good agreement with measurements. The corresponding relationship between nondimensional altitude and Richardson's number is

$$h/\ell' = \frac{R_i}{(1 - \gamma' R_i)^{1/4}}$$

An explicit expression for the mean wind shear and, consequently, the mean wind speed in terms of h/ℓ' cannot be found, but such a relationship can be determined numerically.

For stable conditions, the log-linear relationship has been found to hold for surprisingly large values of h/ℓ'; for very stable conditions, knowledge is poor. The best expression found for very stable conditions is

$$\phi(h/\ell') = (1 + \alpha')$$

which once again results in a shear inversely proportional to altitude. The corresponding mean wind profile is

$$\overline{V}_W = \frac{u_{*0}}{k}\left\{\ln\left(\frac{h + z_0}{z_0}\right) + \alpha' \left| 1 + \ln(h/\ell') \right| \right\} \qquad \ell' > 1$$

For $h/\ell' > 1$, Richardson's number and nondimensional altitude are related by

$$h/\ell' = (1 + \alpha')R_i$$

Combining the descriptions of $\phi(h/\ell')$ adopted provides the nondimensional shear as a function of h/ℓ', as shown in Figure 2. The corresponding function $f(h/\ell')$ for the mean wind equation is shown in Figure 3. The combined relationships between h/ℓ' and R_i are shown in Figure 4.

The wind above the edge of the boundary layer (geostrophic wind) is that which remains invariant with

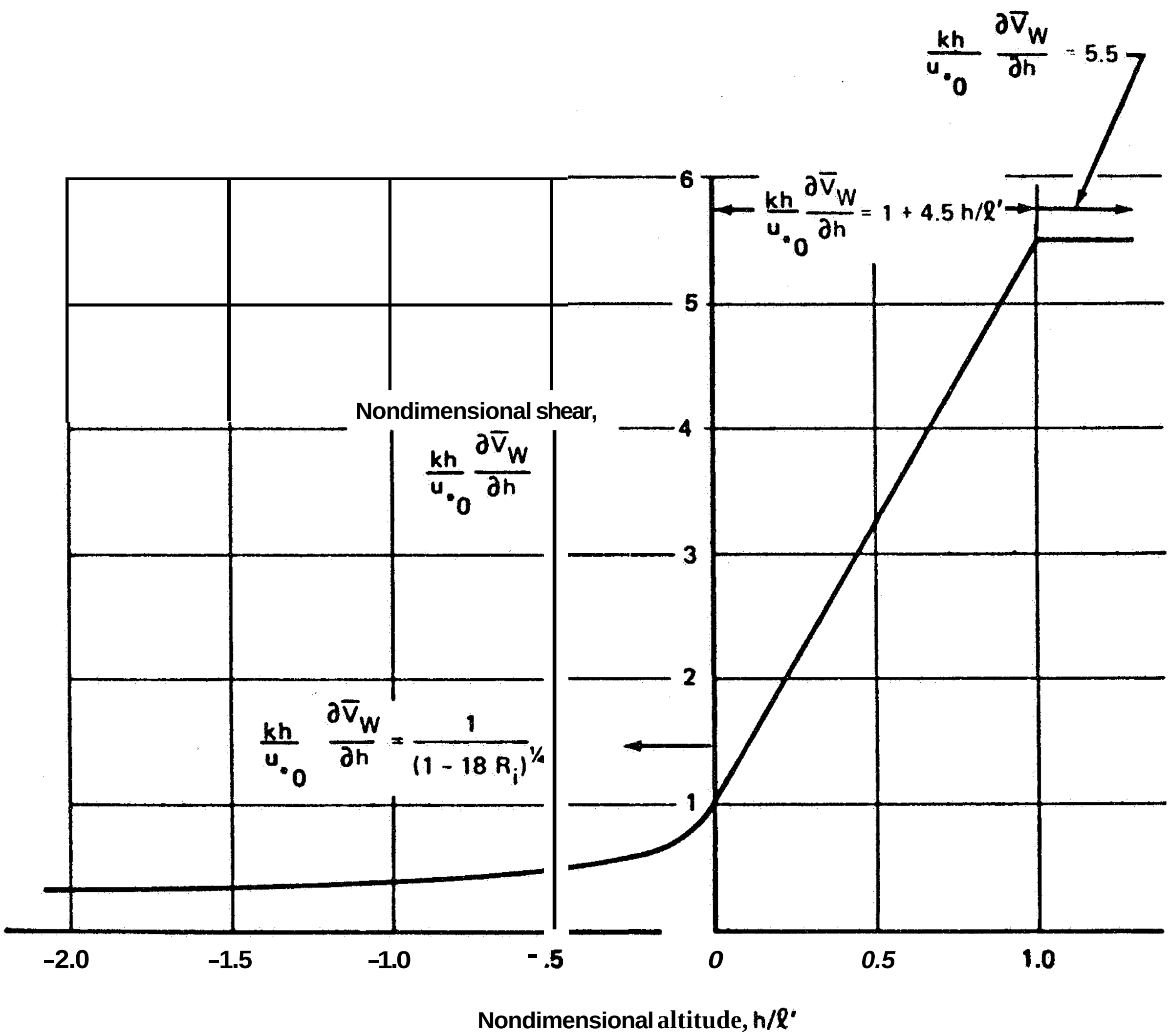


FIGURE 2.– SELECTED NONDIMENSIONAL SHEAR DESCRIPTION

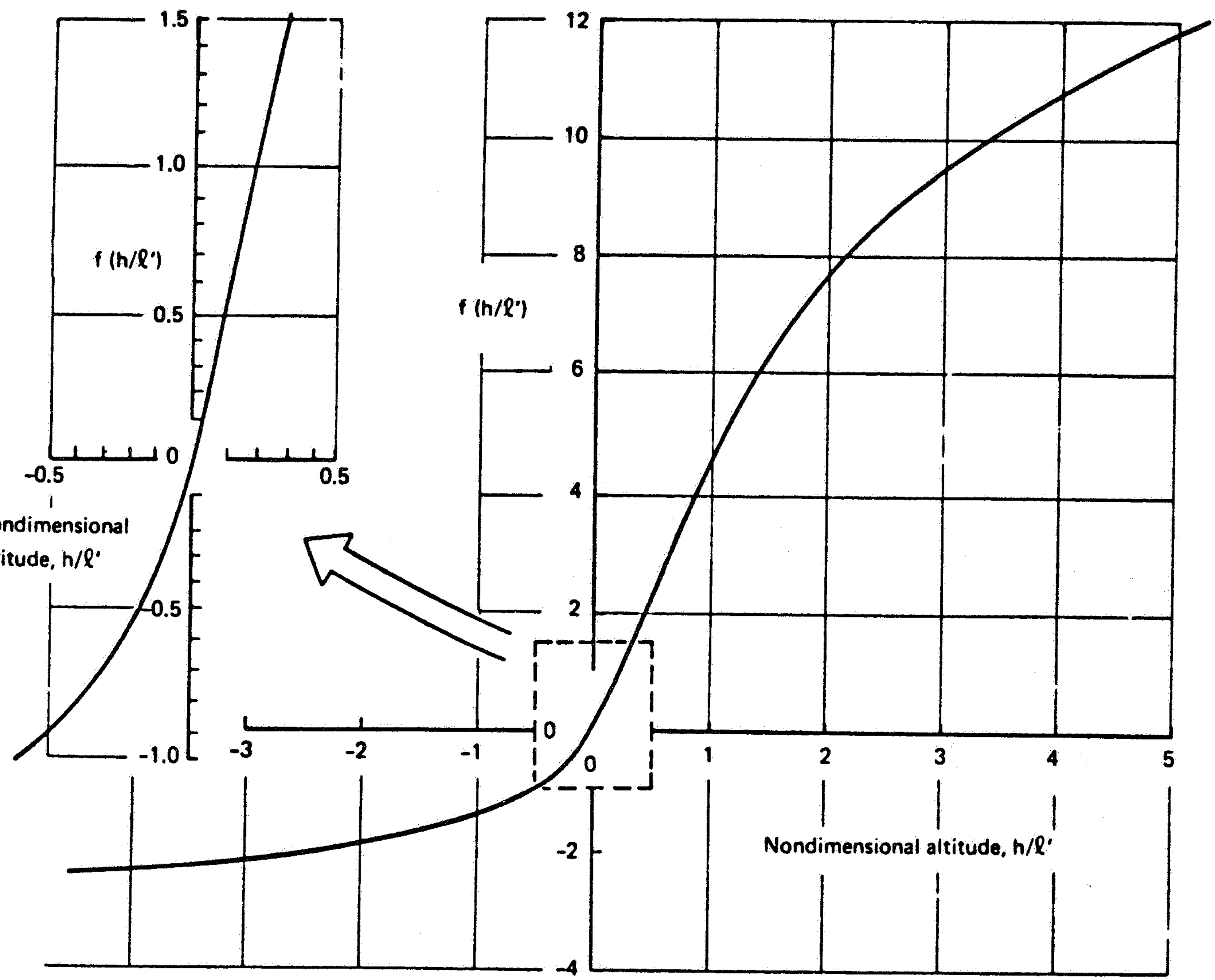


FIGURE 3 –CONTRIBUTION OF NON-NEUTRAL STABILITY TO MEAN WIND

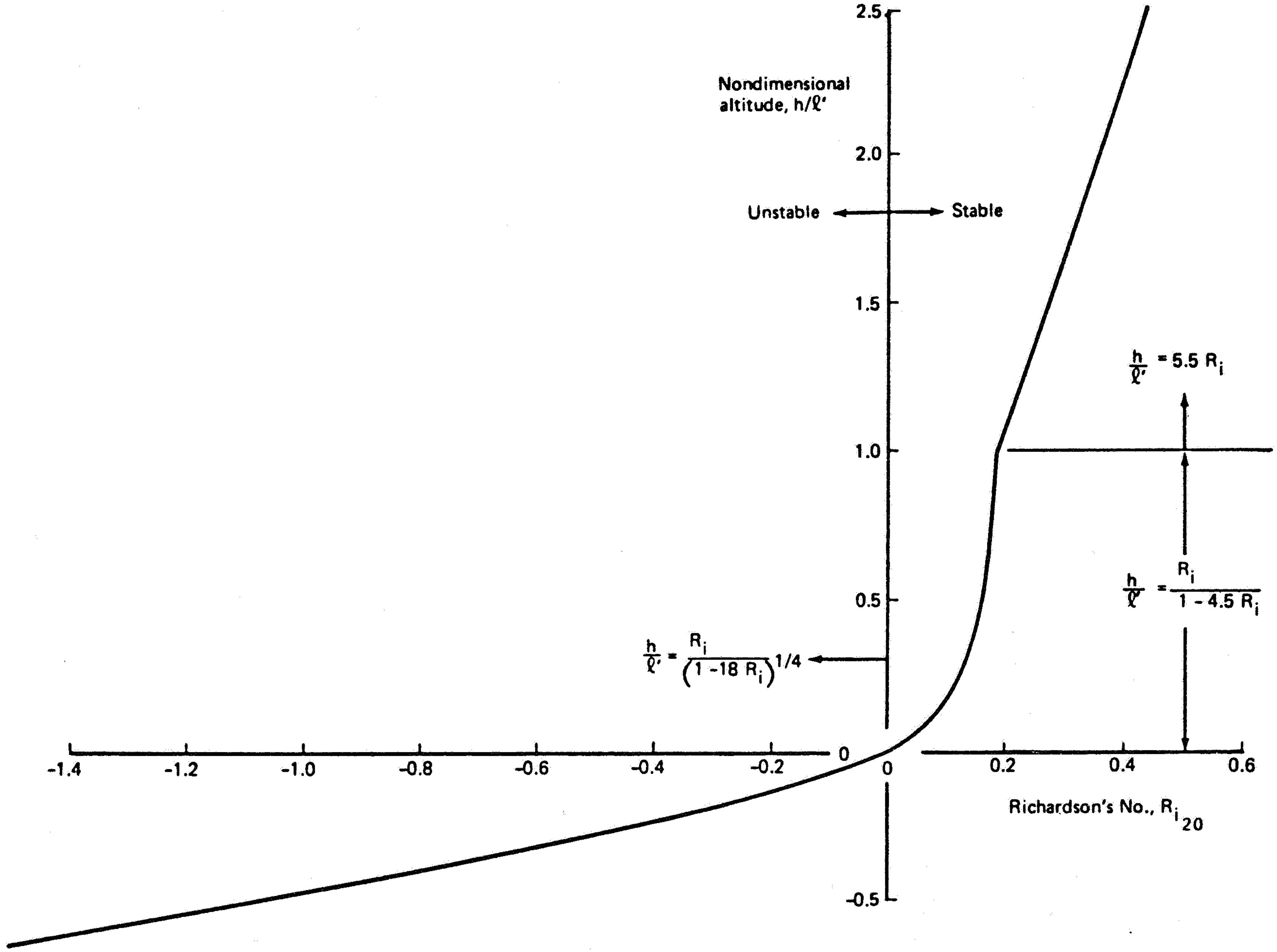


FIGURE — LOW ALTITUDE RICHARDSON'S NUMBER PROFILE surface conditions and atmospheric stability in the boundary layer. There are little data on geostrophic winds, and relationships between winds near the surface and above the boundary layer are poor. Rather than relating low-altitude wind conditions to the geostrophic wind, the wind profile is extrapolated from low-altitude winds. The American standard for airport wind measurement is 20 feet. The extrapolation of winds and shears based on wind speeds at 20 feet is performed through the determination of friction velocity:

$$u_{*_0}/k = \frac{V_{20}}{\ln\left(\frac{20.15}{0.15}\right) + f(h_{RE}/\ell')} \qquad \text{(Fig. 5)}$$

Figure 5 shows friction velocity to continually decrease for increasing stability. The nondimensional shear, Figure 2, is constant for $h/\ell' > 1$. Thus, the shear, given by

$$\frac{\partial \overline{V}_W}{\partial h} = \frac{\overline{V}_{20}}{h}\left(\frac{u_{*_0}/k}{\overline{V}_{20}}\right)\left(\frac{kh}{u_{*_0}}\frac{\partial \overline{V}_W}{\partial h}\right)$$

must decrease for $h/\ell' > 1$.

The scaling length, ℓ', may be determined for Richardson's number measured at another altitude different from 20 feet, but since the choice appears arbitrary, $1/\ell'$ is determined from Figure *4* for Richardson's number measured at 20 feet. The description provided thus far still suffers from a restriction: the dimensional analysis descriptions are valid only over the altitude region for which shear stress differs insignificantly from that at the surface. Insignificant variations of the shear stress have been variously estimated to occur up to 65 to 650 feet, significantly less than the objective of 1000 feet. At progressively

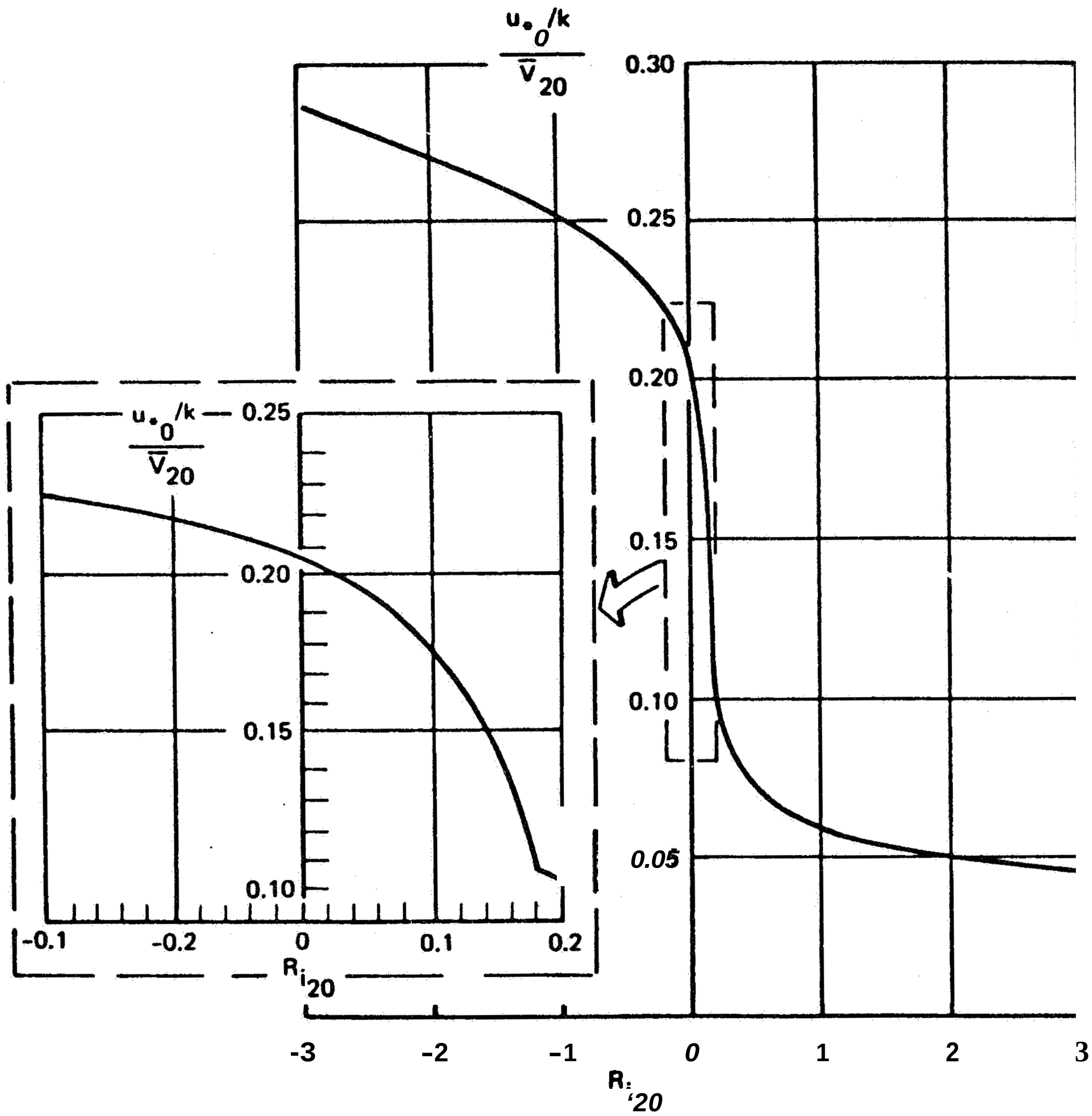


FIGURE 5 – MEAN WIND PROPORTIONALITY CONSTANT

higher altitudes, a progressively greater overestimation of the mean wind speed and shear occur; the description of the mean wind never does provide a constant mean wind with altitude above the boundary layer. A mechanism for adjusting the description has been found through descriptions of shear stress (friction velocity) variations throughout the boundary layer.

By expanding shear stress with altitude about conditions at the boundary layer (where shear stress is zero) using a Taylor series, expressions for friction velocity variations with altitude and for the boundary layer depth, d, are developed:

$$u_* = u_{*_0}(1 - h/d)$$

$$d = u_{*_0}/5.35\ f$$

where

f = Coriolis parameter

$= 2\omega_E \sin \lambda$

ω_E = angular velocity of the earth

A = latitude

Most of the United States and a majority of the world airport activity lies between 30" and 50" latitude, so a fixed latitude, A = 40°, is adopted for determining the boundary layer depth. Then,

$$d = 2000\ u_{*_0}$$

To incorporate the shear stress variation into the mean wind description, the assumption that the shear is proportional to friction velocity at the surface is dropped, and it is assumed that the shear is proportional to the local level of friction velocity. Then,

$$\frac{\partial \overline{V}_W}{\partial h} = \frac{u_*}{kh} \phi(h/\ell') = \left(\frac{u_*}{u_{*_0}}\right) \frac{u_{*_0}}{kh} \left(\frac{kh}{u_*} \frac{\partial \overline{V}_W}{\partial h}\right)$$

$$= \left(1 - \frac{h}{d}\right) \frac{\overline{V}_{20}}{h} \left(\frac{u_{*_0}/k}{\overline{V}_{20}}\right) \left(\frac{kh}{u_*} \frac{\partial \overline{V}_W}{\partial h}\right)$$

The shear now smoothly decreases to zero at the edge of the boundary layer with increasing altitude. Near the surface, where $h/d \cong 0$, the constant shear stress model is unaffected.

The corresponding expression for the mean wind speed is

$$\overline{V}_W = \overline{V}_{20} \left(\frac{u_{*_0}/k}{\overline{V}_{20}}\right) \left[\ln \left(\frac{h + z_0}{z_0}\right) + f(h/\ell') - \frac{h}{d}\, g(h/\ell')\right]$$

The function, $g(h/\ell')$, (Fig. 6) is derived from $f(h/\ell')$. It is always positive, is equal to one for neutral stability, and increases with increasing stability.

Probabilistic Description

The additional parameters required to complete the description of the mean wind speed and mean wind shear are specifications for wind speed and Richardson's number at a 20-foot altitude.

Based on Weather Service reports at U.S. airports, a description of airport wind speeds has been developed that describes 10-minute averages measured each hour for 10 years. The data were taken prior to establishing 20 feet as a standard anemometer height, so anemometer heights varied

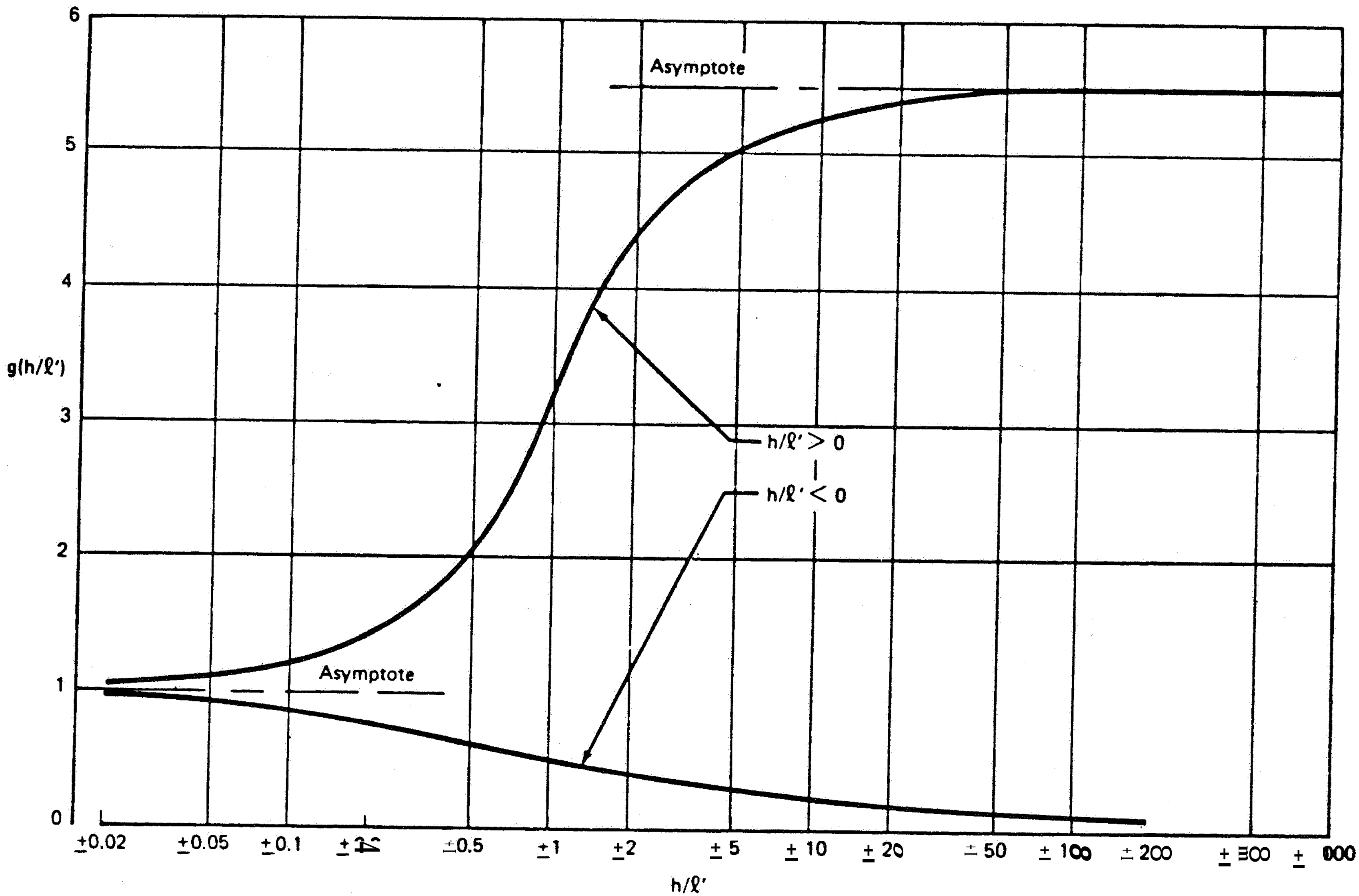


FIGURE 6 — VARIABLE SHEAR STRESS CORRECTION TO WIND PROFILE

widely from airport to airport. From data for 132 U.S. airports, data were selected from 24 sites where anemometer heights varied from 20 to 35 feet with an average height of about 26 feet. The remaining sites have anemometers located from above 35 to 120 feet above the ground and were considered to be too high to represent wind speeds at 20 feet. In developing a composite description for all 24 airports, the distributions from each site were weighted equally. The resulting descriptions, Figure 7, provide for 8 knots exceeded 50% of the time and 22.7 knots exceeded 1% of the time. For 39 of the same 132 sites, data for the wind speed distribution when visibility was less than 0.5 mile (prepared by the Weather and Flight Service Station Branch of the FAA) are presented. For low visibility, wind speeds are much lower than for clear conditions; for low visibility, 4.5 knots is exceeded 50% of the time and 14 knots is exceeded 1% of the time.

From the data for the 24 U.S. airports, distribution of wind components along and across runways was developed, assuming the runway is aligned to the prevailing wind. Crosswinds from the left and right were found to be equally likely. The distribution of crosswind magnitude, Figure 8, provides for exceeding a 5-knot crosswind 50% of the time and a 19-knot crosswind 1% of the time. When the distribution of crosswinds is plotted for both positive and negative crosswinds, the distribution is closely Gaussian (standard deviation equal to 6.5 knots), with deviations from a Gaussian distribution occurring in the tails (1.65 standard deviations from zero crosswind).

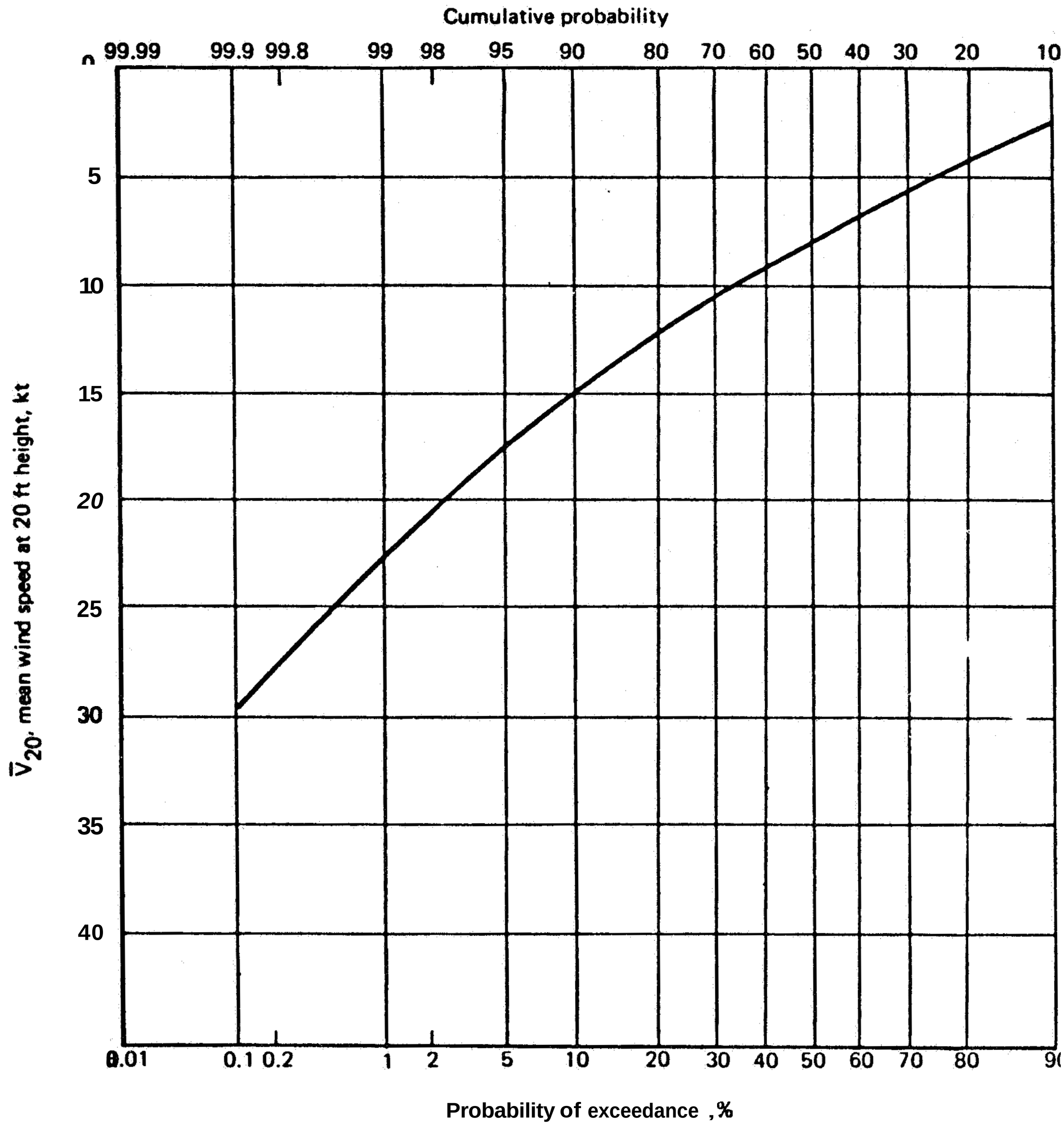


FIGURE 7 – MEAN WIND CUMULATIVE/EXCEEDANCE PROBABILITY

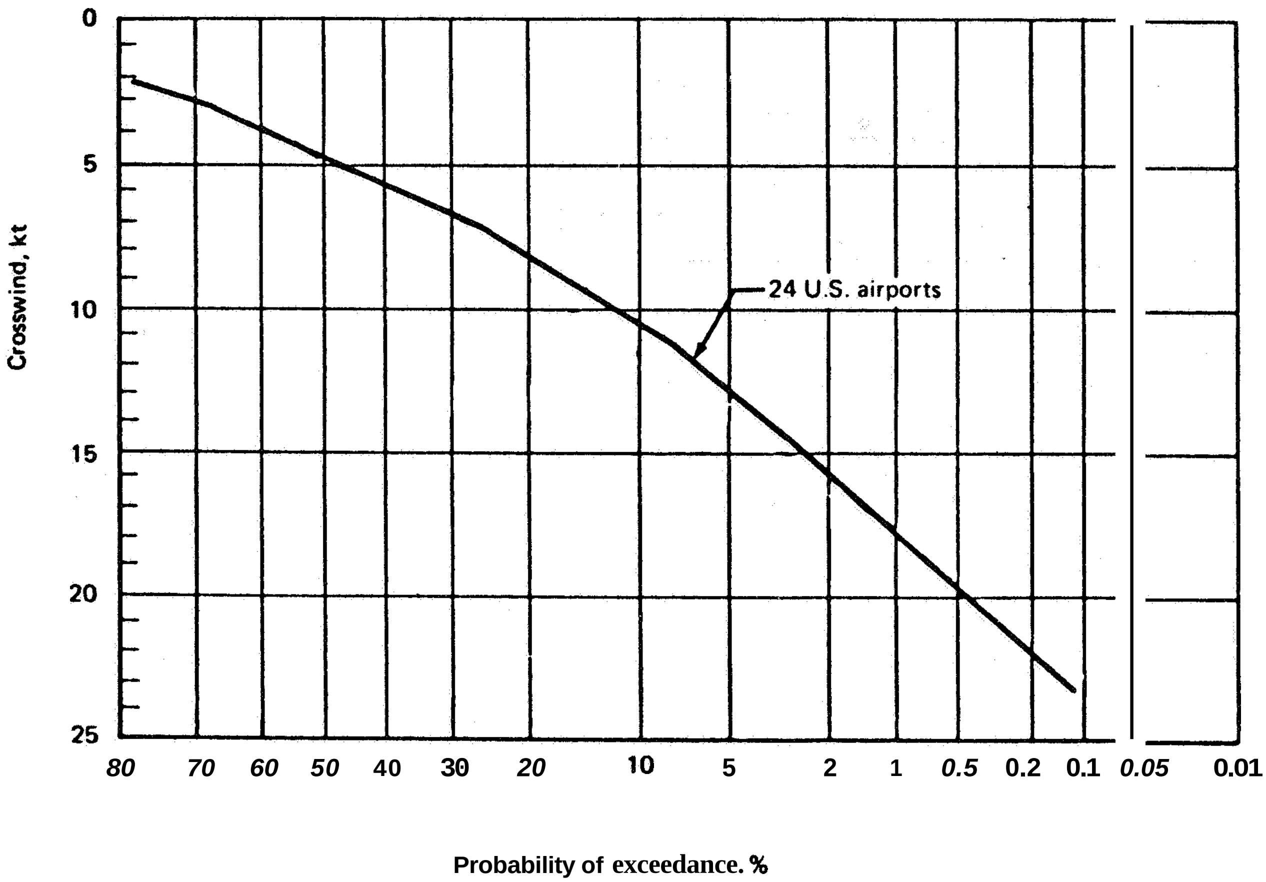


FIGURE a – TOTAL CROSSWIND INFORMATION COMPILED FROM 24 US. AIRPORTS

The distribution of down runway components is also closely Gaussian (Fig. 9) with a mean and standard deviation of 1 and 7 knots, respectively. The probability of a wind component in the direction of the prevailing wind is 59%. The distribution for the magnitude of the component of mean wind aligned to the runway (Fig. 10) provides for 5 knots exceeded 50% of the time and 19 knots exceeded 1% of the time.

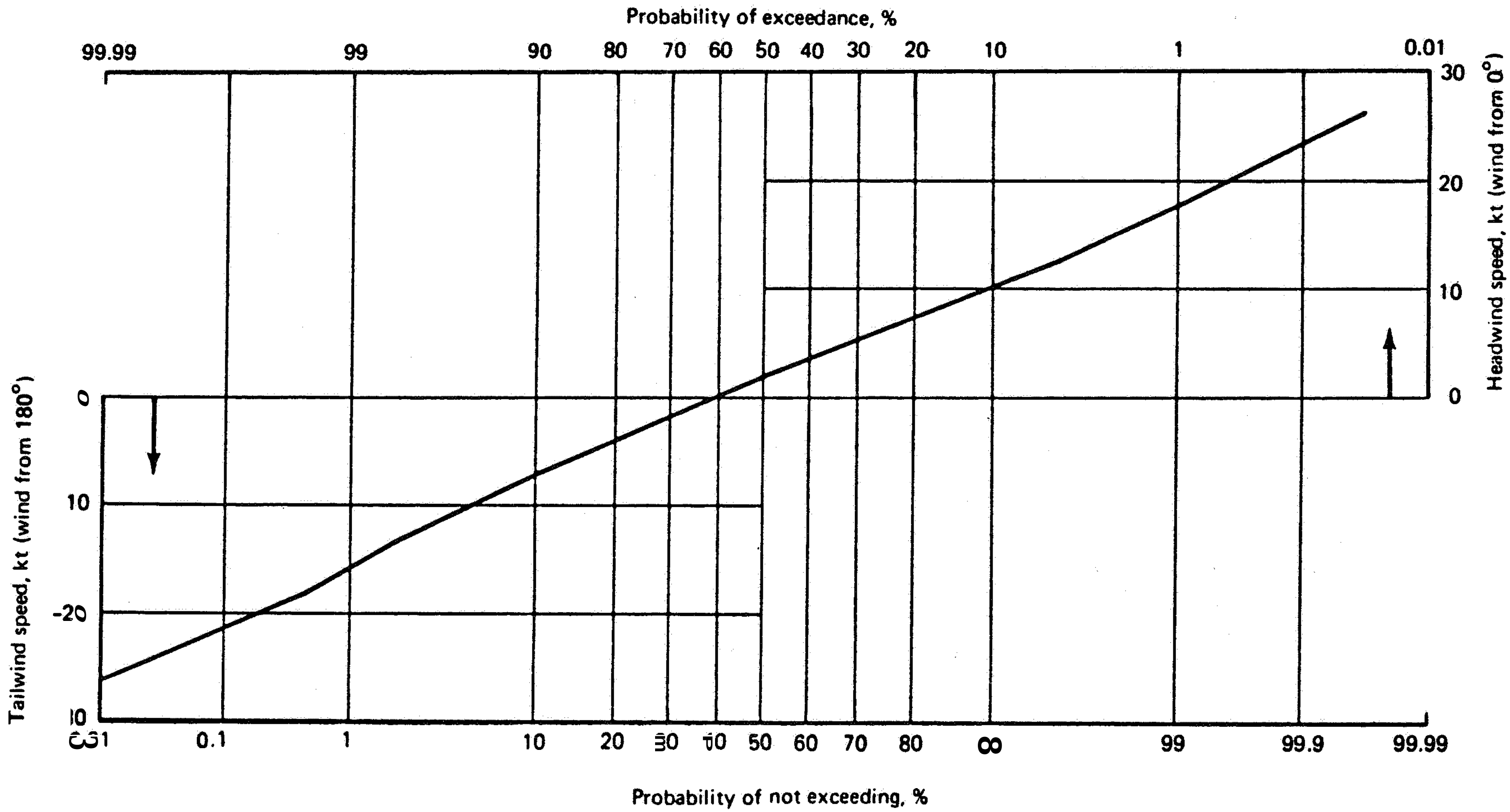


FIGURE 9 – HEADWIND–TAILWIND DESCRIPTION COMPILED FROM 24 U.S. AIRPORTS

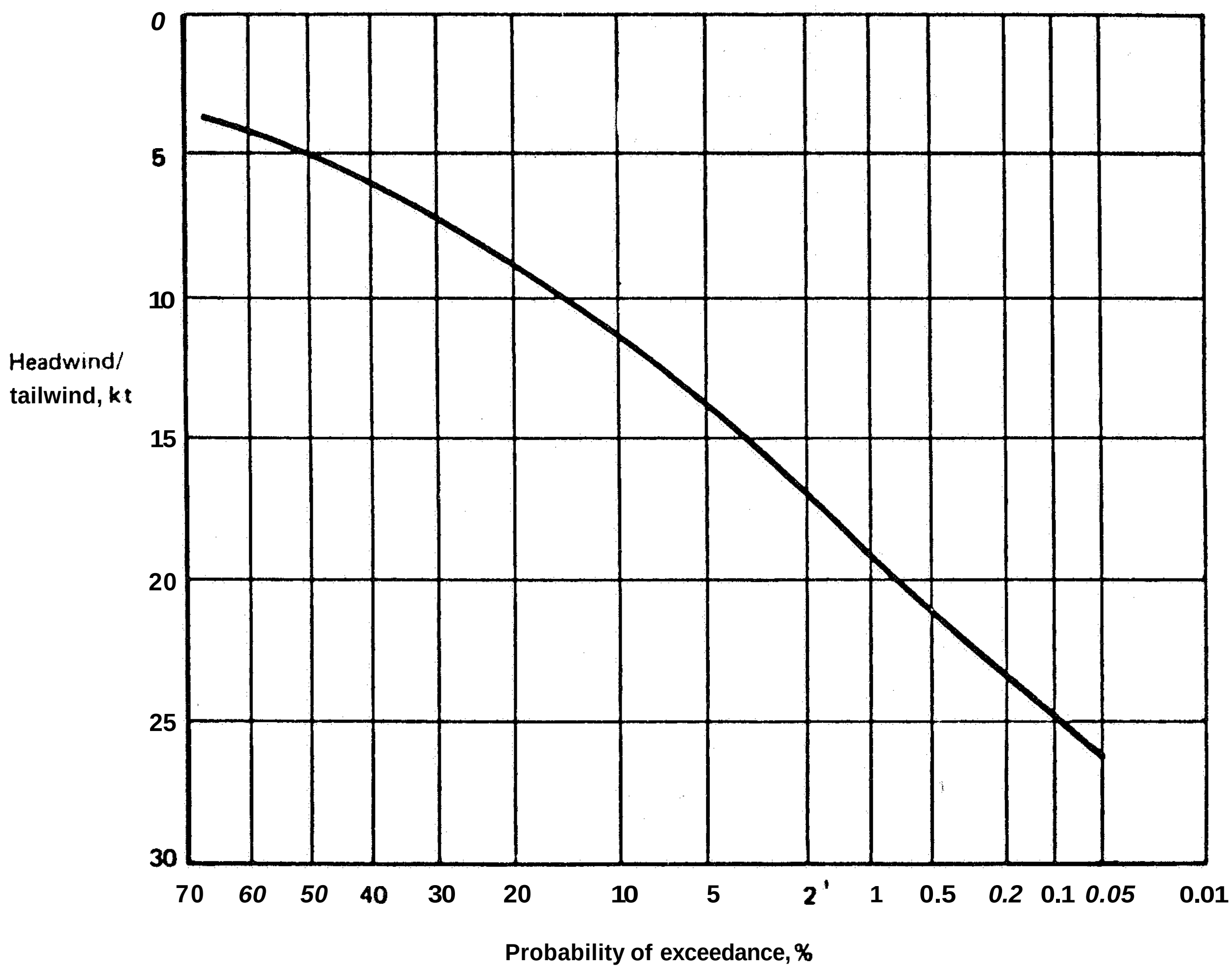


FIGURE 10 – TOTAL HEADWIND–TAILWIND MEAN OF 24 U.S. AIRPORTS

Distribution of mean wind shears was also investigated. Distributions were much broader near the surface than at higher altitudes, conforming to the analytic description. The introduction of atmospheric stability into the mean wind description in such a way that wind shears increase with increasing stability (up to a point), as well as with wind speed and the finding that atmospheric stability is inversely related to wind speed, introduce confusion as to whether maximum shears occur at high wind speeds where stability is close to neutral or at low wind speeds where stability is high. Data from the literature show the greatest shears occur at the most stable lapse rates and at low wind speeds (both average and maximum wing shears decrease monotonically with increasing wind speeds at high wind speeds), conflicting with commonly employed wind models that assume neutral stability and increasing shears with wind speed, thus emphasizing the importance of atmospheric stability as a mean wind parameter.

The literature was not productive for describing distributions of atmospheric stability, so probability distributions were generated by reducing data from towers located at Cedar Hills, Texas, and Cape Kennedy, Florida. The distributions for the two sites differed substantially (Fig. 11), with the Cedar Hills data being more stable. Evaluation of the climatology and wind characteristics of the two sites led to the conclusion that the Cape Kennedy stability data were more representative of average airport conditions. Consequently, the Cape Kennedy data were selected for use with the model. Although the Cape Kennedy data reflected the lesser stability, over 70% of the cases at the site were stable (versus 90% of the cases at Cedar Hills).

The strong interdependence between the distribution of atmospheric stability and near-surface wind speed can be seen

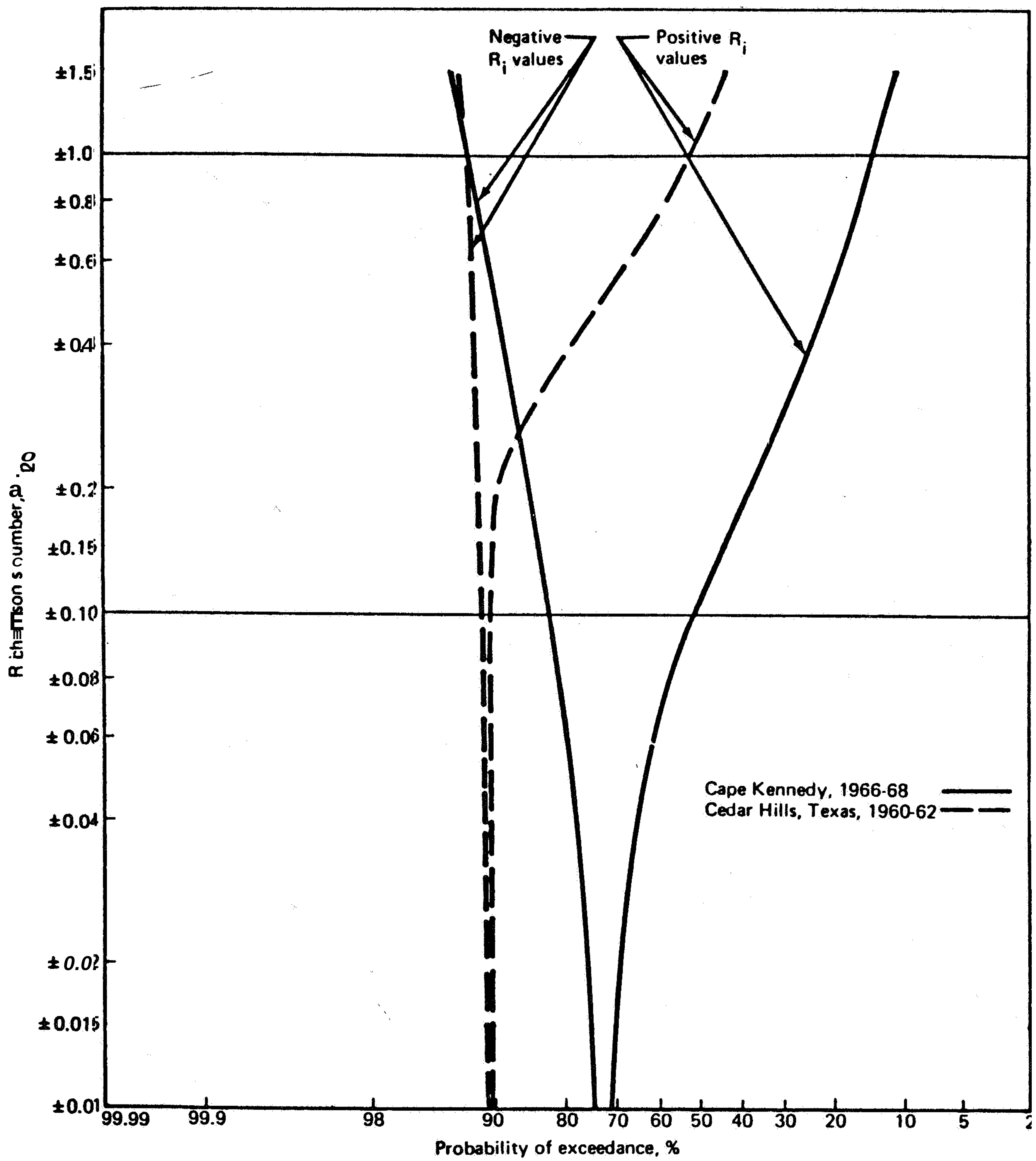


FIGURE 11 – PROBABILITY OF EXCEEDANCE OF R_i FOR ALL WIND SPEEDS

in Figure 12. Although the atmospheric stability distribution narrows substantially about neutral conditions at increasing wind speeds, the distribution remains significantly broad at high wind speeds. The data in Figure 12 were faired and extrapolated to account for the relatively small data sample (one site for three years with near-calm wind speed conditions excluded) and have been cross plotted at constant 20-foot-altitude wind speeds in Figures 13, 14, and 15.

The mean wind speed and atmospheric stability distribution curves may be used by (1) defining wind speed/stability regions and assigning average values of wind speed and Richardson's number to each region; (2) by simulating the aircraft for each wind speed/Richardson's number combination; and (3) by combining the results of the simulation according to the joint; probabilities of each region. Alternately, the simulation may be used to define random combinations of mean wind speed and Richardson's number. A random number generator, providing a uniform distribution between zero and one, is used to determine two random numbers. A mean wind speed at an exceedance probability equal to one of the random number generators is found. The Richardson's number associated with the exceedance probability for the mean wind speed determined equal to the second random number is found. The Richardson's number and mean wind speed then determine the mean wind speed and shear profiles. When this process is repeated, the joint distribution of wind speed and Richardson's number is reproduced.

Application to Aerodynamics

In order to determine the aerodynamic forces and moments, the mean wind must be resolved into body axis components, an axis system attached to the airplane. The

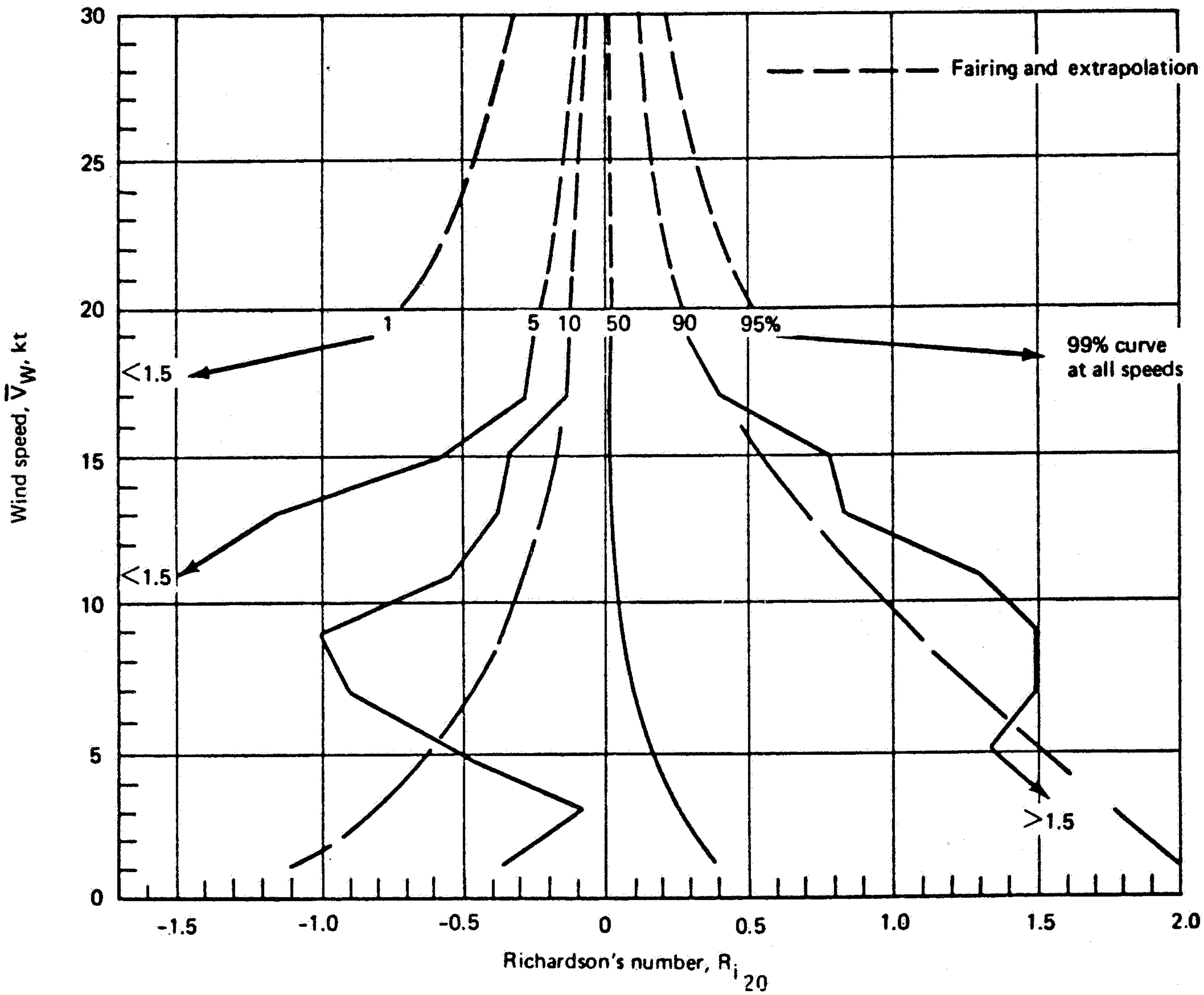


FIGURE 12 — PERCENT FREQUENCY OF OCCURRENCE, WIND SPEED VS R_i, CAPE KENNEDY, 1966-68

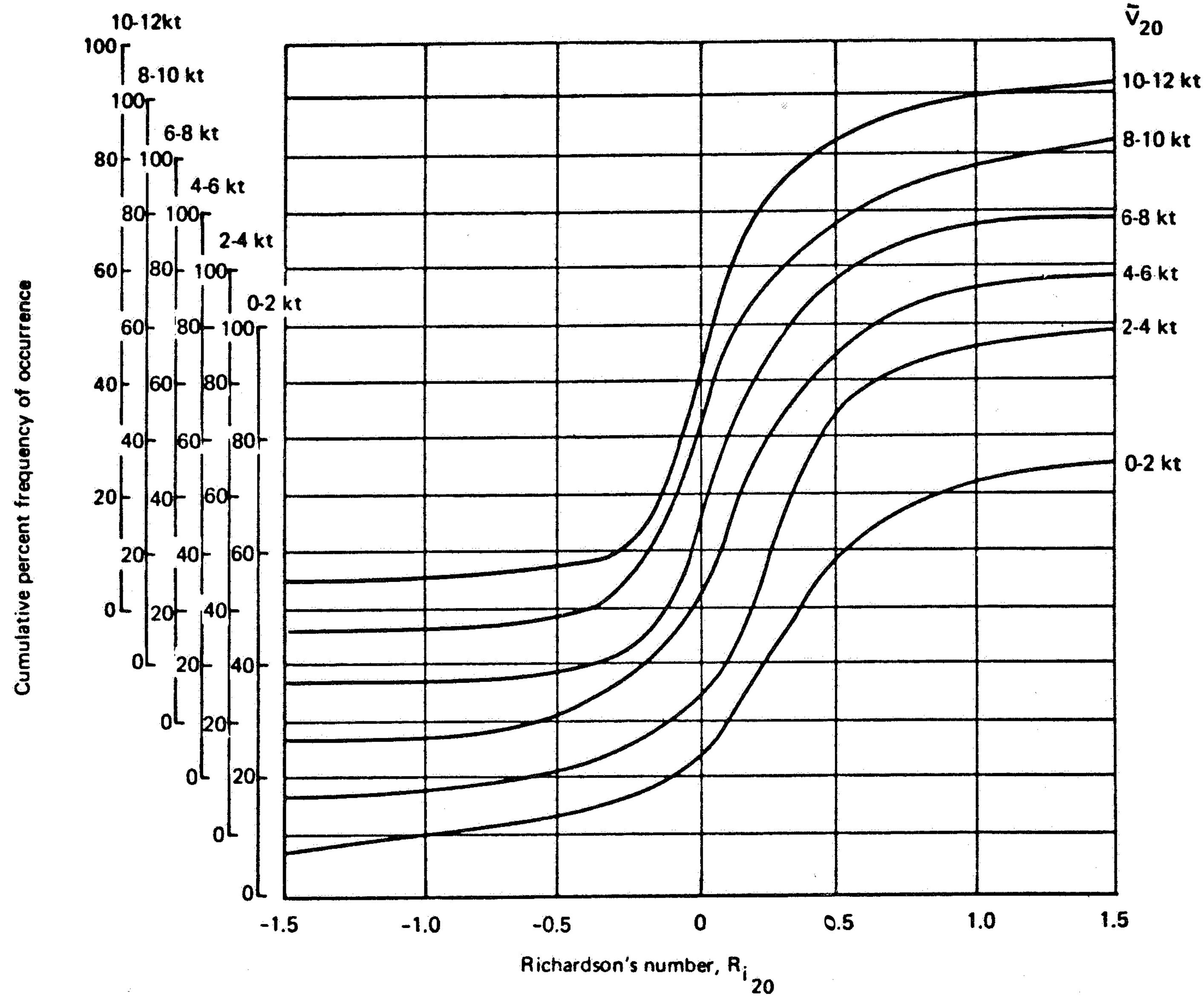


FIGURE 13 — CUMULATIVE PERCENT FREQUENCY OF OCCURRENCE OF R_i AT GIVEN WIND SPEEDS, 0 TO 12 KNOTS

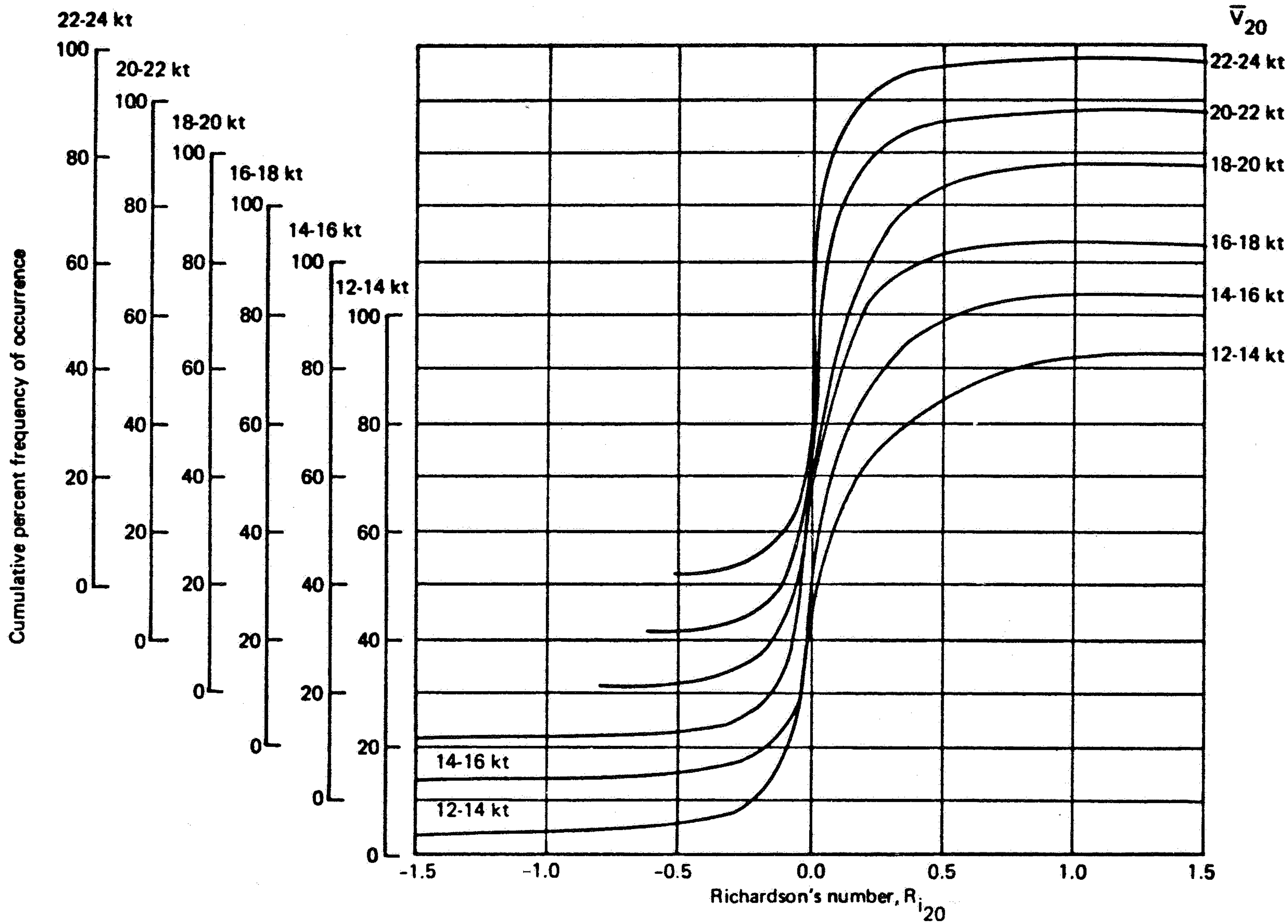


FIGURE 1c — CUMULATIVE PERCENT FREQUENCY OF OCCURRENCE OF R_i AT GIVEN WIND SPEEDS, 12 TO 24 KNOTS

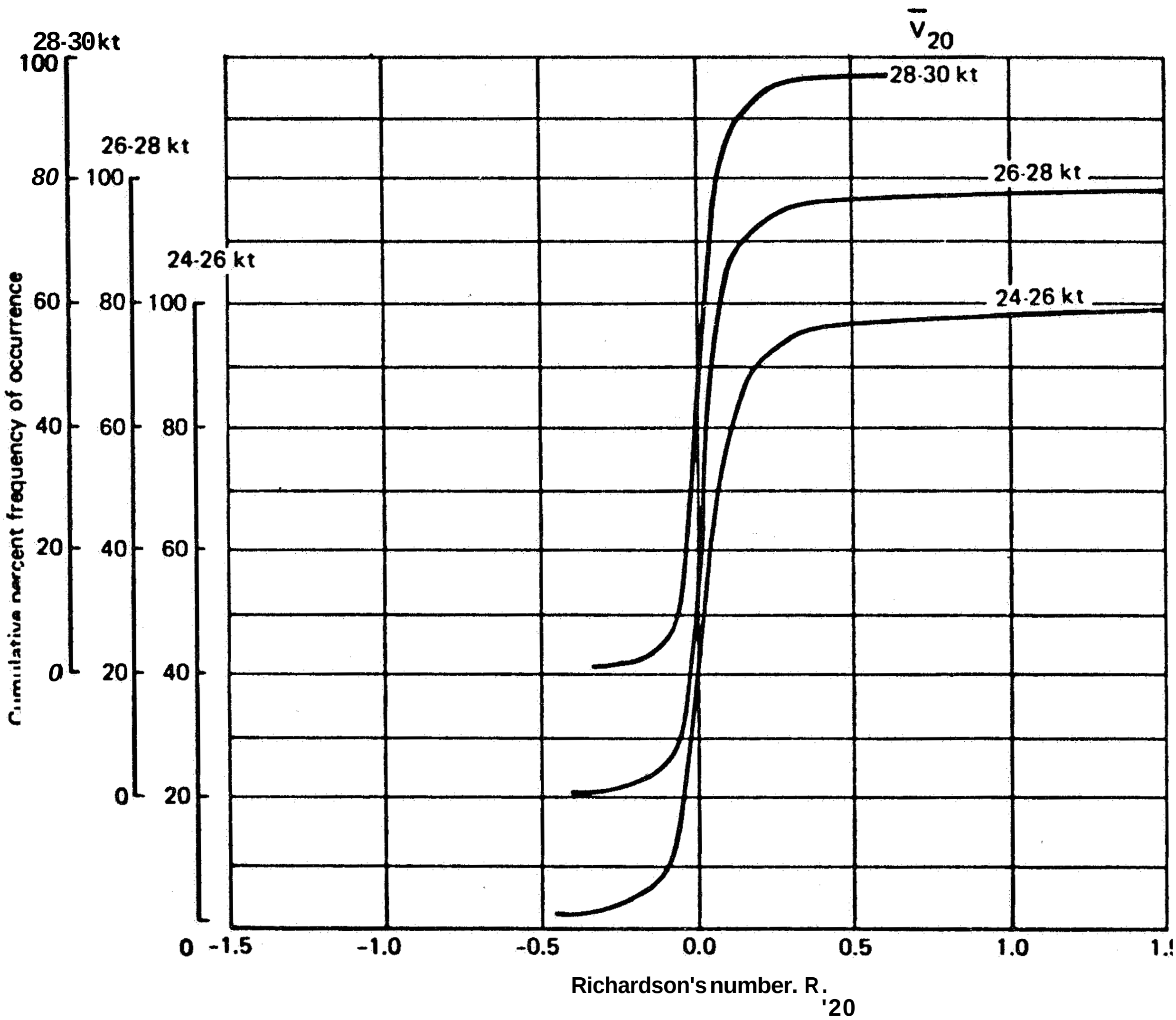


FIGURE 15 – CUMULATIVE PERCENT FREQUENCY OF OCCURRENCE OF R_i AT GIVEN WIND SPEEDS, 24 TO 30 KNOTS

transformation required is presented in Figure 16 and depends on the orientation of the airplane's body axis with respect to the wind, defined by the Euler yaw, pitch, and roll angles and the direction to which the wind is blowing (negative of conventional wind heading). The introduction of wind heading presents an additional mean wind parameter that must be known at each altitude. A variation of wind heading with altitude (heading shear) has an effect on the shear that the airplane sees that is added to the mean wind speed shear effect.

Analytic descriptions for the variation of wind heading with altitude have been investigated, but these descriptions lack empirical support. A small amount of heading shear probability distribution data was found in the literature. The data indicate a majority of heading shears are within ±3°/100 feet and a greater tendency to rotate counter-clockwise while approaching the surface. The tower data used to determine the atmospheric stability distribution were also evaluated for heading shear information. Distributions tended to be larger near the surface but constant above about 150 feet. No consistent trend of the profile shapes could be found. Heading shear was found to be uncorrelated with both wind speed and atmospheric stability. In order for the heading shear to be significant, the wind speed must also be large (body axis shear components involve the combination $\overline{V}_W \, d\overline{\psi}_W/dh$ only). The probability of having a large heading shear and wind speed shear is sufficiently remote and the information for specifying the variation of wind heading with altitude is sufficiently poor so that a representation of wind heading dependence upon altitude is not attempted; the wind heading is assumed to remain constant and equal to that at the surface. The distribution of wind

BODY AXIS MEAN WIND COMPONENTS

$$\begin{Bmatrix} \bar{u}_W \\ \bar{v}_W \\ \bar{w}_W \end{Bmatrix} = \begin{Bmatrix} \cos(\psi - \bar{\psi}_W) \cos \theta \\ \cos(\psi - \bar{\psi}_W) \sin\theta \sin\phi - \sin(\psi - \bar{\psi}_W) \cos\phi \\ \cos(\psi - \bar{\psi}_W) \sin\theta \cos\phi + \sin(\psi - \bar{\psi}_W) \sin\phi \end{Bmatrix} \bar{V}_W$$

BODY AXIS MEAN WIND SHEAR COMPONENTS

$$\begin{Bmatrix} \frac{\partial \bar{u}_W}{\partial h} \\ \frac{\partial \bar{v}_W}{\partial h} \\ \frac{\partial \bar{w}_W}{\partial h} \end{Bmatrix} \cdot \begin{bmatrix} \cos(\psi - \bar{\psi}_W) \cos 0 \\ \cos(\psi - \bar{\psi}_W) \sin\theta \sin\phi - \sin(\psi - \bar{\psi}_W) \cos\phi \\ \cos(\psi - \bar{\psi}_W) \sin \quad \cos + \sin(\psi - \bar{\psi}_W) \sin\phi \end{bmatrix} \frac{d\bar{V}_W}{dh}$$

BODY AXIS TURBULENCE COMPONENTS

$$u_{A_P} = \left[\cos\alpha \cos\beta \cos\theta + \sin\beta \sin\theta \sin\phi + \sin\alpha \cos\beta \sin\theta \cos\phi\right] V_{A_{CG}}$$

$$v_{A_P} = [\sin\beta \cos\phi - \sin a \cos\beta \sin\phi] V_{A_{CG}}$$

$$\Delta\psi = -\tan^{-1} \frac{v_{A_{TG}}}{u_{A_{TG}}} \cong -\beta$$

$$\begin{Bmatrix} u_T \\ v_T \\ w_T \end{Bmatrix} = \begin{bmatrix} \cos\Delta\psi \cos\theta & \sin\Delta\psi \cos\theta & -\sin\theta \\ \cos\Delta\psi \sin\theta \sin\phi - \sin\Delta\psi \cos\phi & \sin\Delta\psi \sin 0 \sin\phi + \cos\Delta\psi \cos\phi & \cos\theta \sin\phi \\ \cos\Delta\psi \sin\theta \cos\phi + \sin\Delta\psi \sin\phi & \sin\Delta\psi \sin 0 \cos\phi - \cos\Delta\psi\ sing & \cos\theta \cos\phi \end{bmatrix} \begin{Bmatrix} u_{T_{TG}} \\ v_{T_{TG}} \\ w_{T_{TG}} \end{Bmatrix}$$

FIGURE 16 — TRANSFORMATIONS

a

heading at the surface was developed from wind roses for the same 24 sites used to determine the wind speed distribution and is presented in Figure 17.

A major factor to which longitudinal touchdown dispersions are attributed is the longitudinal wind shear component. Considerable literature has been written on the subject, but conflicting conclusions are provided. Some predict a headwind shear will cause an overshoot, while others predict an undershoot. Some of the differences of opinion can be attributed to different trim and operation procedures. However, it is concluded that one of two airplanes can overshoot while the other undershoots due to a wind shear, even if both are operated in the same manner.

The effect of a steady wind is to alter the pitch attitude (θ) at which to trim to hold a given glideslope (γ):

$$\theta \cong \left[1 + \frac{\bar{V}_W \cos(\psi - \bar{\psi}_W)}{V_A} \right] \gamma + \alpha$$

where $\bar{\psi}_W = 0$ is a tailwind. For a headwind and a negative glideslope, the pitch attitude must be increased by $(\bar{V}_W/V_A)\gamma$ from that for still air and the thrust increased by $\Delta(\text{thrust}) = W\Delta\theta$, or the airplane will touch down short.

If the airplane is trimmed for a headwind at a high altitude and the headwind decreases with altitude, the pitch attitude must be decreased throughout the approach and thrust correspondingly decreased, or else the airplane will touch down long due to the attitude effect.

There is also a second effect of a wind shear. If the approach is to be performed at constant airspeed, changes in the wind speed must be matched with changes in the inertial speed. To provide inertial acceleration, thrust must be changed by

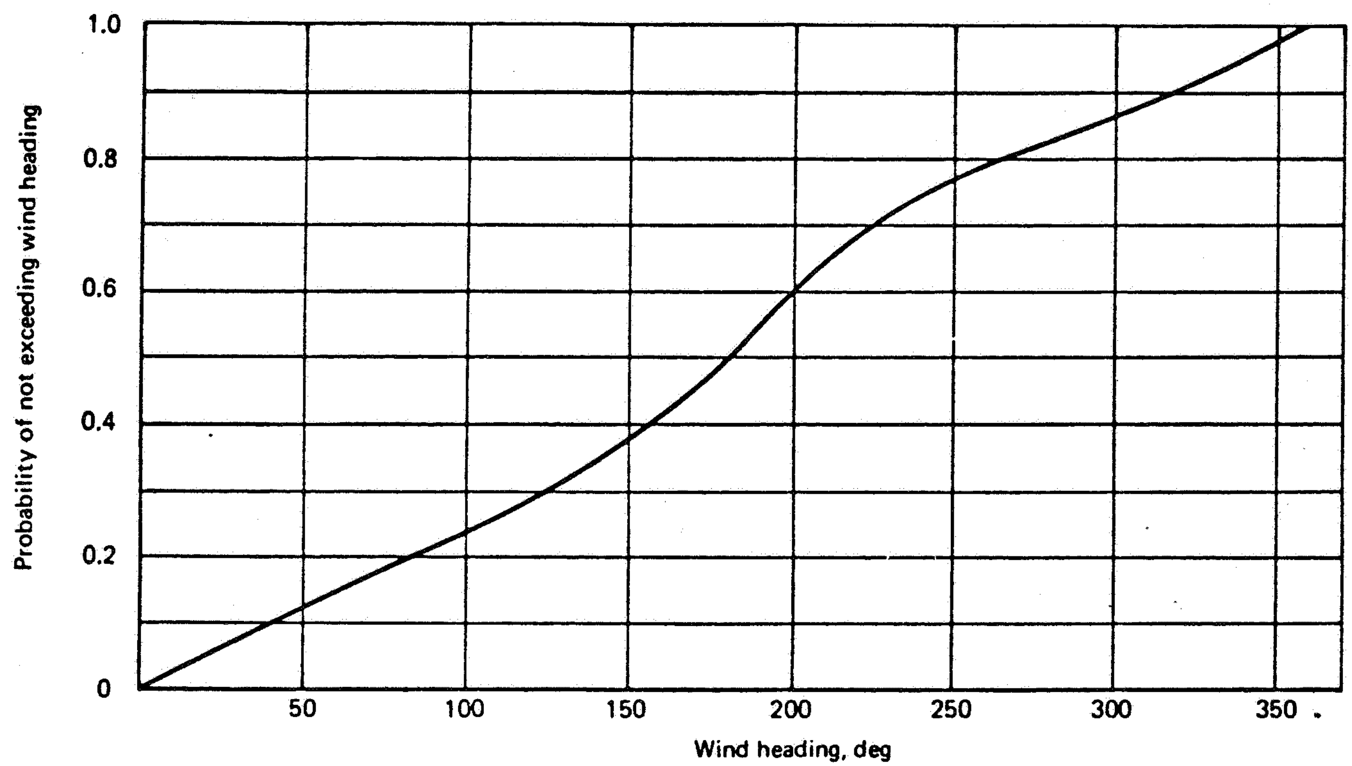


FIGURE 17 — WIND HEADING CUMULATIVE PROBABILITY MODEL

$$\Delta(\text{thrust}) \cong \frac{W(V_A + \bar{V}_W)}{g} \frac{d\bar{V}_W}{dh} \gamma$$

For a headwind that diminishes during an approach

$$\frac{d\bar{V}_W}{dh} \gamma > 0$$

and thrust must be increased or the touchdown will be short.

The combination of the attitude and acceleration effects is

$$\frac{\Delta T}{W} \cong \gamma \frac{\Delta V_W}{V_A} + \frac{(\bar{V}_A + \bar{V}_W)}{g} \frac{d\bar{V}_W}{dh}$$

So long as the magnitude of the wind increases with altitude and the airplane is trimmed for the high attitude wind, the two terms have opposite signs. For airplanes with low airspeeds, the attitude effect tends to dominate. For a given airplane, the acceleration effect will be stronger at lower altitudes where the shear is relatively strong compared to the total change of wind speed. This evaluation presumes the airplane is controlled in an open-loop manner. The ability to attain closed-loop control, either by the pilot or the autoland system, depends in part upon the open-loop stability of the aircraft-autoland system.

Airplane stability is affected by the wind shear: aerodynamic forces and moments are dependent on the components of wind speed, motion is dependent on aerodynamic forces and moments, and the components of wind speed are dependent on airplane motion. If the aerodynamic characteristics can be considered to be concentrated at the center of gravity, only longitudinal stability, principally phugoid or long period stability, is affected by wind shears.

A headwind shear can either stabilize or destabilize the phugoid, depending on the characteristics of the airplane's stability derivatives. If a headwind shear has stabilizing effects, a tailwind has destabilizing effects, and vice versa.

The effects of a wind shear may not be adequately represented by considering the aerodynamic characteristics to be concentrated at the center of gravity. Due to the change of wind speed with altitude, there is a distribution of wind speed over the vertical tail that introduces a rolling moment. When the airplane is disturbed from zero pitch attitude and wings level, the different parts of the airplane in the plane of the wings will be at different altitudes and there will be a distribution of wind speed about the airplane and a corresponding change in the distribution of lift.

The distribution of wind about the airplane may well be represented as being linear in three dimensions. Then the components of wind at some point (x,y,z) are represented by

$$\bar{u}_W = \bar{u}_{W_{CG}} + \frac{\partial \bar{u}_W}{\partial x} x + \frac{\partial \bar{u}_W}{\partial y} y + \frac{\partial \bar{u}_W}{\partial z} z$$

$$\bar{v}_W = \bar{v}_{W_{CG}} + \frac{\partial \bar{v}_W}{\partial x} x + \frac{\partial \bar{v}_W}{\partial y} y + \frac{\partial \bar{v}_W}{\partial z} z$$

$$\bar{w}_W = \bar{w}_{W_{CG}} + \frac{\partial \bar{w}_W}{\partial x} x + \frac{\partial \bar{w}_W}{\partial y} y + \frac{\partial \bar{w}_W}{\partial z} z$$

The derivative of body axis wind components are expressible in terms of the mean wind shear and can be interpreted as effective angular components of wind. For example, the distribution of the lateral component of wind about the vertical dimensions of the fin appears as a roll rate, which generates a rolling moment proportional to the fin's contribution to the roll rate derivative of rolling moment.

Linear analysis predicts that the distributed lift effects of the mean wind shear appear primarily for lateral-directional motion. These effects are due to the headwind-tailwind component of the shear. The wind shear alters all of the lateral-directional stability characteristics, but the sensitivity of the characteristic roots to wind shear are configuration dependent.

Representation of the distributed lift effects is the only reason for computing the mean wind shear at each altitude. If the distributed lift effects can be shown to be insignificant, the computation of the shear can be left out of the simulation.

TURBULENCE

Analytic Description

For unstable atmospheric conditions, amplified displacement of air particles from their initial positions due to buoyancy forces cannot increase without bound. Turbulence is the mechanism by which the effects of instability are constrained through the mixing of hot and cold air particles, which produces equilibrium locally. The appearance and disappearance of turbulence with changing atmospheric stability involves a hysteresis effect, but it is predicted to occur at the critical Richardson's number, related to the log-linear mean wind profile constant:

$$R_{i_{CRIT}} = \frac{1}{a'} = 0.222 \text{ for } a' = 4.5$$

The equations of motion for turbulence have been developed from the Navier-Stokes equations, but the severe nonlinearity of these equations has prevented their solution. Even if they could be solved, it is questionable as to whether they could be practically applied. From observations relating to these equations, some characteristics have been determined:

- Turbulence transports energy from large eddies, where it is generated mechanically and thermally to smaller eddies until it is finally dissipated viscously.
- Turbulence can only occur nonlinearly in three dimensions.
- Turbulence is diffusive and far more efficient for the transport of mass, momentum, and heat properties than molecular motion.
- Turbulence is a continuum having a smallest dynamically significant scale much larger than molecular or intermolecular dimensions.
- Turbulence is approximately an equilibrium phenomenon for homogeneous terrain having very low rates of change of kinetic energy.
- The diffusive, continuous, and equilibrium characteristics tend to produce homogeneity for turbulence in a horizontal plane,

Using these properties of turbulence, a statistical description of turbulence is developed. The basic statistical function is the average product of two turbulence components measured at two points of time and space, the correlation function:

$$R_{ij}(t_1,t_2,\vec{r_1},\vec{r_2}) = \overline{u_i(t_1,\vec{r_1})u_j(t_2,\vec{r_2})}$$

When $\vec{r}_1 = \vec{r}_2$ (measured at the same point in space) and $t_1 = t_2$ (measured at the same time), the correlation function becomes the covariance. When, in addition, $i = j$, the correlation function is the variance.

By invoking homogeneity (turbulence properties independent of absolute position in space) and stationarity (turbulence properties independent of absolute time), the parameters reduce to just the displacements in position and time between the measured components:

$$R_{ij}(t_1,t_2,r_1,r_2) = R(\tau\ \vec{\xi})$$

$$\tau = t_2 - t_1$$

$$\xi = \vec{r}_1 - \vec{r}_2$$

By additionally applying Taylor's hypothesis (frozen field concept), which assumes airplanes fly at speeds large compared to turbulent velocities and their rates of change, the time displacement can be related to a component of the position displacement, leaving statistical turbulence properties defined only in terms of space.

The correlation function can be transformed into the three-dimensional spectrum function by applying the Fourier integral:

$$\theta_{ij}(\vec{\Omega}) = \frac{1}{(2\pi)^3} \int_{-\infty}^{\infty} R_{ij}(\vec{\xi})\, e^{-i\vec{\Omega}\,\vec{\xi}}\, d\vec{\xi}$$

The parameter $\vec{\Omega}$ is the spacial frequency vector having units of rad/ft and is related to distance as temporal frequency in rad/sec is to time. The transformation can be reversed by the inversion formula:

$$R_{ij}(\vec{\xi}) = \int_{-\infty}^{\infty} \theta_{ij}(\vec{\Omega}) e^{i\vec{\Omega}\vec{\xi}} d\vec{\Omega}$$

When $\vec{\xi} = 0$, the correlation function becomes the covariance and the spectrum function can be seen to be the distribution of the covariance with spacial frequency:

$$\sigma_{ij}^{2} = \int_{-\infty}^{\infty} \theta_{ij}(\vec{\Omega}) d\vec{\Omega}$$

Simulation of turbulence can be performed only by a temporal process, but only one component of spacial frequency (that in the direction of flight) can be related to time or temporal frequency through Taylor's hypothesis, $\omega = \Omega_1 V_A$. To obtain a spectrum function in terms of the component associated with the coordinate in the direction of flight ($\Phi(\Omega_1)$) integration of the spectrum function over the other two Components is performed. Then

$$\sigma_{ij}^{2} = \int_{-\infty}^{\infty} \Phi(\Omega_1) d\Omega_1$$

Important characteristics of the one-dimensional spectrum function, $\Phi_{ij}(\Omega_1)$, have been derived by Batchelor for the special case of isotropic turbulence, for which the statistical properties of turbulence are invariant with coordinate system rotation or translation. Batch'elor showed that there were but two one-dimensional spectrum functions: one for two parallel longitudinal turbulence components (components aligned to the vector separating them), $\Phi_{PP}(\Omega_1)$, and one for parallel transverse components (components normal to the vector separating them), $\Phi_{NN}(\Omega_1)$. All spectra for orthogonal components are zero. The variances for all components are equal. The two spectra are related by

$$\Phi_{NN}(\Omega_1) = \frac{1}{2}\left[\Phi_{PP}(\Omega_1) - \Omega_1 \frac{d\Phi_{PP}(\Omega_1)}{d\Omega_1}\right]$$

Determination of one of the isotropic spectrum functions provides the other.

Corresponding to the two spectrum functions are two nondimensional (divided by variance) scalar correlation functions: one, $f(\xi)$, for two parallel longitudinal components, and the other, $g(\xi)$, for two parallel transverse components, which are also interrelated:

$$f(\xi) = \frac{\overline{u_P^2}(\xi)}{\sigma^2}$$

$$g(\xi) = \frac{\overline{u_N^2}(\xi)}{\sigma^2}$$

$$g(\xi) = f(\xi) + \frac{\xi}{2}\frac{df(\xi)}{d\xi}$$

The fundamental correlation functions are analogous to serial correlation functions.

A measure of the average eddy size, the integral scale may be determined from the fundamental correlation functions:

$$L_P = \int_0^\infty f(\xi)d\xi$$

$$L_N = \int_0^\infty g(\xi)d\xi$$

For a separation distance, ξ, equal to the integral scale, the area under the corresponding correlation function is divided into equal parts. Through the relationship between the fundamental correlation functions, it can be shown

$$L_P = 2 L_N$$

The integral scales provide means for normalizing distance. It is then postulated that $f(\xi/L_P)$ and $g(\xi/L_N)$ are universal functions. The one-dimensional spectrum functions must correspondingly have the form

$$\Phi_{ii}(\Omega_1) = \sigma_{ii}^2 G(L_i, L_i \Omega_1) .$$

That is, spacial frequency appears only in combination with the integral scales.

Theory and empirical investigation have led to additional requirements for the isotropic one-dimensional spectra:

- The high frequency asymptotes (excluding viscous dissipation) of the spectra are of the form $\Phi_{ii}(\Omega_1) \sim \Omega^{-5/3}$ This leads to a ratio of the transverse-to-longitudinal spectrum equal to 4/3 at high frequencies.
- The low-frequency asymptotes are frequency invariant. This leads to a ratio of the transverse-to-longitudinal spectrum equal to 1/2.
- Isotropic spectra must be symmetric about $\Omega_1 = 0$.

A number of isotropic spectra forms have been proposed. The best-known forms for aeronautical applications are the Dryden and von Karman forms, presented with related functions in Figure 18.

Van Karman	Dryden

Longitudinal correlation function:

$$f(\xi) = \frac{2^{2/3}}{\Gamma(1/3)}\left(\frac{\xi}{aL}\right)^{1/3} K_{1/3}\left(\frac{\xi}{aL}\right) \qquad f(\xi) = e^{-\xi/L}$$

Transverse correlation functions:

$$g(\xi) = \frac{2^{2/3}}{\Gamma(1/3)}\left(\frac{\xi}{aL}\right)^{1/3}\left[K_{1/3}\left(\frac{\xi}{aL}\right) - \frac{\xi}{2aL} K_{2/3}\left(\frac{\xi}{aL}\right)\right] \qquad g(\xi) = e^{-\xi/L}\left[1 - \frac{\xi}{2L}\right]$$

Longitudinal onedimensional power spectrum:

$$\Phi_{PP} = \frac{\sigma^2 L}{\pi} \frac{1}{\left[1 + (aL\Omega_1)^2\right]^{5/6}} \qquad \Phi_{PP} = \frac{\sigma^2 L}{\pi} \frac{1}{\left[1 + (L\Omega_1)^2\right]}$$

Transverse onedimensional power spectrum:

$$\Phi_{NN} = \frac{\sigma^2 L}{2\pi} \frac{1 + 8/3\,(aL\Omega_1)^2}{\left[1 + (aL\Omega_1)^2\right]^{11/6}} \qquad \Phi_{NN} = \frac{\sigma^2 L}{2\pi} \frac{1 + 3(L\Omega_1)^2}{\left[1 + (L\Omega)^2\right]^2}$$

Energy spectrum:

$$E(\Omega) = \frac{55}{9\pi} \sigma^2 L \frac{(aL\Omega)^4}{\left[1 + (aL\Omega)^2\right]^{17/6}} \qquad E(\Omega) = \frac{8\sigma^2 L}{\pi} \frac{(L\Omega)^4}{\left[1 + (L\Omega)^2\right]^3}$$

Definitions:

$a = 1.339$

$\Omega = |\vec{\Omega}| = |\Omega_1 \hat{\imath} + \Omega_2 \hat{\jmath} + \Omega_3 \hat{k}|$

Φ_{PP} and Φ_{NN} such that $\sigma^2 = \int_{-\infty}^{\infty} \Phi_{PP}\, d\Omega_1 = \int_{-\infty}^{\infty} \Phi_{NN}\, d\Omega_1$

$L = \int_0^{\infty} f(\xi)\, d\xi = 2\int_0^{\infty} g(\xi)\, d\xi$

$K_{1/3}\left(\frac{\xi}{aL}\right)$ and $K_{2/3}\left(\frac{\xi}{aL}\right)$ are modified Bessel functions of the second kind.

FIGURE 18 — VON KARMAN AND DRYDEN CORRELATION AND SPECTRA FUNCTIONS

The Dryden form is simpler and is based on an exponential shape of the fundamental correlation functions. The Dryden function fails to meet the high-frequency requirement.

The von Karman forms result from a curve fitting expression for the energy spectrum and satisfy all isotropic requirements. In numerous investigations the von Karman forms have been shown to be superior to the Dryden forms. The von Karman one-dimensional spectra are those accepted for the model.

Although high-altitude turbulence is well represented by isotropy, low-altitude turbulence is clearly nonisotropic. Specifically:

- The statistical functions describing the field of turbulence are not invariant with coordinate rotation; variances of turbulence components are not equal and the longitudinal and transverse integral scales vary with coordinate rotations.
- Low-altitude turbulence exhibits a lack of homogeneity with altitude; the variances and integral scales of turbulence vary with altitude.
- A non-zero correlation between turbulence in the direction of the mean wind and vertical turbulence has been found. Isotropic turbulence requires zero correlation between orthogonal components.

There are, however, limited conditions of isotropy found to hold for low-altitude turbulence:

- At sufficiently high spacial frequencies (short separation distances), low-altitude turbulence is isotropic. This is referred to as "local isotropy" and requires the high-frequency spectrum asymptotes to be invariant with coordinate rotations.

- The existence of a single non-zero correlation function between the downwind and vertical components of turbulence is compatible with horizontal isotropy (invariance of the horizontal statistical functions with rotations of the axis system in the horizontal plane). Horizontal isotropy must be viewed as an approximate characteristic for low-altitude turbulence, for the variance of horizontal turbulence perpendicular to the mean wind is frequently reported as being somewhat greater than the variance of the component in the direction of the mean wind.

The spectra that have been developed specifically for low altitude tend to be for small regions of altitude near the surface and do not tend to full isotropy at higher altitudes. A frequently employed technique that is employed in this report is to adopt isotropic spectra for low altitude by permitting the variances and integral scales to be different for each component. The von Karman spectra are used. These low-altitude forms become:

$$\Phi_u(\Omega_1) = \sigma_u{}^2 L_u \frac{1}{\left[1 + (1.339\ L_u\Omega_1)^2\right]^{5/6}}$$

$$\Phi_v(\Omega_1) = \frac{5_v{}^2 L_v}{2\pi} \frac{1 + 8/3(1.339\ L_v\Omega_1)^2}{\left[1 + (1.339\ L_v\Omega_1)^2\right]^{11/6}}$$

$$\Phi_w(\Omega_1) = \frac{\sigma_w{}^2 L_w}{2\pi} \frac{1 + 8/3(1.339\ L_w\Omega_1)^2}{\left[1 + (1.339\ L_w\Omega_1)^2\right]^{11/16}}$$

These spectra were originally written in terms of the longitudinal integral scale, which is twice the transverse integral scale for isotropy, so L_v and L_w must be redefined as twice the area under the corresponding correlation functions,

Although a cross spectrum, Φ_{uw}, has been found to exist, it has been concluded that the cross spectrum has a significant magnitude only at frequencies too low to be important.

Simulator Representation of Turbulence Spectra

The spectra in terms of temporal frequency are obtained by substituting $\Omega_1 = \omega/V_A$ (Taylor's hypothesis) and by requiring the variance to be the same in either domain:

$$\sigma_i^2 = \int_{-\infty}^{\infty} \Phi_i(\omega)\,d\omega = \int_{-\infty}^{\infty} \Phi_i(\Omega_1)\,d\Omega_1$$

Then

$$\Phi_i(\omega) = \frac{1}{V_A}\,\Phi_i\left(\Omega_1 = \frac{\omega}{V_A}\right)$$

When a random variable is modified by a transfer function, the output spectrum is given by

$$\Phi_O(\omega) = M^2(\omega)\,\Phi_N(\omega)$$

where:

$\Phi_O(\omega)$ = output spectrum

$M(\omega)$ = amplitude frequency response of the transfer function

$\Phi_N(\omega)$ = power spectrum of the random function or noise

Turbulence is represented by finding a transfer function such that

$$M(\omega) = \sqrt{\frac{\Phi_O(\omega)}{\Phi_N(\omega)}}$$

where the output frequency response is equal to that desired. When white noise is used, $\Phi_N = 1$ by definition. Then to match a desired power spectrum, it is only necessary to find a transfer function with a frequency response equal to the square root of the spectrum.

It is not possible to exactly reproduce the von Karman spectra with linear transfer functions (filters) due to exponents of frequency that are noneven integers, so an approximation is sought.

The significant criteria for evaluating an approximation to a power spectra is to require the contribution of each incremental frequency range to the variance to be correct for the frequency range in which the airplane's response is important. Directly plotting $\Phi(\omega)$ versus ω lacks resolution over the entire frequency range. Plots of $\omega\Phi(\omega)$ versus log (ω) provide the necessary resolution and the area under such a curve is also equal to the contribution to the variance:

$$\Delta\sigma^2 = \int_{\omega_1}^{\omega_2} \Phi(\omega)\,d\omega = \int_{\mathrm{Log}\ \omega_1}^{\mathrm{Log}\ \omega_2} \omega\Phi(\omega)\,d(\log\ \omega)$$

The validity of transfer functions representing spectra may be assessed by comparing plots of this type for the transfer function frequency response squared and the power spectrum.

Filters exactly duplicating the Dryden spectra are often assumed to match the von Karman spectra well for rigid airplane responses even though it is conceded the Dryden spectra are not substantiated by theory and empirical evidence. This is seen not to be true in Figure 19, for the Dryden spectra provide greater contributions to the variance than the von Karman spectra by as much as 25% at frequencies where contributions to the variance are greatest. Approximate filters that do a much better job of matching the von Karman spectra are presented in Figure 20 (where the corresponding mechanization is also shown). Comparisons of the filters in Figure 20 with the von Karman spectra are shown in Figures 21 and 22.

The white noise may be generated by either hardware or software (digitally), There are several methods available, each with different shortcomings.

When the noise is generated digitally, it is only approximately random and the noise spectrum is only approximately flat and equal to one. The digital generation of white noise consists of three main steps:

1) Random numbers having a uniform distribution between 0 and 1 are generated.
2) From the uniform distribution, the distribution assumed to hold for turbulence is generated.
3) The noise thus far produced will have a unit variance and a spectrum amplitude of $\Delta t/2\pi$ (At = frame time or sampling interval) no matter what distribution is used in 2). To provide white noise for which the spectrum amplitude is one, the output from 2) is multiplied by $\sqrt{2\pi/\Delta t}$.

Turbulence velocities within a single patch of turbulence are assumed to form a Gaussian distribution. Although

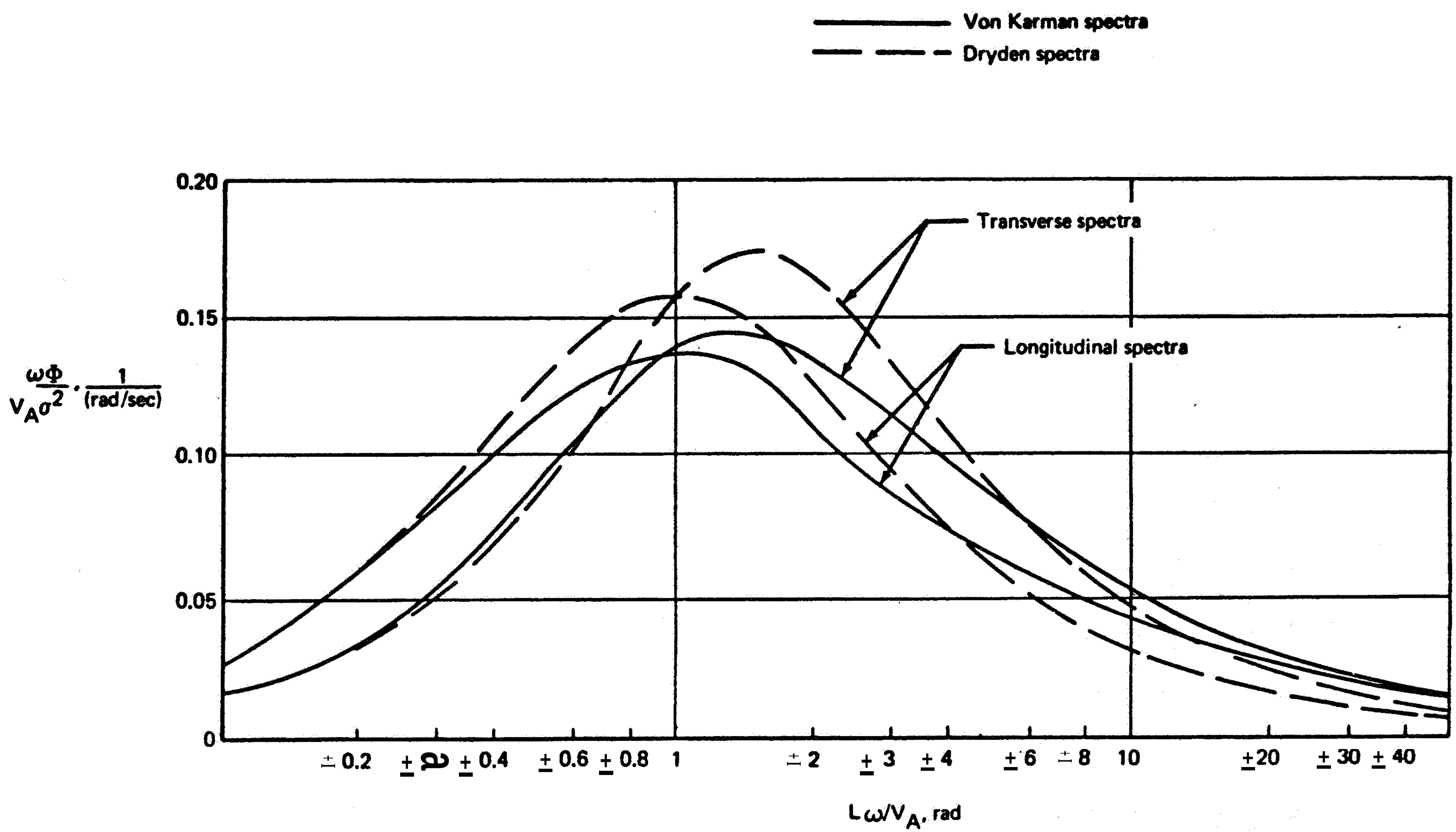
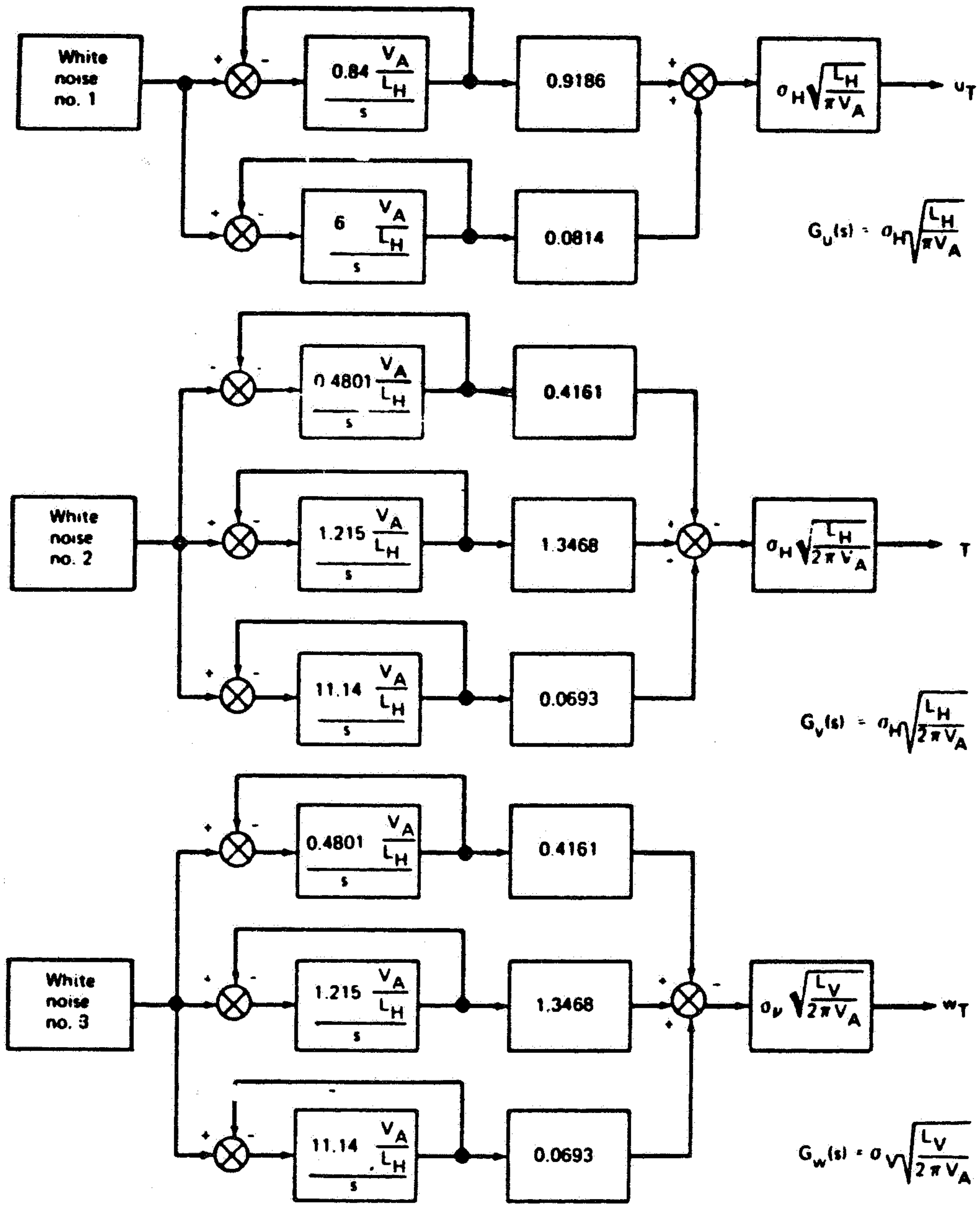


FIGURE 19 —COMPARISON: DRYDEN AND VON KARMAN VARIANCE DENSITY



$$G_u(s) = \sigma_H \sqrt{\frac{L_H}{\pi V_A}} \; \frac{1 + 0.25 \frac{L_H}{V_A} s}{(1 + 1.19 \frac{L_H}{V_A} s)(1 + 0.167 \frac{L_H}{V_A} s)}.$$

$$G_v(s) = \sigma_H \sqrt{\frac{L_H}{2\pi V_A}} \; \frac{(1 + 2.618 \frac{L_H}{V_A} s)(1 + 0.1298 \frac{L_H}{V_A} s)}{(1 + 2.083 \frac{L_H}{V_A} s)(1 + 0.823 \frac{L_H}{V_A} s)(1 + 0.08977 \frac{L_H}{V_A} s)}$$

$$G_w(s) = \sigma_V \sqrt{\frac{L_V}{2\pi V_A}} \; \frac{(1 + 2.618 \frac{L_V}{V_A} s)(1 + 0.1298 \frac{L_V}{V_A} s)}{(1 + 2.083 \frac{L_V}{V_A} s)(1 + 0.823 \frac{L_V}{V_A} s)(1 + 0.08977 \frac{L_V}{V_A} s)}$$

FIGURE 20 — SCHEMATIC FOR TURBULENCE FILTERS

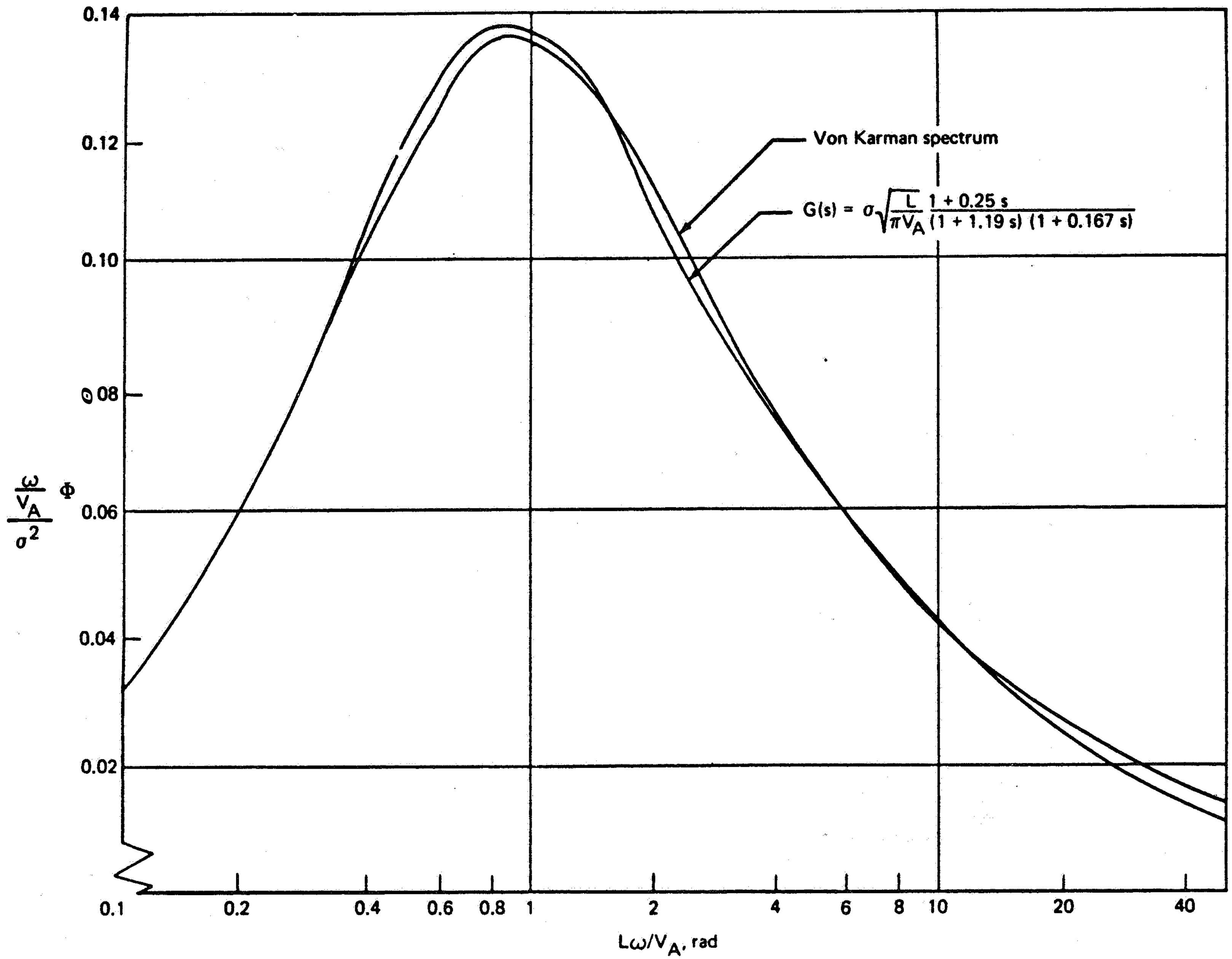


FIGURE 21 – APPROXIMATE LONGITUDINAL TURBULENCE FILTER ACCURACY

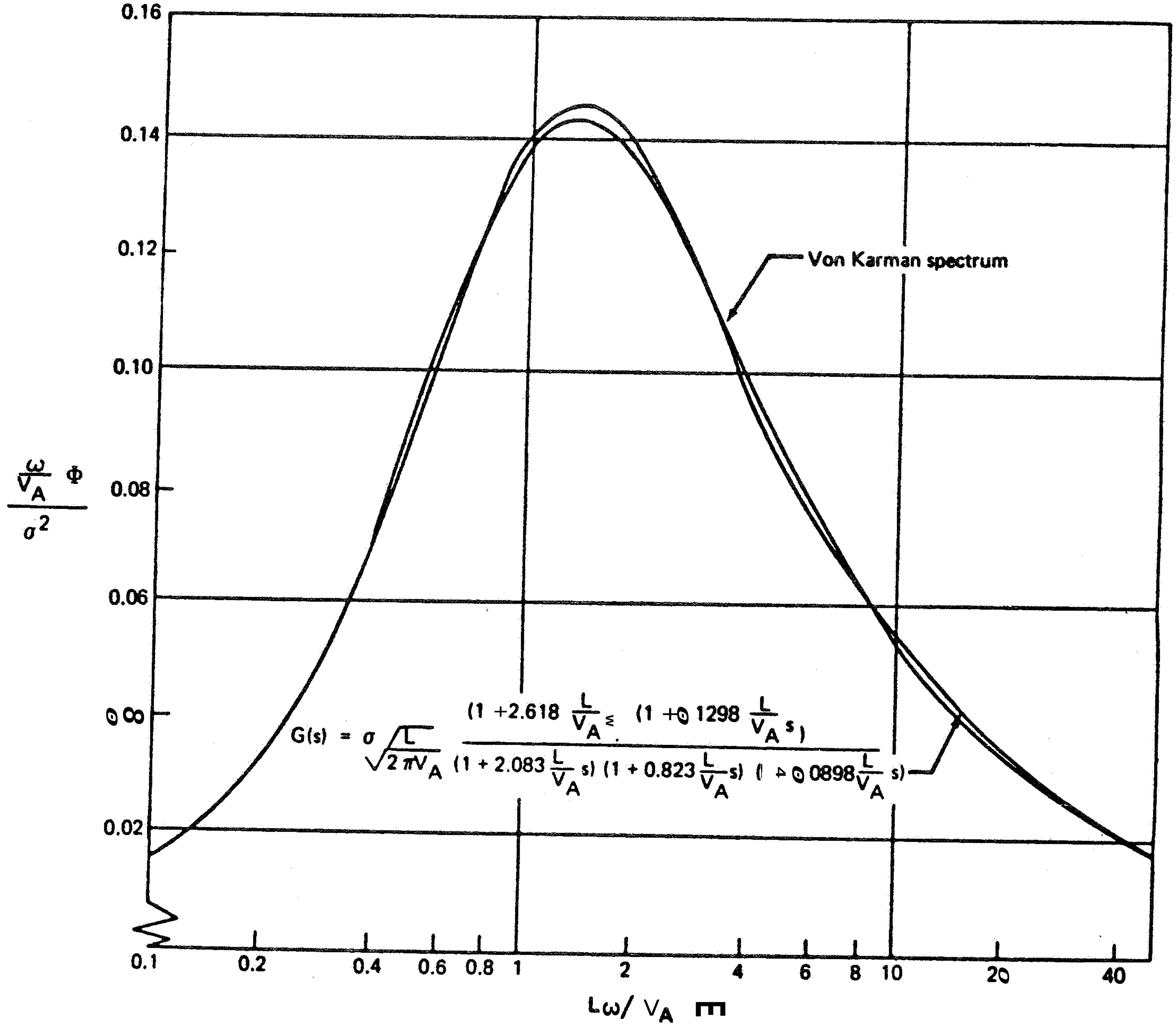


FIGURE 22 — APPROXIMATE TRANSVERSE TURBULENCE FILTER ACCURACY

the distribution of turbulence velocities for the sum of all turbulence patches have been shown to be non-Gaussian, this is not inconsistent with a Gaussian distribution for a single patch of turbulence.

Turbulence Scale and Magnitude

The simulator model for turbulence in Figure 20 lacks definition of the variances and integral scales. The measurements and theory for these statistical parameters of turbulence are measured in an axis system aligned to the mean wind.

Dimensional analysis leads to a description of the vertical turbulence standard deviation for unstable conditions

$$\frac{\sigma_w}{u_*} = C\left[\frac{kh}{u_*}\frac{\partial \overline{V}_W}{\partial h} - \left(\frac{D}{C}\right)^3 \frac{h}{\ell'}\right]^{1/3}$$

D and C are constants

For neutral conditions where the nondimensional shear at the surface $(kh/u_*)/\partial\overline{V}_W/\partial h)$, is 1,

$$\frac{\sigma_w}{u_*} = 1.3 = C$$

is well accepted. For extremely unstable conditions, the nondimensional shear is negligible and the equation reduces to

$$\frac{\sigma_w}{u_*} = D\left(-\frac{h}{\ell'}\right)^{1/3}$$

The constant, D, is well represented by 1.7, hence

$$\frac{\sigma_w}{u_*} = 1.3\left[\left(\frac{kh}{u_*}\frac{\partial \overline{V}_W}{\partial h}\right) - 2.236\left(\frac{h}{\ell'}\right)\right]^{1/3}$$

The nondimensional shear has been described as a function of h/ℓ' only, so σ_w/u_* is also completely described by h/ℓ'. For near neutral conditions and slightly stable conditions, the shape of σ_w/u_* versus h/ℓ' has been made to match that of measured data. The standard deviation of vertical turbulence is reduced abruptly beginning at $h/\ell' = 1$, above which the nondimensional shear is constant, to $\sigma_w/u_* = 0$ at $h/\ell' = 1.22$, which corresponds to the critical Richardson's number ($Ri_{CRIT} = 0.222$). The combined description for σ_w/u_* is presented in Figure 23. The procedure for computing the rms level of turbulence vertical to the earth is:

$$\sigma_w = u_*\left[\frac{\sigma_w}{u_*}\left(\frac{h}{\ell'}\right)\right]$$

$$= 0.4\overline{V}_{20}\left(\frac{u_{*_0}/k}{\overline{V}_{20}}\right)\left(\frac{u_*}{u_{*_0}}\right)\left[\frac{\sigma_w}{u_*}\left(\frac{h}{\ell'}\right)\right]$$

where:

$\dfrac{u_{*_0}/k}{\overline{V}_{20}}$ determined for the mean wind model

$\dfrac{u_*}{u_{*_0}} = 1 - \dfrac{h}{d}$, as determined from the mean wind model

$d = 2000\, u_{*_0}$, as determined for the mean wind model

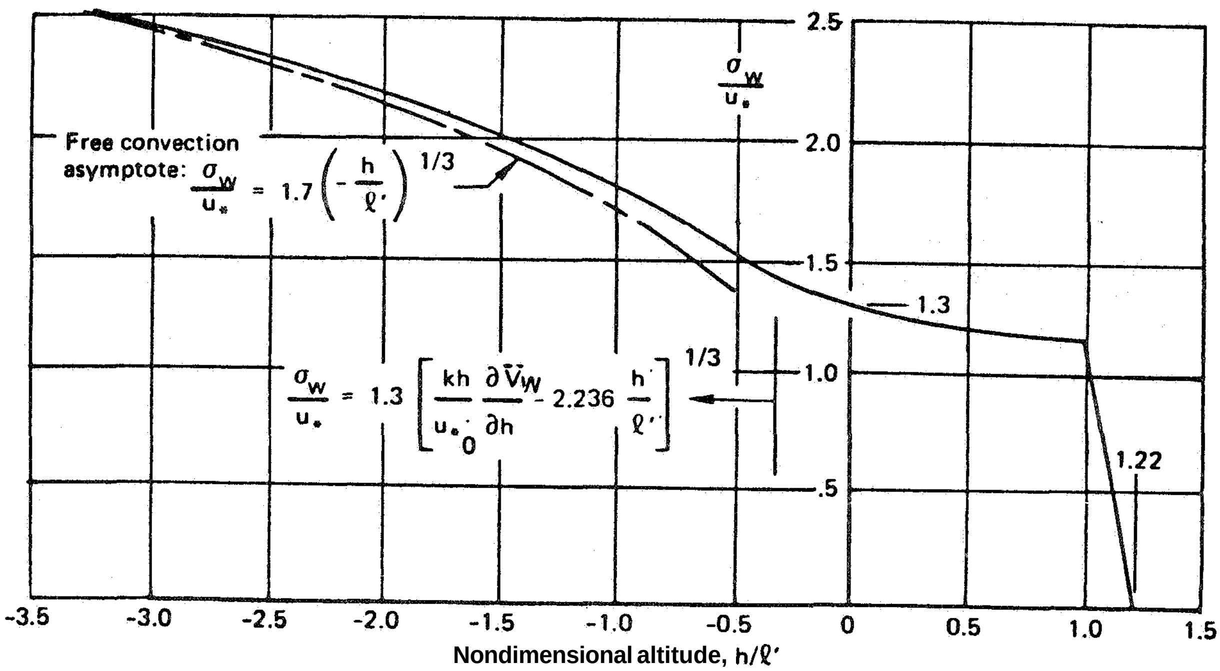


FIGURE 23 – σ_w/u_* VARIATION WITH STABILITY

The standard deviation for vertical turbulence is described as being proportional to the mean wind speed at 20 feet, as decreasing and finally disappearing with increasing atmospheric stability, and as tending toward zero as altitude approaches the boundary layer. The variation of σ_W with altitude for different surface wind and atmospheric stability conditions is shown in Figure *24.*

Dimensional analysis relationships for the variances of horizontal components of turbulence have not had good empirical support. At the surface, the magnitudes of the horizontal components are significantly greater than magnitude of the vertical component with the component in the direction of the mean wind frequently reported as greater than the horizontal component normal to the mean wind. The

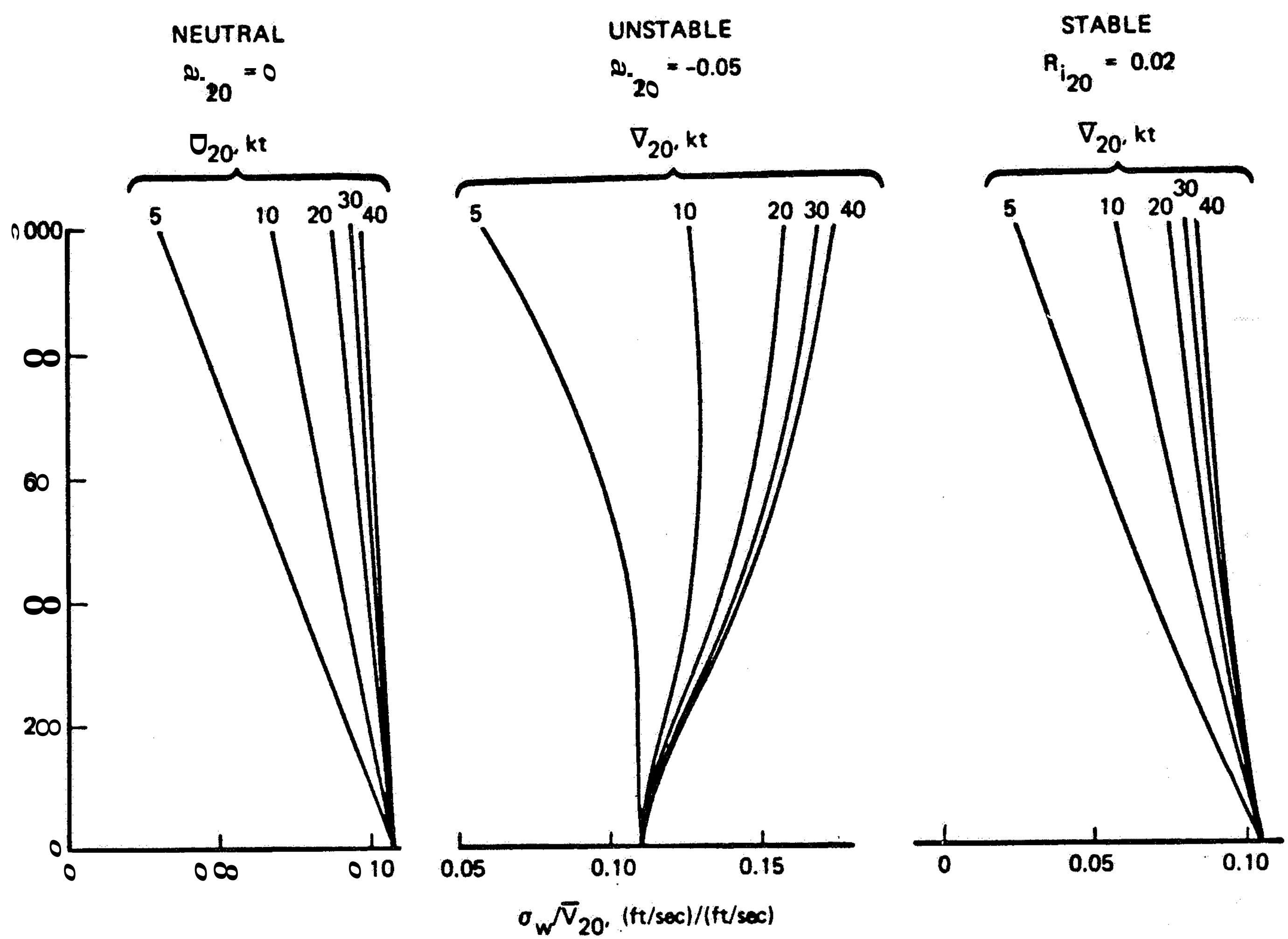


FIGURE 24 — PROFILE OF VERTICAL TURBULENCE RMS, SELECTED DESCRIPTION

data do not indicate any clear relationship between the variances for the horizontal turbulence components but do show them to be approximately equal, so horizontal isotropy ($\sigma_u = \sigma_v$, $L_u = L_v$) is assumed. This enables describing turbulence characteristics according to whether turbulence components are vertical or horizontal. A corresponding change of nomenclature is adopted: σ_V replaces σ_w, L_V replaces L_w, σ_H replaces σ_u and σ_v, and L_H replaces L_u and L_v (subscripts **H** and V refer to horizontal and vertical components).

The change in nomenclature aids in differentiating between turbulence components aligned to the mean wind and turbulence components aligned to other axis systems.

It is assumed that the horizontal components of turbulence have variances €hat change identically with stability. Qualitatively, this is not correct, but any other quantitative descriptions based on the information in hand would be just as arbitrary but more complex. As a result, the standard deviation for horizontal turbulence may be described by

$$\sigma_H = \left(\frac{\sigma_H}{\sigma_V} \right) \sigma$$

At the surface $\sigma_H/\sigma_V = 2$ is a good compromise of the data. Above a sufficiently high altitude where complete isotropy begins, h_I, $\sigma_H/\sigma_V = 1$. There is little information to describe the variation of σ_H/σ_V with altitude, so an interpolation equation,

$$\frac{\sigma_H}{\sigma_V} = \begin{cases} \dfrac{1}{\left[0.177 + 0.823 \dfrac{h}{h_I} \right]^{0.4}} , & h < h_I \\ 1 , & h \geq h_I \end{cases} \quad \text{(Fig. 25)}$$

$$\frac{\sigma_u}{\sigma_w} = \frac{\sigma_v}{\sigma_w} = \begin{cases} \dfrac{1}{\left[0.177 + 0.823\, h/h_l\right]^{.4}} & , h < h_l \\ 1.0 & , h \geq h_l \end{cases}$$

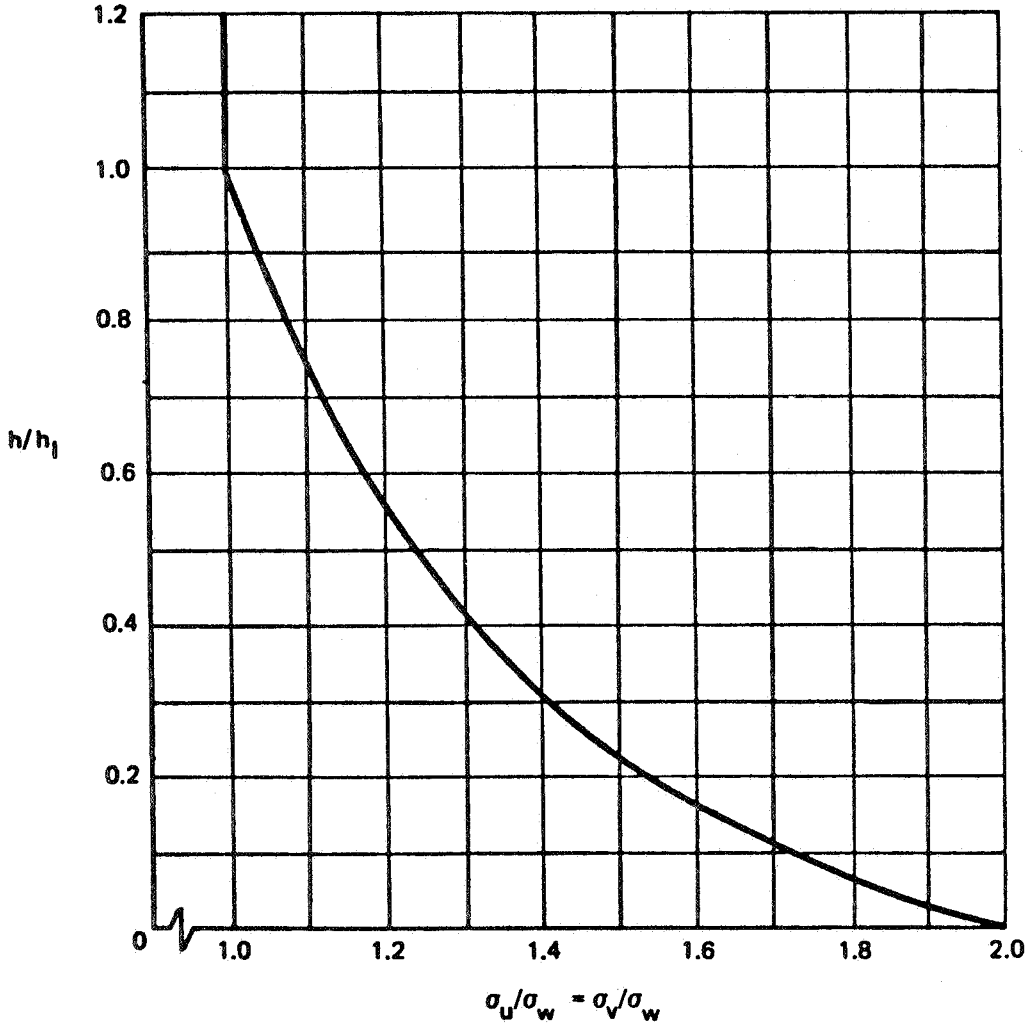


FIGURE 25 – SELECTED DESCRIPTION FOR VARIANCES OF HORIZONTAL TURBULENCE COMPONENTS

was developed that is qualitatively similar to other variations proposed.

Implied estimates for the altitude above which isotropy exists (h_I) range from 300 to 2500 feet. The latter number is an extreme. A value of h_I = 1000 feet is chosen, is adequately supportable, and provides integral scales comparable with other models.

The integral scale for vertical turbulence is predicted by dimensional analysis to have the form

$$L_V = [B(R_i)]h$$

That is, the vertical turbulence integral scale is linearly related to altitude with the proportionality constant dependent upon stability.

The atmospheric stability dependence of the proportionality constant is apparently weak, at least for a wide range of stability conditions, and is assumed to be constant. Estimates for B range from 0.125 to greater than 4, with most estimates centered about 0.5 and 1. Unit proportionality is assumed. The estimates about 0.5 may be for the literal definition of integral scale equal to the integral of the correlation function rather than the redefinition of twice that area. Hence, the estimates of 0.5 may be consistent with the unit proportionality assumed for the redefinition. In keeping with isotropy about 1000 feet, L_V = 1000 feet for h $\geq$ 1000 feet.

The integral scale for horizontal turbulence is the parameter for which knowledge is poorest. It may be derived from the condition of local isotropy at low altitudes, which can be shown to require:

$$L_H = \left(\frac{H}{V}\right)^3 L_V \qquad \text{(Fig. 26)}$$

$$L_w = \begin{cases} h, & h < h_l \\ d, & h = h_l \end{cases}$$

$$L_u = \begin{cases} L_w \left(\dfrac{\sigma_u}{\sigma_w}\right)^3 = \dfrac{h}{\left[0.177 + 0.823\, h/h_l\right]^{1.2}} & , h < h_l \\ d & , h \geq h_l \end{cases}$$

$$L_v = L_u$$

h_l = Altitude above which turbulence is isotropic

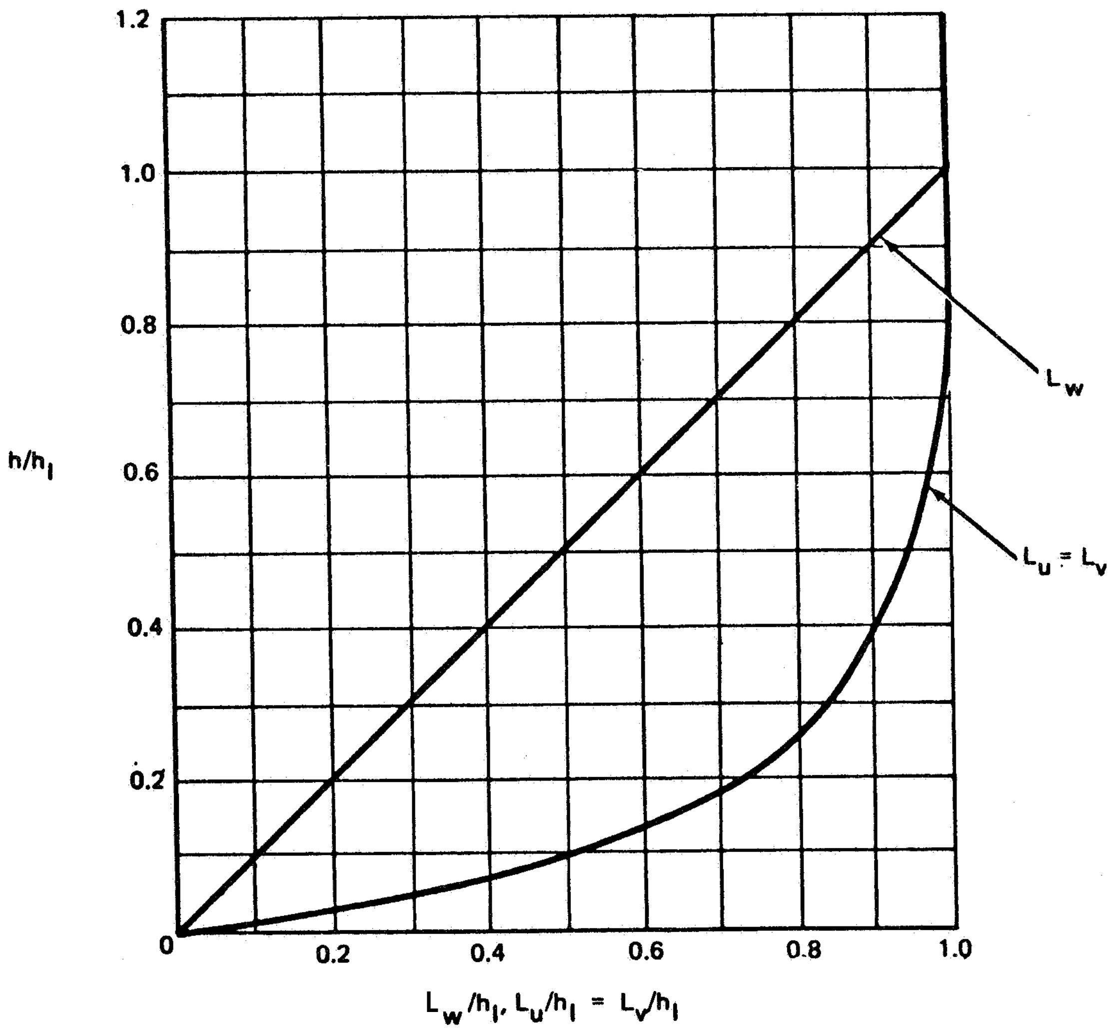


FIGURE 26 – SELECTED INTEGRAL SCALE DESCRIPTION

This description provides a horizontal turbulence integral scale greater or equal to that vertical turbulence. At the surface, $L_H = 8\ L_V$. Above 1000 feet, where isotropy is assumed to exist, the integral scales are equal. These characteristics are in agreement with observations.

Turbulence Axis Systems

There is an inconsistency in the turbulence model developed: the power spectra are for turbulence components aligned to the airplane's velocity with respect to the air mass and the standard deviations and integral scales are for turbulence components aligned with respect to the plane of the earth and the mean wind heading. Both sets of components can, in general, coincide only for an observer whose position with respect to the earth is fixed.

One exact approach for resolving the differences in axis systems consists of transforming the variances and integral scales from the mean wind axis system to the axis system attached to the relative wind where the spectra shapes are known. Turbulence components would then be generated in the relative wind axis and transformed to the body axis. Transformations for the integral scales and variances have been developed, but are quite complex. Complete tensor transformations have been developed and reveal that when the airplane's relative velocity is not aligned to the mean wind and when wings are nonlevel, nonnegligible cospectra exist in the body axis (components of body axis turbulence are correlated). Since the power spectra shapes are in general not known in the mean wind axis system and the cospectra forms are not known for a body axis system, the exact method cannot be performed.

Errors from approximate methods were examined. It was revealed that for low-altitude turbulence, it is much more important to have the correct alignment for the variances and integral scales than for the spectra shapes. The greatest error in the spectra magnitude at any frequency for turbulence normal to the airplane that can occur due to misalignment of the spectra shape is a factor of 2, while the greatest error possible due to misalignment of the statistical parameters is a factor of *64.* The best compromise found was to generate turbulence in an axis system that is in the plane of the earth but aligned to the heading of the airplane's relative velocity vector with the filters in Figure 20 and the specified rms levels and integral scales. The components of turbulence are then transformed to the body axis system. The transformation required is presented in Figure 16.

Application to Aerodynamics

When the aircraft can be adequately represented as though the aerodynamic forces and moments were concentrated at the center of gravity, turbulence affects forces and moments through the computation of body axis velocities relative to the air mass:

$$u_A = u - u_W, u_W = \bar{u}_W + u_T$$

$$v_A = v - v_W, v_W = \bar{v}_W + v_T$$

$$w_A = w - w_W, w_W = \bar{w}_W + w_T$$

$$V_A = u_A^2 + v_A^2 + w_A^2$$

u, v, w = inertial velocity components along the x, y, and z body axis coordinates

u_A v_A w_A = components of airplane velocity relative to the air mass

$u_W \; v_W \; w_W$ = components of wind relative to the earth

$\bar{u}_W \; \bar{v}_W \; \bar{w}_W$ = components of mean wind relative to the earth

$u_T \; v_T \; w_T$ = components of turbulence velocities relative relative to the earth

The relative velocity components are used to determine the parameters, which in turn determine the aerodynamics forces and moments:

$$\alpha = \tan^{-1} \frac{w_A}{u_A} = \text{angle of attack}$$

$$\beta = \sin^{-1} \frac{v_A}{V_A} - \text{sideslip angle}$$

$$\bar{q} = \frac{1}{2} \rho V_A^2 = \text{dynamic pressure}$$

$$\dot{\alpha} = \frac{u_A \dot{w} - w_A \dot{u}}{u_A^2 + w_A^2}$$

$$\dot{\beta} = \frac{(u_A^2 + w_A^2)\dot{v} - v_A(\dot{u}_A u + w_A \dot{w})}{V_A^2 \sqrt{u_A^2 + w_A^2}}$$

Note that for the point representation, $\dot{u}_W = \dot{v}_W = \dot{w}_W = 0$.

The attenuation of the high-frequency response of forces and moments due to the fact that lift cannot respond instantaneously to changes in angle of attack (unsteady aerodynamics) can be handled approximately through use of the Kussner and Wagner lift growth functions,

In general, it is not adequate to assume the aerodynamics may be represented by a point for the purpose of simulating the effects of turbulence; there is a distribution of turbulence about the airplane that causes a change in the distribution of lift. The point representation has been estimated to be accurate only up to:

$\lambda_1 \quad > 120\ell_T$

$\omega \quad < 60\bar{c}$ for tailless aircraft or for the wing only

or

$< 0.1\ V_A/\ell_T$

$< 0.05\ \frac{V_A}{\bar{c}}$ for tailless aircraft or for the wing only

$\lambda_2 \quad > \pi b$

where:

λ_1, λ_2 = wavelengths in the longitudinal and lateral directions, respectively

ℓ_T = tail length

b = wing span

$\bar{c}$ = mean chord

Only one method of representing all the distributed lift effects suitable for simulation has been found. This method represents the distribution of turbulence linearly, just as was done for the distributed lift effects of the mean wind. The derivatives of turbulence with respect to the coordinates are related to effective angular components of turbulence:

Effective Turbulence Angular Velocities

Wing	Tail
$p_T = -\frac{\partial w_T}{\partial y}$	$p_T = \frac{\partial v_T}{\partial z}$
$q_T = \frac{\partial w_T}{\partial x}$	$q_T = \frac{\partial w_T}{\partial x}$
$r_T = \frac{\partial u_T}{\partial y}$	$r_T = -\frac{\partial v_T}{\partial x}$

p_T, q_T, r_T = effective body axis roll, pitch, and yaw rates due to turbulence with respect to the earth

The effective angular velocities are generated through matching the spectra for the turbulence derivatives and their cospectra with the linear velocities of turbulence in a manner similar to that used for generating linear components of turbulence.

The effective angular velocities affect body axis forces and moments in the same way as did the linear components of turbulence. For example, the yaw rates of the airplane with respect to the air mass are computed by

$$r_A = r - r_W, \quad r_W = \bar{r}_W + r_T$$

Separate yaw rates for wing and tail are computed as the effective yaw rates of the wind are different. A total force or moment due to yaw rate is the sum of the contribution of the wing force or moment derivative with respect to yaw rate times the wing yaw rate with respect to the air mass and the contribution of the tail to the force or moment derivative with respect to yaw rate times the tail yaw rate with respect to the air mass.

At lower and lower turbulence frequencies, the linear representation of the distribution becomes exact. The linear distribution becomes poor at high frequencies; relating effective angular velocities to turbulence derivatives produces infinite variances of angular velocities due to the error of the representation at high frequencies. The spectra for the angular velocities must be attenuated at high frequencies or truncated.

A comparison of representing the distribution of turbulence in this manner with the point representation has been made and it is concluded that a factor of 10 improvement in the maximum frequency to which the representation is valid occurs for representing the longitudinal distributions. This does not mean that the lateral and vertical distributions of turbulence are insignificant, just that they cannot be accurately modeled. However, from a simpler analysis, it is concluded that the rolling moment due to turbulence roll rate will generally be insignificant compared to the roll rate caused by the lateral component of turbulence.

The power spectra and cross spectra for turbulence pitch and yaw rates that provide longitudinal distributions of turbulence are represented by simply filtering the vertical and lateral components of turbulence by

$$q_T \cong - \frac{1}{V_A} \frac{s}{1 + \frac{4\ell_T}{\pi V_A} s} w_T$$

$$r_T = \frac{1}{V_A} \frac{s}{1 + \frac{4\ell_T}{\pi V_A} s} v_T$$

The terms $1/V_A \ s \ w_T$ and $1/V_A \ s \ v_T$ represent the derivatives of turbulence with respect to the longitudinal coordinate:

$$\frac{\partial}{\partial x} = \frac{\partial}{\partial t} \frac{dt}{dx} = \frac{1}{V_A} s$$

s = Laplace transform operator

The additional filter

$$\frac{1}{1 + \frac{4\ell_T}{\pi V_A} s}$$

attenuates the effective angular velocity at the maximum frequency to which the representation is valid assuming eight straight line segments are the minimum number that can adequately represent a sine wave. That is, the effective angular velocities are attenuated at a frequency corresponding to a wavelength that is eight times the distance over which the distribution of turbulence is provided. The power spectra that result are shown in Figure 27. There are also body axis accelerations due to distributed lift:

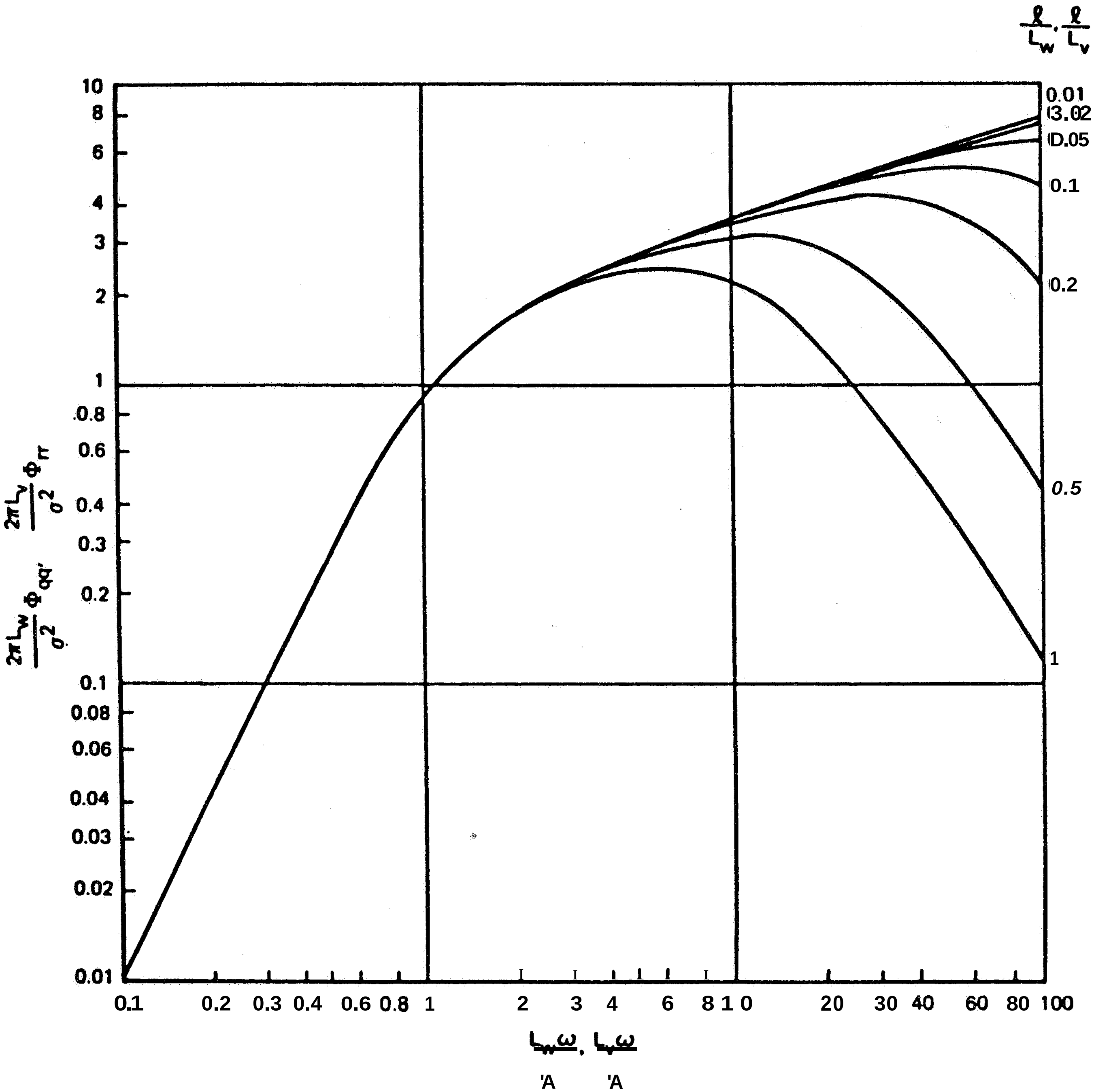


FIGURE 27 – TURBULENCE PITCH AND YAW RATE SPECTRA

$$\dot{u}_T = \frac{\partial u_T}{\partial x}\frac{dx}{dt} = \left[\frac{s}{1 + \frac{4\ell_T}{\pi V_A}s}\right] u_T$$

$$\dot{v}_T = \frac{\partial v_T}{\partial x}\frac{dx}{dt} = \left[\frac{s}{1 + \frac{4\ell_T}{\pi V_A}s}\right] v_T$$

$$\dot{w}_T = \frac{\partial w_T}{\partial x}\frac{dx}{dt} = \left[\frac{s}{1 + \frac{4\ell_T}{\pi V_A}}\right] w_T$$

To accommodate the linear accelerations due to turbulence, the equations for $\dot{\alpha}$ and $\dot{\beta}$ are revised to

$$\dot{\alpha} = \frac{u_A \dot{w}_A - w_A \dot{u}_A}{u_A^2 + w_A^2}$$

$$\dot{\beta} = \frac{(u_A^2 + v_A^2)\dot{v}_A - v_A(\dot{u}_A u_A + w_A \dot{w}_A)}{v_A^2 \sqrt{u_A^2 + v_A^2}}$$

where:

$$\dot{u}_A = \dot{u} - (\overline{\dot{u}}_W + \dot{u}_T)$$

$$\dot{v}_A = \dot{v} - (\overline{\dot{v}}_W + \dot{v}_T)$$

$$\dot{w}_A = \dot{w} - (\overline{\dot{w}}_W + \dot{w}_T)$$

For the representation of the longitudinal distribution of turbulence only (gust penetration), there is an alternate technique based on the frozen field hypothesis. The turbulence velocities may be considered to be frozen with respect to the air mass as rates of change of turbulence velocities are small compared to the speed and dimensions of an aircraft. The turbulence velocities that strike the airplane at its center of gravity will occur at the tail a time $\Delta t = \ell_T/V_A$ later. The turbulence at the tail may be represented on a digital simulator by storing turbulence velocities occurring at the cg for the appropriate time lag, then using them for turbulence velocities at the tail. If digital noise generation is used, two identical random number sequences displaced in time by $\Delta t = \ell_T/V_A$ may be used. Alternately, linear filter representations for a transport lag may be used. Separate buildups of angle of attack, sideslip angle, and dynamic pressure are provided for the tail, and the forces and moments due to the tail are built up separately from those due to the wing-body.

The highest frequency to which gust penetration is accurate using the transport lag method is

$$\omega < 0.1 \frac{V_A}{\bar{c}}$$

which may not be as good as the restriction for the linear distribution method of

$$\omega < 0.5 \frac{V_A}{\ell_T}$$

The two methods may be combined by separate wing and tail representations using the transport lag plus a linear distribution representation for the wing. The maximum frequency then increases to

$$\omega < \frac{V_A}{\ell_T}$$

The need to provide more and more accurate representations, or rather the sufficiency of any approximation, depends on whether the variance of airplane motion parameters are significantly altered. Approximations that can be shown to be conservative may be acceptable for certification but provide economic penalties due to over-design. Care must be taken to demonstrate the suitability of assumptions. As the airplane descends, the frequency at which the greatest turbulent energy occurs changes by a factor of 50, drastically altering the response of the airplane. Generally, the lower the speed of an airplane, the more accurate the representation required and the greater the coupling between forces and moments along one coordinate with wind and turbulence components along another coordinate.

WIND MODEL FOR AUTOMATIC LANDING SYSTEM CERTIFICATION

The applicant should account for the aerodynamics of the airplane being evaluated including aeroelasticity, plus the distributed lift effects of steady winds and the longitudinal distribution of lift due to turbulence, unless it can be shown that these effects are insignificant.

The surface mean wind is defined as that at 20 feet above the ground. The automatic landing system need not be certified for surface wind speeds exceeding 25 knots nor for tailwind components exceeding 10 knots. The probability distribution of surface wind speeds ($\overline{V}_{20}$) is presented in Figure 7. The probability distribution for the direction to which the wind is blowing, ($\overline{\psi}_W$), is presented in Figure 17 and is uncorrelated with the surface wind speed. The probability distribution of atmospheric stability as defined in terms of Richardson's number, (Ri_{20}), is correlated with wind speed and is presented in Figures 13 and 14. The stochastic combinations of surface wind speed and heading and atmospheric stability may be generated by the model in Figure 28.

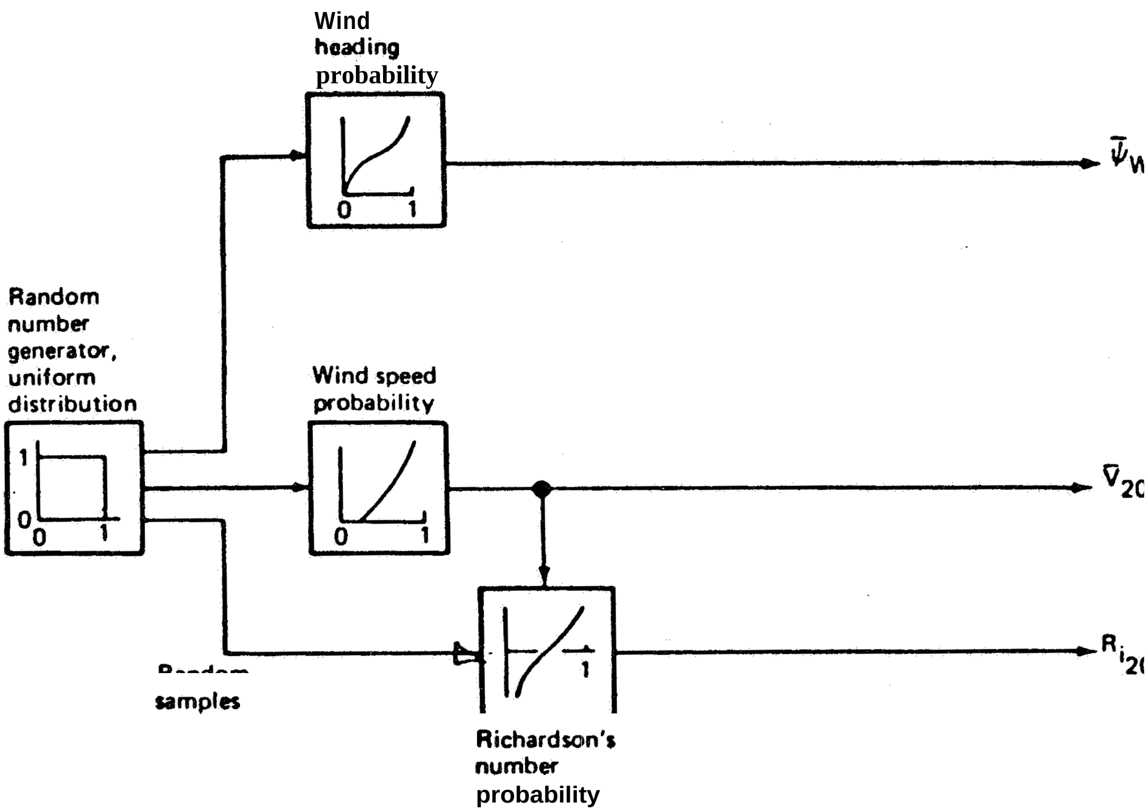


FIGURE 28 – PROBABILITY MODEL SCHEMATIC

The mean wind at any altitude is computed from the equation:

$$\bar{V}_W(h) = \bar{V}_{20}\left(\frac{u_{*_0}/k}{\bar{V}_{20}}\right)\left[\ln\left(\frac{h}{0.15}\right) + f(h/\ell') - \frac{h}{d}\, g(h/\ell')\right]$$

where

$$\frac{u_{*_0}/k}{\overline{V}_{20}}$$ is given on Figure 1-7 as a function of $R_{i_{20}}$

$$d = 800 \frac{u_{*_0}/k}{\overline{V}_{20}} \overline{V}_{20}$$

$h \leq d$ no matter what the actual altitude

$1/\ell'$ is given in Figure 29 as a function of $R_{i_{20}}$

$f(h/\ell')$, $g(h/\ell')$ are described in Figures **3** and 8, respectively.

The mean wind shear at any altitude, needed only to define the distributed lift effects of the mean wind, is given by

$$\frac{\overline{V}_W}{h}(h) = \frac{\overline{V}_{20}}{h} \left(\frac{u_{*_0}/k}{\overline{V}_{20}} \right) \left(1 - \frac{h}{d} \right) \phi \left(\frac{h}{\ell'} \right)$$

where $\phi(h/\ell')$ is described in Figure 2 and where, once again, $h \leq d$ no matter what the actual altitude.

The power spectra for uncorrelated components of turbulence in an axis system parallel to the earth but aligned to the direction of the airplane's airspeed vector are given by

$$\Phi_u(\omega) = \frac{\sigma_H{}^2 L_H}{\pi V_A} \quad \frac{1}{\left[1 + (1.339\ L_H\omega/V_A)^2\right]^{5/6}} - \frac{(\text{ft/sec})2}{\text{rad/sec}}$$

$$\Phi_v(\omega) = \frac{\sigma_H{}^2 L_H}{2\pi V_A} \quad \frac{1 + 8/3(1.330\ L_H\omega/V_A)^2}{\left[1 + (1.339\ L_H\omega/V_A)^2\right]} \sim \frac{(\text{ft/sec})}{\text{rad/sec}}$$

$$\Phi_w(\omega) = \frac{\sigma_V{}^2 L_V}{2\pi V_A} \quad \frac{1 + 8/3(1.339\ L_V\omega/V_A)^2}{\left[13(1.339\ L_V\omega/V_A)^2\right]^{11/(}} - \frac{(\text{ft/sec})^2}{\text{rad/sec}}$$

where the spectra are defined such that

$$\sigma_H{}^2 = \int_{-\infty}^{\infty} \Phi_u(\omega)\,d\omega = \int_{-\infty}^{\infty} \Phi_v(\omega)\,d($$

= variance of a horizontal component of turbulence

$$\sigma_w{}^2 = \int_{-\infty}^{\infty} \Phi_u(\omega)\,d\omega$$

= variance of the vertical component of turbulence

and where

$$\sigma_V = 0.4\bar{V}_{20}\left(\frac{u_{*_0}/k}{\bar{V}_{20}}\right)\left(1 - \frac{h}{d}\right)\left(\frac{\sigma_V}{u_*}\right)$$

$\frac{\quad}{u_*}$ defined on Figure 23 is a function of h/ℓ'

$$\sigma_H = \left(\frac{\sigma_H}{\sigma_V}\right)\sigma_V$$

$\frac{\sigma_H}{\sigma_V}$ given as function of altitude on Figure 25.

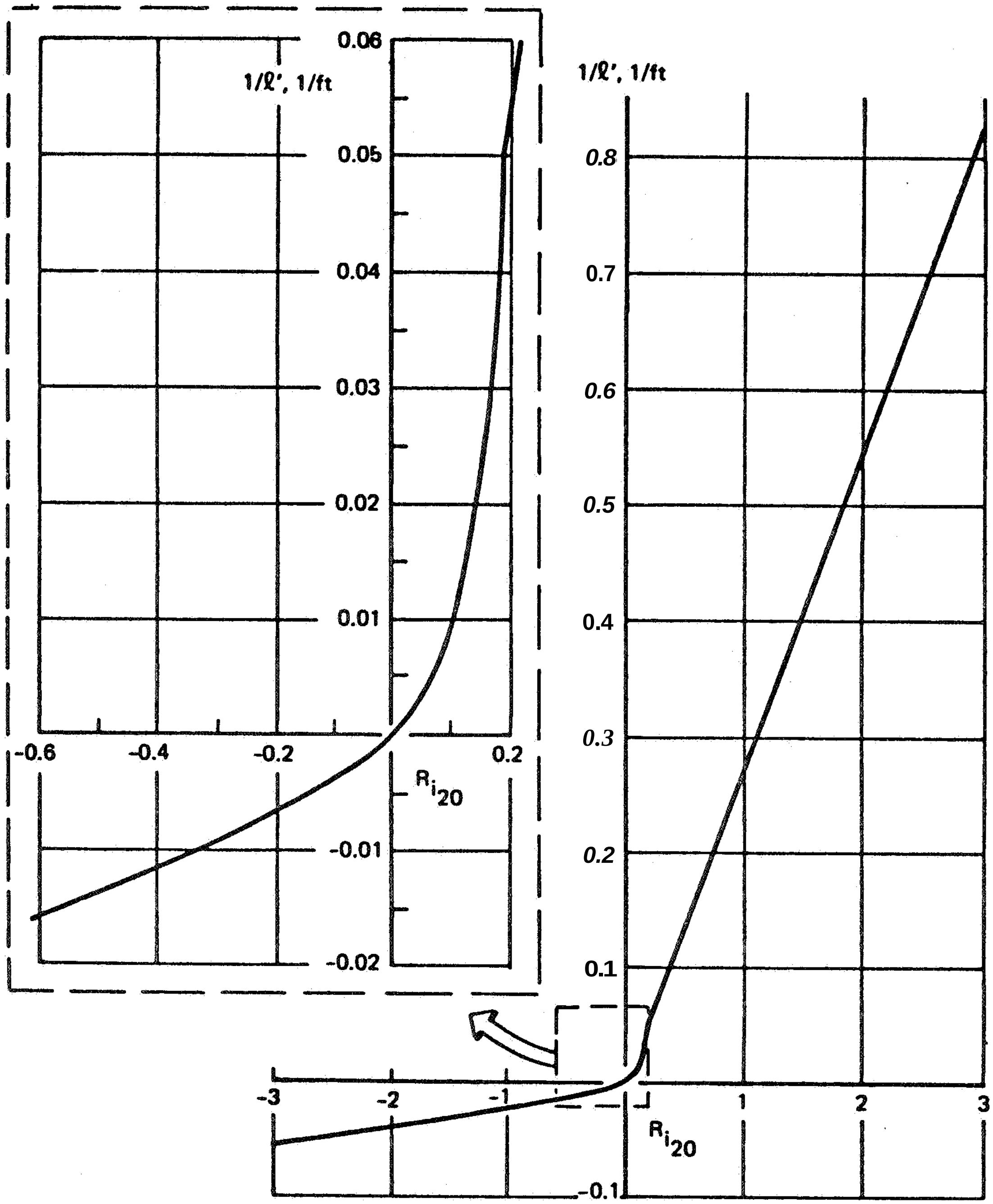


FIGURE 29 – SCALING LENGTH

$$L_V = \begin{cases} h & , h < 1000 \text{ ft} \\ 1000 \text{ ft} & , h \geq 1000 \text{ ft} \end{cases}$$

$$L_H = L_V(\sigma_H/\sigma_V)^3$$

The spectra are well represented by generating turbulence components equal to passing uncorrelated Gaussian white noise through the filters in Figure 20.

Body axis components of mean wind, mean wind shear, and turbulence are found by means of the transformations in Figure 16.

The interrelationships between the components of the wind model and the other elements of the simulation are described in Figure 30.

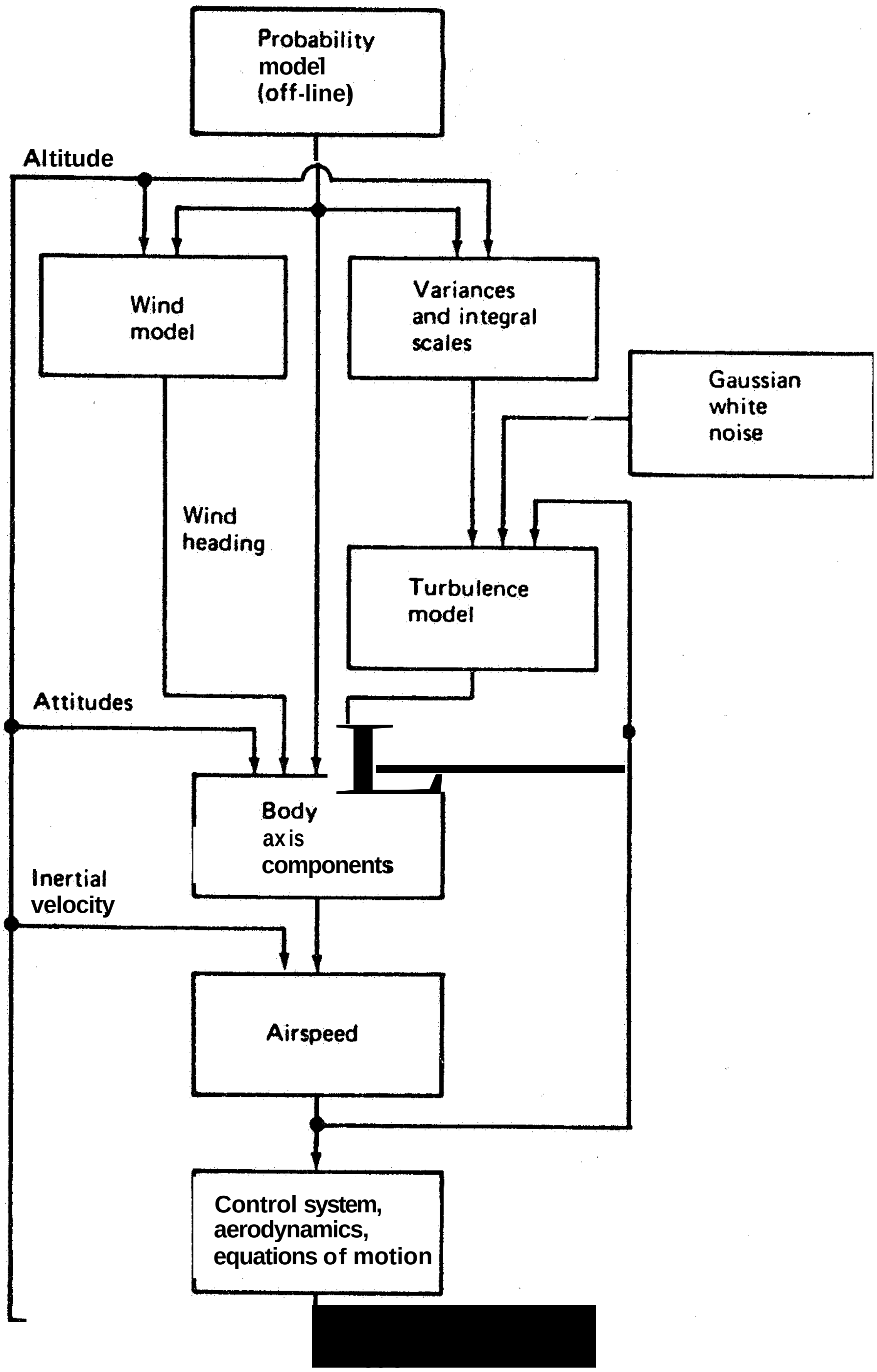
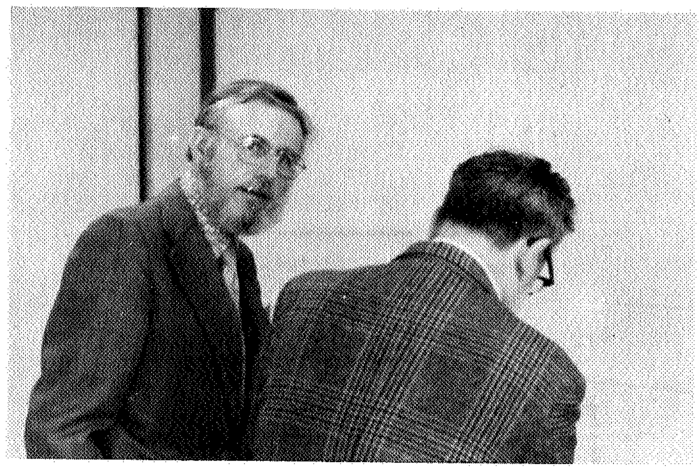


FIGURE 30 –COMPUTATION FLOW DIAGRAM



SECTION III

COMMITTEE REPORTS

SUMMARY REPORT OF THE AIRCRAFT DESIGN COMMITTEE

Robert J. Woodcock
Principal Scientist
Control Criteria Branch
Flight Control Division
Air Force Flight Dynamics Laboratory

Members of the Aircraft Design Committee and their principal background in aircraft design were:

Robert J. Woodcock (Chairman), Air Force Flight Dynamics Laboratory, flying qualities

Arthur E. Kressly, Douglas Aircraft Company, stability and control

John C. Houbolt, NASA/Langley Research Center, atmospheric models and structural analysis

Jack Hinkleman, FAA, Systems Research & Development Service

Douglas E. Guilbert, Aeronautical Systems Division, Staff Meteorologist

Meetings were held with the four "rotating committees" for interchanges based on a list of suggested questionsprovided to stimulate discussion.

Considerable interest was also shown in aircraft operations. First, design must be based on operational methods and problems. Aircraft design for the worst atmospheric disturbances is an impossibility. Instead, the most extreme cases must be predicted and avoided. In particular, there are limits on the magnitude of wind shear and (at least for transports and such low-load-factor aircraft) thunderstorm turbulence that can be designed for. A recent example was the C-141 lost at Mildenhall in an encounter with a very severe thunderstorm cell. Also cited was the reluctance or inability of air traffic controllers or tower operators to take the responsibility of directing aircraft around storms or relling pilots not to land, particularly during heavy traffic and bad weather conditions when such a responsibility would interfere with their primary responsibility of separating aircraft. Communication problems, including language differences, have been noted among engineers, meteorologists and operators--and even among engineers of various disciplines.

Discussions generally were lively. There was some consensus, but also much domination by a few who were most familiar with a particular subject.

I. Structures

The first two questions concerned structural design for turbulence: adequacy of engineering procedures, their form, and the data base. The concern expressed was for methods that could be applied to new concepts for which past rules of thumb might not apply, but keeping the requirements flexible enough to allow different design approaches as warranted. It still has not been completely determined that present criteria are adequate for all composite structures, with larger defelctions, different frequencies and modes possible.

One problem is the age of the old standards, some over forty years old. New criteria can't be retrofit to aircraft designs already certificated. And because the basis is accumulated experience, old requirements, such as the 75 ft/sec design gust, cannot be applied with confidence to radically new designs. Even the von Karman and Dryden gust spectra go back to the 1930's. At least the numbers should be self-consistent. Some dispute remains on the exact shape of the power spectra at low frequency. Houbolt, in particular, prefers the power spectral approach over use of discrete gusts. For linear systems, the former can get the same results as easily, and do more too--for example, uncover the high-response modes. He would use a design envelope for strength, mission analysis for fatigue.

Away from the ground, available design methods are generally adequate for consideration of atmospheric disturbances; any question would be about their application. Exceptions are a poor understanding of turbulence nonstationarity, patchiness or intermittency, and the spatial distribution. Houbolt noted that rolling often has accompanied vertical gusts he has experienced, and that in a number of accidents turbulence has caused one wing to break off but not the other. He suggested using an airplane fitted with angle of attack and sideslip probes at each wing tip and the tail to measure correlations.

For structural design, wind shear does not appear to be a problem (Question 5). But more data are needed on patchiness.

A tremendous amount of meteorological data exists which has not been analyzed. But some digging would be required to determine the suitability of specific data for a given purpose.

Light aircraft too, the Piper Navajo and Beech 35 were mentioned, have had structural failures in turbulence. Of the Part 23 airplanes the larger, heavier ones are thought to be more susceptible.

Helicopter and VTOL problems were recognized to be completely different, and received little attention in the discussions.

II. Flight Control

Under Question 3, concerning turbulence simulation, were discussed flying qualities and flight control system design. Related to this is Question 6, on the importance of wind shear to aircraft flight control systems. In the last 100 to 200 feet of altitude, wind shear can cause a hard landing. At 300 to 400 feet it can cause an airplane to land short. Knowledge of shear corresponds to our knowledge of gusts 25 to 50 years ago.

On approach, a tail-to-headwind shear is particularly troublesome and a common frontal encounter. In order to maintain glideslope, less throttle will be used anyway with a constant tailwind. Then upon entering a decreasing tail-wind shear, airspeed tends to increase because of aircraft inertia. To avoid overshooting, a pilot is inclined (even instructed) to throttle back more. The resulting deceleration can match the wind shear's effect, thus making airspeed fairly constant as long as the wind continues to shear. But below the altitude at which the shear stops, the aircraft will continue to decelerate, now losing airspeed rapidly. With limited maximum thrust and engine lag too, the pilot will be hard put to maintain the flight path. A DC-10 at Buffalo gained 25 kt airspeed but then ended up 25 kt slow. Confronted with this wind shear, a pilot must limit use of throttle. Shear rate then, not just the instantaneous change, is important. In the same altitude range the pilot may be switching from instrument to visual flight, an adjustment that may take several seconds to make.

The opinion was expressed that unaided, a pilot can handle a shear gradient no greater than 4kt/100 ft. For automatic landing certification, FAA requires simulations with an 8kt/100 ft wind shear gradient. Even higher values have been encountered. Associated downdrafts can compound the problem. Autoland systems are more sensitive than a pilot, have more data, and so may do better.

Capt. John Bliss, after a close call on approach, has devised and is patenting a system for onboard use that monitors the changing difference between ground speed and true airspeed to warn pilots of shear and tailwinds. Some commercial jumbo jets have inertial navigation systems from which ground speed is available. Doppler radar could be used. DME is thought to have too much lag for speed measurement useful in shears. With no help, present procedures definitely lead to trouble. Pilots need warning from the west side of the airfield when to keep away because of eastward-moving fronts.

Good design criteria are needed for performance margins to counter wind shear. Some aircraft have a large pitot-static error in airspeed indication, which doesn't help. Up to 9 or 10 m/sec downdrafts have been found near the surface. A representative sample of wind shears which encompass expected variations would be a very useful design help. The need to sample extremes which should be avoided gives problems of several sorts. Work is in progress and some data are available, but adequacy could not be assessed. Trying to forecast wind shear from synoptic data at seven East-Coast airports is just about impossible. The East Coast has large wind shears. In five or six cases warm fronts were found to be much worse than cold fronts, an apparent anomaly, since it is not common to associate severe weather with warm fronts. There are T arrays at Elizabeth and White Sands and towers at Brookhaven and elsewhere for measurements. There is work by Aeronautical Research Associates of Princeton and University of Oklahoma for NASA, and at UTSI, Frost is measuring flow around and in the wakes of actual buildings, etc., and mapping the flow field throughout the vertical plane. NOAA at Boulder is looking at major fronts that way. Aircraft in service would make excellent wind shear and gust probes. But operators fear use of the data in violation proceedings; legislation might be needed.

For some aircraft a change in approach flap setting might be helpful to alleviate wind shear effects, but this is limited to settings for which certification was obtained (stopping distance being critical). The DC-9 originally had only 60° and 25° settings usable, but a 40° setting now has been approved.

For the take-off, cargo operations have a problem dragging out at maximum gross weight. Pulling power back for noise abatement at 1500 ft, before drag reduction, the airplane just sits there with no acceleration. This is a problem even with no wind shear, though noise abatement is forgotten if a critical performance problem develops. The current 3.2% climb gradient on a hot day with all engines is marginal for wind shear. A related concern is that unknowledgeable airport managers may be pressed to emphasize noise abatement at the expense of safety.

Wake vortices from aircraft were not much discussed. Severe upsets have been experienced, leading to much effort at analysis and prediction. Apparently these efforts are thought to be sufficient as far as meteorological aspects are concerned.

Another operational problem, noted by Green of American Airlines, has been engine compressor stall in crosswinds on the ground. The cause seems to be insufficient design consideration rather than limited design capability.

For flying qualities and flight control design, the same instantaneous spatial distributions of horizontal and vertical gusts are needed that are needed for structural design, and also the characterization of patchiness and intermittency, mentioned earlier, at all altitudes. Near the ground more data are needed on eddy size, spanwise gradients, lateral gusts, correlation with wind, etc. These are important for both analysis and simulation. For example, recent work at **NASA** Langley has shown deteriorating pilot ratings of aircraft flying qualities as the turbulence 'simulation becomes more sophisticated.

Thunderstorms, downdrafts, etc., combine both design and operational problems in finding suitable aircraft limits and ways to avoid exceeding them. The data appear to be available and avoidance work is in progress. This committee wants to emphasize the need. **A** coordinating panel was suggested to guide the work.

Extreme gusts can be avoided by staying clear of storms with *40* db or greater radar reflectivity, although the most intense gusts may be ten to fifteen miles from the point at which reflectivity is highest. Faced with a 200 mile squall line, then, a private pilot had better wait or go completely around it. Doppler, however, can do better for large aircraft.

Durrett noted one operational problem with thunderstorms for the space shuttle. **A** 1½-hour lead is needed for de-orbit and return to Kennedy Space Center, but there a thunderstorm can build from a clear sky in that time.

111. Data Needs

On meteorological data (Question *4)*, one additional need is for an inventory of atmospheric data for aircraft design. 130 or *so* data accumulation programs have been run. It was beyond the ability of this recorder to keep track of the data sources mentioned, and some of the references weren't all that clear anyway. Ramsdell had just surveyed micro-meteorological data, and FAA is correcting low-level data as well as generating new data. Someone should correlate existing thunderstorm data. The Aircraft Design Committee strongly endorsed undertaking a survey of what is available, its format and limitations. A consensus was that aircraft are the best data probes.

Operationally, improvement is needed in forecasting and reporting atmospheric conditions. Especially in the terminal area, the occurrence of shear and turbulence needs to be related to the existence of "bad weather," although shear has been observed also in smooth air. Enroute, systematic reporting of atmospheric conditions is needed to improve forecasting capability. A start is to be made by collecting wind, temperature, etc., data continuously via satellite from a few commercial airliners. Most airlines are reluctant to volunteer to carry around the extra 75 poinds needed to do that, but this will be a vast improvement over radiosonde data.

IV. Lightning

None of the Aircraft Design Committee members was knowledgeable on lightning protection, Question 7. We listened with interest, at some length, to Plumer at one session and to Durrett at a later one.

From Plumer we learned something of the mechanism of lightning on aircraft. It is the return stroke from the ground that is the big jolt. Discharge takes about half a second, skipping down the length of the aircraft from nose to tail and holding onto the trailing edge. The charge is most intense initially, dropping off as the strike progresses aft. Damage may occur either directly or from currents induced in aircraft systems. There is a theory that lightning strikes ringing back and forth from nose to tail at the speed of light induce extremely high voltage. A nose pitot boom makes a good lightning rod. So does the *747's* wing tip probe. Lightning follows the pitot heater power cord. Static discharges will quiet noise but are ineffective against lightning.

A major problem with design criteria is uncertainty about the maximum voltages to be expected at altitude. Small-scale zaps give scary transients when scaled up to the 200,000 amperes measured at ground level.

Two design trends increase the severity of the lightning problem. One is sophisticated electronics in applications critical for flight safety, as in the basic flight control system. Digital operation and the low voltage level in current electronics applications cause special concern for the effects of electrical transients. The second trend is to composite structures. Not only do composites lack the shielding and grounding properties of metal structures, they also may be more susceptible to damage by lightning strikes. Lightning has also been observed to cause engine compressor stall. The integrity of composites can probably be assured by adding another layer of laminate, changing the resin composition, or some such procedure.

Successful protection is thought possible, and not too costly, through good design practice. On NASA's Orbiter this includes two-wire systems, short ground lines, shielding of analytically-determined strike and maximum-field-intensity points, and nose diverter strips (insulation underneath is affected by a strike). It is important to consider lightning early in the design phase. Testing is expensive, but at least one sample of each component should be tested. The first one generally fails in test, requiring some redesign. The expense and risk preclude lightning tests on the complete assembled Orbiter. There is concern about re-entry if a lightning strike is sustained on the way up, which might cause spalling of the heat shield, for example. For aircraft, a lightning hole in a radome can be enlarged by rain.

There continue to be enough fires and explosions related to aircraft fuel systems to generate uncertainty that we know enough about sources of ignition by lightning. Kerosene is better than JP-4 fuel, which is more volatile and flammable at altitudes for lightning strikes. There is a thought that rather than lightning causing an accident, possibly the aircraft breakup and fuel spill might induce lightning.

Plumer would very much like to get reports of "interesting" lightning strikes--that is, ones affecting aircraft structure or equipment which have been experienced in aircraft operation. It was noted that NASA will be flying a Lear Jet with Air Force Flight Dynamics Laboratory instrumentation at Kennedy to find out if the induced current really is less at altitude or not.

V. Other Factors

Questions 8 and 9 concern temperature, rain, hail, icing, pressure, density, corrosives, abrasives, etc. While operational problems are recognized, it is felt that sufficient data are available for design. How to apply the data isn't always as clear. Mention of icing brought out some scary stories of quick, large buildups; pilot awareness is needed.

SUMMARY REPORT OF THE GENERAL SERVICES COMMITTEE

John H. Enders
FAA

Members of the General Services Committee were:

John H. Enders (Chairman), FAA
Robert Curry, HQ Air Weather Service, USAF
Rodger Flynn, Air Transport Association of America
William W. Vaughan, NASA/Marshall Space Flight Center
N. A. Lieurance, Alden Electronics

Terms of Reference

The frame of reference for operation of the General Services Committee encompassed the broad area of meteorological services to aviation. The discussions addressed meteorological services in terms of: 1) Assessment of adequacies of present services; 2) Acquisition and processing of data not now available, but deemed vital to improvement ef the aviation system; and 3) Delivery of an adequate meteorological service to various users within the National Aviation System (NAS), yet responsive to changing system requirements.

Discussions began in an informal manner during each session, allowing anecdotal information to stimulate interest in topical areas of concern to the assembled participants within the context of effectively transmitting meteorological information within the NAS. A list of questions provided in a handout was covered in its entirety, though not by each and every floating committee. Problem areas surfacing consistently throughout the four workshop sessions centered about three areas: Information, Training, and Research.

Each of these three areas was explored through discussion in terms of:

- Adequacy of current effort or service
- Availability and accessibility of information
- Quality of information
- Effectiveness of current training
- Utilization of research results
- Usefulness of on-going research
- Dissemination of raw and processed data
- Automatic or manual handling of data
- Diverse needs of aviation community (i.e., general aviation, air carriers, military)

Information

Meteorological information available within the present system was examined and the general feelings expressed by the participants indicated that, though considerable improvements could be made in quality and content, nowhere near all of the information existing was being used, nor was some of it accessible to the operator, especially the private pilot. This situation appeared to be due to several possibilities, including: overcrowding of work schedules with limited manpower; lack of trained manpower; limitations of data transmission speeds; and location of Flight Service Stations (FSS) and weather offices remote from pilots' departure of flight planning locations.

The credibility of meteorology information in the eyes of the aviator is vital to its use. The receptiveness of the pilot to weather information is, in part, a function of the aviator's experience with actual weather encounters and with accuracies of past weather briefings.

The dependability of available and accessible data was criticized. As an example, the ATIS report being broadcast during the Eastern 66 accident at JFK was several hours old and did not contain information on the severe weather transiting the airport. Other viewpoints expressed support for the generally "good" weather system (acknowledging rare insufficiencies), noting that substantial further improvements would cost disproportionately more to upgrade the information quality.

Problems of comprehending, in functional terms, the meaning of probabalistic forecasts, both long and short term, were expressed. The value of a particular forecast will vary according to the different uses of the same data. The value is also phenomena-dependent. It was questioned whether a probabalistic forecast was of any real use to tightly-scheduled operations, and line pilot members of the group felt it to be of use largely in establishing mental concepts of trends in the synoptic and local situations.

There was some concern raised as to the adequacy and timeliness of severe weather information furnished to airport ground support operations, where snow forecasts, freezing rain forecasts, or severe wind and hail forecasts carelessly done could unnecessarily cause large expenditures of scarce resources or conversely delay timely action to protect ground equipment.

Dissemination of information within the National Weather Service (NWS) was discussed in terms of speed and timeliness problems. While the present situation presents longer-than-desired delays, it was believed that when the AFOS (Automated Field Operations and Services) system goes "on line" these delays will be reduced and services will be improved.

An observation, endorsed by several participants, that <u>accurate</u> low level (<3000 ft.) wind forecasts were lacking in the system, was contested by NWS staff representatives. While NWS is strictly correct in its position on this question, several users of currently-available low level forecasts expressed feelings that since air carrier operations are now conducted at higher jet altitudes, the attention given to accurate forecasting emphasizes the higher altitudes at the expense of surface and low altitude wind forecasts. The disagreement seemed to stem from conflicting definitions of what was accurate or effective, and seemed to typify many of the interface communications problems identified at this workshop.

Satellite-furnished information is generally regarded at this time as "nice to have," but expensive in terms of the true value of data presently available, with one exception: long-range overwater flights, where a good interpretive picture can help to identify areas of severe weather not detectable by other means.

Discussions also centered around the proper role of NWS and FAA in dissemination of weather data in a timely and efficient manner to both air carrier and general aviation users, keeping in mind pilots.' problems in applying the weather information furnished to them. There appeared to be a general feeling that the links between NWS and FAA need to be closer in order that the dissemination of data can be improved.

Training and Personnel

At a symposium on severe weather held in February at Scott AFB, it had been pointed out that a great deal of training continued to take place during routine forecaster-to-pilot briefings prior to flight. This point was reemphasized during the workshop, with the additional observation that as plans for further automation are implemented, pilot contact with forecasters will decrease with an unknown, but likely detrimental, effect on the effectiveness of information transfer to the pilot. As ADP is phased in, it is imperative that trained forecasters monitor the quality of the data furnished to the operator, in order to ensure the credibility of the data.

Present initial meteorological training of aviators was criticized, with the point strongly made that satisfactory accomplishment of the weather portion of the written pilot certification exam should be a license requirement, which is not the present case.

Strong impressions from civil and military participants are that younger pilots in the system today do not have strong weather training, nor appreciation of weather vagaries. The AOPA/FAA flight safety workshops were praised for their effectiveness and should be encouraged to continue and increase a stressing of weather training.

The absolute necessity for attention to a common, non-ambiguous vocabulary in simple, plain language is essential to maintaining pilot interest in meteorology briefings, whether personal or automatic.

The biennial flight check for general aviation pilots should include a verbal or written weather refresher, and some attention should be given to development of a vital, regularly-updated weather training program, either for class or self-study use.

Research Needs and Responsibilities

Considerable discussion of this topic resulted in few clear ideas suitable for development. At least eleven different Federal agencies were identified as having legitimate aviation weather research interests. BOB Circular No. 13 was discussed, and it is evident that it has effectively diluted coordinative action by directing each agency with aviation meteorology needs to fund its own research and met services. The job of Federal Coordinator for Meteorology was established in 1969 to coordinate met research, but has not effectively functioned in this role of late.

Research needs identified were for:

- Dependable wind shear detection and reporting
- Dependable fog forecasting and dispersal
- Finer-scale forecasting of critical weather (e.g., snow/rain; freezing level; thunderstorms, etc.)
- Structure of thunderstorms
- Better understanding of electrical structuring of the atmosphere at altitude and its effect on weather systems and aircraft

Conclusions

The overriding considerations of Information, Training, and Research are that they must serve their intended purpose; that of providing the user with the information needed to perform a task in non-ambiguous, efficient, and timely fashion. If this purpose is not served, then all of the discussion, training, automation, information handling, and research is of little use, and this thought must be uppermost in our minds as we set out to improve the system.

The Committee members were unanimous in their opinions that this workshop was of high value and that subsequent workshops should become regular events. The unique aspect distinguishing this workshop from others was the diversity of the participants and the achievement of finally communicating across the interface boundaries between pilots, meteorologists, airplane designers, researchers, as well as between military, civil, general aviation and commercial interests.

SUMMARY REPORT OF THE SIMULATION COMMITTEE

Richard L. Kurkowski
Technical Assistant
Flight Systems Research Division
National Aeronautics and Space Administration

The Simulation Committee consisted of the following:

Richard L. Kurkowski (Chairman), NASA/Ames Research Co.
Charles R. Chalk,'Calspan Corporation
Paul L. Jernigan, Douglas Aircraft Company
Jim Luers, University of Dayton Research Institute
Dwight R. Schaeffer, Boeing Aerospace Co.

As in the case of the other standing committees, this committee held a two hour session with each of the four rotating committees. The sessions were not highly structured so as to allow a free exchange to determine the status of aircraft/meteorology simulation technology, what the problem areas were, and what additional work was needed. Each of the four sessions was surprisingly fresh, non-repetitive, and with slightly different emphasis; however, the discussion relative to wind shear seemed to dominate these meetings, as well as the topic presentations.

The multitude of individual points of concern and information supplied in the four sessions have been summarized and organized using the following outline:

I. Simulators and Their Uses
II. Atmospheric Disturbance Modeling Requirements
III. Status of Simulator Capabilities for Modeling Disturbances
IV. Status of Atmospheric Disturbance Models

V. Specific Problem Areas
   A. Definitions, Data Measurements Analysis, and Formats
   B. Simulation Studies Criteria
   C. Atmospheric Disturbance Models
   D. Aircraft/Atmospheric Disturbance Response Modeling
   E. Critical Case Studies
   F. Atmospheric Disturbances and Meteorological Conditions
   G. Pilot Learning Effects
   H. Operations Related Discussions

I. Simulators and Their Uses

Simulators come in all shapes, sizes, complexities, and costs. A software model of a system without pilot or hardware involved can be considered a simulator in a loose sense, and this approach is used extensively for paper studies of aircraft and aircraft systems concepts. These studies include: aircraft performance, system performance, structural response, guidance navigation and control, failure mode analyses, etc. Increased complexity comes with adding hardware such as in "iron bird" control system simulators, or with the addition of a pilot station including controls and displays. A pilot simulator can be static base or moving base. In training, static cockpits are used for procedures training with moving base simulators used for critical flight phases and failures where motion affects the pilot's control and systems management tasks. Training as used here includes initial checkouts, type transitions, and recurrency or proficiency checks. Engineering and research simulators are generally more flexible devices wherein conditions and systems characteristics can be quickly varied so that a range of system parameters may be studied.

By their nature, Research Simulators tend to be the most flexible of any simulators and can be as complex as the task and size of the mission under study requires. Piloted simulator studies include: flight dynamics, handling qualities, control systems, guidance systems, navigation, ATC interface, certification criteria development, failure mode analyses, displays, and human factors. In addition, more and more use is being made of the piloted simulator to recreate the critical flight situation for aircraft accident investigations.

II. Atmospheric Disturbance Modeling Requirements

Atmospheric disturbance used in simulations include ground level mean wind, wind shear and turbulence. Wind shear models should include both horizontal and vertical shears with time or altitude change. Turbulence models normally include all three velocity components, oriented to the body axis of the aircraft, i.e., longitudinal, lateral, and vertical (u, v, w). The sophistication and fidelity of models for atmospheric disturbances vary as a function of: the type of simulator, the study objectives or task to be performed, and the resources (time, manpower, and money) available to the project.

For training simulators, representative disturbance models can be used with some variation in intensity to expose pilots to a range of situations. For instance, representative wind shears should be used to train pilots to recognize the shear situation and learn how to cope with shear conditions. Research simulators have varying requirements for disturbance modeling. For piloted simulators, again, representative models with varying intensity can be used. For autopilot studies, criteria development and structural design, accurate statistical and temporal models are required to assure accurate study results. For accident investigation simulations, exact duplication of weather (ceiling and visibility, ground winds, wind shear, and turbulence) existing at the time of the accident are required.

The common approach to simulating disturbances is to use filtered random noise generator signals to simulate turbulence and to superimpose this on top of wind shear profiles which are stored as table look ups. For some simulation tasks these models can be frozen (i.e., no altitude variation). Others such as landing approach require variation with altitude and horizontal space. Some complex models have been mechanized with 4-D (x, y, z, t) characteristics.

111. Status of Simulator Capabilities for Modeling Disturbances

The question was raised as to the capacity and capabilities of simulators to handle atmospheric disturbance data and models. This is a function of the specific simulator. With most simulators using large memory capacity, there has been no problem in simulating local disturbances acting upon simulated aircraft. Most training simulators have the capacity to implement the turbulence and shear models. The point was made that even though the models are adequate, the implementation of the turbulence and wind models in training simulators may be improperly mechanized.

The ability of the simulator to duplicate motion cues is highly variable depending upon the specific simulator and its degrees of freedom and "wash out" program. Very few simulators can duplicate the very high acceleration associated with severe turbulence environments, especially when you consider the low frequency, large amplitude, portion of the response spectrum. Visual displays also start to limit and exhibit lags if driven outside their nominal amplitude-frequency envelope.

IV. Status of Atmospheric Disturbance Models

Atmospheric disturbances may be divided into categories such as ground level mean winds, low level wind shears, terminal area wind shears, low altitude turbulence and high altitude turbulence. Using these categories a table was prepared by the group chairman to indicate the approximate status of disturbance model data as reflected by the committee meetings. This status is shown in Table I.

Table I

Status of Atmospheric Disturbances Models

	Data for Models		
	Adequate	Needs Assimilation Dissemination	More Needed
Ground Level Mean Wind	J	?	?
Wind Shear			
Low Level			
Localized Effects (buildings, terrain, carriers, non-aviation ships)		J	√
Terminal Area			
Stable Atmosphere			
Inversion		√	√
Warm Front		√	√
Unstable Atmosphere			
Thunderstorm		√	√
Atmospheric Turbulence			
Low Altitude		J	√
High Altitude		√	√

Ground level mean wind data and models are generally adequate, although specific unique sites may require assimilation of existing data or additional data. Models of low level wind shear with unique site characteristics such as buildings, terrain features, aircraft carrier, and "non-aviation" ships, are not readily available although work is progressing in this area. Assimilation of existing data and additional data is needed to model shears in warm front and inversion conditions. This is also true of gust. front wind shears associated with thunderstorms like the JFK accident conditions. More accurate data on this type of wind shear is needed to scope the magnitudes and characteristics which can be expected in aircraft operations.

Atmospheric turbulence models are in fair shape although additional data and analysis of existing data is desirable. One of the problems in this area is that there are too many models and some sort of standardization is required. Additionally, the models may not be implemented properly in the simulation. Patchy qualities and intermittency of atmospheric turbulence needs to be specified. Some studies have shown that for piloted simulations, small variations in spectral models are not significant to pilot ratings of aircraft handling qualities. Additional data is needed for VTOL aircraft operations and to answer spatial distribution effects questions.

V. Specific Problem Areas

This section points out specific problem areas which were discussed in various categories and indicates in some instances, potential research to solve the problems.

A. Definitions, Data Measurement, Analysis, and Format

There is a need for standardized definition of terms, e.g., what is the difference between turbulence and wind shear? Basically it's a matter of frequency content but the cutoff between the two can vary depending upon type of aircraft and approach speeds. Further definition is required. Terminology for wind shear should be standardized.

Considerable meteorological data has been gathered over the years. Most of this data is not aircraft control-related and is more aimed at synoptic modeling with very low frequency characteristics. Data suitable for aircraft application has been and is being generated, however. But these data need to be analyzed and translated into models which are in a format that the aeronautics user can apply. The models should not be so complicated that whole computers are used up. Leadership and direction are needed in this area. Models should not be so complicated that they permit duplication of all possible atmospheric cases. The models need to be "simplified" and generalized for simulation purposes. Cooperation between meteorologists and engineers is required.

Turbulence models need to be standardized. Boeing, for instance, has some fifteen or more models in use in the company. Some Government organization should be involved to cause this standardization to come about. The turbulence model in MIL-F-8785B provided a start in this direction. However, users of the turbulence section of MIL-F-8785B document should be cautioned to consult AFFDL-TR-72-41, titled "Revisions to MIL-F-8785 (ASG), Proposed by Cornell Aeronautical Laboratory." TR-72-41 contains proposed revisions to section 3.7, Atmospheric Disturbances, including:

1) New definition of the values for σ_u, σ_w, σ_v
2) Interpretation of rotary gust disturbances
3) Development of a wind shear model

B. Simulation Studies Criteria

Many simulation studies and analyses are made for the purpose of determining a system's characteristics relative to a set of accepted criteria. In military aircraft handling qualities, for instance, MIL Spec. F-8785B has been the guide for acceptability. Such criteria must be carefully determined so as to not lead to meaningless tests. Work on autoland systems was sighted as an area for better criteria. Present requirements state a goal of one fatal accident on 10^{-9} landings. Companies are interpreting this criteria literally and devising simplified analog simulation which is run at fast time for many, many trials. Complex digital simulations which run at real time or slower can become very expensive and time-consuming. More guidance is required in this area. It was felt that narrower error dispersions should be required. New approaches were suggested such as used by Foster and Neuman (NASA-Ames) wherein turbulence and wind shear disturbance cases for autoland were limited to those which could cause large dispersions and hard landings.

C. Atmospheric Disturbance Models

With regard to wind shear, a need was expressed for more information on local effects of terrain, buildings, etc., on flow in the local environs of airports, STOL ports, or VTOL pads. Specific concern was expressed over the St. Thomas, Virgin Islands, situation. The FAA would like a model of the flow for this airport which they could use as a guide on wind sensor locations for providing landing aircraft pilots with better information than is presently available. One technique for flow visualization of such situation was suggested. This would entail photographs of snow showers and the flow patterns. This would not work, of course, for warm climates but maybe smoke pots could be used for this approach.

Models are needed to define the shear environment in the vicinity of thunderstorms where the most severe cases occur. NSSL severe thunderstorm data bank is extensive and additional spring storms data is in the process of being gathered. Analysis and modeling of this data will be used to try to forecast storm severity and turbulence especially for gust fronts, and to predict turbulence and shear magnitudes to be expected.

For training simulators, representative wind shear models are needed, including severe conditions, in order to expose pilots to wind shear situations, especially those which exceed the performance capabilities of transport aircraft.

With regard to atmospheric turbulence modeling for simulation, there was no unanimous agreement on any one of the many turbulence models now in the literature and under development. It was felt that the MIL spec F-8785B turbulence model was a very good start but more work is required. Additional analysis is required on the variation of scale length and rms intensity with altitude. Indications are that the scale length for low altitude should be smaller than specified in the MIL spec model. Considerable work has been done on non-Gaussian models which exhibit more patchy and more intermittent characteristics similar to those observed in measured data. Some controversy developed over this point. It was suggested that the present Gaussian models would also appear patchy if the proper axis reference system was used. Most turbulence model mechanizations are oriented to the aircraft body axis system. It was argued that the turbulence should be modeled in an earth reference wind axis system and then transferred to the aircraft body axis as a function of aircraft heading, etc. Additional information was provided which showed a strong coherence of turbulence data at various altitudes. The question was also raised as to the coherence of the u,v,w components of turbulence. When they are highly correlated, high structural loads can be induced such as on a T-tail aircraft. Also, high pilot workload results when multiple axes upsets occur.

Thunderstorm turbulence model in MIL-F-8785B was questioned. Was it meaningful? Are different modeling methods required? Some data has been collected in Project Rough Rider wherein various aircraft (T-33, F-100, F-105, B-57B, F4) were used to collect thunderstorm data in the U.S. and southeast Asia. Most of the collection is at high altitude (45-60 thousand feet). Thunderstorm turbulence spectra appear to be similar to clear air with the 5/3 roll off. The knee of the curve may be different or be a function of storm size. The location of the knee of the curve may be important for very fast aircraft:.

The distribution of spatial effects of turbulence velocities over the span and length of an airplane was discussed. It was not clear how important this effect is for piloted simulations. For structural loads it may be quite important and required. Further work and testing is required. Battelle, (PNL) Pacific Northwest Laboratory, has data from towers which were spaced close enough to show spatial distribution for aircraft. This FAA funded program does not include this type of analysis. It was suggested that the government should fund such an analysis and publication. Tower data has been shown to correlate with flight measurements from instrumented airplane "fly by." The University of Washington has done some work in this area for NASA-Ames and a report will be out shortly on the results of low altitude flight measurements with dual wing tip gust probes. A question was raised with regard to Taylor's Hypothesis, i.e., how low can aircraft speed become before the hypothesis tends to be violated?

There is need for turbulence models for VTOL aircraft when airspeed goes to zero. There is no standard model for this case. The MIL Spec model can be tricked into working for this case by including very small mean velocities in the model. In addition, there is a need for turbulence and wind shear models for VTOL aircraft landing on small ships, in some cases on a notched step on the stern of the ship. The wake of the ship could cause considerable control problems.

D. Aircraft/Atmospheric Disturbance Response Modeling

More attention must be given to mechanization of atmospheric disturbances and related modeling of aircraft responses to these disturbances. Many simulation reports come out without any documentation of the algorithms used in the mechanization. It was suggested that future reports should include this information or at least give reference to such documentation. One such undocumented variation is the axes system used. As stated earlier, most mechanizations orient mean wind to earth reference and turbulence to body axes. Yet considerable statistical and tower turbulence data is referenced to the mean direction of the wind. As stated, simulations should be done with turbulence and mean wind referenced to earth and transformed to aircraft body axes. It was noted that airline training simulators are not generally programmed properly to simulate wind shear. They do have approximations of shear which can scare pilots a bit but most need to be reprogrammed to more properly simulate representative shear profiles. Further work is needed in methods to model disturbances as distributed lift rather than the common single point model. Information is needed on VTOL airplane response to large sideslip situations. This is the critical area for most high performance VTOL aircraft. Wind tunnel data is required.

E. Critical Case Studies

Further information is needed to determine what the critical wind shear profiles and magnitudes are which would induce hard landings for various types of aircraft. Different aircraft types will have different response to the same wind shear. For a given aircraft, variations should include configuration and weight variations and engine out cases. For training simulators, only a limited number of wind shear models need be defined (maybe four). Magnitudes should be varied to include limit situations and less severe cases. For research and engineering simulators, a limited number of profiles need to be defined. These should include variable shear and variable direction. For structural design only extreme cases need to be defined. One method of analysis was suggested based on Boeing SST studies wherein joint probabilities of turbulence and failure states were determined for various criticality levels. Possibly a wind shear analysis could be made in an analogous manner.

F. Atmospheric Disturbances and Meteorological Conditions

Some discussion was held on the relationship of disturbances and meteorological condition (i.e., ceilings, visibilities). For instance, there are some areas of the world where high wind and fog exist simultaneously, but this is not the general case. Generally, speeds are low and turbulence is low when fog exists. Correlation between visual observations of thunderstorms or rain showers and severity of disturbances cannot be reliably made. For instance, John Bliss, the Flying Tiger captain who preceded the fatal EAL 727 flight in approach to JFK in June '75, stated that he had flown through lots of rain showers that looked worse than this one at Kennedy.

G. Pilot Learning Effects

Some discussion centered on the learning effects in piloted simulations. There is a risk that if only a few models are used, pilots can learn the wind shear profile and "outsmart" the simulator; however, the problem may not be significant for "production" training programs where there generally is not very much time to take a long look at special situations. For research and engineering simulations where case after case is run, project engineers need to guard against the learning effect for valid results.

H. Operations Related Discussions

It was suggested that aircraft equipped with inertial navigation systems be used to measure wind conditions and be used as real time probes on a routine basis. This information could be automatically transmitted to approach control for use in advising subsequent aircraft during their landing approach. It may even be possible to use the transponder to transmit wind info directly back up to other aircraft.

The question of autoland vs. pilot role was raised. Specifically, it was suggested that much of the problem with wind shear during approach disappears if the autoland is left engaged. This was countered with the fact that most aircraft do not have autoland systems. Even if they did, a CAT III beam must be used to touchdown and not many airports have CAT III qualified ILS systems. So autoland is not the total answer to the problem. It was suggested that a potential research program should examine further the pilot's role during autoland approaches especially in the event of strong wind shears. If the pilot dislikes the autoland approach and disengages at low altitude, large transients due to the disengage could be more than the pilot can handle.

SUMMARY REPORT OF THE GENERAL AVIATION COMMITTEE

Wallace C. Goodrich
Aircraft Owners and Pilots Association

The General Aviation Committee consisted of the following:
Wallace C. Goodrich (Chairman), Aircraft Owners and Pilots Association;

Bertha M. Ryan	Naval Weapons Center
James C. Pope	FAA, Office of General Aviation

The committee reviewed and discussed the list of suggested questions provided in conjunction with the members of the floating committees. It was agreed that the format of the meeting was unique and that the atmosphere created was extremely conducive to open discussions on the problems addressed.

National Transportation Safety Board Special Studies entitled "Fatal Weather-Involved General Aviation Accidents" (NTSB-AAS-76-3), and an AOPA study conducted by Mr. Samuel V. Wyatt entitled "Criteria for Weather Observations at General Aviation Airports", coupled with several recent serious wind shear landing accidents, were the cornerstones of committee deliberations.

It was generally agreed that:

(1) Weather information in the system today is not readily accessible to the pilot for proper preflight decisions or in-flight considerations and that forecasts tend to be pessimistic, thus tempting the pilot after several false alarms to ignore the forecast.

(2) Meteorologists generally do not seem to have sufficient understanding of general aviation requirements.

(3) There is a wealth of weather data available within the Department of Defense which is not available in the system for civil use.

(4) Pilots are not aware of the meteorological services and publications which are available to them.

(5) There is an urgent requirement for weather information on many more general aviation airports. Automatic weather observation equipment appears to be the long-term solution.

(6) Student pilots are not sufficiently indoctrinated in the area of in-flight adverse weather.

(7) Unicom capability is not being utilized to the degree possible.

(8) Pilots tend to be intimidated by controllers and tower operators who are not necessarily pilots and thus not always cognizant of the pilot's problems.

(9) Pilots do not always meet their responsibility for the submission of in-flight weather reports on significant weather and/or unforecast conditions. In this regard development of airborne sensors appears appropriate.

(10) Mass dissemination broadcasts such as PATWAS AND TWEB are not current.

(11) Preflight briefings are not always complete and lack standardization. Current programs to automate the retrieval of data for use by the FSS briefer (AWANS/MAPS) and the Weather Forecaster/ Briefer (AFOS) appear to be the solution. Further, the ongoing program for use of computer generated voice briefings via telephone and possibly via the standard television receiver is a promising solution to the general aviation problem.

(12) Pilots on IFR flights have difficulty in obtaining weather information on uncontrolled airports which are their final destination.

In light of the above, the committee recommends the following actions.

(1) Student pilot training programs include actual in-flight weather experience accomplished through instructor training.

(2) FAA publish a bibliography of available meteorological services and publications in AIM Part I.

(3) The priority for PATWAS and TWEB update in the functional responsibilities of the flight service specialist be increased.

(4) FAA publish a "Good Operating Practices" circular for Unicom operators.

(5) NWS review its quality control procedures and criteria.

(6) NWS participate in more general aviation activities such as air shows and industry annual conferences to give the meteorologist a greater understanding of the pilot's problems and vice versa.

(7) Efforts be made to make real time weather data available to the pilot from all sources to include military installations, Unicom operators, tower and approach controllers and air traffic controllers.

(8) Emphasis be placed upon the establishment of weather observations at general aviation airports particularly where an instrument approach exists.

The initial capability to be met with trained observers to be replaced with automatic observation equipment when available. The program should be supported with monies from the Aviation Trust Fund.

In addition to the above, the committee feels that the workshop was a great success and should be repeated periodically in the future. Suggested improvements are:

(1) Circulate proposed discussion questions to conferees in advance to permit study and consideration.

(2) Schedule at initial and periodic intervals for the fixed committees to meet as a unit separate from the floating committees.

(3) Schedule plenary sessions of the fixed committees.

(4) Encourage participation by representatives of the aviation manufacturers.

(5) Encourage representation by air traffic controllers and flight service specialists.

SUMMARY REPORT OF COMMITTEE A

Charles H. Sprinkle
National Weather Service

Committee Composition: (See Table 4, page 11)

I. Session with Standing Committee on Aircraft Design

It was stated that current procedures for designing structural (strength) components with respect to turbulence forcing functions are adequate; however, it was emphasized that we must be sure to separate structural (strength) components and control components in our discussions. Engineering procedures are adequate (aircraft do not break up in flight). It was agreed that there is sufficient turbulence data available to do adequate modeling; however, it may be well to look into an updated discrete gust model. Newer, more sophisticated aircraft do not behave like the old aircraft.

Spectral models are an improvement over discrete gust models. Spectral models give you everything the discrete gust model gives you, plus more. The amount of effort is identical; however, the numbers may need updating--at least someone should take a look at it. We're in a better position to give better numbers now.

A need to update meteorological data below 2,000 ft. was expressed. The atmosphere is very different below 2,000 ft. We need more information on low level eddies, also need more information on the patchiness of turbulence at all levels. There is a lack of correlation at low altitudes in the U, V, and W components at the same time. Rolling effects should be considered in aircraft design. Information is also needed on wind shear for design purposes. Need wind profiles, and they should be incorporated into specifications. For thunderstorms and other severe weather we can't design for the worst cases. As for wind shear, it's not a design (structure) problem, it's a control problem!

With respect to lightning, more detection design work is needed. Data are not sufficient and not fully understood. We really don't know the impact of lightning on onboard digital systems.

The state of the art for forecasting meteorological elements is sufficient for design purposes.

II. Session with Standing Committee on Simulation

There are no standard models. In fact, there are several within one company. There are several types of wind and turbulence models. Some models are better for some things than others. Models are generally oversimplified. Simulator models <u>cannot</u> take care of all cases. There must be a bounds placed on the simulation (average, extreme, and moderate).

In reference to turbulence model studies, authors should be encouraged to include mathematical methods for solution in their papers. Frequently it's not readily apparent as to how to arrive at the solution.

The persons more deeply involved in simulation stated that current turbulence simulation models are adequate. Also, the meteorological data is sufficient to simulate the effects of icing, temperature variations, humidity variations, etc.

It was pointed out that a wealth of data is currently being collected in the form of profiles in the lower atmosphere. The FAA (NAFEC) will be the principal source of this data. It will be possible to have this new data available shortly (within the next year).

111. Session with Standing Committee on General Services

At the outset, it was agreed that the ultimate goal of aviation weather services is the delivery of accurate and timely information to the cockpit flight crew.

a

There were several items raised which demand action to provide better service. They were:

- More frequent updates of the Transcribed Weather Broadcasts (TWEB)--make it a higher priority job within the Flight Service Stations **(FSS)** (need someone from the **FSS** side of the house within FAA to speak to this problem);
- SIGMET's not being broadcast on VOR;
- NAMFAX circuit has too much information moving on it that does not support aviation (NWS will examine the circuit and attempt to remove some extraneous charts).

Other items and questions raised were:

- There is a need for a pilot's satellite "handbook" to aid the pilot in the interpretation of satellite information.
- With regard to the dependability of data, the question was asked, "How much are you willing to 'pay' for small improvement in an already good system?" This was unanswered.
- With respect to the shortage of personnel in meteorology and aviation weather services, little hope was offered for increased personnel. The aviation industry pointed out to NWS that quality control of products and services is vital and should be sought at every opportunity.
- **As** far as weather training as a service, it was noted that forecaster-to-pilot briefing <u>is</u> an education to <u>both</u> of the participants in the exercise.
- The responsibility for aviation weather research was noted to be splintered among many agencies. NOAA, DOD, **FAA**, **NASA**, etc., all appear to be

doing something. To what extent are the programs coordinated? It was felt that the role of the Federal Coordinator should be brought more into play, defining the content and quality of R&D as well as defining the direction we are heading. Question was asked concerning follow-ups of National Transportation Safety Board (NTSB) recommendations--who has the authority? FAA pointed out that there is now a specific office within FAA, formed recently, that is bird-dogging NTSB recommendations.

Discussion concluded with recommendations on a future aviation workshop:

- A more structured meeting in 1-2 years;
- Attempt to include representatives from some groups absent from this initial effort;
- Include persons with decision-making authority; and
- A more complete package to participants in advance of the workshop (some important inputs could be gathered before coming to the meeting).

IV. Session with Standing Committee on General Aviation

The initial item under discussion centered around education. How do you make pilots aware of what is available and where to get it (films, etc.)? A publication (such as the Airmen's Information Manual) could list available information. Also, some feeling was expressed that student pilots should be given some actual in-flight experience with bad (IFR) weather (under proper supervisions, of course). Education should also pass from the pilot to others. Pilots should be informed that they have the responsibility of passing weather information to the tower, **UNICOM**, etc., in regard to wind shear, winds not as forecast or not as indicated, etc. There is a real need for timely exchange of safety information between all concerned.

Several other items were touched upon briefly. They included:

- Too much background noise on ATIS (Automatic Terminal Information Service)--difficult to understand;
- TWEB/PATWAS updating not frequent enough--"Updating TWEB is 9 or 10 on the FSS priority list";
- 927 airports have instrument approaches without observations;
- Need an FAA publication on good practices of UNICOM operations (should include altitude restrictions on UNICOM);
- In the A.I.M., the section on good operating practices should be examined for things that do not apply to all aircraft and airports. A rewrite is needed to bring them in line with the real world;
- Not enough emphasis is placed on the human factor in accident investigation--especially in general aviation accidents;
- What are the time definitions of ocnl, vrbl, etc. . . . (the definitions are available in NWS and FAA publications).

In conclusion, it was pointed out the importance of proper attitude in pilots. Proper attitude must be instilled --you cannot legislate common sense!

SUMMARY REPORT OF COMMITTEE B

Prepared from Session Notes Furnished by:

Donald H. Lenschow
National Center for Atmospheric Research

Committee Composition: (See Table 4, page 11)

I. General Aviation and Services

- Can military weather information be made available to General Aviation? Since the military role is different from General Aviation, there are limits to the use of its weather information because of operation schedules and budget limitations. For example, military weather recordings are not always available on weekends.
- Weather information provided by Flight Service Stations (FSS) is often not uniform and is too pessimistic. Although winds aloft data are available every 12 hours, there is a problem in timely distribution. There appear to be many complaints about the availability of weather information on the West Coast of the United States. The cause is attributed to lack of communication, upstream reporting stations, and knowledge of the availability of local information. More information is needed on the availability of cloud top heights. Some concern was expressed about whether or not the future AFOS program (Automation of Field Operations and Services within the National Weather Service) will have the right kind of data needed by General Aviation.
- Private pilots need to be more knowledgeable about weather. Student pilots should have some exposure to flying in clouds before being licensed.

- Improvement is needed in providing General Aviation pilots with changes in the weather reporting and forecasting system.
- FAA should develop more "single concept" type training films on weather.

II. Aircraft Design

- There appear to be no standards or specifications for reducing lightning damage. Static discharge system reduces radio noise but not lightning strikes. Not enough information is available to do adequate design. Solid state systems on wide-bodied aircraft are particularly subject to problems from lightning strikes. Composites and fiberglas give problems because of poor electromagnetic shielding--not unsolvable! Additional measurements on aircraft are needed, including characteristics of lightning. It is believed that systems can be protected with reasonable expense if considered at the beginning level. Fuel systems nay still be a problem. FAA examiners should consider the lightning danger when certifying fuel tanks so explosions can be avoided. Lighting can also cause compressive stalls on some aircraft. There is a problem in these areas in transferring technology from research to General Aviation manufacturers.

III. Simulation

Concern was expressed for determining the limits and procedures for landing aircraft in wind shear.

- What is the maximum value of wind shear?
- What is the limiting value beyond which a landing should not be attempted?

- Under what conditions does one take out autoland?
- Would more wind information from the aircraft to the ground station contribute to improved shear advisories?

There should be some simulation of various severe shear profiles in training simulators, although there is still a problem in simulating shear conditions using mathematical models and data.

SUMMARY REPORT OF COMMITTEE C

William Horn, Jr.
National Business Aircraft Association, Inc.
Washington, D.C.

Committee Composition: (See Table 4, page 11)

Aviation Weather Research- Who really is in charge of this important facet of aviation support? Jack Enders started listing agencies that had a piece of the action in this area and by the time he had gone through twelve (12) different major agencies it was obvious that we were spending an awful lot of money on the subject, but without any sort of direction or hope that the results of this diversified activity would ever be distilled into meaningful aviation weather support for the aviation user community. The who, how and why of what should be done was not discussed because of time restraints, but it is rather obvious some review of the entire area of aviation weather support must be accomplished at a fairly high government level.

Slant Range Visibility- There was full agreement that this should have a high priority for funding and close review by the Federal Government and the aviation users. Speaking from an operators view, I have had many discussions with the Terminal Procedures Committee (TERPS) regarding the "look-see" privilege which allows Part 91 operators to continue approaches even though the reported weather is alleged to be below minimums. ALPA and ATA are in continuous disagreement over the validity and the proper minimums for non-precision approaches. An accurate measurement of slant range visibility could have a major economic impact on the aviation community.

Automatic Aviation Weather Observations-The General Aviation Associations are on record and in agreement on the philosophy of co-location of Flight Service Stations and Air Route Traffic Control Centers. The one major concern we have is the manner and quality of weather observations that will be available when the FSS's close down. We must have no reduction in weather observations-contract weather observations are at best minimum satisfactory. Automated aviation weather sensors should be a high priority subject.

Mass Weather Dissemination- There have been improvements in this area in the last two years. However, a major program is necessary to insure that all available aviation weather parameters are fed into the system, that their flow through the system not be impeded, and that the weather information provided to the pilot be real time. Six hour forecasts are very nice for planning, but the flight crews aloft must be provided with short term updates-we really require "now casts."

Airborne Weather Probes-As part of the aircraft design we should include certain weather probes that are an inherent part of the airframe. Probes similar to the transponder and automatic altitude readout equipment should provide pertinent weather data to the appropriate ground dissemination system without any pilot input.

Pilot Education- We should insure that the Airmans Information Manual (AIM), The Aviation Weather Manual and the Instrument Flying Handbook agree in all important details where they discuss aviation weather. Additionally, the AIM should list a bibliography of required aviation weather publications for the concerned pilot. The entire committee felt that weather training was a weak link in the preparation of our new pilots for entry into the National Airspace System (NAS). With the continued reduction of eyeball to eyeball briefings and the limited exposure the pilot will have had to various weather charts, the increase in aviation weather education is imperative.

Weather Personnel Problems-With the increasing use of automated observing and forecasting equipment we will have a problem in utilizing trained meteorologists. Some provisions should be incorporated within the ADP structure and the user charge format to insure that we provide on-site weather technicians in areas that constitute rapidly changing and severe weather activities.

Airports- With the limited number of major airports in the NAS, the reduction of capacity of any one due to weather can seriously impact air transportation in this country. In particular, emphasis must be placed on snow prediction-time, amount, duration of fall, including wind direction data for the airport manager so that he can clear the most important wind runway first.

SUMMARY REPORT OF COMMITTEE D

(Manuscript not available for publication)

APPENDIX A

Acronyms

ADP	Automatic Data Processing
AEDC	Arnold Engineering Development Center
AFOS	Automation of Field Operations and Services
AIM	Airmans Information Manual
ALPA	Airline Pilots Association
ARTCC	Air Route Traffic Control Center
ATA	Air Transportation Association
ATC	Air Traffic Control
ATIS	Automatic Terminal Information Service
AV-AWOS	Aviation-Automatic Weather Observation System
CRT	Cathode Ray Tube
CTOL	Conventional Take-off and Landing Aircraft
DFDR	Digital Flight Data Recorder
DOD	Department of Defense
FAA	Federal Aviation Administration
FSS	Flight Service Stations
GA	General Aviation
GFWS	Gust Front Warning System
IAD	Dulles International Airport
IFR	Instrument Flight Rules
INS	Inertial Navigation System
MOS	Model Output Statistics
MSFC	Marshall Space Flight Center
NAFEC	National Aviation Facility Experimental Center
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NAVAIDS	Navigational Aids
NCC	National Climatic Center

Acronyms (cont.)

NDC	National Distribution Circuit
NHC	National Hurricane Center
NMC	National Meteorological Center
N O M	National Oceanic and Atmospheric Administration
NSSFC	National Severe Storms Forecast Center
NSSL	National Severe Storms Laboratory
NTSB	National Transportation Safety Board
NWA	Northwest Orient Airlines
NWS	National Weather Service
OAST	Office of Aviation Safety Technology
PATWAS	Pilots Automatic Telephone Weather Answering Service
PIREP	Pilot Report
PJS	Pressure Jump System
PNL	Pacific Northwest Laboratory
SDC	State Distribution Circuit
SMCC	Systems Monitoring and Condination Center
SRI	Stanford Research Center
SST	Super sonic Transport
STOL	Short TAke-off and Landing Aircraft
SVR	Slant Visual Range
TAP	Terminal Alert Procedures
TERPS	Terminal Procedures Committee
TWEB	Transcribed Weather Broadcast
UTSI	University of Tennessee Space Institute
VFR	Visual Flight Rules
V/STOL	Vertical and Short Take-off and Landing Aircraft
WPL	Wave Propagation Laboratory
WSFO	Weather Service Forecast Office

APPENDIX B

Roster of Workshop Participants

John H. Bliss
2740 Graysby Ave.
San Pedro. CA 90732
213-831-1813

Dennis W. Camp
NASA/MSFC
ES82
Huntsville, Ala. 35812
205-453-2087
FTS 872-2087

Charles R. Chalk
4150 Harris Hill Rd.
Williamsville, N.Y. 14221
716-632-7500

C.L. Chandler
Delta-Flt Control
Atlanta, GA 30320
404-346-6478

John W. Connolly
NOAA
Rockville, MD 20852
202-377-3277

Frank Coons
HQ FAA
SRDS, ARD 402
2100 2nd St. S.W.
Washington, D.C. 20591
202-426-9350

Robert Curry
AWS/DNP
Scott AFB, IL 62225
Autovon 271-4741

William R. Durrett, DL
Kennedy Space Center
FL 32899
305-867-4552
FTS 823-4552

John H. Enders
FAA HQ
Office of Aviation Safety
AFS-30
Washington, D.C. 20591
202-426-2605/3704

George H. Fichtl
Environmental Dynamics Branch
NASA/Marshall Space Flight Center
Mail Code ES43
Marshall Space Flight Center
Alabama, 35812

Charles A. Fluet
NTSB
Bureau of Tech/TE60
Washington, D.C. 20594
FTS 202-426-3980

Roger G. Flynn
209 N. Water St.
Chestertown, MD 21620
301-778-1077

Walter Frost
Director of Atmospheric Science
Division
UTSI
Tullahoma, TN 37388

R. Craig Goff
NAFWC/FAA
ANA-430
Atlantic City, N.Y. 08405
609-641-820 x 2257

Wallace C. Goodrich
AOPA
Box 5800
Washington, D.C. 20014

Douglas Guilbert
AFAL/WE
Wright Patterson AFB, OH 45433
513-255-2207
Autovon 785-2207

James T. Green
American Airlines Flt. Academy
Greater Southwest Int'l Airport
Ft. Worth, TX 76125
817-267-2211 x 119

Edward M. Gross
National Weather Service
8060-13 St.
Silver Spring, MD 20910
FTS 301-427-7726

Jack Hinkleman
FAA
SRDS, ARD-451
2100 2nd St. S.W.
Washington, D.C. 20591
202-426-8427

William Horn, JR.
NBAA
Suite 401
425-13 St. N.W.
Washington, D.C. 20004
202-783-9000

John C. Houbolt
NASA/Langley Res. Center
MS/116
Hampton, VA 23665
804-827-3285

Paul L. Jernigan
Douglas Aircraft MS 41-56
3855 Lakewood Bld.
Long Beach, CA 90846
213-595-1898

Arthur E. Kressly
5099 Saratoga Ave.
Cypress, CA 90630
213-593-2475

Richard L. Kurkowski
Flight Systems Research Div.
NASA/Ames Research Center
Moffett Field, CA 94035
415-965-6219
FTS 448-6219

Jean T. Lee
NSSL/NOAA
1313 Halley Cir.
Norman, OK 73069
405-329-0388
FTS 736-4916

Donald H. Lenschow
NCAR
P.O. Box 3000
Boulder, CO 80307
303-494-5151

Newton A. Lieurance
1800 Old Meadown Rd.
#501
McLean, VA 22101
703-356-3283

Jim Luers
Univ. of Dayton Research Ins
Dayton, OH 45469

Charles A. Lundquist
NASA/MSFC
ES-01
Huntsville, AL 35812
205-453-3105

William W. Melvin
Airline Pilots Assoc.
1101 W. Morton
Denison, TX 75020
214-463-1246

Hubert McCaleb
TE30
Bureau of Technology
NTSB
Washington, D.C. 20594
202-426-3936

William L. Olson
FAA
800 Independence Ave
Washington, D.C. 20591
202-426-8784

J. Anderson Plumer
Manager Environmental Electro-Magnetic Unit
General Electric Company
100 Woodlawn Ave.
Pittsfield, Mass. 01201
413-494-3575

Charles L. Pocock
AFISC/SEF
Norton AFB, CA 92409
714-382-2226
Autovon 876-2226

James C. Pope
FAA
Office of General Aviation
AGA 200
Washington, D.C.
202-426-3713

J. Van Ramsdell
Pacific Northwest Laboratories
Battelle Blvd.
Richland, WA 99352
509-946-2749
FTS 444-7511 request 946-2749

Bertha M. Ryan
Aerothermodynamics Branch
Naval Weapons Center, Code 3161
China Lake, CA 93555
714-939-2877

Dwight R. Schaeffer
Boeing Military Airplane Div.
Boeing Aerospace Company
P.O. Box 3707
Seattle, WA 98124
206-655-5055

Rance Skidmore
Air Weather Service
Scott AFB, I1 62225
618-256-4741
Autovon 638-4741

Joseph F. Sowar
Chief, Aviation Weather Systems Branch, SRDS
2nd and V St., S.W.
Transpoint Building
Washington, D.C. 20591
202-426-8427

Charles Sprinkle
NOM NSW
W116 8060-13 St.
Silver Spring, MD 20910
FTS 301-427-7726

Joseph W. Stickle
NASA/Langley Research Center
MS/246A
Hampton, VA 23665
804-827-2037

William W. Vaughan
NASA/MSFC
ES-81
Huntsville, Ala. 35812
205-453-3100
FTS 872-3100

Robert J. Woodcock
AFFDL/FGC
Wright Patterson AFB, OH 45433
513-255-3709

Andrew D. Yates, Jr.
7413 Park Terrace Drive
Alexandra, VA 22307
703-765-7423

Appendix C

The following related reports are recommended for review in connection with these proceedings:

1. Criteria for Weather Observations at General Aviation Airports, Samual V. Wyatt, Aircraft Owners and Pilots Association, Washington, D.C. 20014.
2. Special Study of Fatal, Weather-Involved, General Aviation Accidents (NTSB-AAS-74-2).
3. Special Study of Nonfatal, Weather-Involved, General Aviation Accidents (NTSB-AAS-76-3).

A SUCCESSFUL CONFERENCE